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Public participation in energy saving retrofitting of residential buildings in China

Wenling Liu [a,b], Jinyun Zhang [a,b], Bettina Bluemling [b,c], Arthur P.J. Mol [b], Can Wang [a,*]

[a] State Key Joint Laboratory of Environment Simulation and Pollution Control (SKLESPC), School of Environment, Tsinghua University, Beijing, China
[b] Environmental Policy Group, Wageningen University, The Netherlands
[c] Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Halle, Germany

HIGHLIGHTS

- We compare public participation in three early cases of residential retrofitting in Beijing.
- Residents' involvement in pre-retrofit activities as well as in the choice and use of technologies varied.
- More involvement of residents during retrofitting improves energy saving performance.
- Taking into account motives and energy use practices of residents improves energy saving through retrofitting.

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ABSTRACT

Retrofitting existing residential buildings has been claimed as one crucial way to reduce energy consumption and greenhouse gas emissions within the Chinese residential sector. In China's government-dominated retrofitting projects, the participation of residents is often neglected. The objective of this paper is to assess the influence level of public participation (before, during and after retrofit) on energy saving by comparing three Beijing neighborhoods with different retrofitting models: a central government-led model, a local government-led model, and an old neighborhood retrofit model. In the three cases data were collected through interviews with neighborhood workers and residents. The results show that residents' involvement in pre-retrofit activities, in technology selection and in the use of technology differs greatly among the three cases. This study concludes that in order to improve the effectiveness of energy saving interventions, the motives, intentions and living habits of residents need to be given more consideration when designing and implementing retrofitting. By highlighting the importance of public participation this paper contributes to energy saving policy development in China.
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1. Introduction

Parallel to rapid economic growth and an increase in living standards, energy use in China has increased steadily from 0.59 billion tons of standard coal equivalents in 1980 to 2.92 billion tons in 2009, an average annual increase of 5.7% [1]. Building energy consumption accounted for 27.5% of the total final energy consumption in 2011 [2]. Yao et al. [3] estimated that this ratio will increase to 35% in 2020. The Building Sector is and will continue to be a major energy end-user in the years ahead [4]. Two factors contribute to the large amount of energy use in buildings: large building area and low energy efficiency in buildings (particularly, residential buildings). The majority of residential buildings in urban China – and particularly those built before 2000 – are low-energy-efficient buildings [5], indicating ample room for energy savings initiatives. In northern China, the heat loss from external walls is three to five times higher and from windows two times higher than that of similar buildings in other northern hemisphere countries [6]. Energy use practices in China also demonstrate considerable inefficiencies. An empirical study has shown that heat loss due to the opening of windows, a common form of wasting energy, was responsible for 25.8% of the total residential heat supply in China [7].

The total gross floor area in China is 43 billion m^2, and it is still increasing rapidly. Of the existing residential building floor area of 5.45 billion m^2 in northern China, 4.16 billion m^2 was energy inefficient, and 3.56 billion m^2 used low energy efficient district

* Corresponding author at: Room 1004, Sino-Italian Tsinghua Ecological and Energy Efficient Building, Tsinghua University, Beijing 100084, China. Tel.: +86 62794115.

E-mail address: canwang@tsinghua.edu.cn (C. Wang).

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heating systems [8]. The growing residential floor area and the energy inefficiency in existing residential buildings increase the need to retrofit buildings in northern China. From 2007 onwards, the Chinese government has promoted and subsidized the energy efficiency retrofitting of existing urban residential buildings. These buildings consist mostly of multi-store apartment blocks. Enhancing the energy efficiency of buildings has also been an integral part of the Low Carbon City policy objectives and measures [9,10].

Retrofitting projects have traditionally been implemented through a rather conventional (for China) top-down policy procedure with governments of various levels playing a dominant role and using large governmental subsidies [11,2]. However, research has shown that resident participation is important for the energy performance of retrofitted buildings [12,13,14,15]. Building renovation and renewal depend on the degree of participation, cooperation and mobilization of the involved actors to attain a common goal through coordinated action. Cirman et al. [16], in their study on Slovenian households, discovered that residents' positive attitudes and their ability to reach an agreement to collective action were particularly important for successful renovation of multi-dwelling buildings. Valciukas [17] compared the implementation of multi-family housing renovations in Stockholm and Vilnius and found that the main obstacle for energy saving renovation was a lack of precise, reliable and verified resident information. McEwen [18] explored six residential energy upgrading programs in five regions in the USA, and concluded that community engagement contributed to the cost-effectiveness, sustenance and growth of upgrading programs. Residents' participation is usually associated with so-called bottom-up approaches and 'grassroots' development [19,20]. While resident participation is important for the effectiveness of energy saving retrofitting, in the context of a top-down policy implementation approach in a place like China, this element is often neglected. Previous research on residential energy use in China did not focus on the potential connection between residents' participation and energy efficiency. Several studies have assessed and evaluated Chinese refurbishment projects by focusing mainly on retrofitting patterns (e.g. [21], the technical measures that were applied and the retrofitted area [22,23,24].

This study attempts to fill this research gap by examining residents' participation in retrofitting residential buildings in China. This paper investigates residents' participation in energy saving retrofitting by analyzing three exemplary retrofitting projects in Beijing, assesses the contribution of participation to successful energy saving in these projects, and finally develops recommendations for future energy saving retrofitting of residential buildings in China.

2. Background of retrofitting existing residential buildings in China

In China, retrofitting existing residential buildings has become an important measure in increasing the energy efficiency of buildings. The central government decided to retrofit 0.15 billion m^2 of existing residential buildings in China's northern heating region (covering 15 provinces, i.e., Tianjin, Henan, Liaoning, Jilin, Shanxi, Ningxia, Shaanxi, Gansu, Qinghai, Xinjiang, Heilongjiang, Inner Mongolia, Shandong, and Hebei) in the 11th Five-Year Plan (which was implemented from 2006 to 2010) [21]. By the end of October 2010, approximately 0.19 billion m^2 of existing residential building floor area in northern China had been retrofitted, which exceeded the target set in the 11th Five-Year Plan. However, the retrofitted residential building floor area only made up 4.6% of the total building floor area that is in need for retrofitting [22]. From 2007 to early 2012, the Chinese central government allocated 18 billion Yuan to support retrofitting of existing residences in the northern heating zone of China [24]. The retrofitted residential building floor area increased to 0.31 billion m^2 by March 2012, leading to an average energy saving of the equivalent of ten kilogram coal per square meter and an increased indoor temperature of three to six degrees[1]. Retrofitting residential buildings in the northern heating region has remained a key energy efficiency project of the Chinese government in the 12th Five-Year Plan (2011–2015). It is expected that China will complete the 12th Five Year Plan task of retrofitting 0.4 billion m^2 residential building floor area by the end of 2015 [5].

