Application and exploration of near zero energy technology system for commercial buildings: a case study of a project

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Abstract. With the goal of achieving near-zero energy consumption of public buildings in cold areas, passive technologies such as high-performance envelope structure and building shading are adopted to minimize the basic demand for building heating and cooling, and active energy saving systems such as high-performance heat recovery, natural ventilation, high-performance air conditioning systems and renewable energy utilization are utilized. The overall energy consumption of the building is reduced on the premise of ensuring indoor comfort, so as to achieve the goal of near-zero energy consumption buildings. Taking "an office building" as an example, this project innovatively combines the composite insulation system, near-zero energy building and prefabricated steel structure building technology and explores the composite insulation method and prefabricated steel structure technology in near-zero energy building, which makes up the gap in existing research and has guiding significance for future similar buildings.

Keywords: near-zero energy building; composite insulation system; prefabricated steel structure building; passive measures

1 Introduction

The construction industry is the world's largest energy consumer and one of the largest greenhouse gas emitters, according to the United Nations Environment Programme (UNEP) hosted by the Global Building Construction Alliance (Global ABC) for global energy consumption in the construction sector, in 2020, the construction industry accounted for 36% of the world's final energy consumption. In China, due to the rapid development of urbanization, the total energy consumption in the construction sector is large and accounts for a high proportion. According to the data of China Building Energy Consumption Report (2021) [1], the total energy consumption in the whole process of construction in 2019 was 2.233 billion tce, accounting for 45.8% of

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the total energy consumption in the country. The proportion of energy consumption in China's construction sector is higher than the global average, and it is urgent to take corresponding energy-saving and carbon reduction measures to reduce energy consumption and carbon emissions in the construction sector.

China's building energy conservation began in the 1980s [2]. In March 1986, the Design Standard for Energy Conservation of Civil Buildings (Heating Residential Buildings) was issued [3], and the target for building energy conservation rate was 30%. After the revision of the Design Standard for Energy Conservation of Civil Buildings (Heating Residential Buildings) in 1995, the target for building energy conservation rate was 50%. On July 23, 2008, the 18th Executive meeting of The State Council passed the Regulations on Energy Conservation in Civil Buildings [4], which made clear provisions on energy conservation in new buildings, energy conservation in existing buildings, energy conservation in building energy use system operation and legal liability. In 2015, the newly revised Design Standard for Energy Saving of Public Buildings (GB 50189-2015) set an energy saving rate target of 65%[5]. The Energy Consumption Standard for Civil Buildings (GB/T 51161-2016) issued in 2016 for the first time put forward the upper limit reference value of the actual energy consumption index of buildings [6]. In 2019, the first national standard for guided ultra-low energy consumption buildings - Technical Standard for Near-Zero Energy Consumption Buildings (GB/T 51350-2019) [7] was promulgated, which clarified the definitions of ultra-low energy consumption, near-zero energy consumption and zero energy consumption buildings, stipulated indoor environmental parameters and energy efficiency indicators, and provided evaluation methods and theoretical basis for medium - and long-term building energy efficiency improvement in China.

In recent years, many scholars have conducted researches on near-zero energy buildings in different countries and regions [8-12]. Previous researches mainly focused on residential buildings, and few researches on near-zero energy buildings in public buildings. At the same time, the existing thermal insulation design of near-zero energy buildings generally adopts external thermal insulation system, and the research on composite thermal insulation and fabricated steel structure is less. Therefore, this paper takes an office building as an example to explore and study the application of near-zero energy technology system for public buildings with steel structures in cold areas, so as to provide reference for similar projects.

2 Project overview

The project is located in an industrial park with a total floor area of 15,000 m2, with 12 floors of the main building and 3 floors of the podium. According to the outdoor ground to the roof, the building height of the comprehensive building is 49.10 m. The industrial park innovatively combines the composite insulation system, near-zero energy building and prefabricated steel structure building process, and explores the core technologies such as composite insulation and prefabricated steel structure technology in near-zero energy building.

