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Original Paper

Practical Exploration of Net-Zero Building Technology in Hot Summer and Cold Winter Regions—Qingdao Sino-German Eco-Park Longfor Guangnian Project as an Example

Wang Jing[1], Chen Lijuan[1], Cao Huili[1], Liu Miaomiao[1], Cheng Qianqian[1], Yang Chuanli[1] & Li Yibo[2]
[1] Qingdao City University, QingDao, ShanDong, China
[2] Longfor Group Holdings Limited, JiNan, ShanDong, China

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Abstract
Energy saving and carbon reduction in the building sector is crucial to the realization of China's "double-carbon" goal, and the development of passive house/net-zero buildings is an important initiative to achieve this goal. This paper takes Longfor Guangnian, a passive house project in Qingdao, as a case study, summarizes the technical practice of net-zero buildings in coastal areas with hot summers and cold winters, and gives an optimization plan in combination with the existing problems of the case. The final result is to improve the building energy efficiency and optimize the building energy structure. It accumulates experience and provides reference for the promotion of net-zero buildings in cold areas, and provides support for green and low-carbon development in the field of housing and urban-rural construction.
Keywords
Green building, Net-zero building, Design optimization

1. Introduction

A Net Zero Energy Building (NZEB) is a building that consumes as much or less energy in a year than the renewable energy it generates. There are various designations for low energy buildings worldwide, mainly including: "Passive House", "Near Zero Energy Building", "Zero Energy Building", "passive ultra-low energy" and so on.

The research on net-zero energy buildings at home and abroad has already achieved some results. In the 1970s, Torben V. Esbensen (EPBD recast, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), 2010) of the Technical University of Denmark put forward the concept of net-zero energy building, and the university designed and constructed a net-zero energy building for the first time in the world. Graca (Gra ça, Augusto & Lerer, 2012, pp. 634-646) analyzed the effects of envelope structure, personnel behavior, equipment efficiency and other impacts on the energy consumption of buildings. Iqbal (Iqbal, 2004, pp. 277-289) discussed the ability of wind energy alone to achieve net-zero energy consumption in buildings in Newfoundland, and Wang (Wang, Gwilliam & Jones, 2009, pp. 1215-1222) simulated photovoltaic (PV) and wind power generation with TRNSYS software, showing that it is theoretically possible to achieve net-zero energy homes in the U.K. Bojić (Bojić, Nikolić, Nikolić et al., 2011, pp. 2407-2419) pointed out that the size of PV arrays has a direct impact on whether or not a building can achieve net-zero energy consumption. The first practical net-zero energy building in China, the net-zero energy clubhouse of Vantone Eco-city Xinxin Garden, mainly adopts the energy-saving design of passive envelope and introduces solar, wind, geothermal, and biomass energy as renewable energy sources to realize the net-zero energy requirement.

Net-zero construction is an important direction for the future development of the construction industry, and is of great significance to the sustainable development of society, economy and environment. At present, there are still many problems and obstacles in the development of net-zero construction, and the results of foreign research are not fully applicable to China. Therefore, this paper discusses the practice of net-zero building in China, analyzes its economy and feasibility, and proposes feasible solutions to provide reference and reference for the development of net-zero building in China.

2. Project Overview

Qingdao Sino-German Eco-Park is one of the key functional zones of Qingdao and is located in the north of Qingdao West Coast New District. The Sino-German Eco-Park is a cooperative project between the Chinese and German governments. The start-up area of the park covers an area of 34.92 square kilometers, and the area overlaps with the Qingdao section of the China (Shandong) Pilot Free Trade Zone (PFTZ) of about 12.86 square kilometers. The Sino-German Eco-Park was signed in July 2010 in the presence of the Prime Ministers of China and Germany, the foundation stone was laid in December 2011 and the construction started in July 2013. The park has innovatively applied technologies and concepts such as zero-carbon buildings, zero-carbon energy, zero-carbon transportation, green finance, zero-carbon culture, etc., and formed a low-carbon lifestyle and community operation mode. The ultra-low-energy building demonstration park is planned and constructed in accordance with the German standard, and it introduces the German passive house technology, with a cumulative total of 1,070,000 square meters of passive houses, which is expected to reduce carbon dioxide by 24,500 tons per year.

Figure 1. Aerial View of Sino-German Eco-Park

Located in Sino-German Ecological Park, Longfor Guangnian project contains villas, multistorey buildings, high-rise buildings and other properties. Among them, the villas and multistorey building are net zero buildings, aiming to create “Five Constant” technological residences: no need for heating in winter, no need for air conditioning in summer, no need to open windows for ventilation, and no need for purifiers to remove haze.

