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# Research on Envelope Energy-Saving Reconstruction of Existing Residential Building

## A case study of a residence for the winter Olympian in Chongli

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***Abstract*—Design standard for energy efficiency of residential buildings (75% energy-saving) " DB13 (J) 63 and "Design standard for energy efficiency of passive low-energy residential buildings" DB13 (J)/T177 of Hebei province were issued in 2015. Both provides theoretical support for energy-saving design and reconstruction of residential buildings for "zero carbon Olympic" in 2022. Taking Chonghehuayuan, a residence for winter Olympian, as an example, this study proposed several reconstruction schemes and simulated energy consumption with DesignBuilder separately. Finally, suggestions were given according to energy saving contribution rate and economic evaluation. The results reveal that (1) the effect of envelope energy-saving reconstruction is not obvious with the improvement of the energy-saving target and that (2) if the envelop reaches the standard of passive buildings, 22% energy will be saved and incremental cost will be recouped within 7 years.**

***Keywords*—existing residential building; energy-saving reconstruction; energy calculation; economic evaluation***

## I. Project Overview

Chongli is located in the northwest of Hebei province, south of Inner Mongolia plateau. It belongs to continental monsoon climate zone, cold air activity is frequent in winter, the temperature rise quickly in spring, the average temperature in summer is 19℃, the average temperature in winter is -12℃, the annual average temperature is 3.7℃. Chungli belongs to cold (C) building thermal partition area, its Heating Degree Days HDD18≥3800℃·d, heating period is 183 days. Existing heating construction area is 2.17 million ㎡,the residential building area is 1.35 million ㎡, annual heating coal consumption is 93200 tons of standard coal. As an important venue area for the "zero-carbon Olympic Games" in 2022, reducing the energy consumption of building heating is an urgent problem to be solved.

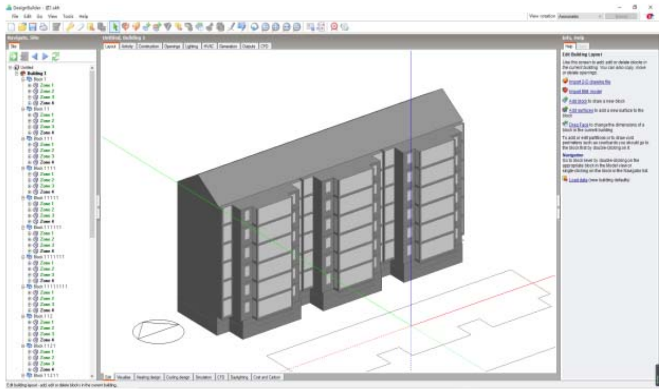

FIGURE I. MULTI-STOREY RESIDENTIAL MODE.

TABLE I. COMPARISON BETWEEN THE DESIGN VALUE OF THE ENVELOP STRUCTURE OF THIS PROJECT AND THE STANDARD OF 65% ENERGY SAVING (TABLE SOURCE: AUTHOR'S SELF-DRAWING)

| *Envelop Structure* | | *Heat transfer coefficient / W·m-2·K-1* | *Standard heat transfer coefficient limit of 65% energy saving (4-8 layers)/ W·m-2·K-1* |
|---|---|---|---|
| Roof | 100mm Reinforced concrete<br>80mm XPS insulation board | 0.40 | 0.40 |
| External wall | 370mm Shale perforated brick<br>55mm XPS insulation board | 0.50 | 0.50 |
| External window | Plastic steel window glass adopts low-e insulating glass with radiation rate of 0.15, and its thickness is (5+12+5). | 1.9(East, west, north) | 1.8(window-wall ratio≤0.3) |
| | | 1.9(south) | 1.7(0.3≤window-wall ratio≤0.4) |
| Basement ceiling | 370mm Shale perforated brick<br>70mm XPS insulation board | 0.60 | 0.40 |
| First floor balcony floor | 100mm Reinforced concrete<br>50mm XPS insulation board | 0.50 | 0.30 |