3 Technical route

According to the "Near zero Energy Building Technical Standard" GB/T51350-2019 near zero energy public building energy efficiency indicators in cold and middle areas, combined with the industrial planning and architectural design of the park, the construction of the industrial park will take innovation as the goal, practice many new technologies, new materials, new construction methods, new models, and formulate project design schemes in combination with the functional environment of the building; Then the energy system is quantitatively analyzed by multi-condition simulation calculation. Based on the analysis results, the optimization index and method are determined, and the optimization scheme is finally formed， see details in Fig.1.

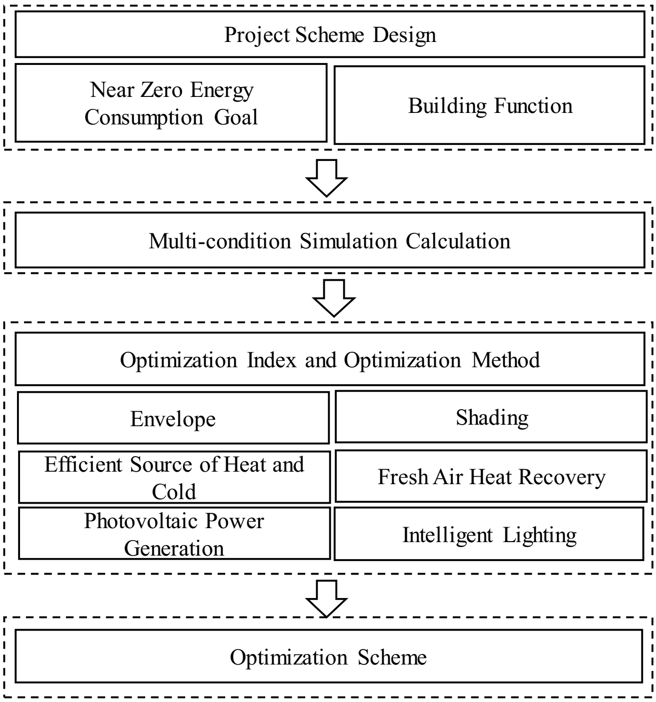

Fig. 1. Project plan technical route.

4 Initial building scheme and reference building scheme simulation

4.1 Initial building scheme simulation

In order to simulate the load and energy consumption results of the buildings in the park, the project determines the thermal performance and other parameters of the reference building envelope according to the current energy-saving design standard

"Energy-Saving Design Standard for Public Buildings" (DB37/5155-2019). The shape, size, orientation, space use function, heating and air conditioning design parameters, running time, lighting, personnel, indoor equipment and other parameters of the benchmark building are consistent with the design building.

According to the original building design scheme and project information provided by the design unit, IBE-e software was used to complete the model construction and simulation calculation of the original building scheme, and the annual cooling and heating load and comprehensive energy consumption of the building were obtained at 140.42kWh/m2·a. The sub-energy consumption values are shown in Table 1.

Table 1. Itemized energy consumption table based on area used.

Item	Energy consumption per unit area (Annual heating energy consumption) (kWh/m2·a.)
Annual heating energy consumption	16.12
Annual cooling energy consumption	42.99
Annual power consumption of transmission and distribution system	20.18
Annual domestic hot water energy consumption	3.15
Lighting system energy consumption	43.47
Annual elevator energy consumption	14.51
Annual comprehensive value of building energy consumption (equivalent of standard coal)	140.42

4.2 Reference building scheme simulation

According to the relevant technical requirements of the "Near-zero Energy Building Technical Standard", the energy consumption level of near-zero energy public buildings should be 60% lower than the current "energy-saving Design Standard for Public Buildings" (DB37/5155-2019). Therefore, it is necessary to establish a reference building model that meets the energy-saving limit requirements of the Design Standard for Energy Efficiency of Public Buildings (DB37/5155-2019), and calculate the building energy consumption as a comparison basis. According to the standard, the thermal performance and other parameters of the envelope structure of the reference building are determined, and the parameters of the building shape, size, orientation, space use function, internal heat setting, running time, lighting, personnel, indoor equipment and other parameters are consistent with the original design building. Refer to the building envelope structure and external window practice as shown in the following Table 2-3.