Constant temperature: Through thickening the periphery and technology system, the indoor temperature can be maintained between 20-26℃ for a long time, and this design makes the indoor noise free of air-conditioning equipment, and the temperature difference is small and the temperature is more uniform, which makes the human body feel more comfortable.

Constant humidity: through upgrading the fresh air system for two-way adjustment, the humidity is maintained at 40%-60% throughout the year, thus avoiding dryness in winter and humidity in summer, which is the least suitable for the growth of viruses and bacteria, and therefore is one of the standards for healthy housing set by the World Health Organization.

Constant Oxygen: 24-hour full replacement fresh air system makes the fresh air after dust removal, filtration, sterilization and disinfection sent into the room constantly, to ensure the content of indoor carbon dioxide less than 1000ppm, so health and safety are guaranteed.

Constant cleaness: through the building’s excellent airtightness, the pm2.5 filtration is up to 90%, which allows owners to stay at home to enjoy the cleanest air quality.

Constant quietness: the three-glass, two-cavity double LOW-E film-covered windows, not only isolate outdoor harmful light ,but also noise at the same time, to insure the indoor noise less than 30dB, greatly enhancing the comfort of home life.

Figure 2. Location of Longfor Guangnian Project

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Figure 3. Sand Table Model of Villas, Multistorey Buildings of Longfor Guangnian Project

3. Project Net Zero Construction Engineering Practice

Longfor Guangnian Project in Zhongde Ecological Park realizes 100% application of passive building energy-saving technology. The main building technical measures include envelope thermal insulation system, passive door and window system, building thermal bridge-free construction, and building airtightness system.

3.1 High-performance Exterior Envelope Thermal Insulation Technology

The main principle of the thermal insulation design of the external enclosure structure is to construct the external enclosure structure of the building by choosing materials with low heat transfer coefficient and high thermal inertia index, so as to effectively reduce the indoor and outdoor heat exchange and maintain the stability of the indoor temperature. When the thermal insulation layer of the envelope reaches a certain thickness, the energy loss through the envelope is minimized, and in winter, with the natural heat gain of the house, the indoor temperature can be more comfortable, and in summer, it is enough to resist the radiation of the sun from being transmitted to the indoor area, and in summer, it shortens the time of air-conditioning and effectively removes humidity.

All non-transparent parts of the envelope in this case study are very well insulated, which means that for most cold climate zones, the heat transfer coefficient (K-value) of the envelope does not exceed 0.15 $W/(m^2{\cdot}k)$, i.e., the heat loss per square meter of exterior surface caused by a unit of difference in temperature is not more than 0.15 W. The exterior envelope insulation structure and the insulation structure of the daughter wall are dealt with as shown in Figs. 4 and 5 below. Fig. 4 and Fig. 5 show. Through the analysis of energy consumption simulation calculation, the thermal insulation system of the outer enclosure greatly reduces the heat loss, thus verifying that the thermal insulation of the outer enclosure is an important means to improve the energy-saving performance of the building and indoor comfort. Through the selection of appropriate insulation materials and construction techniques, it can effectively reduce indoor and outdoor heat exchange, reduce the operational energy consumption of heating and cooling equipment, and improve human comfort. At the same time, this is also in line with the current social requirements for sustainable development and environmental protection.

