Energy-plus Building and Energy-plus Community Research on Definition, Technical Indicators and Industrial Development

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Foreword

At the general debate of the 75th UN General Assembly, President Xi Jinping proposed that China will strive to achieve peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. The energy consumption of buildings accounts for a large proportion of China's total energy consumption, so it is imperative to reduce energy consumption in the design and construction phases. Energy-plus building and energy-plus communities are important components to achieve the goal of carbon neutrality by 2060.

This study includes five aspects: definitions of energy-plus building and energy-plus communities, the analysis of energy-plus building potential and technical indicators, the energy-plus community indicator system, key technologies and industrial development, and policy recommendations.

Firstly, definitions of energy-plus building and energy-plus communities, based on time and space, are put forward. By analyzing the physical boundary, balance period, energy consumption calculation range and measurement indicator of energy-plus building and energy-plus communities, definitions of energy-plus building and energy-plus communities are determined, which provide the basic conditions for its popularization in China. As one of the zero-energy buildings and communities, energy-plus building and energy-plus communities require that the annual capacity of renewable energy in buildings, communities and surrounding areas be greater than 110% of the total annual energy consumption.

Secondly, according to different building types in different climatic regions, the classification of energy-plus building based on energy matching is constructed. The performance of the building envelope of different building types in different climatic regions is analyzed and studied, and the benchmark building models of high-performance building envelope (high-performance exterior wall, high-performance window and air-tightness) in different climatic regions are established. The load, energy consumption and renewable energy characteristics are analyzed, the load characteristics of different building types in different climatic regions are determined, the selection scheme of building energy systems is provided, and the renewable energy allocation mode is optimized.

Thirdly, based on the typical cases of energy-plus communities, six types of first-class energy consumption indicators and 20 second-class indicators with building technology feasibility are established. Based on its actual situation, the energy-plus community determines the target value of indicators with regional characteristics, which can cover the whole process of community planning, construction, operation, and management.

Furthermore, according to the space-time characteristics of productivity and energy consumption of energy-plus building and energy-plus community, the key technologies of different building types in different climatic regions are determined. The main key technologies are heat preservation technology of the external envelope, efficient heat recovery technology, renewable energy utilization technology, and micro-grid and energy storage technology. Through a series of building technologies, building energy consumption can be effectively reduced, and the utilization efficiency of renewable energy can be improved, thus providing a guarantee for realizing the energy-plus building and energy-plus community.

Finally, based on China's current reality, this paper puts forward some policy suggestions that are suitable for energy-plus buildings and communities: strengthen the top-level design of China's energy-plus building and energy-plus community development, and carry out sub-regional guidance; strengthen the ability of technical research and innovation; improve the standard system and standardize the construction and operation of energy-plus buildings and energy-plus communities; improve the construction of systems and mechanisms to stimulate market vitality; enhance education, personnel training, and publicity.

1. Study of the definition of energy-plus building and an energy-plus community

1.1 Influencing factors of the definition of energy-plus building and an energy-plus community

Energy-plus building and energy-plus communities emphasize climate suitability and are performance-oriented. The definition of energy-plus building should explain the essential characteristics, connotation and extension of building, accurately and briefly, and quantify the key characteristics such as energy efficiency and energy consumption.

1.1.1 Physical boundary

The classification of physical boundary mainly affects the source of renewable energy consumed by buildings. Usually, the physical boundary of buildings is divided into inside and outside, such as photovoltaic power generation, ground source heat pump and power from the power grid using clean energy. Professor Anna Marszal et al. clearly divided five physical divisions of building renewable energy supply in the article: Net Zero Energy Buildings [1], as shown in Table 1.1 .

Table 1.1 Classification of Renewable Energy

No.	Physical classification	Renewable Energy Sources	Examples
1	Building footprint	Using low energy consumption technology to reduce energy consumption of the building	Natural lighting, efficient energy system, natural ventilation, etc.
2	On-site	Utilizing renewable energy resources of the building	Photovoltaic, solar hot water, wind power generation, etc.
3	On-site	Renewable energy resources in the construction site	Photovoltaic, solar and wind power generation in the site
4	Off-site	Transport the renewable energy resources outside the site to the site to provide energy	Biomass power generation, waste heat power generation or heating, etc.
5	Off-site	Purchase renewable energy resources outside the site	Power grids using wind power and photovoltaic power generation, or clean energy points purchased remotely, sometimes including hydropower generation

1.1.2 Energy consumption calculation range

The actual energy consumption of buildings involves heating, air conditioning, ventilation, lighting, domestic hot water, cooking, sockets and other systems. Building energy systems actually measure the total energy consumption of buildings. The main influence factors of energy consumption in various systems are different, and will be affected by user behavior, external climate conditions, indoor environmental parameters and so on. There are many calculation ranges for evaluating the energy consumption of buildings. For example, EN15603:2008 stipulates that building energy consumption must include energy consumption independent of user behavior, actual meteorological conditions and other actual (indoor and outdoor) environments, i.e. energy consumption of heating, air conditioning, dehumidification, humidification, ventilation, domestic hot water and lighting (for public buildings). In the field of building energy efficiency in China, the range of building energy consumption used to judge building compliance is generally the energy consumption of heating, air conditioning, ventilation and lighting systems. In the architectural design stage, the above can be controlled by design standards.