Table 2. Mandatory standard requirement.

Envelopes	Performance requirement (Heat transfer coefficient) W/(m^2·K)
Roof	0.40
Exterior Wall	0.50
Partition wall between non-heated stair-well and heated room	1.2
Ground	1.2

Table 3. Exterior window performance requirement.

Orientation	Heat transfer coefficient W/(m^2·K)	SHGC
South	2.0	0.48
North	2.0	0.48
East	2.4	0.52
West	2.4	0.52

TRNSYS 18 software is used to complete the model construction and simulation calculation of reference building scheme. After calculation, the comprehensive energy consumption value of the building is 179.87kWh/m2. Compared with the reference building, the comprehensive energy saving rate of the original building is 21.93%, which does not meet the near-zero energy consumption public building energy consumption level required in the "near-zero Energy Consumption building Technical Standard" GB/T51350-2019 should be 60% lower than the benchmark building. Therefore, it is necessary to complete the simulation calculation and comparative analysis of the energy-saving effect by using different energy-saving technology combination schemes for the original building technical scheme, and obtain the key indicators and energy-saving measures affecting the energy-saving property of the building scheme.

This project intends to build a near-zero energy building through the rational use of near-zero energy building technology. The scheme should comprehensively consider the use of optimized building schemes, fresh wind and heat recovery, natural ventilation, high-performance building envelope, high-performance doors and Windows, shading design, high air tightness and intelligent lighting, to minimize the building's cold and heat demand, while using renewable energy sources such as efficient cold and heat sources and solar photovoltaic power generation systems to improve the building's comprehensive energy saving rate and renewable energy utilization rate.

5 Optimization scheme

5.1 Envelope

5.1.1 Insulation design

This project can avoid building thermal bridge, reduce building cold and heat loss, protect the main envelope structure, reduce temperature stress and increase the life of the structure through efficient insulation technology of the envelope structure. Based on the building simulation model of the complex building of this project, with other parameters kept constant, the thermal performance of the external wall and roof of the building was adjusted, the simulation calculation of different working conditions was completed, and the change of K value was simulated and analyzed. The K value of the envelope structure applicable to this project was analyzed. The calculation results of the heat transfer coefficient of the external wall were shown in Fig. 2.

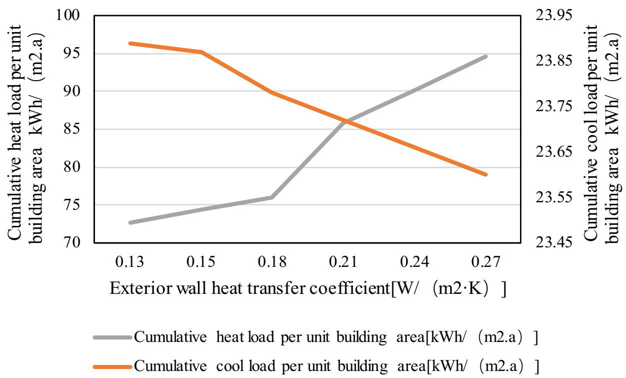

Fig. 2. Sensitivity analysis of exterior wall heat transfer coefficient

From the above results, it can be seen that the average heat transfer coefficient K value of building exterior wall and roof has an impact on the building heat demand. With the decrease of K value, the building heat demand continues to decrease. When the K value of external wall reaches 0.15 ~0.18W/(m2·K), the change trend of building load gradually slows down with the decrease of K value. Similarly, the heat transfer performance coefficient of roof and exterior window can be obtained.