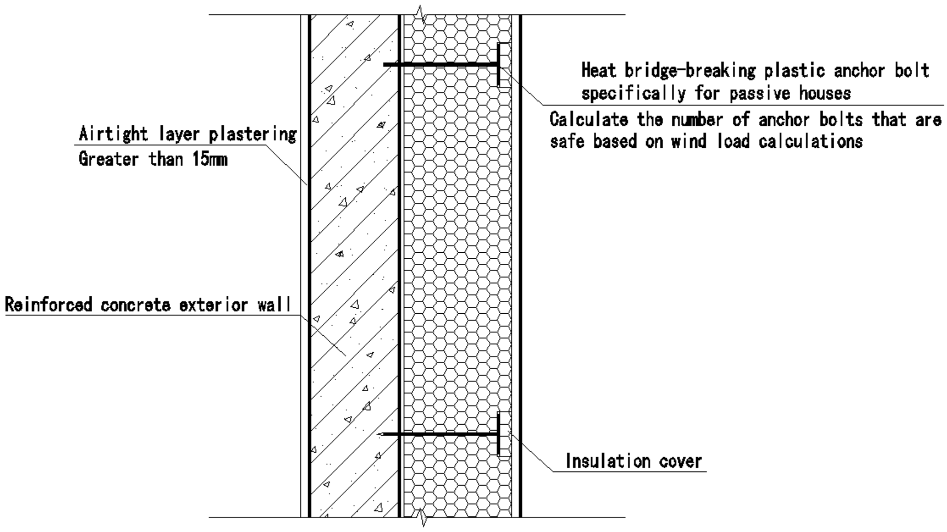

Figure 4. Exterior Enclosure Structure Heat Preservation Construction Practice

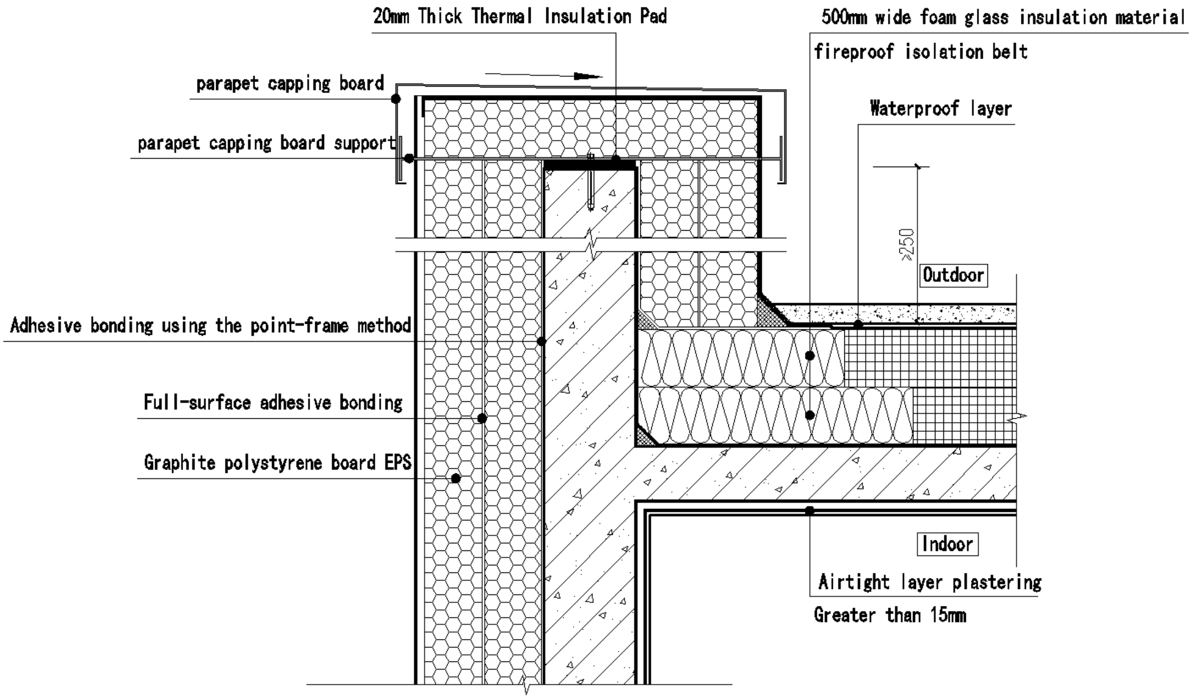

Figure 5. Insulation and Waterproof Construction Practice of Flat Roof Daughter Wall

3.2 High-performance Passive Window and Door Technology

Exterior windows are an important link in generating energy consumption and have a considerable impact on the internal thermal environment of the building, especially in hot summer and cold winter regions, where the amount of solar radiation is high in the summer, windows receive solar radiation, the indoor temperature rises, and the air conditioning load increases; therefore, the heat transfer from the windows themselves, the shading of exterior windows, and the ratio of window-to-wall area are all important factors influencing the energy consumption of the building. Passive windows and doors are windows and doors that have the characteristic of automatically completing actions such as opening and closing, and these actions usually do not require any external force. They can open or close automatically under different climatic and lighting conditions to ensure safety and save energy. Passive windows and doors utilize advanced materials and technologies that allow them to respond efficiently and intelligently to environmental changes.

The windows in this case study project were installed externally, with a K-value of ≤0.85W/(m²·k) for the entire window installation. Firstly, high efficiency and energy saving, passive windows and doors adopt multi-layer glass structure and high efficiency sealing design, which can effectively reduce the temperature difference between indoor and outdoor and save energy consumption. Secondly, good heat and sound insulation, passive doors and windows are equipped with one or more heat insulation layers in the middle of the glass, which can effectively isolate the temperature difference between inside and outside and ensure indoor comfort. Thirdly, waterproof vapor barrier film and waterproof vapor permeable film are pasted on the inner and outer sides of doors and windows respectively to ensure the air and water tight performance of door and window installation ,There is an aluminum sill board at the lower entrance of doors and windows to avoid the damage of rain and external force on the sill part of doors and windows, and the parts of the intersection of heat preservation and doors and windows are connected with a special connection strip for doors and windows, and external rainwater is prevented from entering into the inner side of doors and windows through the expansion seal. Finally, the passive window and door materials meet the requirements of environmental sustainability, the materials used in passive windows and doors are often sourced from sustainably managed forests or other environmentally friendly materials, and their production process also utilizes environmentally friendly adhesives and coatings, which are in line with environmental standards. The exterior window construction is shown in Fig. 6 and Fig. 7.