1.1.3 Measurement indicators

At present, there are four indicators that can be used to measure zero-energy buildings: terminal energy consumption, primary energy, energy bills, and energy carbon emissions. Because there are many climatic zones in China, and there is a big difference between the north and the south, according to the actual situation in China, it is necessary to determine one or multiple measurement indicators, which need specific analysis. For example, a building can generate electricity through its own PV system in summer, and it needs to burn biomass energy or fossil fuel for heating in winter, so the balance calculation of its production capacity is relatively complex, and it is difficult to balance it with one parameter. However, for new buildings whose system is relatively simple, it is more convenient for all parties to agree on the definition and system simulation calculation by using terminal energy as the calculation unit, which is convenient for work promotion. The rationality of technical indicators must consider the architectural characteristics, the climate characteristics and the related industries of the local country. Technical indicators of different countries are not comparable, however, as long as they adapt to local conditions, they are reasonable.

1.1.4 Equilibrium period

Most experts think that it is simplest and most reasonable to calculate the energy balance in years [6], but Professor Paul Torcellini and others think that 30 or 50 years can also be used as the equilibrium period, because usually in 30 or 50 years the building will undergo a major overhaul, which will have a great impact on the building, and the building materials and construction stages can also be taken into account in the whole life cycle of the building[7].

1.2 Definition of energy-plus building and energy-plus community

1.2.1 Definition of energy-plus building

Energy-plus building: As a manifestation of zero-energy buildings, energy-plus buildings are connected with renewable energy generation and heating systems, and the total renewable energy generated by buildings and within 100m around them is greater than the energy consumption of heating, air conditioning, ventilation, lighting and other equipment by 110%. The output of renewable energy in energy-plus buildings cannot only meet the building's own needs, but also supply energy to the outside. Without considering renewable energy, the annual equivalent power consumption of energy-plus buildings should be no higher than $50kWh/m^2a$.

1.2.2 Definition of energy-plus community

Energy-plus community: A comprehensive area integrating industrial development, supporting services and residence, which is connected with the renewable energy generation and heating system, and the renewable energy capacity in the area is 110% larger than the energy consumption of heating, air conditioning, ventilation, lighting and other equipment in the community. Compared with energy-plus buildings, energy-plus communities not only consider the renewable energy of buildings in the community, but also consider the renewable energy output of land in and around the community within 3km.

2. Application potential and technical indicator analysis of energy-plus buildings in different climatic regions

2.1 Model establishment

2.1.1 Establishment of benchmark building model

Based on China's relevant building energy efficiency codes and actual building investigation, 10 benchmark building models which can represent most buildings in China are established, which are; rural residential buildings, 4-storey residential buildings, 8-storey residential buildings, 15-storey residential buildings, large office buildings, small office buildings, large hotel buildings, small hotel buildings, schools and shopping malls.

The building load is greatly affected by the meteorological conditions of its location. China has a vast territory and is divided into five climatic zones: severe cold region, cold region, hot summer and cold winter region, hot summer and warm winter region and mild region. Examples selected include Harbin in a severe cold region, Beijing in a cold region, Shanghai in a hot summer and cold winter region, Guangzhou in a hot summer and warm winter region and Kunming in a mild region.

2.2 Study of the influence of building envelope on load

2.2.1 Study of the performance of high-performance exterior walls and windows

High-performance exterior wall, roof and ground insulation are the most effective and most feasible energy-saving means with the lowest cost for building energy conservation. High-performance building envelope structure has also been widely used in ultra-low energy consumption demonstration buildings currently built in China. For example, the external wall of the energy-saving demonstration building of China Academy of Building Research, a Sino-US joint research center for clean energy, adopts 35mm insulated vacuum board, and the external wall heat transfer coefficient is 0.12 $W/(m^2K)$. A demonstration building in a severe cold area adopts 300mm extruded board XPS and 300mm EPS module, and the external wall heat transfer coefficient can be reduced to 0.10-0.15 $W/(m^2K)$.

2.2.2 Study of load characteristics in severe cold areas

It can be seen from Figure 2.1 that the heating load of benchmark buildings in severe cold areas accounts for most of the annual load, including 88.1% in rural houses, 92.6% in 4-storey residential buildings, 88.7% in 8-storey residential buildings, 93.4% in 15-storey residential buildings, 89.1% in large office buildings, 94.6% in small office buildings, 88.3% in large hotel buildings, 92.9% in small hotel buildings, 84.2% in shopping malls, and 92.1% in schools. For high-performance envelope buildings, the proportions of building heating load in the whole year's load have decreased and they are 53.1% in rural houses, 51.1% in 4-storey residential buildings, 46.1% in 8-storey residential buildings, 67.9% in 15-storey residential buildings, 59% in large office buildings, 76.2% in small office buildings, 53.1% in large hotels, 54.8% in small hotel buildings, 49.7% in shopping malls, and 71.3% in schools, among which the heating load of medium and small office buildings and schools still account for 70%. The reason why the heating load of school buildings still accounts for a large proportion is that, when the demand for cooling load is large in summer, the school is in the summer vacation, which causes the cooling load to be small, resulting in a larger proportion of the heating load in school buildings.