Retrofitting existing buildings is a complex engineering project, as it deals with technological, policy, funding, organizational and management challenges [21]. Retrofitting schemes mainly involve energy efficiency retrofits for building envelopes, the installation of energy efficient windows, retrofitting heat metering; and temperature regulation of heating systems. Almost every retrofit project inevitably includes building envelopes and the installation of energy efficient windows. Most residents have never used energy metering, and introducing energy metering is one of the central government's plans to motivate residents to save energy. In the start-up phase, the central government has provided a subsidy of 6 yuan/m^2 to provincial finance departments for the installation of local heat metering devices. However, apartment-based heat metering has not been applied in all retrofitting projects. Additionally, retrofitting the temperature regulations of the heating system is not always included in retrofitting projects. For example, by the end of 2008, the retrofitted area in China reached 71.48 million m^2, of which only 15.47 million m^2 (or 22%) was retrofitted with both heat metering and heating system temperature regulation [25].

3. Analytical framework and methodology

The analytical framework for studying the participation of residents in retrofitting residential buildings in China consists of three key elements: the actors involved, the distinct type of retrofitting projects, and the different phases of retrofitting.

Agencies and residents are key actors involved in retrofitting. Public and private retrofitting agencies (governments and firms) include not only central and local government authorities, heating supply firms, property firms, house owners, and energy saving service firms, but also planning and design firms, material and equipment suppliers, construction firms, and supervisory and property management agencies [22]. Besides these agencies, residents (individuals) are also important actors in retrofitting. Some scholars argue that bottom-up processes and 'grassroots innovations' with intensive resident participation are key factors to ensure successful retrofitting of residential building projects (e.g. [26]. Education strategies that provide energy tips, information, and factual knowledge, and relevant social interaction in social networks of residents have been acknowledged as playing an important roles in determining household energy use behavior [27,28]. When households do not know, understand or accept advanced energy saving technologies related to retrofitting, implementing such energy efficient technologies can only provide sub-optimal results [29,30].

Retrofitting residential buildings has taken place for several years in China, and three distinct retrofitting models have emerged and spread widely. These models include: (1) the central government-led model, (2) the local government-led model, and (3) the combined retrofit-and-renewal model. The central government-

[1] Data source: http://www.mohurd.gov.cn/zxydt/201203/t20120321_209186.html.

led model represents the earliest retrofitting demonstration projects, in which the Chinese government cooperates with foreign governments or companies. The local government-led model is the simplest retrofitting model, where local governments drive the achievement of retrofitting targets. In the combined retrofit-and-renewal model, an energy efficiency retrofitting project is combined with an old neighborhood renewal project. This model has a double purpose and is most common in the suburbs of large cities.

In this paper, three phases are distinguished and analyzed in retrofitting processes for each of the three models. In phase one (pre-retrofit), we analyze how agencies and residents are involved in the planning and design of retrofitting. Propaganda activities, identifying investment sources, and learning and communicating are assumed to influence residents' support for and agreement on retrofitting. In phase two (actual retrofit), we focus on what energy saving technologies agencies offer to residents and what technologies each household select. In phase three (post-retrofit), we investigate residents' actual use of the implemented technical measures and innovations and their corresponding behavioral change.

Fig. 1 presents the analytical framework of this study. We evaluate how different actors (particularly residents) participate in distinct retrofitting models. As outlined above, we distinguish three retrofitting models and divide the retrofitting process (per model) into three periods. We compare how (public and private) agencies and residents are involved in the entire retrofitting process in the three models and in the end compare the energy performance of the retrofitted projects.

3.1. Methodology: case study selection

Three neighborhoods in Beijing were selected as case studies, as Beijing is a leading city in energy efficiency and the retrofitting of residential buildings. Through media reports, expert interviews and government documents, three typical retrofitting models were identified in Beijing. For each model, one case study was selected. The three models loosely correspond to the three implementation "waves" of retrofitting projects. The first wave of projects was characterized by central government-initiated energy saving, Sino-German technical cooperation project to explore how to implement energy saving retrofitting in China. This model started with demonstration model projects in several cities, often involving international technical cooperation. In the second wave of projects, the retrofitted target area was broken down into different provinces and cities, and local governments took the lead in energy

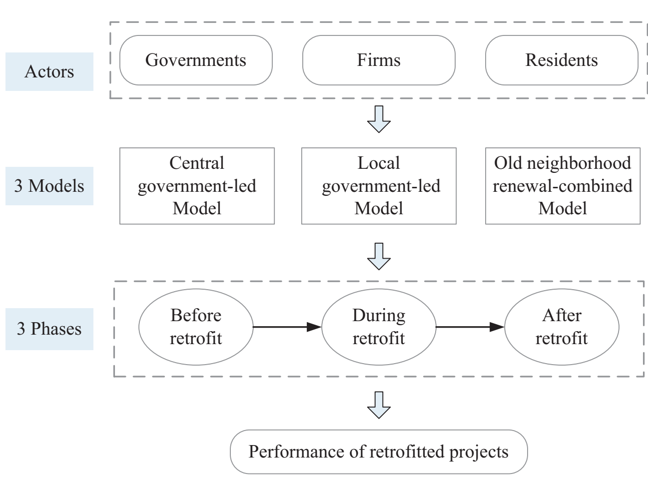

Fig. 1. Analytical framework.

saving retrofitting in order to meet their target areas. The third wave of projects began in 2012, when the Beijing government began combining both retrofit-and-renewal projects, to increase citizen's well-being and enhance residential energy saving in old neighborhoods.

