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ECOLOGICAL RENOVATION PROCESS OF
NANJING’S HOUSING STOCK BUILT BETWEEN 1840 AND 1949, CHINA

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Abstract: Numerous in number and mostly still in use, buildings built between 1840 and 1949 are valuable assets in the rapid development & renovation of Chinese cities. However, due to lack of maintenance and being inhabited mainly by the elderly and people with low incomes, many of these buildings are in poor condition and have much higher possibilities of being demolished. The objectives of ecological renovation presented in this paper are to improve building performance and to achieve higher levels of comfort and lower levels of energy consumption. The housings in Zhong-nong-li block in Nanjing are used as an example in this paper to show how a strategy of “basic” Renovation and “thorough” Renovation used in the ecological renovation of housing stock

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between 1840 and 1949 in China. The paper demonstrates that these are very practical steps for this building stock in China, and could not only help to balance social and economic factors in practice, but also improve the living conditions of the residents, and endow the old houses with a new, long life. Numerical simulations of the natural daylighting and ventilation situations before and after renovation are made to show the improvement in building performance after renovation.

**Keywords:** Ecological Renovation, Housing Stock built between 1840 and 1949, Higher Levels of Comfort, Low Levels of Energy Consumption, Basic Renovation, Thorough Renovation

1. INTRODUCTION

1.1 THE BACKGROUND AND PURPOSE OF THE RESEARCH

Located in the delta economic zone of the Yangtze River, Nanjing has always been one of the most important cities in China. With an urban population of 8.16 million (2013), Nanjing is the second largest commercial center in eastern China, after Shanghai. It has been ranked at the fourth place by Forbes magazine in its listing of "2008 Top 100 Business Cities in Mainland China", and also was awarded the title of 2008 Habitat Scroll of Honor of China, Special Award of UN Habitat.
Scroll of Honor and National Civilization City. Nanjing was the capital of the Republic of China before the Chinese Civil War. It is renowned for buildings built between 1840 (Opium War) and 1949 (establishment of People’s Republic of China). (Fig. 1 and Fig. 2). This building stock in China is an important part of Chinese modern architecture (1840-1949), symbolizing the crucial transition from traditional to modern architecture in the history of Chinese architecture. Numerous in number and mostly still in use, these buildings are valuable assets in the rapid development & renovation of Chinese cities.

Zhong-nong-li block lies in the downtown of Nanjing. Most of the housing here was built in the Republic of China era (1911–1949). Due to being built very long ago and suffering from a lack of maintenance, the housing is in poor condition (Fig. 3, Fig. 4), leading to the situation of high levels of energy consumption and low levels of comfort. With the rapid renovation of Chinese cities, poor building conditions and performance are usually the main reasons for buildings (even whole blocks) to be demolished. At the same time, because the inhabitants are mainly elderly and people with low incomes, this situation not only threatens the protection of these buildings, but also affects the health of the occupants.

Therefore, ecological renovation is crucial for improving building performance so as to provide inhabitants with living environments that have a high level of comfort and low energy consumption, and at the same time, preserve the invaluable cultural value of these buildings. The purpose of this paper is to explore ecological renovation methods of the buildings built between 1840 and 1949 in China so that they can better fulfill the need of current and future life.

1.2. RECENT DEVELOPMENTS AND CURRENT LITERATURE IN THIS FIELD

Ever since the UNESCO Nairobi Declaration in 1976 and the Washington Charter of 1987 set out the need for the preservation of historic cities to be integrated with development to make them "adapted to contemporary life," significant progress has been made in the study of historic building conservation and renewal at home and abroad. A great deal of research has been conducted, and renovation projects implemented, providing the background for the research reported here.

The research on the renovation of historical buildings in architecture can be divided into three phases.

1) Restoration of historical buildings

As early as the 18th century, Western architects focused on the authenticity of restoration, based on historical information and the original style in order to continue the historical and cultural value of historical buildings.

2) Adaptive renovation and functional updating
Adaptive renovation refers to the process of adapting old buildings to new functions on the premise of preserving their historical characteristics. In 1977, the United States Secretary of the Interior formulated a standard for the restoration and adaptation of historic buildings (the standards for rehabilitation), which was later revised in 1990 and again in 1995. The standard made restrictions on the possible new functions of buildings in order to minimize the influence of the renovation on the historical building.  

3) Technical/ecological renovation and building performance improvement

With sustainable development becoming a new imperative, more and more attention is being paid to the improvement of building performance of old buildings by technical/ecological renovation, especially in the United States and Europe. In the United States, Harvard University is a good example for this. The "Green Campus Plan" has become an important direction for future development of the university, with a large number of projects appearing in recent years. The author made a detailed research on Harvard's "Green Campus Plan" when acting as a visiting scholar at Harvard in 2007.