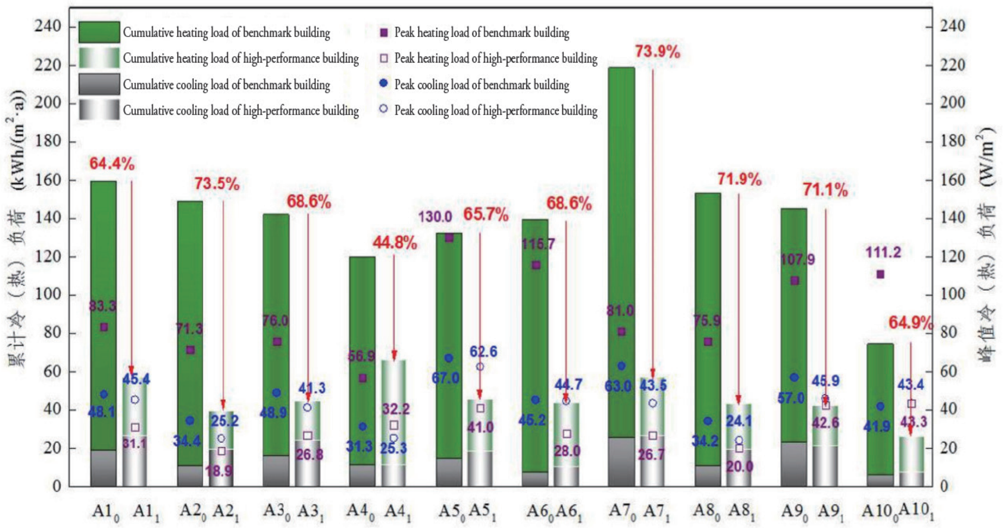


Figure 2.1 Load comparison diagram of benchmark buildings and low energy consumption buildings in severe cold areas

2.2.3 Study of load characteristics in cold regions

It can be seen from Figure 2.2 that the building heating load of benchmark buildings accounts for about 50% - 60% of the annual load. Winter heating load in cold areas accounts for most of the annual load, among which 58% in rural houses, 55.3% in 4-storey residential buildings, 50.8% in 8-storey residential buildings, 61.5% in 15-storey residential buildings, 45.8% in large office buildings, 65.5% in small office buildings, 57.9% in large hotels, 62.1% in small hotels, 55.7% in shopping malls, and 64.2% in schools. With the adoption of high-performance building envelope, the annual heating load of buildings has dropped significantly, and all other buildings except school buildings have dropped by more than 50%. The decline of school buildings is small, only 38.8%.

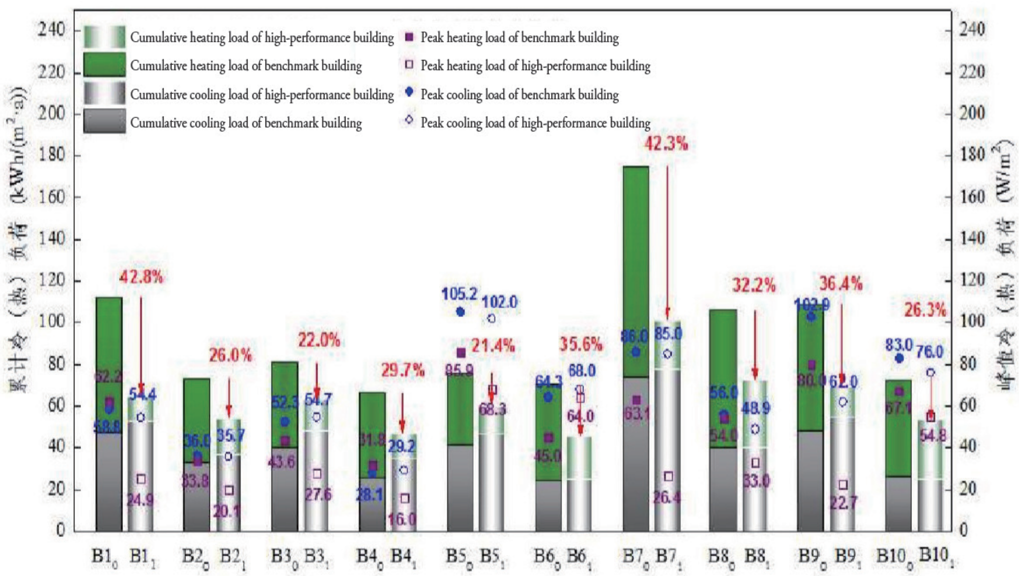


Figure 2.2 Load comparison diagram of benchmark buildings and low energy consumption buildings in cold areas

2.2.4 Study of load characteristics in hot summer and cold winter areas

It can be seen from Figure 2.3 that the building heating load of the benchmark building accounts for about 60% - 80% of the annual cumulative load, including 62% for rural houses, 70% for 4-storey residential buildings, 75% for 8-storey residential buildings, 62% for 15-storey residential buildings, 82% for large office buildings, 66% for small office buildings, 66% for large hotel buildings, 56% for small hotel buildings, 84.4% for shopping malls, and 78% for schools.

