A Review of the Existing Residential Building Retrofit in Tianjin, China

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Abstract. Tianjin, situates 120 km southeast of the capital city Beijing, is the largest open coastal city in northern China and has high economic status. From the beginning of the 20th century, the municipal government has done a lot on residential building retrofit. In China, the policies as well as standards of local governments play an important role in guiding and supporting the building industry. This paper clarify the characteristics of the existing residential buildings, and attempts to review the policies, standards and retrofit pilot projects implemented by governments since the beginning of 20th century in Tianjin. Four stages of retrofit process toward residential buildings in Tianjin are indicated: reconstruction of shanty housing, retrofit of basic function including building facade beautification, outdoor environment update and balcony reinforce, energy saving retrofit and comprehensive retrofit based on sustainable conception. In each stage, policies, retrofit principles and typical cases are analysed. We also shows that lots of retrofit technologies have been applied which can reduce energy consumption effective and make living environment more comfortable. But it also has many problems of residential retrofit, such as lack of local standards and financial strategy. Meanwhile, the trend of retrofit is predicted, which is based on sustainable concept, aimed at building performance, integrated with environmental protection, energy saving and high efficiency. At last, some suggestions are also presented for existing residential buildings retrofit in Tianjin.

1. Introduction
In China, the existing buildings that cannot meet the demand for use accounts for about 30-50% of the total building energy consumption [1]. In the National Science and Technology Support Program for the 11th Five-Year Plan, the research and demonstration of key technologies for comprehensive building retrofit have been emphasized. Subsequently, the Special Planning for Scientific and Technological Development of Green Building in the 12th Five-Year Plan period also specifies that green retrofit of existing buildings should be treated as a key task.

As the north economic center of China, Tianjin has its unique regional culture and architectural style. Since the impact of 1976 Tangshan (a city near Tianjin) earthquake, lots of buildings in Tianjin need reconstruction. But the buildings built in this period cannot meet the demand of today’s people [2-3]. It is imperative to retrofit on account of the development for socio-cultural factors.

Tianjin has promulgated many policies and standards, and became one of the earliest cities to carry out large-scale existing residential buildings retrofit (ERBR) projects. There are many scholars focus on the ERBR in China, but most of them only pay attention to any one or two aspects of policies, financial model and pilot projects to get some conclusions. As we all know, it is essential to understand policies and standards clearly to complete the retrofit process. This paper summarized primary policies,
standards and pilot projects of ERBR, pointed out achievements and shortcomings of different retrofit methods, in order to dissect policy trend and comprehensive the concept of retrofit. Finally, some comments for ERBR in future were given to provide reference.

2. Existing Residential Building Stock

According to the statistics, by 2016, urban residential buildings accounted for 43.89% of the total building area in China, which occupied 37.71% of the total building energy consumption [4]. Since 1986, Chinese government has attached great importance to building energy conservation, and promulgated relevant policies [5-6]. But most of the residential buildings built until the end of the last century cannot meet the standards because of unbalanced development of regional economy and society [7-8].

Tianjin is located in the North China Plain, 120 km away from Beijing. It is hot and rainy in summer, cold and dry in winter. On the basis of China's thermal design zoning, Tianjin belongs to cold climate (B) zone [9], which regulated that in the process of building design, it should meet the needs of thermal performance in winter and take into account the heat prevention in summer [10].

At the end of last century, the old residential buildings in Tianjin were demolished and reconstructed in a large scale due to earthquake disasters, also for meeting the requirements of population explosion. At that time, all reconstructed building were set up according to the design standards formulated by Tianjin Architectural Design Institute. These buildings are structurally stable and can continue to be used. [11-14]. Most envelop material of them are 370mm solid brick combined with the steel concrete as load-bearing components (Figure 1). These buildings have flat roofs, one or two rooms, and the typical floor plans are shown in Figure 2 to Figure 4 [15]. Because there is no insulation layer, caused lower indoor temperature in winter and higher in summer, resulting in cooling and heating loss.