Chonghehuayuan (the residence of Olympic athletes) is a four-family per stair apartment building. The project overall area is 3922.74 ㎡, residential area is 3373.38 ㎡, the basement area is 549.36 ㎡. The building faces south, as shown in figure 1. Making energy-saving reconstruction for this building according to "Design standard for energy efficiency of residential buildings" DB13 (J) 63-2011 (hereinafter referred to as 65% energy saving standard). There is still a gap between the main parameters of the building and the 65% energy saving standard. As shown in table 1. The present heat consumption index is 23.41W/㎡, far more than 16.7W/㎡. From the simulation results of energy consumption, the heating energy consumption is 106 KWh/ (㎡·a), is equal to 33.9kgce/㎡, far more than 19kgce/㎡ from the national standard "Energy consumption standards for civil buildings" GB/T 51161-2016.

## II. RECONSTRUCTION SCHEME AND ENERGY SAVING CALCULATION

### A. Reconstruction Scheme

Hebei province issued "Design standard for energy efficiency of residential buildings" DB13 (J) 185-2015 (hereinafter referred to as 75% energy saving standard) and "Design standard for energy efficiency of passive low-energy residential buildings" DB13 (J)/T177-2015 (hereinafter referred to as 90% energy saving standard) in 2015. These two standards can support and guide the reconstruction of the project. The reconstruction scheme 1 and scheme 2 were designed with reference to two standards for Improving indoor comfort degree and reducing heating energy consumption, as shown in table 2.

TABLE II. HEAT TRANSFER COEFFICIENT LIMITS OF SCHEME 1 AND SCHEME 2 (SOURCE: AUTHOR'S SELF-DRAWING)

| *Envelope structure* | *Scheme 1* | *Scheme 2* |
|---|---|---|
| Roof | 0.3 | 0.15 |
| External | 0.4 | 0.15 |
| External window | 2(window-wall ratio≤0.3)<br>1.8(0.3≤window-wall ratio≤0.45) | 1.0 |
| Basement roof | 0.35 | 0.15 |
| First floor<br>Balcony floor | 0.3 | 0.15 |

### B. Energy Saving Calculation of Reconstruction Scheme

As for the calculation of building energy saving, two standards give different calculation methods. The 75% standard continues the 65% standard, gives the calculation method and the limit value of the heat consumption index. The 90% standard introduces the time - to - time calculation method of passive house energy consumption. Both methods belong to the static method. The former is in W/㎡, indicating the average load needed to maintain the indoor temperature of the building envelope. Although the latter takes KWh as the unit of energy consumption, the static calculation ignores the thermal storage performance of building materials and the calculation step length of 1h, with low accuracy. Therefore, the dynamic simulation software is recommended to be used in this study.

TABLE III. BOUNDARY CONDITION SETTING TABLE FOR SIMULATION CALCULATION (SOURCE: AUTHOR'S SELF-DRAWING)

| *The total items* | *Subitem* | *Parameter* |
|---|---|---|
| Activity | User density in the room | 0.03people/㎡ |
| | User's indoor activity schedule | default residential building schedule |
| | Initial heating temperature | 18℃ |
| | Initial temperature of refrigeration | 26℃ |
| Construction | Construction | refer to the energy saving design standard limits |
| Lighting | Lighting density | 7w/㎡ |
| | Lighting control type | linear |
| HVAC | Types of heating energy | coal |
| | COP | 0.78 |
| | Refrigeration energy type | electricity |
| | COP | 2.6 |
| | The heating time | 6 months |

In view of the current popular building energy consumption simulation software, Design Builder was selected as the main energy consumption calculation in this study after comparison from multiple angles. Its computing kernel is Energy plus, which adopts dynamic load theory. In this software, the reaction coefficient method is widely used in the simulation of air conditioning equipment system and heat supply, refrigeration and natural ventilation in buildings and buildings. User can select a specific city meteorological parameters, at the same time, can also according to need to set the parameters of the building materials, indoor personnel flow, electric lighting, air conditioning equipment operating conditions, the movement of the air natural ventilation, the type of energy used for cooling and heating, and so on. Finally, the software can simulate the total energy consumption of buildings for the entire year, and it can also observe the energy consumption of the building systems.