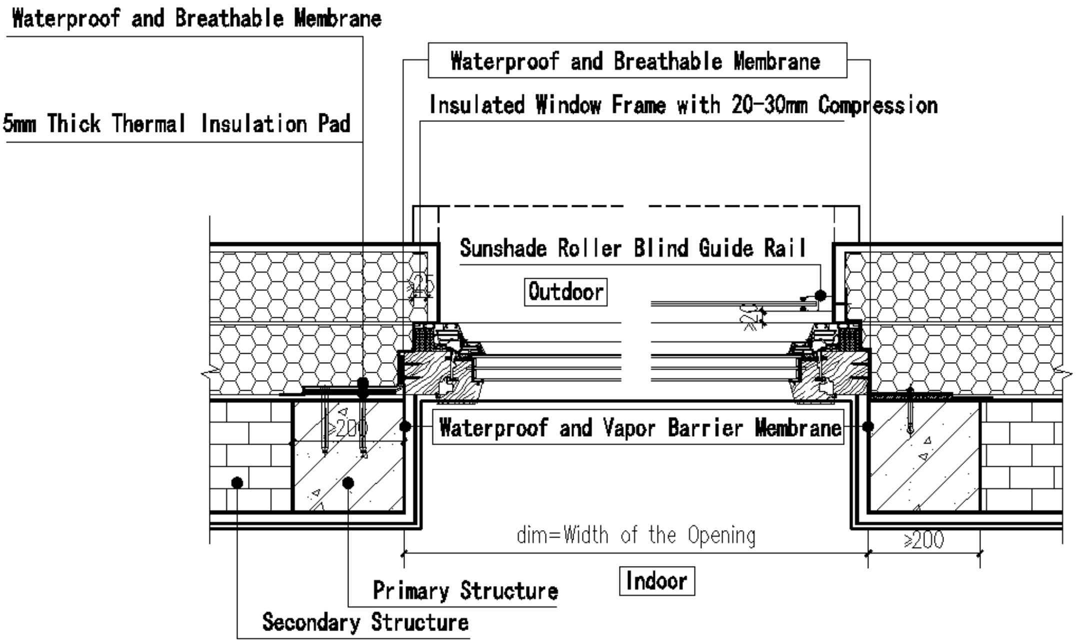

Figure 6. Passive Window Large Sample Node (Transverse Section)