Germany, France, the United Kingdom and other Northern European countries are taking a leading role in the research of sustainable development in the renovation of historical buildings. The University of Nottingham Jubilee (Jubilee Campus) is regarded as the milestone in Green Building. Being one of the most remarkable green community projects in Denmark, the ecological renovation of the Hedebygade community in Copenhagen successfully revitalized the neighborhood in the old city through ecological renovation. The project integrated a number of low-energy technologies, which not only provided a comfortable living environment for residents through building performance improvement, but also achieved considerable energy-saving results.

In China, increased attention has been put on renovation of historical buildings for the purpose of sustainable utilization. WU Zhiqiang and his team of Tongji University, applied foreign technologies in the exploration of ecological renovation of Wenyuan Building, Tongji University. Professor LIU Shao-Yu of the University of Hong Kong and his team applied green building renewal technologies in the renovation of News & Media Research Centre in the east wing of Eliot Hall, the University of Hong Kong.

In regard to quantitative evaluation of building ecological performance, the most successful system is the Leadership in Energy and Environmental Design (LEED) green building rating system in the United States. The green building evaluation system in China is divided into "Green Building Design Label" and "Green Building Label".

2. ECOLOGICAL RENOVATION PROCESS OF THE RESEARCH PROJECT (METHODOLOGY)
The ecological renovation research in this paper focuses on the housing in the Zhong-nong-li block as an example to show the process and methods of the design. The research used quantitative simulation & analysis methods to provide effective and feasible ways, helpful to avoid unnecessary damages caused by renovation unsupported by careful analysis.

2.1. CONTENTS AND PROCESS OF ECOLOGICAL RENOVATION

The ecological renovation process in this paper contains a number of steps: “Field investigation- Building performance evaluation- Renovation design-Summaton- Design adjustment(if needed)”. The contents and process are as follows. (Fig. 5)
1) Field investigation and building performance evaluation
To obtain information of the performance of the buildings, we chose extreme climates both in winter and summer, adopting questionnaire and measurement methods to investigate and measure the selected buildings in
the Zhong-nong-li. A total of 30 valid questionnaires were collected and measuring was taken in 7 consecutive days per quarter. The investigation included both the basic information & health condition of residents and the basic information & physical condition of the buildings. Building performance was evaluated according to the data collected.

2) Ecological Renovation process
Based on the performance information obtained in the field investigation, renovation goals & strategies are clarified. Then the performance standards were set according to both renovation goals & strategies and building codes in China. Ecological renovation process forms a two-way loop with quantitative simulation & evaluation and performance standards. If the simulation & evaluation show the performance standards are fulfilled, the ecological renovation process is complete. Otherwise, further improvement and adjustment are made to the design and also further simulation & evaluation will continue to make sure the effect of design until the performance standards are fulfilled.

3) Quantitative simulation and evaluation
Numerical animation & analysis software such as ECOTECT\textsuperscript{13} and CFD\textsuperscript{14} are used to make quantitative simulation of the real effects of ecological renovation process. Comparison is made between the effects of ecological renovation design and the performance standards, enabling evaluation of the design effect and further improvement. Changes in the status of natural lighting and ventilation before and after renovation are compared to show the improvement in building performance.

3. ECOLOGICAL RENOVATION PROCESS: TAKING THE ZHONG-NONG-LI PROJECT AS AN EXAMPLE

Ecological renovation as discussed in this paper is a very sophisticated job. There are two facts that make this work special and difficult.

1). Building envelopes cannot be changed easily due to the rules for cultural & architectural value preservation in China. Possibilities of interior spatial change must also be considered based on the realities of the existing space layout, structural system and piping layout from the very beginning. Therefore, ecological methods and technologies that can be used effectively for new buildings might not be suitable for old buildings.

2). The inhabitants are mainly elderly and people with low incomes. Ecological technologies for building performance improvement must therefore be economical in both initial construction and future maintenance phases.
3.1. Field Investigation and Measurement

To some extent, the problems the selected buildings face are very typical for all housing stock built between 1840 and 1949 in China.\(^{16}\)

The special situation for most housings in China is that cooling and heating are available only in some buildings in the hottest and coldest months, while all the other housings - and in other seasons – mainly depend on natural day lighting and ventilation. This is especially true in the housings in Zhong-nong-li. According to our field investigation, more than 39% of the occupants are low-income retired elders (more than 60 years old), with living area per household only 41-60 square meters (42%). Fewer than 1/3 of the dwelling units have air conditioning (mechanical heating and cooling) and among them only 1/2 (48%) would use air conditioning when it is intolerably cold or hot. (Fig. 6).