Modeling in the DesignBuilder is shown in figure 2. According to "Design code for heating ventilation and air conditioning of civil buildings" GB50736, the indoor Activity and HVAC settings of the building are shown in figure 3 and figure 4, The simulated boundary conditions are set as shown in table 3.

TABLE IV. SIMULATION CALCULATION RESULTS OF CURRENT SITUATION, SCHEME 1 AND SCHEME 2 BUILDING ENERGY CONSUMPTION (TABLE SOURCE: AUTHOR'S SELF-DRAWING)

| *Scheme* | *Total annual energy consumption for building heating* (kWh/㎡ • a)* | *Energy consumption per unit area of the building (kWh/㎡ • a)* | *Energy saving rate (compared to the status quo)* |
|---|---|---|---|
| The status quo | 357312 | 105.9 | —— |
| Scheme 1 | 316489 | 93.8 | 7% |
| Scheme 2 | 276355 | 81.9 | 22.6% |

*The summer cooling energy consumption in this area is 0, so no comparison is made

The simulation results of the present situation and the reconstruction scheme are shown in table 4. Scheme 1 will save 7% more energy than the current one. According to analysis [3] of the 75% energy saving standard, the energy saving of the building envelope should be about 20% after the reconstruction.

That is to say, when the building envelope is reconstructed according to the 75% energy-saving standard, the energy saving effect is not obvious. Investigate its reason, with the progress of energy-saving technology, the insulation performance of building envelope has reached a high level. On this basis, a small improvement in insulation performance of the envelope structure (compared with the 65% energy saving standard, the limit value of each part of the envelope structure in the 75% energy saving standard is not much improved) cannot significantly reduce the building energy consumption.

After greatly improving the insulation performance of the envelope structure, the energy saving rate of scheme 2 reached 22.6%. Compared with scheme 1, the second scheme uses the passive house standard and ideas, trying to maximize the envelope structure heat preservation performance and airtight performance, with the minimum of building energy consumption to obtain the biggest comfort, this not only verified the applicability of the passive house in cold region in China, but also verified that, the energy saving effect is not obvious after small improvement of insulation of envelope structure. Therefore, in this study, the second scheme with more significant energy saving effect was selected as the energy saving reconstruction scheme of this project.

For scheme 2, Compared with the current situation, the energy consumption is simulated to analyze the energy saving effect after the reconstruction of each part of the envelope structure, as shown in figure 5. The energy saving contribution rate is calculated as shown in figure 6. After comparison, found that after the first-floor balcony floor replacement, heat transfer coefficient changes little, energy-saving contribution is small, and the economic cost is high, the impact on the indoor life is big, so  it is not suitable to replace the first-floor balcony floor, and take other measures to make up for it.

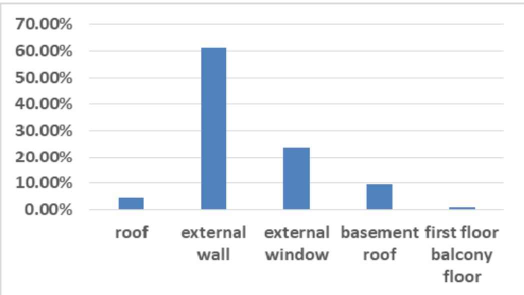


FIGURE II. ENERGY SAVING RATE OF EACH PART AFTER RECONSTRUCTION.

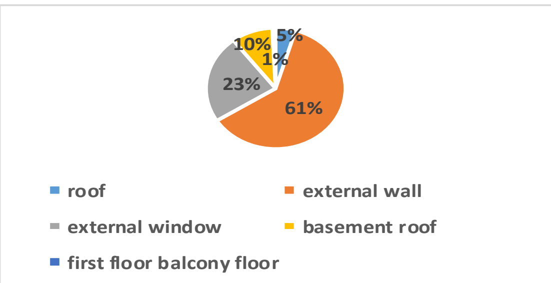


FIGURE III. CONTRIBUTION RATE OF EACH PART OF ENERGY-SAVING RECONSTRUCTION

### C. *Energy Saving Practice*

Refer to table 2 for the reconstruction of the envelope structure. Passive house not only requires good insulation performance of the envelope structure but also requires no thermal bridge design. The thermal bridge in the cold area not only affects the energy saving effect but also causes condensation, mildew, and frost on the inner wall of the wall, which can easily lead to the cracking and seepage of the external insulation system. As shown in figure 4.5.

