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Research on ultra-low energy consumption renovation of teaching buildings in severe cold areas under EPC mode

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Abstract. In order to explore the energy saving benefits and economy of ultra-low energy consumption renovation of existing buildings in cold areas under the contract energy management (EPC) mode under different renovation schemes. On the basis of the existing net present value and net present value increment, the net present value rate is proposed as the evaluation index of the transformation plan, so as to realize the comprehensive benefit evaluation of a variety of transformation schemes. The results show that the energy-saving transformation scheme of the project with an external wall of 120 mm rock wool board, a 150 mm extruded polyphenylene board on the roof, and a three-glass single Low-E argon-filled glass on the exterior window has the greatest comprehensive benefits and meets the ultra-low energy consumption standard, the energy saving rate of the envelope transformation reaches 28.07%, and the static recovery period is 5.27 years. This paper provides a design method and reference basis for the ultra-low energy transformation of existing buildings in cold areas using EPC mode.

1 Introduction

EPC first originated in the United States in the seventies of the twentieth century and was used in different industries [1]. In the construction industry, the EPC model is a market-based energy-saving mechanism for energy-saving renovation of buildings to generate economic benefits.

Research on the comprehensive benefit evaluation index of building energy-saving renovation scheme under EPC mode. Yong H et al. [2] conducted a measured study of 27 buildings in the United States, using the net present value and payback period as evaluation indicators, and obtained the optimal combination of building types and renovation plans with high return on investment and renovation. Shang T C et al. [3] combine the EPC model with carbon emission rating, and convert the fluctuation size of the fuzzy data parabola in the price range into an evaluation index to guide investment strategy. Su L [4] revealed the intrinsic function relationship between the internal rate of return and the net present value rate of cash flow by introducing the recovery coefficient and excess return rate of cash flow. It can be seen that the EPC model can use different evaluation indicators to guide the energy conservation work of the building industry, but the research on ultra-low energy transformation projects using the EPC model in cold areas is relatively lacking.

2 Comprehensive benefit evaluation indicators

In this study, a project benefit model is established for the comprehensive benefit evaluation system of energy-saving transformation. In financial and financial analysis, net present value and net present value increment are two commonly used evaluation indicators, NPV is the difference between the present value of net cash flows over the life of the project and the original investment [5]. Its expression is:

$$NPV = \sum_{i=0}^{t} (CI - CO)(1 + DR)^{(-i)} \qquad (1)$$

Formula: CI is cash inflow, yuan; CO is cash outflow, yuan; DR is the discount rate, which is the expected minimum return on investment; t is the life of the project, years; i is the year.

$$\Delta \mathrm{NPV} = \sum_{i=0}^{t} \begin{bmatrix} \left(CI_A - CO_A\right)_t \\ -\left(CI_B - CO_B\right)_t \end{bmatrix} \qquad (2)$$

Formula: CI_A, CI_B is plan A, B cash inflow, yuan; CO_A, CO_B is the cash outflow of plan A, B, yuan.

When ΔNPV >0, it indicates that the economic benefits of the energy-saving transformation project of plan A are higher. Conversely, if ΔNPV<0, option B is more beneficial. It can be seen that the ΔNPV index can only compare and evaluate the benefits of the two technical solutions, so the application of the above evaluation index in the EPC mode is more limited. Therefore, the Net Present Value Rate (NPVR) index was used in this study to conduct a comparative analysis

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of the comprehensive benefits of various energy-saving technology solutions. The net present value rate is an extension and supplement to the net present value and net present value incremental indicators, which refers to the ratio of the net present value of an investment project to the current investment cost. An evaluation index that can be used to measure the comprehensive benefits of a variety of renovation options, and its expression is:

$$NPVR_N = NPV_N / CI_N \quad (3)$$

Formula: $NPVR_N$ is the net present value rate of scenario N.

It can be seen from the formula that NPVR can better reflect the risk level of the investment plan taking into account the cost of investment, so as to choose a more competitive investment plan.

3 Energy-saving renovation scheme design

3.1 Project introduction and pre-renovation energy consumption analysis

The case study of this study is a primary school teaching building in Shenyang, located in the cold area C in the cold area. The building before the renovation is shown in Figure 1, and the external insulation area of the building is 1825 m^2, the external door and window area is 745 m^2, and the roof area is 1423 m^2. The heat transfer coefficient of the enclosure before the renovation is shown in Table 1. The project uses the EPC mode to carry out ultra-low energy consumption transformation, which saves the project transformation investment while saving energy and carbon reduction to the greatest extent.