To demonstrate the central government-led model, we have selected the retrofitting of Building No. 12 in the Huixin Western Street Neighborhood. Starting in 2007, it was the first energy efficient retrofitting demonstration project carried out by the Beijing Municipal Commission of Housing and Urban–Rural Development. It was a project under the Sino-German technical cooperation initiative, which was arranged by the central government. The project received technical and financial support from the German Technical Cooperation Organization [24], and was implemented by the Beijing Uni-Construction Group, the property owner of the neighborhood. The Huixin No. 12 building was built in 1988, consists of 144 apartments on a construction area of about 11,000 m^2, and has its own natural gas boilers located. More than half of the household residents have worked for the Beijing Uni-Construction Company. Many have lived for more than two decades in the same neighborhood and have their primary social network in that neighborhood. During retrofitting, residents continued to live in their apartments.

For the local government-led model, we selected buildings buildings 4 and 5 in Tidong apartment complex. The Tidong apartment complex was retrofitted in 2012, and many other apartment complexes in Beijing were retrofitted in a similar way as Tidong apartment complex. Buildings 4 and 5 of the Tidong complex were built between 1988 and 1989 and residents moved into the buildings between 1990 and 1991. The two buildings have the same design, with eighteen floors in each building and ten apartments per floor. Floors 1–16 of both buildings accommodate relocated residents whose former houses were demolished. Employees of two property companies (Bank of China and Ministry of Public Security) are living in the apartments on floors 17 and 18. During retrofitting in 2012, residents continued to live in their apartments.

For the third model, the combined retrofit and renewal model, we have selected buildings 32, 33 and 35 of the Fuyuan apartment complex, which was constructed in 1986 and consists of 180 apartments. The energy conservation retrofitting of these buildings was finalized in 2013. Because it is located in one of the suburbs of Beijing, the retrofitting differs from retrofitting in the city center. The property company went out of business, so the investment for retrofitting was paid by the local government. During retrofitting, residents moved out of the buildings for several months. Together with Hong Fu Da Senior Home, which is close to the Fuyuan apartment complex, the three buildings were heated by an independent coal-fed boiler. Because the senior residents in Hong Fu Da need a high room temperature to feel comfortable, the boiler used large quantities of coal and the indoor temperature of the three residential buildings during the heating season was higher than residential buildings in other neighborhoods.

3.2. Methodology: data collection

In each case study, several interviews were conducted with the apartment complex worker's committee. Committee members were asked about the operation and execution of the retrofitting project and the participation of different agencies and residents. This committee was elected by the residents to assist the local government regarding questions of residents' social security, public health, or youth education. As these committees serve as the link between local governments and residents, their members are expected to be knowledgeable on the retrofitting project. In addition, between October and December 2013, a survey was carried out of a random sample of residents. Residents entering or leaving

Table 1
Characteristics of the survey sample.

Case	No. (and %) of households	Age			Years of education			Male (%)	Family size			Monthly income <5000 (%)
		Average	Min	Max	Average	Min	Max		Average	Min	Max	
Huixin	77 (53%)	60	28	93	10.3	0	16	47	3.0	1	6	77
Tidong	25 (7%)	62	29	86	10.8	6	19	24	3.1	1	5	64
Fuyuan	27 (15%)	51	26	84	11.0	0	19	48	3.2	1	5	63

the buildings were asked to participate in the survey. The survey was conducted in the apartment complex offices using a semi-structured questionnaire, and a small gift (cup or gloves) was given afterwards to the respondents. The semi-structured questionnaire included four parts: (1) background information such as age, gender, education and income; (2) the resident's participation in pre-retrofit activities; (3) the resident's selection of energy saving technologies for the apartment and (4) the resident's use of technologies and his/her attitude toward metered heat fee charging in the future. Furthermore, respondents were encouraged to discuss heating energy consumption in residential buildings during the winter. A total of 129 questionnaires were collected, representing 129 households (see Table 1). Overall, respondents have a lower income, lower education, and lower environmental knowledge than the national and Beijing average.

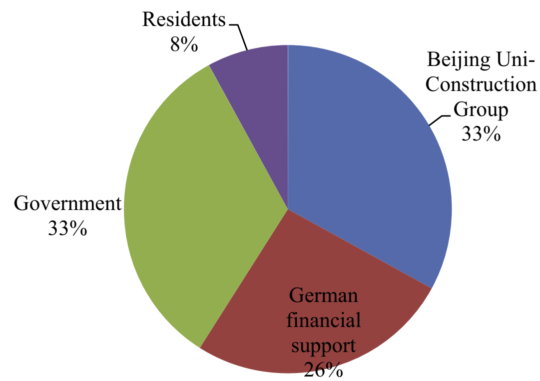

Fig. 3. Investment sources of Huixin case.

4. Results and discussion

The three cases represent completely different retrofitting models, as shown in Fig. 2. The Huixin case, which represents the central government-led model, can be called a public–private partnership, in which the government, the property firm, the German organization and the residents all invested in retrofitting (Fig. 3). Each household paid approximately 2000 RMB (282 USD) for the retrofit. The property firm functioned as project manager, and signed the contract with residents. One respondent from the Huixin case (H1) mentioned the favorable financial terms of this construction for residents: "*I just upgraded my apartment. After I finished my apartment, I heard the news that our building will be retrofitted. I already bought and installed new windows and new radiators. Now the project offered all residents the same. I feel regretful. If I had postponed upgrading my apartment, I would get the unified windows and radiators of the retrofit, and I would have saved 60–70% of the investment costs.*" From Fig. 2, the Tidong and Fuyuan cases seem rather similar. However, the Tidong case, which represents the local government-led model, followed a common procedure in which only wall insulation and energy efficient windows are applied in a rather non-participatory way. The investment for wall insulation was completely paid by the local government. The Fuyuan case, which represents the combined retrofit-and-renewal model, is a welfare project for old apartment complexes. Besides energy saving technologies, a lot of other technologies were applied, such as washbasin, faucets, and water and drainage pipes. The government paid a rent compensation of about 12,500 RMB (1760 USD) to residents who moved out of their apartment for several months during the retrofitting. Some households took the opportunity to decorate their apartments during the retrofitting.