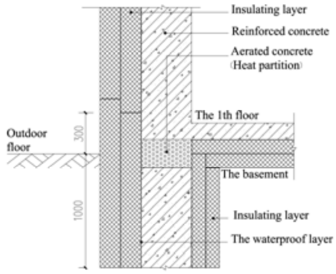


FIGURE IV. CONSTRUCTION OF NON-HEATING BASEMENT ROOF AND EXTERNAL WALL INSULATION JOINTS

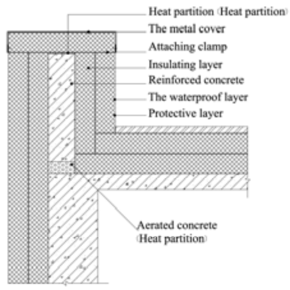


FIGURE V. PARAPET WALL INSULATION CONSTRUCTION

## III. Economic Analysis of Energy Saving Reform

Compared with the national standard for energy-saving 65%, the incremental cost for newly-built passive houses is between 1,500 and 2,000 RMB/m$^2$ [9]. Cost is an important factor restricting the development of passive houses in China. In order to judge the economic feasibility of the energy saving reconstruction, the two economic evaluation indexes of the static investment payback period and the dynamic investment payback period should be compared if they are less than the base investment payback period.

### A. *Calculation of Energy-saving Renovation Costs*

Energy-saving renovation costs are mainly for energy-saving materials, labor costs, and mechanical costs. The calculation method is calculated according to (1).

$$I_0 = \sum_{i=1}^{k} (p_i + c_i + m_i) s_i \tag{1}$$

In the formula $I_0$ --Energy-saving renovation costs;

$p_i$ -- The Unit prices using the number i materials;

$c_i$ -- The unit labor cost of using the number i materials;

$m_i$ -- The unit mechanical cost using the number i materials;

$s_i$ --Use the number of number i materials;

$k$ --Use of energy-saving materials.

According to the construction price list of Hebei province. Calculated as 179649.5 RMB.

### B. Energy Savings Calculation

After the energy-saving reform of the existing residential building envelope structure, the thermal performance is improved, and the heating and cooling energy consumption of the operation stage is reduced, thereby forming an energy-saving benefit. Regardless of the increase in energy prices over time, the annual energy-saving benefits after the renovation are calculated according to (2).

$$I_t' = (Q_t - Q_t')p \tag{2}$$

In the formula $I_t'$ --The benefits of energy conservation reform;

$p$ --Energy price;

$Q_t - Q_t'$ --Saving energy consumption in t year after renovation.

In the case that winter heating and summer cooling are all based on electricity, the local residents' electricity tariff is 0.5283 RMB/kWh, which is calculated to be 4,2769.6 RMB.

### C. Static Payback Period $T_p$

Regardless of the increase in energy prices and the time value of funds, the calculation of the payback period for retrofit investments is based on formula (3)

$$\sum_{t=0}^{T_P} I_t' - I_0 = 0 \tag{3}$$

Calculate the sum on behalf of the formula = 4.2 years. That is to say, from the perspective of static investment recovery period, the cost can be recovered in only 4.2 years.