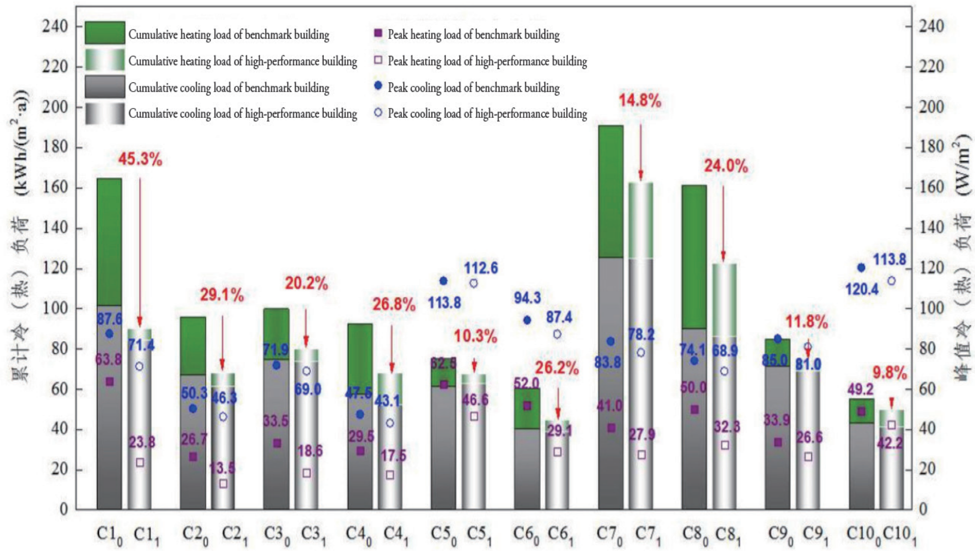


Figure 2.3 Load comparison diagram of benchmark building and low energy consumption building in hot summer and cold winter area

2.2.5 Study of load characteristics in hot summer and warm winter areas

It can be seen from Figure 2.4 that the building cooling load of the benchmark building accounts for more than 90% of the annual cumulative load, including 94.8% for rural houses, 96.7% for 4-storey residential buildings, 96.2% for 8-storey residential buildings, 94% for 15-storey residential buildings, 97.6% for large office buildings, 93.4% for small office buildings, 91% for large hotel buildings, 86.9% for small hotel buildings, 99% for shopping malls, and 98% for schools.

It can also be seen from Figure 2.4 that the winter heating load of various buildings in Guangzhou is almost zero and can be ignored. The cooling load decreased slightly, especially in rural houses which decreased by about 34.4%, while the load of other buildings was not particularly obvious. The reason for the obvious decrease of rural residential cooling load is that the building model partition is simple, and the internal heat is small, which results in the great contribution rate of building envelope to building cooling load. There are many thermal divisions in other buildings types and because of the internal heat gain, the decrease in cooling load is not obvious. .

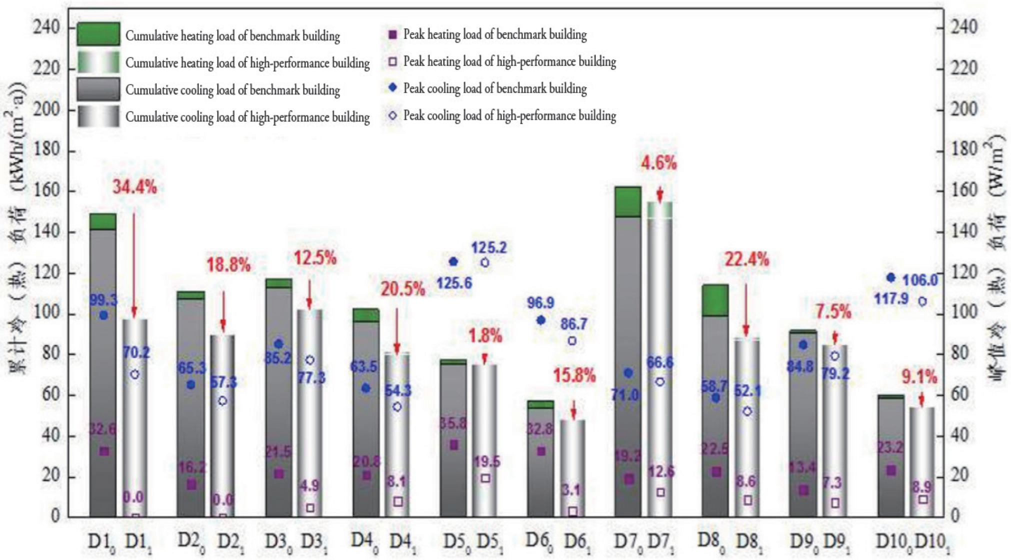


Figure 2.4 Load comparison diagram of benchmark building and low energy consumption building in hot summer and warm winter area

2.2.6 Study of load characteristics in mild areas

Figure 2.5 shows the load comparison diagram of benchmark buildings and low-energy buildings in mild areas. It can be seen that the cold and heating loads in mild areas in China are relatively small, and the change of building function has little effect on building load. After adopting high-performance envelope, the building load does not drop significantly. It can be concluded that the climatic conditions in mild areas are relatively good, and the building load is not large, so adopting a high-performance envelope has little effect on building energy saving.

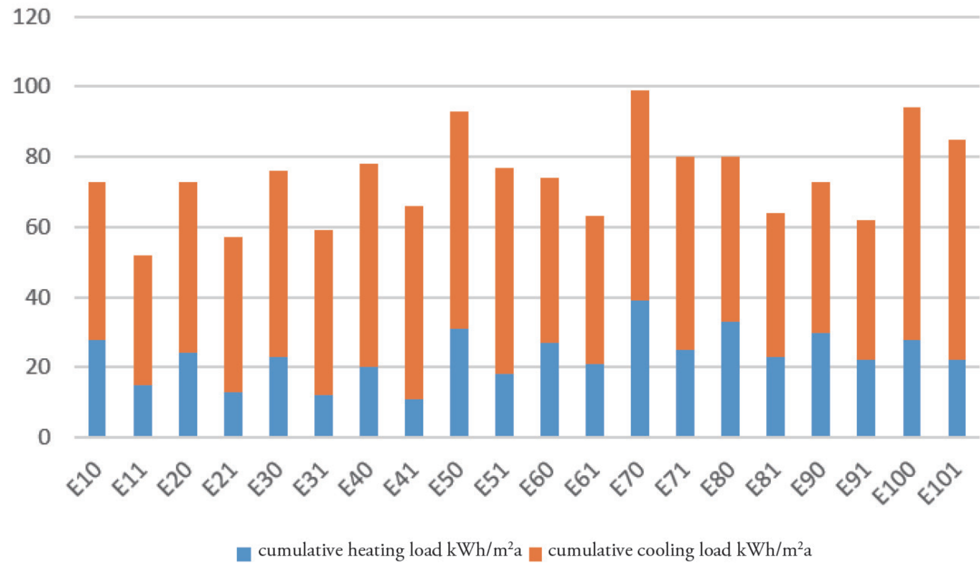


Figure 2.5 Load comparison diagram of benchmark building and low-energy building in mild areas