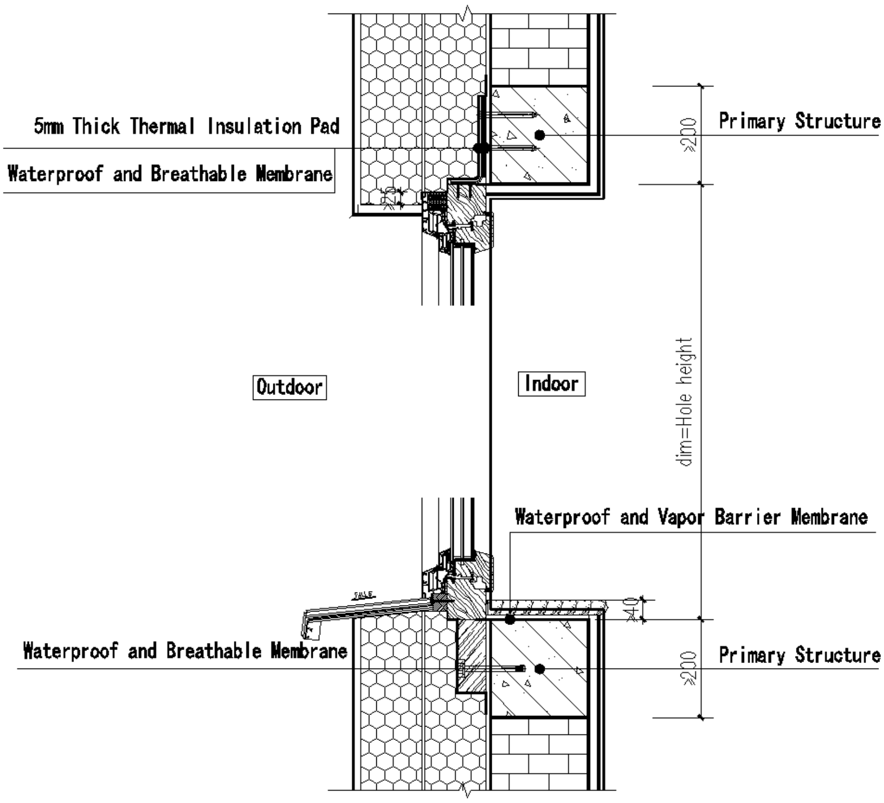

Figure 7. Passive Window Large Sample Node (Longitudinal Section)

3.3 Disconnect the Thermal Bridge and Airtightness Technology

A significant increase in heat flow density in the building envelope is known as a thermal bridge. Thermal bridges have a more significant impact on passive houses. Passive houses strictly control the generation of thermal bridges by designing the building envelope without thermal bridges, as shown in Figure 8 below. In addition, good airtightness can reduce cold air infiltration in winter, reduce the increase in cooling demand due to uncontrolled ventilation in summer, avoid mold, condensation and damage to the building caused by moisture intrusion, reduce the impact of indoor noise and air pollution and other undesirable factors on the indoor environment, and improve the quality of life of the occupants. Air conditioning refrigerant piping and power supply through the exterior wall insulation airtight node construction details are shown in Figure 9.