3.2. Building Performance Evaluation

Field investigation in both the hottest summer and coldest winter proved that most of the housing in the Zhong-nong-li block, although having great cultural & architectural value, were in poor physical condition. Lack of maintenance, poor or no thermal insulation, high energy consumption and poor interior environments are the major problems in these buildings.

Most of the residents couldn’t afford heating and/or air conditioning for their homes. When the exterior temperature was -2°C (Centigrade) in winter, the interior temperature was only 2°C (Centigrade). Among the residents, 63% thought it was intolerably cold in winter and 62% thought it was intolerably hot in summer. The gap between measured interior average temperature and people’s thermal comfort range is 17.5 °C (Centigrade)! We can imagine how uncomfortable the interior living environments could be. (Fig. 7, Fig. 8)

Second, most of the buildings were constructed without insulation and damp-proofing treatments. Over time, the walls get very wet and seriously mildewed. According to the field investigation, almost half (48%) of the walls and furniture get seriously mildewed in summer and almost 1/3 (31%) got seriously mildewed in winter.

In this case, it is almost impossible to further improve building performance of these buildings by simple renovation (painting, façade renovation, etc.). We need more thorough ecological renovation to get real improvement in building performance and levels of comfort.

3.3. Ecological Renovation Process in two steps
With consideration of economic factors, ecological renovation in this paper follows two steps: basic renovation for short-term improvement and thorough renovation for the long run.

Basic renovation provides the most economical way for immediate improvement in living environments. It is applied to housing with high cultural value but in poor condition, and with few opportunities for thorough renovation in the near future. The contents of basic renovation include building repairs (especially roofs), shadings and the installation of energy-efficient doors and windows if possible. On the other hand, thorough renovation, although costing much more, could insure comfortable interior environments in the long run, especially for those units converted into other functions.

Numerical animation & analysis software such as ECOTECT and CFD were used to make quantitative simulation of the real effects of ecological renovation, enabling easy evaluation and further improvement. Changes in the

**Situation of households using air conditioner**

- **Cooling**
  - Use when extremely cold: 24%
  - Use when cold: 43%
  - Seldom use: 9%

- **Heating**
  - Use when extremely cold: 24%
  - Use when cold: 28%
  - Seldom use: 48%

**Temperature of Interior Space**

- **Summer**
  - Use when extremely cold: 25%
  - Use when cold: 62%
  - Seldom use: 13%

- **Winter**
  - Use when extremely cold: 4%
  - Use when cold: 63%
  - Seldom use: 33%

**Measured Interior Temperature**

- Average temperature: 5 °C
- Lowest temperature: 2 °C
- Highest temperature: 7.3 °C

**Thermal comfort range**

- Temperature: 20-25°C
- Humidity: 25-75%

**Interior temperature is too low in winter, Very uncomfortable.**
status of natural lighting and ventilation before and after renovation were shown. We can see that improvement in building performance is significant.

3.3.1. Basic Renovation for Short-term Improvement

In basic renovation of the Zhong-nong-li project, much attention was paid to shading of openings (Fig. 9). According to our previous research, shading is among the most economical and efficient ways to improve building thermal performance in the hottest season. Shading is widely used in buildings in China and other countries. In the Chinese national green building code, it is required that “Shadings should be used on buildings when needed.”

1) Shading design in the Zhong-nong-li project

A key point of shading design is that it should not only follow the form of the original façade, but is also make sure the shadings could prevent excessive direct radiation from entering buildings in summer while allowing as much sunshine as possible in winter.
In the Zhong-nong-li housing, shading devices were designed according to the original facade. Horizontal louvers were designed on the south façades to keep out the direct radiation at noon at higher solar altitude while vertical shadings were used on the east and west facades to provide shelter from morning and afternoon direct radiation at much lower solar altitudes. The form and size of shadings were decided by calculation.

Mostly painted in chestnut color or brown, wood is widely used in housing stock built between 1840 and 1949. Therefore, in ecological renovation the materials we chose for new shadings were mainly wood and bamboo commonly found south of the Yangtze River. Through waterproof and anticorrosive treatment, wood and bamboo in clear water-based paint worked well with red bricks of the old buildings.

2) Evaluation of the performance of shading

Numerical animation showed that application of shading devices could reduce interior temperatures by 3-5 °C (Centigrade). If further upgrading of windows were done at the same time, in total the interior temperature could be reduced by 4-6 °C (Centigrade).