2.2.7 Comprehensive analysis

The accumulated values of cold and heating loads of ten typical building types in five climatic regions under benchmark conditions and high-performance envelope conditions are calculated and analyzed. It can be concluded that the impact of high-performance envelope on the accumulated values of loads is greatest in severe cold regions and cold regions, and the annual accumulated heating loads of buildings in severe cold regions can be reduced by 75%, with an average reduction rate of 70%. The annual cumulative heating load reduction rate of buildings in cold areas is above 50%, and the cumulative cold and heating load can be reduced by 30%-40%. The annual cumulative heating load reduction rate of buildings in hot summer and cold winter areas can reach 80%, and the annual cumulative cold and heating load can be reduced by 20%-30%. Because the building load in hot summer and warm winter areas is basically a cooling load, the high-performance envelope has limited effect on reducing the building load in hot summer and warm winter areas. The climate in mild areas is suitable all the year round, and the cold and heating loads in this area are low all the year round, so the effect of high-performance envelope on reducing the load can be ignored.

Table 2.1 List of load types of various high-performance buildings

Load characteristics	Rural houses	4-story residential building	8-story residential building	15-story residential building	Large office buildings	Small office building	Large hotel buildings	Small hotel buildings	Shopping malls	Schools	Areas
Heating-based				P	P	PP				P	Severe cold area
Cooling-heating balance	PP	P	P				P	P	P		
Cooling-heating balance						PP		P		P	Cold area
Cooling-based and heating-needed		P					P				
Separate cooling	P		P	P	P				P		
Cooling-heating balance	P										Hot summer and cold winter area
Cooling-based and heating-needed				P			P	P			
Separate cooling		P	P		P	P			P	P	
Separate cooling	P	P	P	P	P	P	P	P	P	P	Hot summer and warm winter area
Cooling-heating balance	P	P	P	P	P	P	P	P	P	P	Mild area

2.3 Building energy consumption analysis and research

2.3.1 Simulation study of building energy consumption in severe cold areas

Table 2.2 Statistical Table of Annual Sub-item Energy Consumption of Building Unit Area in severe cold areas

Simulated working condition	Heating energy consumption (kWh/m^2)	Energy consumption of air conditioner (kWh/m^2)	Energy consumption of lighting (kWh/m^2)	Other energy consumption (kWh/m^2)	Total (kWh/m^2)
Benchmark building	57.24	5.82	23.22	25.78	112.06
Low energy consumption building	25.34	5.31	14.55	12.68	57.88

The annual energy consumption of the benchmark building and high-performance building are shown in Table 2.2. It can be seen that the heating energy consumption in the benchmark building accounts for more than 50%, which shows that there is great potential to reduce the heating energy consumption in winter in severe cold areas, with the energy consumption of air conditioning only 5.82 kWh/m^2, and the total energy consumption of lighting and other energy consumption is about 50 kWh/m^2.

With the adoption of a high-performance envelope and a high-efficiency energy system, the energy consumption of heating is significantly reduced by more than 50%, and the energy consumption of lighting and other equipment is also reduced. The total energy consumption of low-energy buildings is 57.88 kWh/m^2, which is 48.4% lower than that of benchmark buildings. The adoption of a high-performance envelope and a high-efficiency energy system can significantly reduce building energy consumption in severe cold areas.

2.3.2 Simulation study of building energy consumption in cold areas

Table 2.3 Statistical Table of Annual Sub-item Energy Consumption of Building Unit Area

Simulated working condition	Heating energy consumption (kWh/m^2)	Energy consumption of air conditioner (kWh/m^2)	Energy consumption of lighting (kWh/m^2)	Other energy consumption (kWh/m^2)	Total (kWh/m^2)
Benchmark building	17.5	32.4	15.8	24.6	90.3
Low energy consumption building	8.3	16.7	9.7	12.7	47.4

The annual energy consumption of the benchmark buildings and low-energy buildings is shown in Table 2.3. It can be seen that the heating energy consumption in benchmark buildings in cold areas has obviously decreased compared with that in severe cold areas, while the energy consumption of air conditioning has obviously increased, accounting for about 30% of the total energy consumption. The energy consumption of lighting and other equipment is 15.8 kWh/m^2 and 24.6 kWh/m^2 respectively. After adopting high-performance enclosure structure and high-efficiency equipment, the energy consumption of air conditioning has obviously decreased from 32.4 kWh/m^2 to 16.7 kWh/m^2. At the same time, the energy consumption of lighting and other equipment decreased to 9.7 kWh/m^2 and 12.7 kWh/m^2, and the final total energy consumption was 47.4 kWh/m^2.