![Figure 1](image1.png)

**Figure 1.** Existing residential buildings in Tianjin

![Figure 2](image2.png)

**Figure 2.** Floor plans of One-bedroom

![Figure 3](image3.png)

**Figure 3.** Floor plans of two-bedroom

![Figure 4](image4.png)

**Figure 4.** Floor plans of three-bedroom

The existing residential buildings (ERBs) we mentioned above built in 1980 to 2000 are in large number and brings a series of problems, such as unreasonable division of indoor functions, high energy consumption and uncomfortable community environment. So corresponding measures should be taken since the development of society. Furthermore, there are many scholars indicate that retrofit is an environmentally better choice than the construction of a new building by use different research methods [16-18]. In this context, we have studied ERBR in detail from many aspects, summarize the experience both here and abroad, and point out the shortcomings in the following section.
3. The Experience of ERBR in Tianjin

3.1. Policies and standards
Initially, the boom in policies issued for residential buildings started after the 1976 Tangshan earthquake. From 2000, according to Technical Specification for Energy Conservation Renovation of Existing Heating Residential Building (JGJ129), Tianjin municipal government began to retrofit the ERBs to do some exploration. At first, the documents called Flat-to-sloping Roof Conversion Implementation Plans promulgated by government provided retrofit content and process of the roofs. The projects alleviated the problem of heat loss through buildings’ roof and beautifies the facades, as seen in Figure 1(c). This conservative retrofit is worth advocating rather than demolishing, raises by scholar Dongfan W [19].

From 2005, Tianjin has become the second city to implement The Third Step Energy Saving in China (i.e. the energy consumption level of newly designed heating residential buildings saved 65% on the basis of the energy consumption level of local general design in 1980-1981). Since 2008, Tianjin has gradually implemented some policies of heating system retrofit and planned to finish some comprehensive retrofit of typical ERBs. Relevant works during this period play an important guiding role in carrying out ERBR projects. In 2011, Tianjin took the lead in The Fourth Step Energy Conservation Plan that saved 75% energy consumption, expanding the area of ERBR gradually, supplementing and updating standards, pointing out the ERBR will become a continuous work. In 2018, the Tianjin government changed the heat source from coal to gas, and began to retrofit the community by the requirements of sponge city. Relevant data is shown in Table 1-3.

| Year | Name                                                                 | Remark                                           |
|------|----------------------------------------------------------------------|--------------------------------------------------|
| 2003 | Guiding Opinions on Pilot Work of Urban Heating System Reform [20]    | Initial exploration of heat metering.            |
|      | Implementing Scheme of Heat Metering and Energy Saving Retrofit for 13 Million square meter ERBs in Tianjin | Implemented heat metering retrofit, explored the organization pattern and financial problem. |
| 2012 | Energy Saving and Emission Reduction in Tianjin during the 12th Five-Year Plan | Indicated that Tianjin completed 12 million square meters of energy saving retrofit of existing buildings. |
| 2014 | Tianjin Green Building Action Plan                                   | Promoted energy saving retrofit and implemented heat metering retrofit. |
| 2017 | Tianjin Construction Commission Implement the Concept of Green Building | There are 43.74 million square meters of energy saving retrofit of ERBs have been completed in five years. |
|      | Notice on Strengthening the Management of Sponge City Construction    | Including the retrofit of permeable pavement, parking lot, green spaces, rainwater collection system and pipe network. |
| 2018 | Pilot Project of Sponge City Retrofit of ERBs in Tianjin has been Launched Extensive |                                                |

Table 1. Policies and works

Notes: Mentioned above come from Tianjin Municipal People's Government Network, http://www.tj.gov.cn/zw/

3.2. ERBR for Energy Saving
Tianjin has completed many projects of ERBR. The stage of demolition and reconstruction mentioned above targeted the shanty houses, has been completed basically. Projects of facade beautification mainly includes the flat-to-sloping roof conversion and some simple methods, such as repainting the building. There are a few projects about outdoor environment update including increasing green space, adding parking spot, repairing pavement and providing leisure space. ERBR for energy saving is the popular method that government promotes vigorously nowadays. Compared with the previous stages, energy saving retrofit has tended to diversify. This section mainly summarizes pilot projects of energy saving retrofit in Tianjin. [21-22]