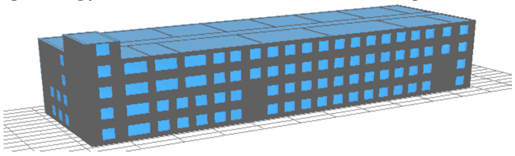

Fig. 1. Model drawing of a primary school teaching building in Shenyang.

Table 1. Heat transfer coefficient of the enclosure before modification.

Retrofit projects	Enclosure material /mm	Heat transfer coefficient /W/(m^2·K)
Facades	Mud mortar 15 + fly ash block 200+ Phenolic plate 90	0.40
roofing	Rock wool board 110+SBS waterproof	0.352
Exterior windows	Single frame double glass plastic steel casement window(5+9Air+5)	2.2～2.7

The heating period of this building is from November 1 to March 31 of the following year. There is no heating in the stairs and aisles, and the heating heat source is central heating, and the end is a radiator. Using Dest-C software, the multi-zone thermal mass balance method and the three-dimensional dynamic heat transfer algorithm were used to simulate and calculate, and the cumulative heating energy consumption in winter was 1.49×106 kWh, and the cumulative heat load index of the building was 57.27 kWh/m^2. It is much higher than the design standard for heat load indicators for public buildings in severe cold areas in GB/51350-2019 "Technical Standards for Near-Zero Energy Buildings"[6]. Therefore, the ultra-low energy consumption renovation of this school building to reduce the heating heat load has a high potential for energy saving. The ultra-low energy renovation project includes the renovation of the building envelope, HVAC system, renewable energy utilization, etc., and this study only analyzes the comprehensive benefits of the renovation scheme of the building envelope, external walls, exterior windows, and roofs.

3.2 Comprehensive benefit analysis of the renovation plan

Due to the poor waterproof performance of the building plastering layer and the paint layer before the renovation, the pulverization of the phenolic board of the insulation layer led to a significant reduction in the thermal insulation performance, and the fire resistance grade of the building was grade II. Rock wool insulation board is an inorganic glass fiber material with low thermal conductivity and high fire resistance, which is 50%~70% lower and 70%~80% lower in weight than prefabricated reinforced concrete exterior wall panels with the same thermal properties, and has a high cost performance [7]. Therefore, the exterior wall renovation plan is: add A-grade fireproof rock wool insulation board on the original basis, fix it on the foundation wall with non-metallic thermal insulation bridge anchors, and finally re-add double-mesh thin plaster and exterior wall paint on the outer layer.

Through Dest-C simulation, the building heat load index and the energy saving rate before the renovation after adding 60-210mm thickness rock wool board, the energy saving rate and the heating consumption cost before the transformation are multiplied as cash inflow CI, and the investment cost of the renovation plan is calculated from the current market price and used as the cash outflow CO, the minimum return on investment is set at 5% according to the bank's return on investment, and the life t of the project is 25 years, and the comprehensive benefits of rock wool insulation boards of different thicknesses are calculated by introducing formulas (1) and (3). The calculation results of NPV, NPVR and energy saving rate of different thickness of rock wool insulation board are shown in Table 2.

Table 2. The comprehensive benefits of rock wool insulation board transformation of different thicknesses.

Retrofit schemes	thickness /mm	Heat transfer coefficient / W/(m^2·K)	Energy saving rate /%	Investment fee/yuan	NPV	NPVR
schemeI	60	0.295	6.455	26317	10233	0.363
schemeII	90	0.248	8.149	35080	12918	0.368
schemeIII	120	0.214	9.390	38588	14885	0.385

schemeIV	150	0.189	10.434	52620	16391	0.311
schemeV	180	0.168	11.082	70165	17577	0.250
schemeVI	210	0.152	11.597	87703	18536	0.211