2.3.3 Simulation study of building energy consumption in hot summer and cold winter areas

Table 2.4 Statistical Table of Annual Sub-item Energy Consumption of Building Unit Area

Simulated working condition	Heating energy consumption (kWh/m²)	Energy consumption of air conditioner (kWh/m²)	Energy consumption of lighting (kWh/m²)	Other energy consumption (kWh/m²)	Total (kWh/m²)
Benchmark building	18.8	29.1	13.4	22.3	83.6
Low energy consumption building	6.7	16	9.7	12.7	45.1

The annual energy consumption of the benchmark buildings and low-energy buildings is shown in Table 2.4. It can be seen that after adopting high-performance envelope and high-efficiency equipment, the heating energy consumption in low-energy buildings of hot summer and cold winter areas has obviously decreased compared with the benchmark buildings, and the energy consumption of air conditioning has also decreased by more than 50%. The energy consumption for lighting and other equipment of the benchmark building is 13.4 kWh/m² and 22.3 kWh/m² respectively; while the energy consumption for lighting and other equipment of the low-energy buildings has decreased to 8.8 kWh/m² and 12.7 kWh/m², resulting in the total energy consumption of 38.8 kWh/m².

2.3.4 Simulation study of building energy consumption in hot summer and warm winter areas

Table 2.5 Statistical Table of Annual Sub-item Energy Consumption of Building Unit Area

Simulated working condition	Heating energy consumption (kWh/m²)	Energy consumption of air conditioner (kWh/m²)	Energy consumption of lighting (kWh/m²)	Other energy consumption (kWh/m²)	Total (kWh/m²)
Benchmark building		33.2	14.5	20.5	68.2
Low energy consumption building		21.5	9.1	10.6	41.2

The annual energy consumption of the benchmark buildings and low-energy buildings are shown in Table 2.5. It can be seen that buildings in hot summer and warm winter areas do not need heating, but the energy consumption of air conditioning is relatively high, with the benchmark building reaching 33.2 kWh/m². High-efficiency air-conditioning equipment is only used in low-energy buildings, which reduces the energy consumption of air conditioning by about 30% to 21.5 kWh/m². The energy consumption of lighting and other equipment in benchmark buildings is 14.5 kWh/m² and 20.5 kWh/m² respectively. The energy consumption of lighting and other equipment in low-energy buildings decreases to 9.1 kWh/m² and 10.6 kWh/m², with the total energy consumption of 41.2 kWh/m².

2.3.5 Simulation study of building energy consumption in mild areas

Table 2.6 Statistical Table of Annual Sub-item Energy Consumption of Building Unit Area

Simulated working condition	Heating energy consumption (kWh/m^2)	Energy consumption of air conditioner (kWh/m^2)	Energy consumption of lighting (kWh/m^2)	Other energy consumption (kWh/m^2)	Total (kWh/m^2)
Benchmark building	7.3	10.8	14.2	15.8	48.1
Low energy consumption building	4.5	7.7	10.1	10.6	32.9

The annual energy consumption of the benchmark buildings and low-energy buildings are shown in Table 2.6. It can be seen that the heating and cooling energy consumption in mild areas is relatively small, with the heating energy consumption of the benchmark buildings being 7.3 kWh/m^2 and the air conditioning energy consumption being 10.8 kWh/m^2. After adopting high-performance enclosure structure and high-efficiency system, the heating energy consumption is reduced to 4.5 kWh/m^2 and the air conditioning energy consumption is 7.7 kWh/m^2, whose reduction is not obvious. The energy consumption of lighting and other equipment in the benchmark buildings is 14.2 kWh/m^2 and 15.8 kWh/m^2 respectively. The energy consumption of lighting and other equipment in the low-energy buildings decreases to 10.1 kWh/m^2 and 10.6 kWh/m^2, and the total energy consumption is 32.9 kWh/m^2.

2.4 Photovoltaic system capacity and building energy matching research

With a building photovoltaic system, the generated power is first used by the building itself, and the rest is connected to the grid. In this case, it is necessary to consider the matching relationship between annual power generation and building energy consumption.

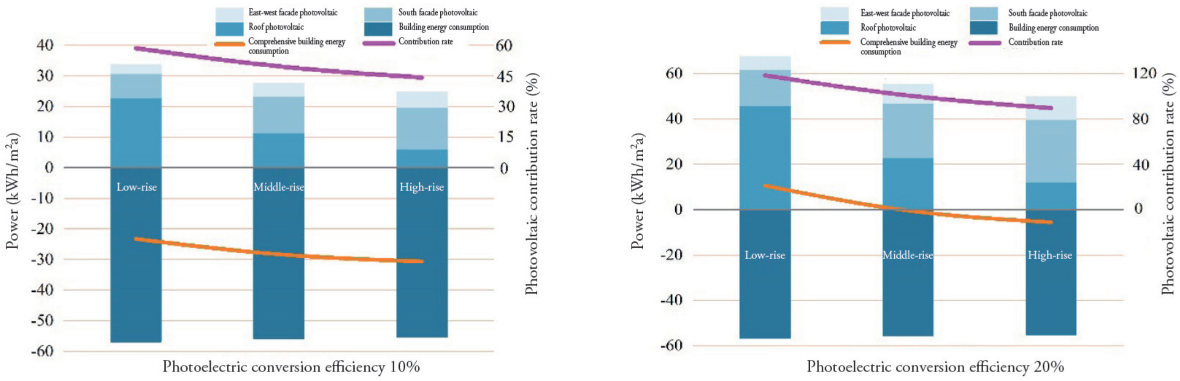
2.4.1 Model setting

In this section, 4-storey, 8-storey and 15-storey residential buildings are selected as examples to study the matching between building photovoltaic system capacity and building energy consumption. Refer to Section 2.1 for building model and setting.