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Table 2. Guideline and atlas

| Year | Name                                                                 | Remark                                                                 |
|------|----------------------------------------------------------------------|------------------------------------------------------------------------|
| 2008 | Technical Guidelines for Heat Metering and Energy Saving Retrofit of Existing Residential Buildings in Tianjin (MOHURD 2008 NO.442) | The main contents included heating system retrofit and roof retrofit. |
| 2009 | Guidelines for Heat Metering and Energy saving Retrofit of Existing Residential Buildings in Tianjin (MOHURD 2008 NO.939) |                                                                        |
| 2009 | Approaches for Acceptance of Heat Metering and Energy Saving Retrofit Projects of Existing Residential Buildings in Northern Heating Areas (MOHURD 2008 NO.216) |                                                                        |
| 2011 | Agreement on Heat Metering and Energy Saving Retrofit of Existing Residential Buildings in Northern Heating Areas |                                                                        |

Table 3. Standards

| Year | Name                                                                 | Remark                                                                 |
|------|----------------------------------------------------------------------|------------------------------------------------------------------------|
| 2001 | Unified Standards for Constructual Quality Acceptance of Building Engineering GB 50300-2001 (Old Version), GB 50300-2013 | The formulation of standards provided comprehensive technical support, achieved technology integration, and formed a relatively complete system for the retrofit of ERBs in Tianjin. |
| 2008 | Specification for Design of Heat Measurement-based Supply System in Residential Building with Central Heating of Tianjin DB 29-26-2008 (Old Version), DB 29-26-2017 |                                                                        |
| 2008 | Tianjin Energy Efficiency Design Standard for Residential Buildings DB 29-1-2010 (Old Version), DB 29-1-2013 |                                                                        |
| 2010 | Tianjin City Accepting Specification for the Quality of Energy-efficiency Engineering of Civil building DB 29-126-2010(Old Version), DB 29-126-2014 |                                                                        |
| 2015 | Assessment Standard for Green Retrofitting of Existing Building       |                                                                        |
| 2018 | GB-T 51141-2015                                                      |                                                                        |
| 2018 | Design Standard of Green Building for Tianjin DB29-205-2015           |                                                                        |

3.2.1. Envelope. Retrofit of envelope is the primary object because of the high heating and cooling energy consumption. Relevant research shows that the energy loss of external wall and window is the main factor of high building energy consumption, and the proportion of exterior wall is larger than window, so the effect is obvious after retrofit. [23]. In Tianjin, the principal method to retrofit the external wall is to increase the insulation layer. The thickness of insulation in the pilot projects are about 50-70 mm and the main material is EPS or XPS which are common used. Exterior insulation is used to reduce the impact of residents and condensation phenomenon of inside walls. The structure diagrams of exterior insulation used in Tianjin are shown in Figure 5 and Figure 6.

Most of the windows in ERBs are aluminum alloy with single glass. There are two difference methods of window retrofit. One is to replace the existing window with double glass (5mm+12mmAir+5mm) plastic steel window (Figure 7), the other is to retain the existing window and add a new layer of single glass (5mm) plastic steel window.

There are two methods for roof retrofit: flat-to-sloping roof conversion and insulation layer added. Flat-to-sloping roof conversion refers to adding a sloping roof on the basis of the existing flat roof, which can not only beautify the facade of the building, but also play an important role in heat preservation by the air interlayer (Figure 8). Steel structures can also be used for sloping roofs, but attention should be paid to their mechanical property and daylighting requirement [24]. In addition, upright roof is used generally for adding insulation layer, which structure is shown in Figure 9.

3.2.2. Staircase and balcony. As the component between indoor and outdoor space, staircase plays an important role in building thermal performance. Most of the staircases in ERBs were not designed the entrance doors at first, which directly led to the loss of heating and cooling. In most projects, insulation doors with self-closing function has been added to improve thermal performance effectively, and
Towards SBE: from Policy to Practice

IOP Conf. Series: Earth and Environmental Science 329 (2019) 012036
doi:10.1088/1755-1315/329/1/012036

intercom system has been installed to ensure the safety of communities. Moreover, some pilot projects also using single glass (5mm) plastic steel window to replace the existing window of staircase.