Combined with the energy saving requirements of the project: In the non-transparent envelope structure, the external walls are insulated by ALC wall panels, the roof and floor floors are insulated by extruded polystyrene panels, and the hot and cold Bridges are treated by STP vacuum insulation panels. The existing design scheme is basically retained. The K value of the external walls is controlled at 0.16W/(m2·K), and the K value of the roof is controlled at 0.15W/(m2·K). The K value of the floor and partition wall of the divided heating and non-heated rooms is 0.22W/(m2·K).

Using the same method to simulate the thermal performance of building doors and Windows, it is concluded that with the decrease of K value, the building heat demand continues to decrease, among which, when the K value of doors and Windows reaches 1.0W/(m2.K), the change trend of building load gradually slows down with the decrease of K value. Therefore, the transparent envelope structure of the project adopts the product with the heat transfer coefficient K of the whole window up to 1.0W/(m2·K). The transparent envelope structure of the comprehensive building of the project retains the existing design scheme, and adopts the broken bridge aluminum window 5Low-E+15A+5Low-E+0.15V+5 white, with the air tightness level not less than 8 and the watertightness level not less than 6.

5.1.2 Shading design

Solar radiation is an important factor affecting the building's demand for cooling in summer. This project uses external shading to reduce the building's heat gain. According to the overall shape and setting conditions of the building, the scheme is convex and fixed shading + south-facing and east-west facades can be adjusted indoor side shading louvers.

5.1.3 Thermal bridge free design

The project applies the construction process of prefabricated steel structure to the near-zero energy consumption building, and the envelope structure adopts the composite insulation and energy saving system. According to 19CJ85-1 "Auto cladated aerated Concrete Panel Enclosure System for prefabricated Buildings", 17J925-1 "Pressed Metal Panel Building Structure" and other standards, the external wall adopts 100mm thick rock wool insulation decorative integrated board +220mm thick XPS insulation board +100mm thick finished ALC. The exterior wall is made of AAC and ALC inner wall panels as the foundation exterior wall, and the outer wall is made of 220 thick extruded panel and 100 thick rock wool insulation decorative integrated panel. I-beam filled with rock wool as insulation layer, the floor lower side room inside filled with calcium silicate board and the floor upper side of the AAC inner wall board as the surface layer plastering as an airtight layer, while making waterproof vapor insulation film; For the thermal bridge, the upper side of the floor is made of 50 thick XPS, and the lower side is made of 10 thick vacuum insulation board.

The exterior wall is prone to thermal Bridges in beams, columns, boards and other parts. The steel beams are wrapped with rock wool, the rock wool insulation decorative integrated board is hung outside the wall, and XPS insulation board is laid on the upper side of the floor, and vacuum insulation board is laid on the lower side of the floor to block the thermal bridge. Air tightness is also easy to produce in these parts, the inside of the wall using calcium silicate board for the initial layer of steam insulation, in the laying of waterproof steam insulation film for further sealing, the outermost use of plaster layer for full coverage, to ensure that the air tightness meets the requirements.

This project adopts a composite insulation method, and its non-thermal bridge design method includes the connecting parts of the thermal insulation layer, the connecting parts of the external window and the structural wall, the parts through the wall or the roof such as pipes, and the parts that need to be fixed by the external envelope structure and may cause the thermal bridge. The thermal bridge node dew checking calculation was carried out on the above nodes, and the results showed that the indoor surface temperature was much higher than the dew condensation temperature. The specific calculation results are as follows:

5.1.4 Airtight design

The air tightness of the house must meet the conditions of indoor and outdoor pressure difference of 50Pa, and the number of air changes per hour does not exceed 0.6 times. That is, N50≤0.6 is met. In order to make the airtightness meet the specified requirements, a series of technical measures need to be taken to deal with the connection nodes of the outer envelope. In the design and construction of this project, high-performance doors and Windows should be selected first, and the air tightness level of external window products should reach a higher level. In the process of architectural design and construction, the performance of key nodes must be guaranteed, among which the holes in the building air duct, water supply and drainage pipe, cable, air conditioning water pipe and rain pipe must be effectively sealed.