2.4.2 Energy matching analysis of a building photovoltaic system in severe cold areas

Figure 2.6 shows the annual matching analysis of photovoltaic system capacity and building energy consumption of residential buildings in severe cold areas. For the same place, there is a small difference in building energy consumption per unit area among low-rise, middle-rise and high-rise buildings. With the increase of building height, heating energy consumption will gradually decrease, but on the contrary, cooling energy consumption will gradually increase.

Harbin is located in the northernmost part of China, and the annual solar elevation angle is small, so the south facade receives more solar radiation, and the photovoltaic power generation in this area is less affected by the number of building floors. Because of the large energy consumption of buildings in severe cold areas, it is relatively difficult to achieve the balance between production and demand of buildings when using components with low photoelectric conversion efficiency (10% film)[9-11].

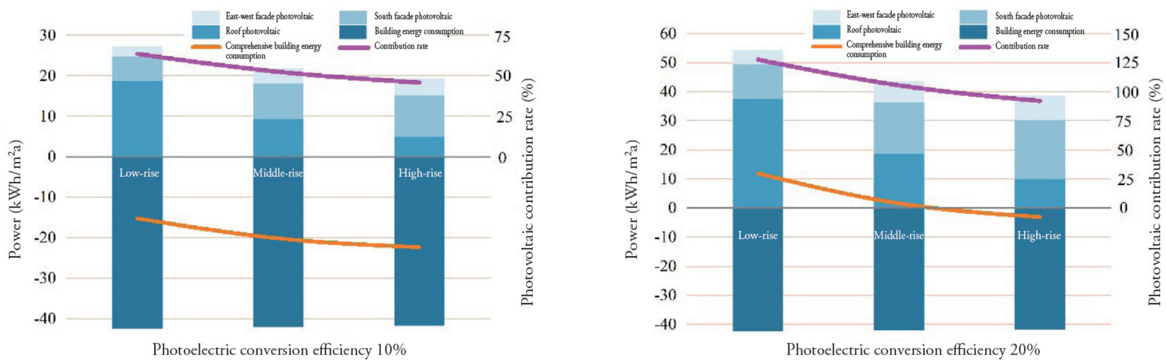


(a) (b)

Figure 2.6 Matching of a Building Photovoltaic System in Severe Cold Areas

2.4.3 Energy matching analysis of a building photovoltaic system in cold areas

Figure 2.7 shows the annual matching analysis of photovoltaic system capacity and building energy consumption of residential buildings in cold areas. For the same place, the difference of building energy consumption per unit area among low-rise, middle-rise and high-rise buildings is very small. Beijing is located in the north of China, and the solar altitude is small all year round, so the south elevation receives more solar radiation[12-14], and the photovoltaic power generation in this area is less affected by the number of building floors.

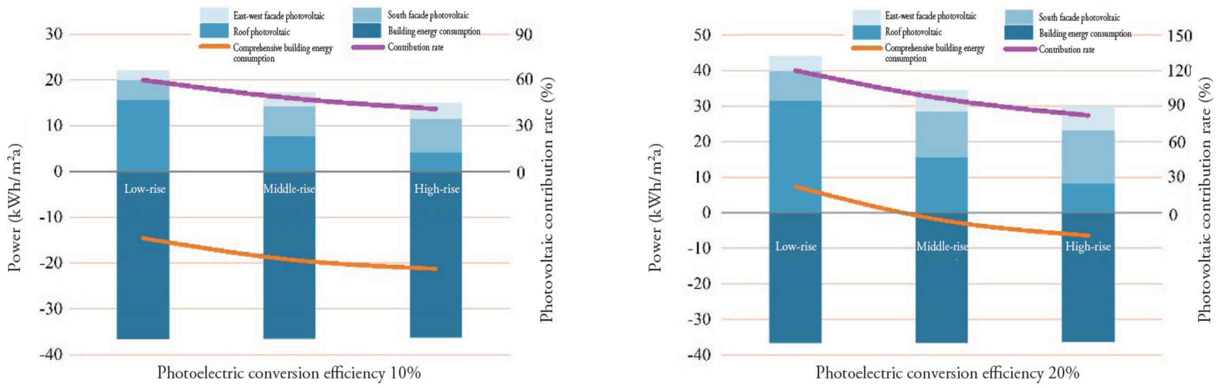


(2) (b)

Figure 2.7 Matching of photovoltaic system in buildings in cold aresa

2.4.4 Energy matching analysis of building photovoltaic system in hot summer and cold winter areas

Figure 2.8 shows the annual matching analysis of photovoltaic system capacity and building energy consumption in residential buildings in hot summer and cold winter areas. For the same place, the difference of building energy consumption per unit area among low-rise, middle-rise and high-rise buildings is very small. Shanghai is located in the south of China, and the solar altitude is large all year round, so the radiation received by the south facade and the east and west facade is not much different all year round. When the photoelectric conversion efficiency is low, it is difficult to meet the requirements of energy-plus buildings in hot summer and cold winter areas in China, but the comprehensive energy consumption can be controlled at 20 kWh/m²a, reaching the requirements of zero-energy buildings.