It can be seen that installing shading elements is a simple and effective way to improve the building performance of buildings in China. If combined with other performance improvement methods (such as updating doors & windows, adding wall insulation, etc.), it will play a greater role in the improvement of indoor thermal environment.
3.3.2. Thorough Renovation for the long run

In thorough renovation, attention was paid to interior spatial adjustments and function improvement. The target buildings were originally row houses. After decades of changes in occupants and ownership units, the current situation is not good, lacking kitchen, toilet and other sanitation facilities. Living space per family is very small, most of them without kitchen and toilet. The indoor natural day lighting and ventilation conditions are also very poor.

Space performance was improved by space adjustment and function improvement as follows.

1) Thorough Renovation for housings still used as housings

In thorough renovation for the housings that will still be used as housings, the original reinforced concrete beam and slab structure was retained. Structural integrity for earthquake design was studied before some of the non-load-bearing walls were removed.

a. Functional improvement

Kitchens and toilets were added to solve the problem of lack in service facilities. The middle parts between the north side and south side of housings were used for new toilets (the blue parts in plan) for every households, and the space on the north side of the first floor were used as kitchen and dining rooms.

b. Space adjustment

On the basis of adding kitchen and bathroom facilities, we adjusted the layout of the floor plan by removing some walls inside the building. For rooms too small or too poor in terms of natural day lighting and ventilation, some partition walls were removed in order to improve the living conditions as well as natural day lighting and ventilation situations.

c. Simulation and Quantitative Evaluation
Through the simulation of Ecotect, we found that through the adjustment of space layout, the improvement in natural day lighting and ventilation in interior space was obvious. Further design was made by adding skylights to improve natural lighting situations in the middle part of the building. According to the analysis of CFD, the situation of ventilation in the room was greatly also improved, especially the wind speed in rooms. (Fig. 10)
2) Further functional changes and space re-organization for housings that will be changed into other functions

Structural reinforcement is necessary for further functional or layout changes. After the structure is reinforced, the interior space will have greater freedom for space reorganization. For the housings in Zhong-nong-li, the space re-organization design were made also on the premise of protecting the original facades. Service spaces were gathered together in the north part so all the other spaces could accommodate future changes in space layout and occupant requirements. (Fig. 11)
3) Building envelope upgrading

According to the rules for renovation of housing stock between 1840 and 1949 in China, the original facade must be retained. Therefore, internal thermal insulation was adopted, and the upgrading design of doors and windows should also follow the original forms of the facade.

In accordance with the principle of cost from less to more, technology from simple to complex, several steps of combining technical methods were tested: shadings, shadings + doors & windows upgrading (double-layer glass), shadings + doors & windows upgrading + 50mm EPS insulation board, and shadings + doors & windows upgrading + 100mm EPS insulation board. Energy Plus was used for simulation and analysis of building energy consumption and thermal performance of each step to show the effect of each step. The following conclusions were got through quantitative simulation and analysis.
a. Shading could greatly reduce the annual energy consumption of cooling in summer but has little effect on the energy consumption of heating in winter. So shading elements have a great effect on reducing the energy consumption of the whole year.

b. Beside shading, the change of single-layer to double-layer glass windows could greatly affect the further reduction of heating energy consumption in winter but has less effect on the cooling energy consumption in summer. So shadings + doors & windows upgrading have a greater effect on reducing the energy consumption of the whole year.

c. Compared with the above-mentioned methods, adding insulation to exterior walls (for this project, internal insulation was chosen as already explained) could greatly reduce the energy consumption during the whole year. EPS insulation boards were attached to the inside of exterior walls. With the addition of 50mm EPS insulation layer, the annual total energy consumption was reduced by 75%, while with a 100mm EPS insulation layer, the annual total energy consumption was reduced by 84%. After adding more than 50 thick EPS insulation layer, the energy-saving of the whole building was much higher than the requirement of 50% energy-saving of new building issued in 2008.

4. A SUMMING UP

While being valuable assets in the rapid development of Chinese cities, and yet in poor condition, improvement of building performance is very important for buildings built between 1840 and 1949 in China. With this paper, we sought to draw attention to the ecological renovation, which proved to be a significant opportunity to achieve the aim of offering occupants living environment with high levels of comfort & low energy consumption in this building stock in China. The two-step ecological renovation process discussed in this paper was very practical for renovation process. By dividing into basic renovation and thorough renovation, ecological renovation design could not only help to balance social and economic factors in practice, but also improved the living conditions of the residents efficiently, and endowed the old houses with new and longer life. Numerical simulation and analysis before and after renovation were also made to evaluate the real effect renovation design, and it demonstrated that there was great improvement in building performance after ecological renovation process.

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