5.2 Efficient heat recovery system

Heat recovery Fresh air exchange system is a kind of ventilation device to recover the cold and hot energy of exhaust air. Based on the building simulation model of this project, the performance of the building heat recovery system was adjusted, the simulation calculation of different working conditions was completed, and the heat recovery parameter requirements applicable to this project were analyzed while other parameters remained constant. See Fig. 3 for details.

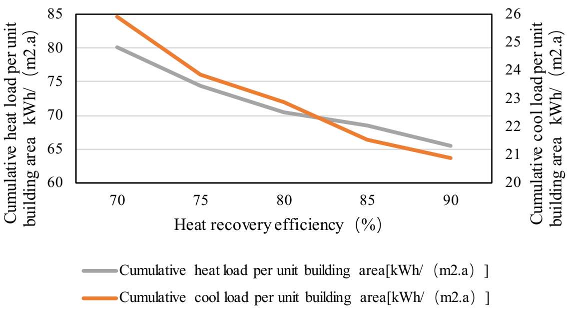

Fig. 3. Sensitivity analysis of heat recovery

From the above results, it can be seen that heat recovery has a significant impact on building heat demand. After the sensible heat recovery efficiency reaches 75%, the change trend of building load gradually slows down with the further improvement of efficiency.

The comprehensive building of this project is an office building with dense personnel and a large demand for fresh air. This scheme requires the building to set up fresh air heat recovery. In the system scheme, heat recovery technology is used to utilize residual cold and residual heat of exhaust air

5.3 Efficient cooling and heat source system

According to the "Design Code for Heating, Ventilation and Air Conditioning of Civil Buildings", considering the energy resource conditions and load characteristics of the project, the comprehensive building is determined to use air source heat pump and water storage system as the main form of cold and heat sources. Due to the requirement of heat storage in winter, water storage system is set up in this project. Water storage tank is used for cold and heat storage, and partial load energy storage is adopted. TRNSYS was used to establish an air source heat pump + energy storage system model, and 8,760 hours of annual simulation calculation were carried out. The variable frequency dynamic performance characteristics of air source heat pump were considered in the simulation. According to the simulation calculation results of this project, the host capacity of the equipment could be reduced and the annual operating cost could be saved when the energy storage capacity was large. However, considering that the equipment of this project needs to be set on the roof, and the volume of the storage water tank of this project should be reduced as much as possible, the project should be configured in accordance with $135m^3$ (about 35.8% of the daily cumulative heat load demand).

The air source heat pump system should choose ultra-low temperature air cooled heat pump, and the performance coefficient can meet the relevant current standards. In addition, the circulating water pump should use variable frequency water pump, and the transmission and distribution system can meet the relevant current standards and specifications.

5.4 Energy-saving lighting design

The energy consumption of the lighting system generally accounts for 20%-40% of the building energy consumption, and the energy saving potential is large. This project will adopt intelligent lighting control technology to carry out intelligent control of lighting system according to personnel activities and outdoor sunshine conditions. The project uses LED high-efficiency lighting system, and the lighting power density value of the unit construction area of the complex building is controlled at 6W/ m2.

5.5 Renewable energy utilization

This project uses solar photovoltaic + storage battery as local power source for regional renewable energy generation. The photovoltaic modules of this power station project are installed on the roof of the joint plant, and BAPV is installed with the slope, and the component installation azimuth is 14°. The photovoltaic module of this power station project adopts high-efficiency photovoltaic single crystal 540W module. The actual installed capacity of the power station project is 2391.12kW, and a total of 4428 photovoltaic modules are used. The power station uses a total of 24 100kW inverters and 6 photovoltaic low-voltage grid-connected cabinets. The installed capacity of the project is expected to be 2.39MW, with an average annual generating capacity of 2.377 million kWh. After the PV is connected to the grid in the park, it will be prioritized for the use of comprehensive buildings and rental housing, which can meet the project's near-zero energy consumption target.