For the open balcony of the ERBs, most of them are already sealed by residents using single glass windows. In the retrofit projects, all of the balcony were sealed by using single glass (5mm) plastic steel windows, reinforced for safety and added insulation for thermal performance.

3.2.3. Heating system. The retrofit of heating system can divide into three parts: indoor heating system, heating pipe network and the heating source. The retrofit of indoor heating system included pipe network maintenance, temperature control system and heat metering system. The retrofit of heating source focused on improving boiler efficiency. In recent years, Tianjin has implemented the transformation of replacing coal with gas, which has greatly improved the efficiency of heating source. The retrofit of heating system can greatly reduce energy consumption in winter. Heat metering retrofit also enhanced the enthusiasm of households and popularized energy saving awareness.

3.2.4. Retrofit mode. In the process of ERBR, it has formed a variety of retrofit models in China, including government-led, heating enterprises-led, energy service companies-led, property rights units-led and other types. Most of the projects in Tianjin are dominated by municipal government who selected and determined the implementing company through bidding. After completion and acceptance, the projects shall be submitted to the superior management department for examination and evaluation. The cost of retrofit mostly funds by the government, and many pilot projects are welfare-oriented.

In summary, Tianjin has done many works of ERBR and formed a retrofit system. This section also summarizes some typical pilot projects, as shown in Table 4. According to the statistical data, the cost of ERBR in Hemu community is about 250 RMB/m². The retrofit can reduce about 40% of heating consumption and 43% of coal consumption. Flat-to-sloping roof conversion completed in Zijin community can also shorten the use time of air conditioning for top level residents by about 30% in summer, which is worthy although it is expensive. [25-28]

3.3. Other research of ERBR

Many scholars at home and abroad have studied about ERBR. These achievements can also provide reference for the future retrofit works in Tianjin.
Table 4. Pilot projects of ERBR

| Community Name | External Wall | Windows & Doors | Roof | Building Structure | Indoor Heating System | Outdoor Heating Network | Heat Source | Outdoor Environment |
|----------------|---------------|-----------------|------|--------------------|-----------------------|------------------------|------------|---------------------|
| Dongjiang Community | -             | Δ               | □    | -                  | √                     | √                      | √          | -                   |
| Taoyuan Community   | √             | Δ               | □    | √                  | √                     | √                      | √          | -                   |
| Hemu Community      | √             | Δ               | □    | √                  | √                     | √                      | -          | -                   |
| Zijin Community     | -             | -               | ■    | √                  | -                     | -                      | -          | √                   |
| Guanyun Community   | √             | Δ               | □    | -                  | √                     | √                      | -          | -                   |
| Tanggu Street NO.1  | √             | ▲               | □    | -                  | -                     | -                      | -          | -                   |

Notes: Δ. Window Replacement, ▲. Add Window, □. Add Insulation, ■. Flat-to-sloping

Numerous researches have shown that retrofit the windows and walls separately is uneconomical, it should combine with the heating system simultaneous. Furthermore, the scholar Shuqin C takes the ERBR projects in north China as an example, suggest that we should have specific target before retrofit. Aimed at reduction of space heating intensity, different retrofit packages can achieve 50% and 65% reduction by use simulation method. [23, 29-31]

On the other hand, many scholars have studied the retrofit of heating system, the results show that energy saving rate of 18.5% can be achieved by using of intermittent regulation of the heat exchange station [32]. Scholar Xin L researched the evaluation system for heat metering by using multi-level expert evaluation method, suggested rewards and punishment mechanism [33]. Another scholar figured out government financial subsidies should concentrate on supporting high-cost retrofits (building envelope measures) only. Heat metering, heating source and pipeline measures are more likely to attract funding in the retrofit market because of their lower cost and greater cost-effectiveness [34].

Due to various reasons, ERBR has not been widely popularized. Only pilot projects have been carried out in some cities. Actually, the effective retrofit methods proved by practice mainly include external wall and heating system retrofit.