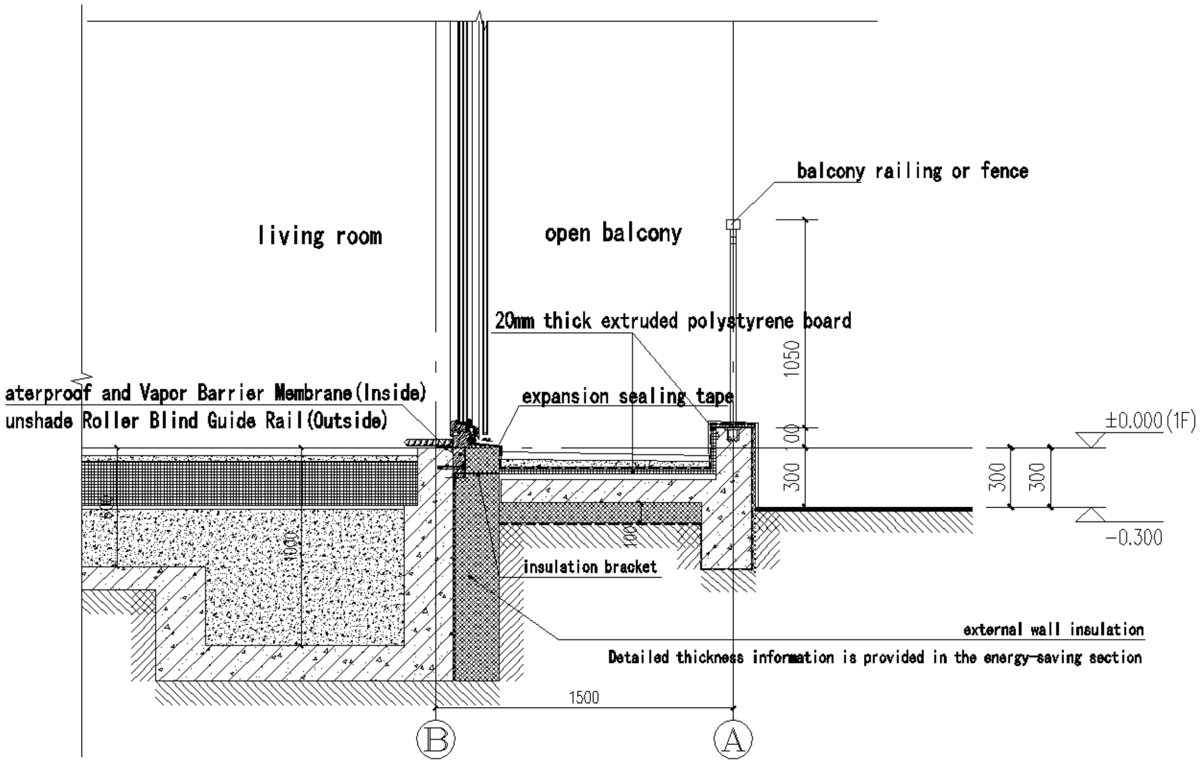

Figure 8. Open Balcony Thermal Bridge Large Sample Node

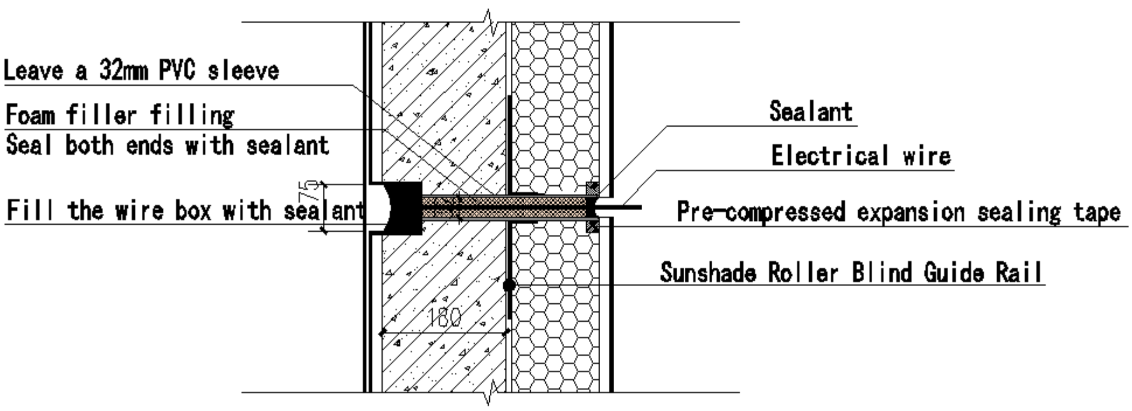

Figure 9. Air Conditioning Refrigerant Piping and Power Supply through the Outer Wall Insulation Airtight Nodes

4. Project Net Zero Construction and Installation Practices

4.1 Indoor Integral Heat Pump Fresh Air System

The project's residential units utilize indoor heat pumps with heat recovery devices for passive houses to ensure a comfortable and clean environment inside the building. Heat pump fresh air integrated machine is the air conditioning and fresh air machine two-in-one combination, so that it can have both the cooling and heating function of air conditioning and can improve the quality of our indoor air.

(1) Fresh air system

1) The fresh air system can not only filter excessive moisture and odor in the air, but also efficiently filter pollen and PM2.5 in the air, providing pure fresh air to the room;

2) In winter working conditions, the new air system with heat recovery can greatly reduce the heat loss of the building, apparent heat recovery efficiency ≥ 75%;

3) In summer working conditions, the system reverses the cycle, can recover more than 80% of the heat, so that the air entering the room is close to the indoor temperature, thus realizing the recycling of heat;

4) The fresh air heat recovery integrated machine has built-in electric air valve, temperature control devices and air quality testing devices on the air conditioning outdoor unit, which can control the starting and stopping of the energy machine and the new air machine according to the temperature of the return air and the concentration of carbon dioxide; each living room is set up with a control panel that has the functions of temperature adjustment and wind speed adjustment, which can realize the adjustment of the temperature and the air volume of the whole fresh air integrated machine.

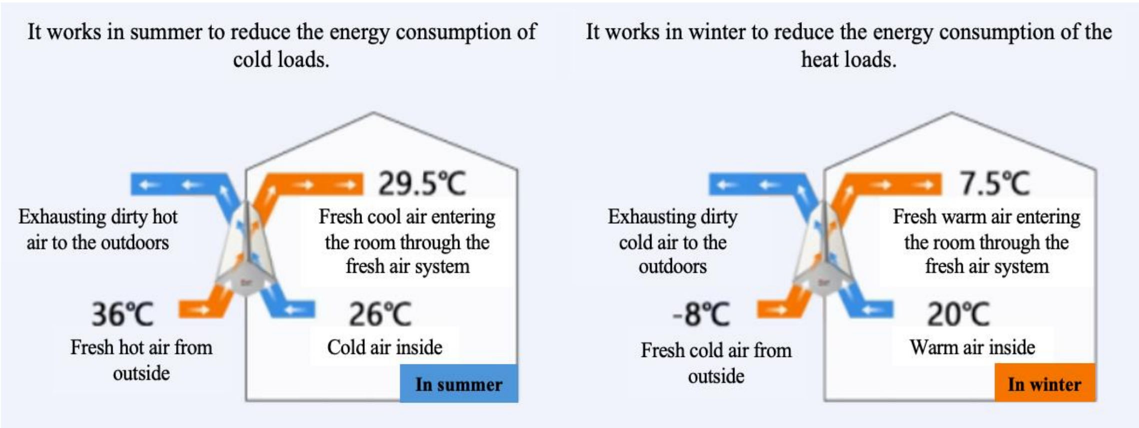

Figure 10. Schematic Diagram of Fresh Air System

(2) Heat pump system

Most air conditioners can withstand ambient temperatures between -7℃ and 43℃, and in the ultra-low temperature environment in the northern region, the frost problem during the heating process seriously affects the system's energy efficiency; while the heat pump technology on the basis of inverter technology, increased jet enthalpy technology, the use of specialized make-up air compressor instead of the two compressors, so that it can withstand ambient temperatures between -25℃ and 48℃ (some of the ultra-low temperature). Type air energy heat pump can also operate normally at -30℃, which not only reduces the cost, but also solves the problem of even oil between the two compressors, increases the