6 Comprehensive energy consumption comparison

After the project building adopts the above optimization scheme, the thermal performance of the building and the heat transfer parameters of the external window are shown in tables 4 and 5.

Table 4. Thermal performance of building envelope after optimization.

Envelopes	Performance requirement (Heat transfer coefficient) $W/(m^2 \cdot K)$
Roof	0.15
Exterior Wall	0.16
Partition wall between non-heated stairwell and heated room	0.22
Ground	0.15

Table 5. Exterior window performance requirement.

Orientation	Heat transfer coefficient $W/(m^2 \cdot K)$	SHGC
South	1.0	0.40
North	1.0	0.40
East	1.0	0.40
West	1.0	0.40

TRNSYS 18 software is used to conduct hourly simulation calculation of the building throughout the year. On the basis of taking good air tightness measures, that is, $N50 \leq 0.6$ times, through simulation calculation, the annual heat consumption and cooling consumption indicators of the building meet the energy efficiency index range of the near-zero energy building, which can meet the energy-saving requirements of the near-zero energy building. The energy consumption of the building's HVAC system, lighting, and domestic hot water is shown in table 6.

Table 6. Itemized energy consumption table based on area used.

Item	Energy consumption per unit area (Annual heating energy consumption) (kWh/m2·a.)
Annual heating energy consumption	13.40

Annual cooling energy consumption	29.02
Annual power consumption of transmission and distribution system	12.74
Annual domestic hot water energy consumption	3.15
Lighting system energy consumption	23.91
Annual elevator energy consumption	11.61
renewable energy power generation	22.90
Annual comprehensive value of building energy consumption (equivalent of standard coal)	70.93

Compared with the reference building, the completion of the project energy saving target is as follows, in which the photovoltaic power generation is calculated according to 90kW, but in order to ensure the photovoltaic on-site consumption, the actual access amount is much higher than 90kW for the park photovoltaic regulation.

According to the current standard, the comprehensive energy saving rate, bulk energy saving rate and renewable energy utilization rate of the complex building have reached the near-zero energy consumption building standard.

7 Techno-economic analysis

Compared with conventional buildings, the incremental cost related to the near zero energy consumption of this project is mainly in the external insulation of the building envelope, external doors and Windows, air-conditioning system equipment, high-performance lighting, photovoltaic power generation system, energy system monitoring platform investment. The comparison between the incremental investment cost of near-zero energy-related technologies and the relevant technology investment cost under the conventional transformation program is as follows: According to the calculation, compared with the relevant investment in the conventional transformation program, the incremental cost per unit area is about 885 CNY/m2. In addition to the initial investment, the incremental cost of the near zero energy building project will also affect the investment of the project construction period, public area and floor height factors.

8 Conclusion

An office building is taken as an example. Measures are taken to improve building energy efficiency through building envelope performance, glass curtain wall door and window system, shading design, fresh air heat recovery measures, efficient cold and heat source system, intelligent lighting and photovoltaic power generation, etc. Building energy consumption is calculated through TRNSYS modeling and compared with reference buildings. After the implementation of the scheme, the requirement of near-zero energy consumption building can be realized.

For the first time, the industrial park innovatively combined the composite insulation system, near-zero energy building and prefabricated steel structure building technology, explored the core technologies of composite insulation and prefabricated steel structure technology in near-zero energy building, and formed the reproducible and extendable technology of prefabricated steel structure near-zero energy building system and composite insulation of steel structure. The thermal insulation system products have been developed, so as to promote the application of prefabricated steel structure construction mode in the province and even the country's near-zero energy building industry.

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