4. Discussion and Conclusion

According to these works of ERBR, envelop and heating system retrofit are the most wildly used as well as effective methods in Tianjin. ERBR is a continuous project, from large-scale demolition to comprehensive retrofit, Tianjin has made many achievements. Social and cultural awareness has been improved than before, which indicate that it will turn to a sustainable retrofit aimed at building performance and integrated with environmental protection, energy saving and high efficiency. However, it also have some problems: a. There is no complete design standards for ERBR in Tianjin, results in most projects were limited to envelop and heating system and lack of retrofit for indoor functional space. b. Although some communities have finished environmental update project, there are some unsolved problems, such as the confined area of parking lot, lack of public space, etc. c. Because most of the cost funded by the Chinese and municipal government, the financing modes, incentive policies and reward mechanisms have not been generalized. For these reasons, ERBR cannot be popularized and still in the stage of pilot projects. d. Few residents participated in the ERBR caused the process slowed down, and the energy saving effect after retrofit was unsatisfactory, which may because the residents’ motives, intentions and living habits were not taken into account during the retrofit projects [35].

Taking Tianjin as an example, this paper summarizes the development process of ERBR, points out the problems to provide reference of retrofit research. Indeed, implementation of the discussed methods
is not always viable, ERBR is difficult in some respects. However, it's remarkable that a comprehensive review based on policies, projects and researches are essential obviously. Furthermore, suggestions are presented: a. In view of the development conception, ERBE should be a long-term works for our country devoted to sustainable development, to attain the goals of energy efficiency improvement and higher life quality for residents, to popularize awareness of energy conservation and environmental protection, to eliminate unnecessary waste of natural resources and to retain the historical value of these ERBs. b. Besides the retrofit funds, it is also an important issue that deficiency in energy saving awareness hindered development. Thus, we deem that highlighting the importance of public participation is contributes to the development of ERBR. c. Building reflects the development of society, economy and culture. It is not suitable to demolish all old buildings. When the structure of residential buildings is firm and safety, considering to the energy consumption, economy performance as well as the research results, it should be retrofit rather than reconstruction.

5. Acknowledgement
The work in this paper was supported by the National Key Research and Development Program of China (2016YFC0700200) and the Program of Introducing Talents of Discipline to Universities (B13011). We would like to thank the anonymous reviewers and the editors for their valuable suggestions and comments.

References
[1] Yutong L, Jun R, Zhou J, Jianping L and Qing Yea 2017 The Existing Building Sustainable Retrofit in China-A Review and Case Study J. Procedia Engineering 205 3638–45.
[2] Tianjin Urban Housing Census Office 2001 Data Collection of Residential Houses of Tianjin City (Tianjin) Tianjin Urban Housing Census Office.
[3] Weixin L 1990 A bold exploration of urban renewal: objectives, stages, experiences and characteristics of old city renewal in Tianjin J. Reform of Economic System 05 64-68.
[4] Special Committee on Energy Consumption Statistics of China Building Energy Conservation Association 2018 China Building Energy Research Report J. Construction and Architecture 02 26-31.
[5] CABR 1986 Energy Conservation Design Standard for New Heating Residential Buildings (JGJ26-86) (Beijing) Ministry of Urban and Rural Construction and Environmental Protection.
[6] CABR 1995 Energy Conservation Design Standard for New Heating Residential Buildings (JGJ26-95) (Beijing) Ministry of Construction of the PRC.
[7] MOHURD 2012 12th Five Year Special Plan of Building Energy Conservation. Document of MOHURD http://www.gov.cn/zwgk/2012-05/31/content_2149889.htm.
[8] Jinhong O, Chunyuan W, Haifeng L and Kazunori H 2011 A methodology for energy-efficient renovation of existing residential buildings in China and case study J. Energy and Buildings 43 2203–10.
[9] MOHURD 2016 Code for Thermal Design of Civil Building (GB50176-2016) (Beijing) China Architecture & Building Press.
[10] Xiaotu L 2010 Building Physics (Beijing) China Architecture & Building Press.
[11] National Bureau of Statistics 1985 China Building Almanac 1984-1985 (Beijing) China Architecture & Building Press.
[12] Zhonglin G 1990 Modern Architecture in Tianjin (Tianjin) Tianjin Science and Technology Press.
[13] Shuwei L 1993 Modern Urban History of Tianjin (Beijing) China Social Science Press.
[14] Department of Science and Technology for Ministry of Construction 1997 A Collection of Demonstration Projects for Well-off Residential Buildings in China (Beijing) China Architecture and Building Press.
[15] Xin L 2006 Research on Development and Renovation of the Old Multi-floor Residence in Tianjin, Tianjin University.
[16] Ireland D 2005 How to Rescue a House: Turn an Unloved Property into Your Dream Home.
(London) Penguin Books.