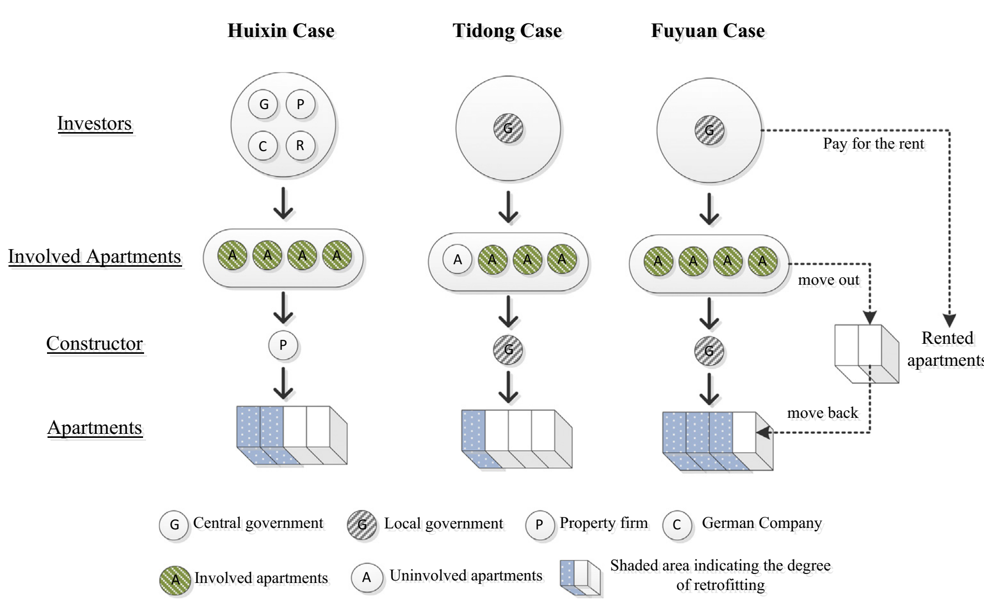

Fig. 2. Operation models of the three cases.

Below, we will describe the three cases in greater detail, focusing on residents' participation in the different phases of the retrofitting process. Following a detailed discussion, we will explore how the participation of residents affected their energy use behavior after retrofitting.

4.1. Involvement of residents before retrofitting

As part of energy conservation retrofitting, apartments can be equipped with wall insulation, energy efficient windows, radiators, valves, fresh air systems and energy metering devices. In order to install wall insulation, there needs to be a collective agreement from the entire building. The decision to install windows, radiators, valves and metering devices, and fresh air systems is to be decided by residents in their individual apartments. If two-third of the households in a building agrees on wall insulation, it is considered a collective agreement and executed as such [31].

Several activities were executed in the three cases to convince residents to join energy conservation retrofitting (see Fig. 4). In the Huixin case, during the planning stage, project managers distributed brochures, notices, and questionnaires about energy efficiency retrofitting to all households in building No. 12. Only 47 (out of 144) valid questionnaires were collected. Most households did not understand retrofitting and reacted indifferently. Subsequently, project managers invited thirteen neighborhood workers to visit the Hebei No. 1 retrofitting demonstration project in Tangshan [25]. These neighborhood workers are each in charge of six floors (twenty apartments) and are known as 'opinion leaders' who opposed energy saving retrofitting. Residents in Tangshan shared their experiences and the visitors experienced the benefits of retrofitting. This visit dramatically increased the support rate to 86% in building No. 12 [25]. A meeting for neighborhood workers and resident representatives and a meeting for all households in building No. 12 further increased support. As decisions were made back in 2007, at the time of research 12 residents found it hard to remember the exact time they agreed on energy retrofitting, while 65 residents did indicate the time they agreed on retrofitting. Fig. 5 depicts the time when residents agreed on wall insulation, with most of them agreeing after the demonstration project visit. Before the retrofitting began, more than 110 contracts were signed between the property owner and residents. At the start of the collective wall insulation, the neighborhood committee office, located on the 1st floor of Building No. 12, was retrofitted with indoor technology. Residents were invited to see energy efficient windows, new radiators, regulation valves, a fresh air system, and metering devices, which persuaded residents to apply for individual energy saving technologies in their homes.

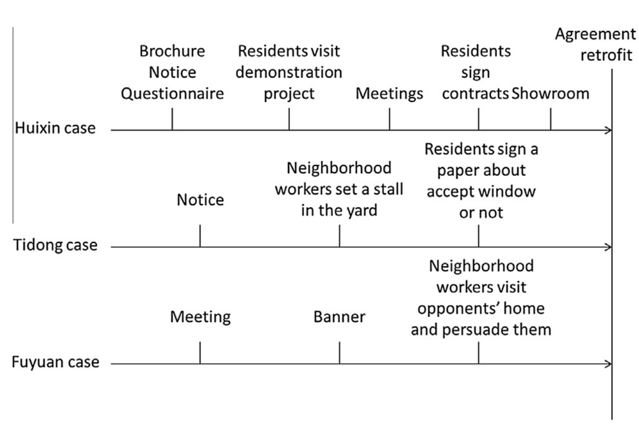

Fig. 4. Promulgation activities for residents. *Note:* The time lines have an ordinal scale, demonstrating the sequence of activities until residents agreed to the retrofit. Promulgation activities usually lasted 3 months before the retrofit.

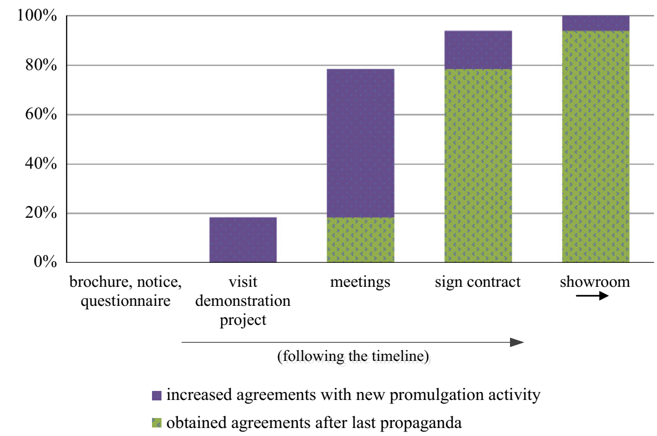

Fig. 5. Residents' agreement on wall insulation in the Huixin case, by percentage ($n = 65$).