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exhaust volume, thus improving the heating capacity of the heat pump system and realizing greater energy saving.

In addition, the heat pump is just nature's porter, it uses a small amount of electricity to carry the heat in the air to heat the water, so it is more energy-efficient than the traditional air conditioning more energy-saving. Moreover, the heat pump system group mainly uses water circulation, the air out of the air is not dry, will not be too much evaporation of indoor moisture, more comfortable.

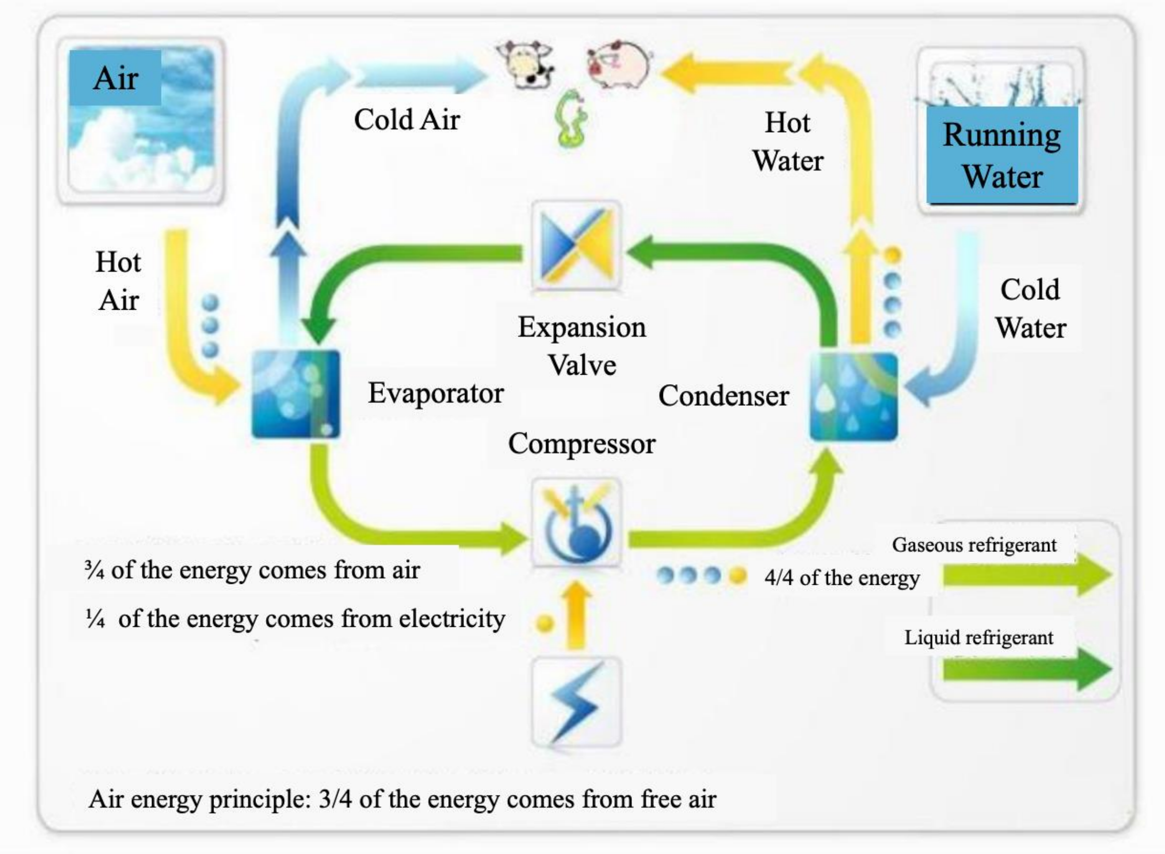

Figure 11. Schematic Diagram of Heat Pump System

4.2 Solar Photovoltaic Power Generation and Hot Water Systems

In terms of new energy utilization, the project utilizes solar water heating system and photovoltaic power generation system.

(1) Solar water heating: solar water heating system is widely used in China with its unique advantages, and the proportion of domestic hot water provided by solar water heating system in this project reaches 100%.