[17] Erlandsson M and Levin P 2005 Environmental Assessment of Rebuilding and Possible Performance Improvements Effect on A National Scale J. Building and Environment 40 1459-71.

[18] Anne P 2008 Does Demolition or Refurbishment of Old and Inefficient Homes Help to Increase Our Environmental, Social and Economic Viability? J. Energy Policy 36 4487–501.

[19] Dongfan W 2002 Historical and Cultural during the Reform of Old Areas: Reflections on Renovation of Old Residential Buildings in Tianjin (Tianjin) Urban Conditions 21, the 46th IFMP World Congress.

[20] Jiangde Y 2011 Policy and Models of Reconstruction of Energy Saving for the Existing Residential Building in Tianjin J. Building Energy Efficiency 39 74-7.

[21] Yan W 2012 Study on Appropriate Strategies for Technologies Renovation of Existing Residential Building in North China: Cases in Tianjin, Hebei University of Technology.

[22] Hongwei Y, Li L, Xiaojun L, Conghong L and Phil J 2016 Tailored Domestic Retrofit Decision Making towards Integrated Performance Targets in Tianjin, China J. Energy and Buildings 140 480-500.

[23] Shuqin C, Jun G, Mark D L, Linna X and Yowargana P 2013 Elaboration of Energy Saving Renovation Measures for Urban Existing Residential Buildings in North China Based on Simulation and Site Investigations J. Building Simulation 6 113–25.

[24] Weiwei W 2008 Techno-economic Study on the Energy Efficiency Transformation of the Extant Residence Buildings, Changan University.

[25] Lifeng Y 2014 Study on Existing Residential Building Energy Saving Reconstruction in Tianjin, Tianjin University.

[26] Ling Z 2017 Study on the Transformation of Old Residential District, Tianjin University.

[27] Shengbo Z 2007 Analysis on Energy-saving Renovation of Existing Residential Buildings in North China: Taking Taoyuan Nanli Residential Renovation in Hongqiao District of Tianjin as an Example J. science 30 595.

[28] Ying G, Yue F, Yiye B, Xiao W and Qiong Z 2016 Comparison of Existing Residential Buildings Retrofit toward Six Cities in North China J. Housing Industry, 05 45-50.

[29] Chuanzhili L, Mengmeng L and Yong W 2012 Research on Indoor Thermal Environment in Winter and Retrofit Requirement in Existing Residential Buildings in China’s Northern Heating Region J. Energy Procedi 16 983-90.

[30] Yuming L and Weijia G 2013 Effects of Energy Conservation and Emission Reduction on Energy Efficiency Retrofit for Existing Residence: A case from China J. Energy and Buildings 61 61–72.

[31] Shuqin C, Jun G, Mark D L, Haiying L and Yowargana P 2015 Evaluation on Retrofit of One Existing Residential Building in North China: Energy Saving, Environmental and Economic Benefits J. Procedia Engineering 121 3-10.

[32] Xin L, Chenchen W, Chuanzhi L, Guohui F, Zekai Y and Zonghan L 2018 Effect of the Energy-saving Retrofit on the Existing Residential Buildings in the Typical City in Northern China J. Energy & Buildings 177 154-72.

[33] Xin L, Yan D, Yujia T, Neng Z and Zhe T 2014 Research on the evaluation system for heat metering and existing residential building retrofits in northern regions of China for the 12th five-year period J. Energy 77 898-908.

[34] Shilei L, Wei F, Xiangfei K and Yong W 2014 Analysis and Case Studies of Residential Heat Metering and Energy-efficiency Retrofits in China’s Northern Heating Region J. Renewable and Sustainable Energy Reviews 38 765-74.

[35] Wenling L, Jinyun Z, Bettina B, Arthur P J M and Can W 2015 Public Participation in Energy Saving Retrofitting of Residential Buildings in China J. Applied Energy 147 287-96.