### D. Dynamic Payback Period $T_p'$

Take into consideration of the energy, the time value of money, namely by energy prices, growth rate, the discount rate will be energy saving profits into the influence of the form of cash flow, cash flow as a basis for the calculation, to transform the dynamic payback period of investment according to (4) to calculate.

$$T_p' = t - 1 + \frac{|ANCT_{t-1}|}{NCT_t} \tag{4}$$

Wherein represents the net cash flow in year t, represents the cumulative net cash flow in year t-1, and t represents the year in which the accumulated cash flow in each year appears positive or zero for the first time. The calculation formula (5), the calculation formula (6) are as follows:

$$NCT_t = I_t'(1+\eta)^t(1+i)^{-t} \tag{5}$$

$$ANCT_t = \sum_{t=0}^{t} I_t'(1+\eta)^t(1+i)^{-t} - I_0 \tag{6}$$

in the formula $\eta$ --Energy price growth rate,

$i$ --Discount Rate.

According to the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development Document “Economy Evaluation Method and Parameters for Construction Projects”, assuming a discount rate i of 6%, based on “Energy Efficiency of Energy-Saving Residential Houses and Empirical Analysis” Energy Price[7]. The growth rate is 7%.

$$NCT_t = I_t'(1+7\%)^t(1+6\%)^{-t} \tag{7}$$

$$ANCT_t = \sum_{t=0}^{t} I_t'(1+7\%)^t(1+6\%)^{-t} - 179649.5 \tag{8}$$

Calculated, when t=7, a positive value appears for the first time, calculation $T_p$ = 6.69 years. In other words, the dynamic investment recovery period for the energy-saving renovation of the residential building envelope structure is less than two years, far less than the benchmark investment recovery period $T_0$= 10 years, and the reconstruction plan is feasible.

## IV. Conclusion

In Chongli county as an example of cold region, has the large stock of existing residential buildings and high energy consumption, the energy saving reconstruction is not only the goal of "zero carbon" Olympic Games, but also is an important respect of the energy conservation and emissions reduction for the building industry. The standards of 75% energy saving and 90% energy saving not only directly guide the energy-saving design of new residential buildings, but also provide references for the energy-saving reconstruction of existing residential buildings. But in the concrete renovation project also need the help of computer software to simulating the envelope structure energy saving effect evaluation, to choosing the efficient energy-saving reconstruction scheme. From the point of energy saving calculation results, when building envelope structure meet 75% energy saving standards, energy-saving effect is not obvious, when reach the passive house standard, energy-saving rate of 22.6%, which not only verified the applicability of the passive house in cold region in China, but also verified that the energy saving effect is not obvious after the envelope structure meet the 65% energy saving standards.

In addition, the economic analysis of the energy-saving reconstruction scheme shows that when the passive house standard is reached, the investment payback period of this project is 7 years, which has full economic feasibility.

## REFERENCES

[1] Hebei province "Design standard for energy efficiency of residential buildings (75%ernergy-saving)" DB13 (1) 63—2015. Hebei engineering construction standards.

[2] Hebei province "Design standard for energy efficiency of passive low-energy residential buildings" DB13 (J)/T177-2015. Hebei engineering construction standards.

[3] Liying Wang, Zhiyu Wang, The key technology research on 75% energy saving of residential buildings in severe cold areas. Journal of Changchun university of engineering (natural science edition), 2015, 16: 65-67.

[4] Liefeng Wang. Research on the application of energy-saving technology in the design of building envelope. Green building materials, 2016, 02: 95-96.

[5] Tao Fang, Zhenzhong Guan, Wenjing He. Study on key parameters of energy saving design of passive house enclosure structure - a case study of Tianjin in cold region. Journal of Shandong Jianzhu University. 2015,06:558-563.

[6] The national development and reform commission, Ministry of housing and urban-rural development. Economic evaluation methods and parameters of construction projects. Edition 3. Beijing: China planning press, 2006.

[7] Xiaolin Cao, Jupeng Wang, Economic benefit and empirical analysis of energy - saving residential life. Building economy. 2008,11:100-103.

[8] Qichen Zhou, Xuan Qin, Chaoxi Zhan. Economic evaluation of energy saving retrofit of existing buildings based on energy consumption analysis. Building science.2010, 08: 53-57.

[9] Wenfeng Lin. Annual research report on the development of passive and low-energy buildings in China. China building industry press.2017.