(2) Photovoltaic power generation: In addition to maximizing the use of natural lighting, this project utilizes the photovoltaic power generation system as much as possible to provide electric energy, such as the Sakura Parking Lot in terms of plant lighting, all the lawn lamps are solar-powered lamps and lanterns; and then there are solar photovoltaic panels on the roofs of both the residential and the public building parts, which provide electronic energy for the public areas.

4.3 Energy Efficiency Analysis

This project is able to maintain constant temperature, humidity, oxygen, static and cleanliness throughout the year, not by relying on the traditional heating and cooling system required for ordinary buildings, but by technical means such as thermal insulation materials, high-performance external windows, airtight design, and high-efficiency heat recovery devices.

Take Longfor Guangnian 7 group 4# building as an example, its total building area is 4870.88 square meters, after calculation, the total heat load is 48.22KW, the air conditioning heat index is 9.9W/m^2; the total cold load is 86.98KW, the fresh air cold load is 8KW, the cold index is 19.5W/m^2. After comparing with the same type of conventional buildings, the heating and cooling energy consumption of this system is only 20% of the conventional buildings of the same type, with obvious energy-saving effect.

Table 1. Comparison of Cooling and Heating Load Indicators

Building Type	cold indicator(W/m^2)	Hot indicators(W/m^2)
General Building	80	60
Passive House	19.5	9.9

5. Project Optimization Recommendations

5.1 Building Optimization Recommendations

(1) After simulation and analysis of the components of the residential building envelope, we reveal the intrinsic correlation between building energy consumption and these components. In terms of window design, it is recommended that the south-facing window-to-wall ratio should be set in the range of 0.4 to 0.6 to ensure that energy saving is maximized without affecting the building’s lighting. Meanwhile, the north-facing window-to-wall ratio should be set to a smaller value to maintain indoor temperature stability. As for the sun-shading facilities, their design principles are similar to those of the window-to-wall ratio. It is recommended that the shading coefficient for the south direction should be controlled between 0.5 and 0.6 to effectively reduce the influence of solar radiation on the indoor temperature. The northward shading coefficient should be set as small as possible to reduce unnecessary energy loss.

(2) There are a large number of existing buildings with high energy consumption and low comfort in China that are in urgent need of energy-saving renovation. The active-passive integrated near-zero energy building system provides an ideal platform for this purpose, and it is suggested that high-performance exterior insulation enclosure modules be combined with existing buildings to reduce the load, shorten the construction period, and improve the thermal insulation and airtightness performance, so as to promote the development of existing buildings towards net-zero energy consumption.

5.2 Installation System Optimization Recommendations

(1) The installation location of the heat pump fresh air equipment should be optimized, and the location should be confirmed according to the indoor house type, so as to minimize the length of the pipeline and ensure a good indoor airflow organization and circulation, thus reducing the energy consumption and loss in the process of conveying cold and heat.

(2) This project only sets up heat recovery fresh air integrated unit in residential indoor, and it is recommended to set up full heat exchanger in the public area outside the house type to ensure fresh air supply and air circulation in the public area, and at the same time, it can recycle the heat in the public area, which in turn reduces the energy loss in the part of the public area.

(3) The public area can learn the water source heat pump system and the end of the hole plate air supply form from the “Sino-German Passive House Technology Center”. Water source heat pump can make full use of the cold and heat of groundwater, reduce energy consumption. Because of the hole plate air outlet uniformity, low wind speed and low noise, it not only ensures the indoor temperature requirements, but also ensures quiet and comfortable indoor environment.

(4) Supporting intelligent control machine energy consumption monitoring system should be designed to monitor the energy consumption operation in real time, collect energy consumption monitoring data, adjust the energy system operation strategy in time, and provide strong support for the efficient operation of passive house energy system in the future.

(5) The basement adopts the traditional lighting well with limited brightness, and the light guide tube lighting system can be utilized to increase the brightness and realize the daytime lighting without electricity, so as to achieve the purpose of energy saving.

(6) As for renewable energy utilization, in addition to solar energy, net zero buildings can also be combined with its own situation to make full use of other renewable energy, such as wind energy, biomass energy and so on.

6. Conclusion

The development of net-zero energy buildings not only responds to the national “dual-carbon” strategic development goal, but also creates a more comfortable living experience for the residents, and also saves money for the long-term use of the building. This paper analyzes the design scheme of passive house in Qingdao Longfor Guangnian project, combines the problems existing in the project practice, and comes up with the optimization scheme. It can provide better design ideas and practical experience for passive houses in other hot summer and cold winter regions.

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