In the Tidong case, the neighborhood committee organized a few activities to promulgate retrofitting. Neighborhood workers put a notice on the building billboard and installed a kiosk in the front yard of the building. Residents were able to choose whether or not to retrofit energy-efficient windows. However, for wall insulation, residents did not have a choice but to accept retrofitting.

In the Fuyuan case, the neighborhood committee arranged several activities to persuade residents to agree on retrofitting. First, the neighborhood committee arranged a meeting between neighborhood workers and resident representatives to discuss the plan of retrofitting. Second, the neighborhood committee put a banner on retrofitting in a conspicuous way to draw attention of residents. Third, neighborhood workers talked face-to-face with 20 residents who disagreed with retrofitting to explain the benefits of retrofitting. In the end, the neighborhood committee workers successfully persuaded all households to approve retrofitting.

If we compare the pre-retrofitting activities of the three cases, the Huixin case stands out for its diversity and number of promotion activities. Furthermore, residents also invested in this project (Fig. 3) and were thus active to learn about retrofitting and the actual effects that could be reached in terms of energy conservation and cost saving. For example, some residents were curious about heat metering devices and asked technical experts how such devices work. In contrast, residents in the Tidong case did not show much interest in retrofitting. They spared little time in exploring appropriate retrofitting measures and viewed retrofitting only as an opportunity for obtaining new windows. Because indoor heat radiators and heat metering and regulation devices were not covered in the retrofitting, the residents did not feel 'ownership' of the process since they did not notice a large change in their apartments. Most residents agreed to retrofit their windows, while a quarter explicitly disagreed either because their windows were pretty new or because they did not want workers to enter their apartments. In the Fuyuan case, neighborhood workers used strong face-to-face persuasion methods. Because residents had to move out, some residents felt that they were forced to agree because neighborhood workers told residents electricity and water would not be available during the retrofitting. Communication between residents and neighborhood committee workers and among residents was more intensive compared to the Tidong case. Residents also expected positive effects of retrofitting.

4.2. Selection of technological combinations

The technology options offered by providers in the Huixin retrofitting case (central government-led model) included thermal

Table 2
Technologies offered and percentage of adoption in the three cases.

Cases	Huixin		Tidong		Fuyuan	
Technologies	Offered	% Adopted	Offered	% Adopted	Offered	% Adopted
External thermal insulation	✓	100	✓	100	✓	100
Energy-efficient windows	✓	97	✓	76	✓	100
Radiators, valves, metering	✓	84	×	–	✓	100
Indoor fresh air system	✓	58	×	–	×	–
From flat roof to pitched roof	×	–	×	–	✓	100
Water and drain pipes	×	–	×	–	✓	100
Ceramic tiles, faucets, washbasin	×	–	×	–	✓	100

insulation of external walls, energy-efficient external windows, an indoor fresh air system, roof thermal insulation and the retrofitting of indoor heating systems (new radiators, regulation valves, metering devices) (Table 2). In Huixin, an indoor fresh air system was introduced in retrofitting projects for the first time. Fans were installed in the bathroom and fresh air entered from the air inlet on the external wall of every room. The fresh air system improves indoor air quality, human health, and reduces energy loss because windows do not have to be opened for fresh air. Although heat metering devices were installed, the heating fee was still based on the area to be heated and not on actual energy use per apartment.

In the Tidong case (local government-led model), the energy saving technologies offered were limited to external wall insulation and energy-efficient windows. This is the most basic technological option in retrofitting projects. External wall insulation was decided by the government and added to the outside of residents' apartments. Residents could decide on whether or not to install energy saving windows, which were offered for free by the government. Windows were constructed inside residents' apartments.

For Fuyuan (combined retrofit-and-renewal model), retrofitting providers offered external wall insulation, energy-efficient windows, radiators in the kitchen and toilet, regulation valves, energy metering, ceramic tiles, faucets, washbasin, changing from flat roof to pitched roof, and new water and drain pipes.

Extra technological innovations involve a more complex change of the apartments. In the Fuyuan case, residents had to move out during retrofitting to facilitate the process and all technologies were implemented uniformly. However, the quality of these technologies was not always satisfactory according to the residents. Because Fuyuan residents did not invest in retrofitting, they complained about the uniformly installed ceramic tiles, faucets and washbasins. Some of the residents even bought new ones. In the Tidong case, many of the residents thought that the retrofit was none of their business. Residents' apartments hardly changed and 24% of residents did not adopt energy-efficient windows. In the Huixin case, most residents chose external thermal insulation, energy-efficient windows and radiators, valves, and metering. Forty-two percent of the residents refused an indoor fresh air system, because they did not think that it would be helpful and it would require drilling many holes in their wall.

4.3. Technology use after retrofitting

Most people were quite happy with the retrofitting, even after several years. The Huixin case is the best illustration of that. One resident (H2) mentioned: "*The newspapers said we are the first retrofitted building in Beijing. This project cost the government and our firm more than 3,000,000 Yuan. I heard Germany provided financial and technical support, which makes me very proud. I think it is very nice to be the pilot or demonstration project. The government paid a lot. We only needed to pay a small amount. I wanted to pay after the construction began. But they wouldn't accept my money. They only collected money after the completion of the retrofitting. I trust in our neighborhood committee, our company, and the government.*" Still, a few residents expressed their continuing concerns. The most frequently mentioned worry was fire-proof performance of the materials (seven respondents). According to one respondent (H3): "*The 1st floor of building 8 once caught fire because of a lit cigarette, even emergency was called to come. The material is foam, very easy to catch fire. This is a vital problem.*" Damage to apartment decoration during retrofitting was another disadvantage, mentioned by four respondents. Two respondents mentioned they fear the instability of the building due to drilling holes for the fresh air system. One resident (H4) expressed: "*Previously it was said that this building can resist a 8–9 magnitude earthquake. I worried about all these holes. The walls were all damaged. The building is now like a honeycomb. I refused to install the fresh air system, which is good for the household upstairs.*"