It can be seen from Table 2 that the NPV value of rock wool insulation board of different thicknesses is greater than 0, indicating that the cost of renovation will be recovered from the energy and operating costs saved after the transformation. The increase of the thickness of the exterior wall insulation board is proportional to the increase of the energy saving rate, and the maximum energy saving rate is 11.597% when the thickness is 210 mm, but the minimum NPVR is 0.211. As shown in Figure 2, NPVR first increases and then decreases with the increase of insulation board thickness, and the NPVR value is maximum 0.385 when scheme III (120 mm thick rock wool insulation board) is adopted, and the energy saving rate is 9.39%. When the thickness of the insulation layer is greater than 120 mm, the growth rate of energy saving rate slows down, the growth rate of energy saving rate decreases by 4.11% at 150 mm, and the growth rate of energy saving rate decreases by 4.91% at 180 mm. According to the relevant provisions in GB/51350-2019 "Technical Standard for Near-Zero Energy Buildings" [6], the K value of the heat transfer coefficient of the exterior wall of ultra-low energy consumption public buildings in cold areas is 0.1~0.25 W/(m^2· K).

Because NPVR is a comprehensive benefit evaluation index calculated through energy saving rate and incremental cost. Therefore, in order to achieve the maximum comprehensive benefits of the renovation, within the specified heat transfer coefficient, the 120 mm rock wool insulation board was preferred as the energy-saving transformation plan of the exterior wall in this project.

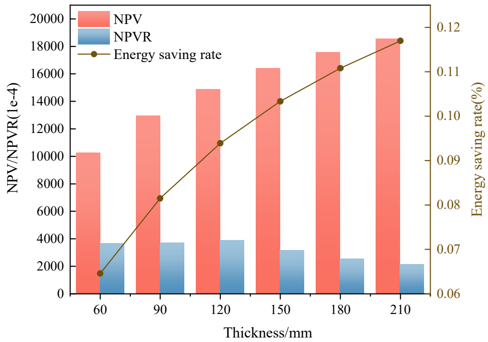

Fig. 2. The comprehensive benefits of rock wool insulation board transformation of different thicknesses

The roof insulation material of ultra-low energy buildings in cold areas is extruded polystyrene board (XPS), which has high thermal insulation, durability and fire resistance.The roof renovation plan is: remove the original waterproof layer on the surface, add XPS board and new SBS waterproof on the basis of the original building, and the roof insulation structure after the transformation is rock wool board + XPS board + SBS waterproofing. After calculation, the comprehensive benefits of XPS board modification of different thicknesses are shown in Figure 3. The calculation is the same as for the façade.

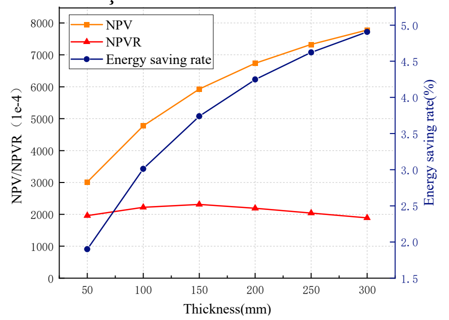

Fig. 3. The comprehensive benefits of XPS board modification of different thicknesses

It can be seen from Figure 3 that the increase in the thickness of the roof insulation board is proportional to the increase in the energy saving rate, and the maximum energy saving rate is 4.907% when the thickness is 300 mm, but the minimum NPVR is 0.189. Therefore, the priority of 150 mm XPS board for roof renovation not only ensures the heat transfer coefficient specified by the ultra-low energy consumption transformation, but also realizes the maximum comprehensive benefits of the scheme.

In the same way as the above-mentioned calculation method for external walls and roofs, the comprehensive benefits of different exterior window renovation results are shown in Table 3. In the specified severe cold areas, the heat transfer coefficient value of the exterior windows of public buildings with ultra-low energy consumption should be ≤ 1.4 W/(m^2· K) [6] , the maximum NPVR value is 0.082 when using Scheme III (three-glass single Low-E argon filled exterior window). Therefore, the heat transfer coefficient of 1.4 W/(m^2· K) Triple glass single Low-E argon-filled glass with solar heat gain coefficient of 0.393 in winter as a transformation scheme.

Table 3. The comprehensive benefits of different exterior window renovations.