When asked about their feelings regarding the effects of retrofitting, residents had diverse opinions. Most residents were very satisfied with the effects of the retrofit on heat preservation. One resident (H5) said, "*My apartment used to be moldy. Now it is November 1st, and I do not feel cold. It is now warm in winter and cool in summer. I do not need the two electrical heaters I used to use. To sleep at night, a blanket and quilt is enough in winter.*" Another resident (H6) claimed that, "*the materials for building 12 are better than those of the other three buildings. Materials were piled in the yard, we could see them. The materials for building 12 are thick and hard, while the materials for the other three buildings are thin, and relatively soft.*" Other residents were less satisfied with the retrofitting effects. One (H7) said: "*The heating supply is not good. There is no difference before and after retrofitting. Sometimes the heating water even leaks. To fix it, I need to find households upstairs and downstairs to identify the leakage, since we are connected. I cannot control and fix my radiators freely. All heating water is circulated among several households. This is really not convenient. I do not know why, but I started to feel very hot in summer this year. It was 4–6 degrees higher. So I installed air-conditioning, which was not needed previously. I think this is related to the retrofitting.*"

In the Fuyuan case, the residential committee persuaded all the residents to move out for several months during the retrofit. Most residents agreed on a temporary move because they were convinced that the pipe system was aged and needed replacement, retrofitting was considered a good thing implemented by the government, there were no financial consequences involved for retrofitting and moving, they had heard positive reports from other buildings being retrofitted, and they were afraid to disturb neighbors in favor of retrofitting. Some residents felt forced to agree and moved because they were told the water and electricity would be turned off. Most residents who expressed worries were concerned with the quality of the materials, especially the fire-proof performance of materials, the damage to their house decorations, and the complications of moving in and out. In particular, the quality of ceramic tiles, washbasin, faucets and pipes was criticized: "*The quality of ceramic tiles, washbasin, faucets and pipes is very poor. They would be broken in several days. I already bought and installed new ceramic tiles, washbasin, and faucets*" by one resident (F1).

In the Tidong case, the residential committee put up a notice in the neighborhood to announce that their buildings were going to be retrofitted to be more energy efficient, and residents had the chance to obtain new energy efficient windows for free. Most residents thought retrofitting was only being implemented on the public part of their buildings, and that nothing would happen to the inside of their apartments. Furthermore, they understood that the main aim of this government project was to make their buildings better. One resident (T1) said "*I don't feel much about retrofit. Because it is a project for the whole building and I just follow what neighborhoods do. When it is constructed in the daytime, I'm at the workplace. New windows are also great. They are better than the old windows*".

4.4. Residents' behavioral change

Some of the installed energy saving technologies only can work when energy use practices are adapted; otherwise energy efficient buildings are not likely to save much energy. Overall speaking, the duration of opening windows extended somewhat after the retrofit, but most residents in the three retrofitted neighborhoods did not fundamentally change (and certainly did not reduce) their behavior of frequently opening the windows. Around sixty-eight percent of the residents in all three cases reported that they opened the windows in the same way before and after the retrofit, while 30% of the residents reported that they opened windows for longer periods and/or more frequently than before. Most residents opened windows in the winter for fresh air or because of the smell or smoke indoors. A few respondents indicated that they opened windows in order to regulate the indoor temperature. Fig. 6 indicates the differences in duration and frequency of opening windows in heating seasons in the three case studies. In the Tidong case, a higher share of interviewed residents reported increased duration or frequency of opening windows. But it is hard to judge if retrofitting was the main cause of changed window opening behavior. Two percent of the residents (all in the Huixin case) reported that they opened windows shorter and less frequently after renovation. According to one of these respondents (H8): *"Now it is not convenient to open windows. In my apartment, I used to open all the windows to the maximum. Now I can only open two windows in the middle and I cannot fully open them. The other windows are just for lighting, and are fixed so that they cannot be opened."* Another (H9) noted that, *"... the air quality of Beijing is deteriorating these days. The number of hazy days has increased and a lot of dust might come in through the windows. So I open windows less frequently than before the retrofit."*

Residents in Huixin and Fuyuan had the choice to install new radiators and regulation valves in their apartments. The radiators and regulation valves were combined in sets and typically there was one radiator and one regulation valve in every room. Of the 77 respondents in the Huixin case, 65 residents accepted radiators and valves, while 12 residents refused them for various financial and practical reasons. One respondent (H10) explained: *"I wanted to agree to retrofit the indoor heating system in my apartment, including new radiators and regulation valves. However, the people upstairs and downstairs refused to install a new indoor heating system, and we are in the same line. Hence I'm influenced by their decisions.* In the Fuyuan case, all apartments were provided with new radiators and regulation valves. Since residents all moved out during the retrofit, the retrofit was smoother and all apartments had the same energy saving technologies installed. Some residents were not even aware of the exact changes in their apartments.

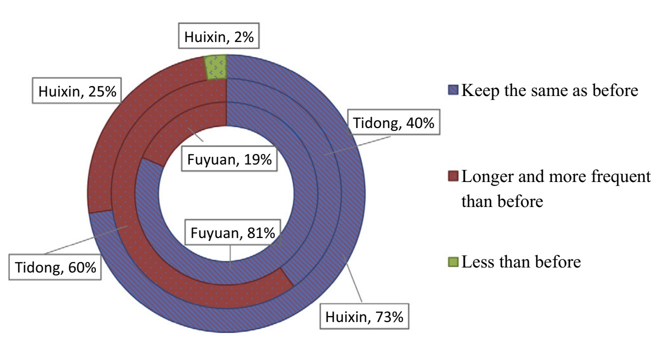

Fig. 6. Change in duration and frequency of opening windows in heating season.

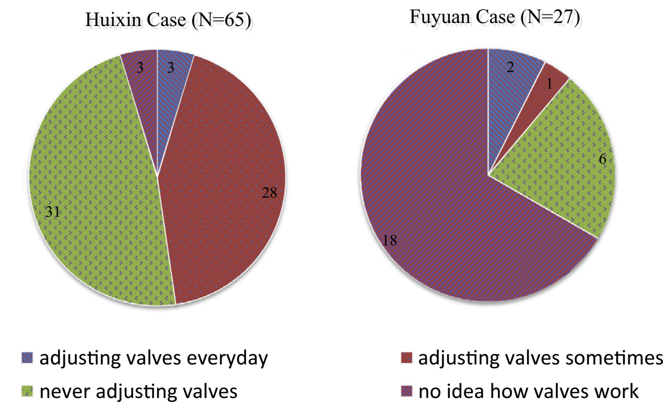

Fig. 7. Regulation valves behavior of residents in Huixin and Fuyuan.