Retrofit schemes	Exterior window type	Heat transfer coefficient /W/(m^2·K)	Solar heat gain coefficient	Energy saving rate /%	Investment fee/yuan	NPV	NPVR
schemeI	Three-glass single Low-E hollow	1.52	0.495	13.440	252480	19720	0.078
schemeII	Three-glass single Low-E filled with argon	1.4	0.393	14.945	269312	22107	0.082
schemeIII	Three-glass double Low-E filled with argon	1.07	0.390	19.123	378720	28729	0.079

3.3 Retrofit effect analysis

After the renovation of the exterior walls, roofs and windows of the teaching building, the heating energy consumption in winter was reduced by 4.19×10^5 kWh, and the energy saving rate was 28.07%. Among them, the material cost of the renovation project is 511,100 yuan, and the static recovery period of the project is 5.27 years without considering the fluctuation of energy prices. According to the third batch of ultra-low energy building design stage certification and evaluation by the China Association of Building Energy Efficiency in 2022, the energy-saving rate of the renovated building itself reached 64.82%, including the energy-saving rate of the building envelope of 28.07% and the utilization rate of renewable energy of 25%.

After the renovation is completed, the monthly energy consumption of the air source heat pump during the heating period is about 4.8×104 kWh, which is equivalent to about 37 tons of coal burning, about 96.2 t/year of CO_2 emissions from heating, and the overall energy saving rate of the building is 63%. The energy-saving effect of the renovation is remarkable, and the difference between the energy-saving rate and the renovation design stage is less than 5%, which has been well received by the inspector. In the future, the long-term energy savings of the building will be analysed and the sustainability of the retrofit materials will be studied.

4 Conclusion

The following conclusions are obtained by comparing and analyzing the comprehensive benefits of different ultra-low energy consumption renovation schemes of existing buildings in cold areas after using the net present value (NPVR) index under the EPC mode.

(1) The EPC mode has a promoting effect on the ultra-low energy consumption and energy-saving transformation of existing buildings in cold areas, and the introduction of NPVR as a comprehensive benefit evaluation index in the scheme design and calculation can improve the rationality and implementation efficiency of the energy-saving transformation project. With a certain degree of generalizability, the renovation scheme can be directly selected according to the energy-saving renovation investment of the study, and the calculation method of NPVR can be used as a reasonable basis for the allocation of renovation investment costs for other types of buildings. And adjust the calculation parameters according to the different investment levels, transformation needs, and specifications.

(2) When the teaching building of a primary school in Shenyang undergoes ultra-low energy consumption transformation in EPC mode, the optimal transformation scheme for the exterior wall, roof and exterior window in the envelope structure is to add 120 mm rock wool board to the exterior wall, 150 mm extruded polyphenylene board to the roof, and replace the exterior window with three-glass single Low-E argon-filled glass, with energy saving rates of 9.39%, 3.74% and 14.94%, respectively.

(3) After the renovation, the energy saving rate of the building itself reached 64.82%, and the energy saving rate of building envelope renovation accounted for the largest proportion (28.07%). The NPVR of the exterior wall, roof and exterior window renovation scheme in the envelope is 0.385, 0.231 and 0.082, respectively, and the comprehensive benefit priority of individual energy-saving renovation is exterior wall, roof and exterior window.

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References

1. Zhang, M.S., Wang M.J., Jin,W., et al. (2018) Managing energy efficiency of buildings in China: A survey of energy performance contracting (EPC) in building sector. Energy Policy., 114.
2. Yong, H., Nuo, L., Jia, J., et al. (2019) Investment decision-making optimization of energy efficiency retrofit measures in multiple buildings under financing budgetary restraint. Journal of Cleaner Production., 215.
3. Shang, T.C., Yang, L., Liu, P.H., et al. (2020) Financing mode of energy performance contracting projects with carbon emissions reduction potential and carbon emissions ratings. Energy Policy. , 144.
4. Su, L. (2013) Harmonized capital budget evaluation methods using the net present value rate. Accounting Newsletter., (17): 65-66.
5. Simon, A.,Wangliang, L.,Siming, Y. (2020)Life cycle assessment and net present worth analysis of a community-based food waste treatment system. Bioresource Technology. , 305.
6. Wang, X.H., Zhang, H. (2021) Experimental study on the durability performance of four insulation materials in different environments. Cryogenic engineering., (02): 83-88.
7. Ministry of Housing and Urban Development, China. (2019) Technical standards for near-zero energy buildings. Beijing: China Architecture and Architecture Press., GB/51350-2019