With respect to regulating valves, the respondents were asked how often they adjust their valves (Fig. 7). Among the 65 Huixin residents, 31 residents reported that they never adjusted their valves, while 28 residents reported that they adjusted their valves sometimes, often one time during several months in relation to the change of seasons. Only 3 residents adjust their valves daily.

Residents, who never adjusted their valves, gave various reasons as to why they do not use the valves. One resident said (H11): "*It isn't warm enough indoors in winter. I want to turn the valves up, but the maximum is still not warm. The heat is not enough.* Another resident gave a different reason (H12), *"The boiler will tune the heat amount according to the weather. We do not have control over the heat. It is collective heating, not self-heating."* Another resident (H7) explained: *"The valves do not work properly. It will sometimes block the heated water from the pipes to the radiators. Last year it was cold in my apartment. Because the valves blocked the water, half of the radiators were heated, the other half were cold.*" Also in the Fuyuan case, most residents did not touch their valves, mostly because they did not understand how their valves function and no one taught them how to use them. These residents left the valves the way they were set by the person who installed them. Some respondents thought the valves were of poor quality and it was better not to operate them. One resident (F2) said: "*I didn't know there was a valve with 5 levels. I only see a cap on the radiator. No one told me I can control the heat. So I just leave it the way it is.*"

Fresh air systems were only installed in Huixin by 53 out of 77 respondents. To work efficiently, fresh air systems should be working 24 h every day. To inquire about their efficiency, residents were asked about the average duration of use. The results are shown in Fig. 8. Only three residents replied that their household uses the air system 24 h a day. In contrast, thirteen residents said their household never uses the system (because they are not satisfied), and fourteen residents said their home uses it for a short time every day, when necessary. Eight respondents (not shown in Fig. 7) even removed the fresh air system after it was installed because they found it too noisy, not easy to use, and consuming too much electricity (and thus costs). The other 24 respondents did not install the fresh air system for various reasons, which can be summarized by three main motives: (1) because an adjacent road would cause indoor noise, (2) because it does not match with opening windows regularly, and (3) following negative advice from neighbors.

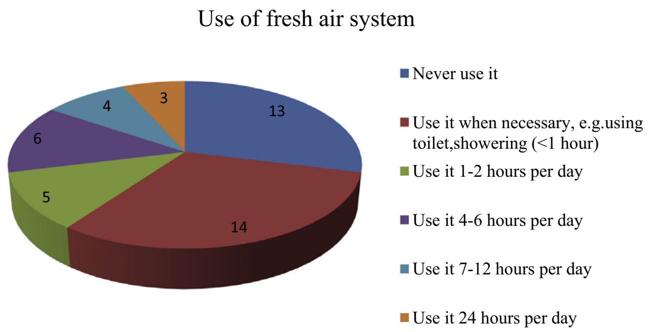

Fig. 8. Use duration of fresh air system in Huixin ($n = 45$).

In the Huixin case, together with the radiators and regulation valves, metering systems were installed in 65 apartments. Every year, after the heating supply stops, the manufacturer collects the devices to return them before winter. Only 13 of the 65 residents indicated that they understood the metering devices, but varied in answers about what was metered: "*temperature*" (H13), "*heat amount*" (H14), "*I didn't pay attention, but I am confident it must be Kcal*" (H7). Only one resident (H15) "*looked at the device very seriously, and I found that there was no number on it, nothing changed on the metering, which is weird*". Most of the Huixin residents were in favor of a meter-based energy charging system that would allow them to decide for themselves the amount of heat used and the related costs throughout the year. Most saw it as an inevitable policy promoted strongly by the government, with the possibility of saving on heating costs. For others the heating costs were paid by their employers (Beijing Uni-Construction Company). However, this argument was also used by residents who opposed meter-based heat fees. A minority (16 out of 77) was not in favor of a meter-based energy fee system, because it was considered unfair as some apartments (on top and facing north) had less favorable conditions and would thus have to pay higher heating costs. A few also calculated that they would most likely have to pay more, as they preferred an apartment with a higher temperature than their neighbors did. In the Fuyuan case, heat metering devices have screens which display consumed energy quantity. Some residents did not notice the numbers, while others did notice the numbers but did not know what the numbers meant. One guessed that the numbers indicated temperature, but another noticed that the numbers went up gradually and did not indicate temperature. In Tidong (without any meters), residents had diverse opinions: many expressed that they did not really understand the principle of meter-based fees, some in favor found it reasonable, while others thought meters were inaccurate or found fixed fees more convenient.

5. Performance and lessons learned

Overall, most residents consider their apartments and buildings warmer and more comfortable after the retrofit, and thus generally have a positive attitude toward the past retrofitting of walls and windows. The satisfaction rate of Huixin, Tidong, Fuyuan cases was 93.5%, 84%, and 74%, respectively. Some expressed worries related to fire-proof properties of used materials and the consequences for earthquake sensitiveness of the building. Energy saving and the environment hardly plays a role in the overall positive evaluation, only insofar as it is related to energy costs. Most residents reported that the reason that they agreed to the retrofit was because they wanted to improve their quality of life and not necessarily because they were interested in protecting the environment by saving energy. While many residents adopted and installed new energy efficient technologies, such as fresh air systems, meters, and valves, only some residents incorporated these in their daily energy use practices and were satisfied with them. Most residents still do not use these new technologies, and some even demolished them.

To some extent, the degree of satisfaction was related to the degree of residents' participation in decision making, and in particular satisfaction was affected by the way residents were involved in the retrofitting process. Residents of Huixin had the most input regarding which technologies would be installed in their homes. This central government-led model was the first demonstration project in Beijing, with technology input by a German company, and with the idea of encouraging public participation. Residents had several possibilities to gain knowledge about and discuss the retrofitting project. These residents responded with the highest satisfaction rate. In the Tidong case, where 84% of the residents were satisfied, external thermal insulation was installed without residents' agreement. In this local-government led case, local governments promoted this 'easy to implement' model to reach their policy target. Although resident participation seemed to be rather low, resident satisfaction was quite high, which may be related to the fact that free-of-charge retrofitting led to an added value for their apartment. The combined retrofit-and-renewal model, the Fuyuan case, shows the lowest satisfaction rate. Although there were more promotion activities than in the Tidong case, the active involvement of neighborhood workers trying to persistently persuade residents to support retrofitting made some residents felt forced to agree. Since the Fuyuan case involved major changes, residents who felt persuaded toward retrofitting may not have been completely satisfied when they moved back into their apartments and saw them substantially changed. This also resulted in demolishing some of the new infrastructure. In sum, voluntary participation of residents in the decision making process is important to ensure residents' high satisfaction. Lastly, economic costs are likely to be prioritized by residents, and should be adequately addressed in any retrofitting project. But resident co-investment may also lead to feelings of ownership, stronger involvement and higher levels of final satisfaction, as the Huixin case seems to indicate.

Behavioral change only took place to a limited degree in the three cases. Overall, residents did not favorably change their routines of opening windows, nor did they use the fresh air systems properly. But participation does seem to make a difference. Part of the impact of the Huixin participatory approach of residents' behavior can be seen in the use of the valves. Nearly half of the respondents reported that they sometimes adjust the valves, far more than in the less participatory Fuyuan project, where the great majority of residents were of the opinion that installers had set the valves correctly. Apparently, information provision and training of residents was not enough in any of three cases. Even in the Huixin case, residents were not well informed and trained in terms of the function and usage of certain new technologies. In all cases, residents did not seem to see a relationship between valves and metering devices. The latter may also be caused by the fact that in all three cases the heating fee remained the same before and after retrofitting, and information on the actual collective energy saving for heating in winter remained absent. Residents could not see the effects of behavioral change in terms of costs.

Based on the three cases, we may conclude that retrofitting projects should not only involve residents, but should also take into account the preferences, motives, knowledge and dwelling practices of residents in implementing these projects. It is not enough to involve residents in the selection of retrofitting technologies. Residents in the Fuyuan case were partly persuaded, with the consequence that some of them threw away some of the infrastructure afterwards and did not change their behavior to make full use of the newly installed technologies. In the Huixin case, residents themselves had invested in retrofitting, but in the end did not monitor energy use nor experience cost savings, and hence were not able to maximize energy use efficiency through behavioral adaptation. A focus on residents' motives, preferences and dwelling practices is needed throughout the whole process (and decision-making) of retrofitting. Furthermore, dissemination of information, extensive explanation and training of using energy saving technologies and devices should continue in the use phase, especially for technologies that cannot be considered common and imply new energy use practices/routines.

The three case studies analyzed in this paper represent three different models of retrofitting for buildings. The differences of the models to a large extent were determined by the variation in the organizers and their targets and priorities. The Huixin case provides a good example of diverse investment sources, various technology alternatives and attempts to fully mobilize participation of residents. In comparison to the other two models, the promulgation activities in the first model were relatively successful. However, subsequent information dissemination, training in terms of technological applications and explanation in the use phase was absent, while these will be essential in order to become a benchmark for retrofitting projects. The local government-led model might be currently the most widely applied model in the area of existing building retrofitting. Local governments seem to be preoccupied to a large extent with political targets on the number of houses retrofitted for energy saving, and have less concern about maximizing energy saving technologies installation costs and energy saving performance. This asks for more specific energy saving performance indicators for retrofitting in the assessment index of local authorities. The Fuyuan case represents the model of building retrofitting combined with renovation of shanty houses ('Penghu Qu'). It shares with the Tidong case model, the preoccupation with political targets on number of houses retrofitted (and now also the number of energy saving technologies installed) and a neglect of actual energy saving performance. Future projects need to also consider and target energy conservation, consumer satisfaction, and living comfort. Involving residents, taking their motives and demands seriously, and monitoring energy changes helps in moving these targets central stage in retrofitting.

6. Conclusion

By analyzing three case studies of retrofitting old residential buildings in China to improve the buildings' energy performance, this paper has proven that public participation is relevant in planning retrofitting, executing the retrofitting and implementation and use of retrofitting technologies by residents. With the exception of wall insulation, executing energy retrofitting in residential buildings as a top-down project of implementing energy efficient technologies will severely limit the energy saving potential. Reasons for this are, among others, that implemented technical options will be delimited when designing projects in a top-down manner, and many retrofitting options require coordination among residents and their active agreement. Furthermore, as our cases show, de facto use efficiency of devices will be low if residents are not involved in the discussion of the rationale behind the technologies, their selection and implementation. Throughout the process, it is important to be aware of the residents' purpose, motives and dwelling practices related to energy retrofitting. For that, residents need to be more fully engaged, informed, and educated about the retrofitting goals, (technological) means and processes. The interactions between project managers, developers, implementers and residents should be strengthened, not only (or even primarily) in terms of finance, but also in terms of decision-making, communication and education. Try-outs, demonstration sessions, asking for feedback, organizing consultations, and extending services at different phases (before, during, after) are all elements of such extended interactions.

Residents, as energy end users, should be given full attention during the retrofitting process, in even more and different ways as happened in the three case studies in Beijing. Residents have their own personal circumstances in terms of age, income level, education, peer groups, lifestyles, and energy use routines. Retrofitting residential buildings with new energy saving technologies without taking these circumstances into consideration might very well play a role in causing dissatisfied residents, misuse of technology, destruction of installed technologies, and waning support for future programs. While our sample size was too small to statistically investigate how personal circumstances and characteristics affect energy saving success, anecdotal evidence from interviews has pointed in this direction. This would be a major avenue for new research in order to let retrofitting programs better take personal circumstances of residents into consideration, and adapt technological options, related supportive (training) programs, information provision, demonstration sites, and 'after sales' services to those circumstances of residents.

There is also one reassuring development. Energy saving retrofitting is high on the agenda of China's energy and climate change policies in the 12th Five-Year Plan and beyond. As China is only just starting to implement such energy saving retrofitting projects in residential buildings, these lessons for better public participation are very timely. With the progression and diffusion of such retrofitting projects we can also expect that urban residents will become more aware and knowledgeable of energy saving technologies, which will contribute to reducing resident dissatisfaction with, and the wrong use and destruction of, (in principle) valuable home innovations.

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