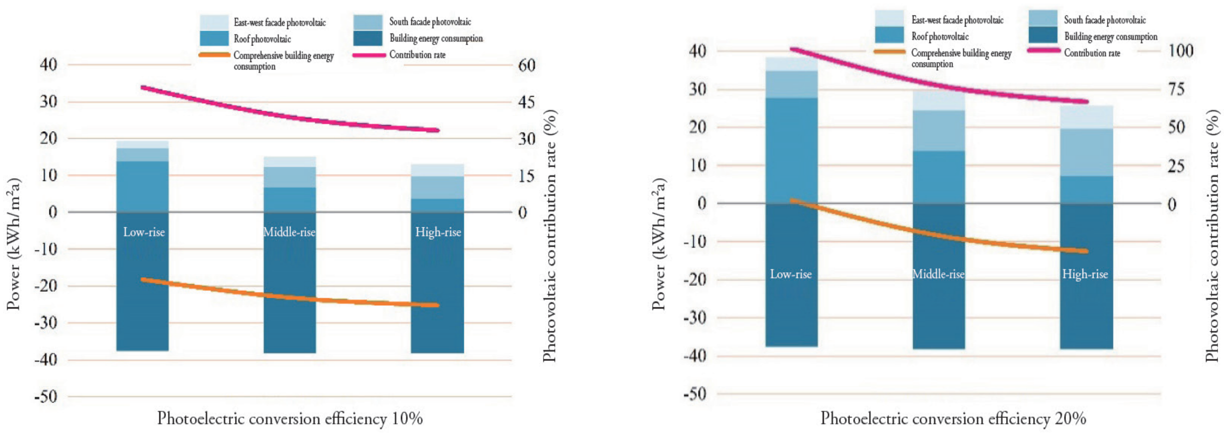


(a) (b)

Figure 2.8 Matching of Building Photovoltaic System in Hot Summer and Cold Winter Areas

2.4.5 Energy matching analysis of building photovoltaic system in hot summer and warm winter areas

Figure 2.9 shows the annual matching analysis of photovoltaic system capacity and building energy consumption in residential buildings in hot summer and warm winter areas. Guangzhou is located in the south of China, and the solar altitude is large all year round, so the radiation received by the south facade and the east and west facade is not much different all year round. When the photoelectric conversion efficiency is low, it is difficult to meet the requirements of energy-plus buildings in hot summer and warm winter areas in China, and its comprehensive energy consumption value is close to 30 kWh/m^2a. With the photoelectric conversion efficiency increased to 15%, the low-rise residential buildings are close to achieving zero energy consumption, which can reach 5 kWh/m^2a, while the middle and high-rise buildings are relatively difficult to achieve this value.

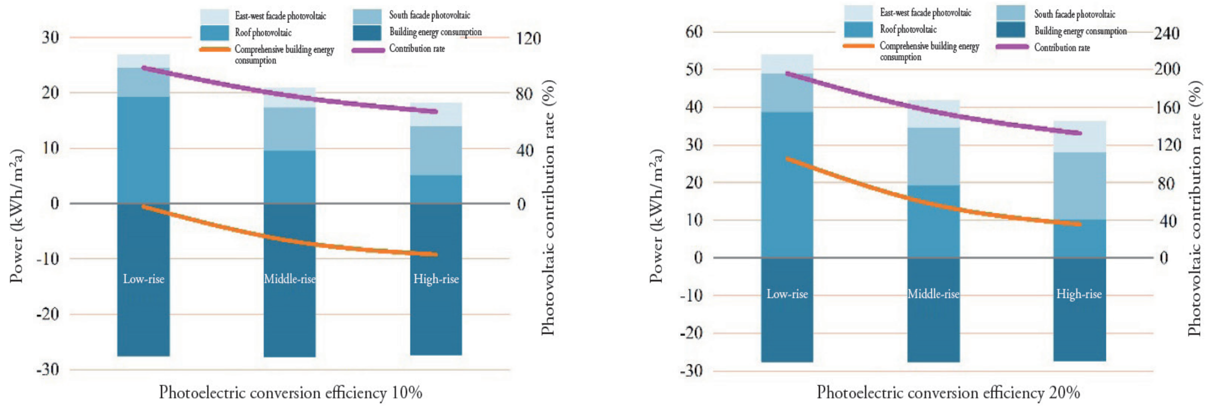


(a) (b)

Figure 2.9 Matching of Building Photovoltaic System in Hot Summer and Warm Winter Areas

2.4.6 Energy matching analysis of building photovoltaic system in mild areas

Figure 2.10 shows the annual matching analysis of photovoltaic system capacity and building energy consumption of residential buildings in mild areas. Mild areas are located in the south of China, and the solar height angle is large all year round, so the radiation received by the south facade and the east and west facade is not much different all year round. When the photoelectric conversion efficiency is low, low-rise buildings in mild areas in China can achieve zero energy consumption, while middle-rise buildings and high-rise buildings cannot meet the requirements due to limited roof area. With the photoelectric conversion efficiency increasing to 15%, low-rise residential buildings and middle-rise residential buildings can achieve energy-plus building, and high-rise buildings can also achieve zero energy consumption standard. When the photoelectric conversion efficiency reaches 20%, three different floors of residential buildings in mild areas in China can all achieve energy-plus building.



(a) (b)

Figure 2.10 Matching of photovoltaic systems in buildings in mild areas

2.5 Technical indicators of energy-plus building

2.5.1 Parameters and indicators of the building envelope

1) High-performance exterior wall, roof and floor insulation is the most effective energy-saving means with the lowest comprehensive cost and the highest feasibility. High-performance exterior wall insulation system with heat transfer coefficient of 0.10-0.15 W/(m²K) and high-performance exterior window with heat transfer coefficient of 0.8 W/(m²K) are the future development direction and goal of external building envelope, which is of great significance for realizing energy-plus buildings in northern China and hot summer and cold winter areas.

2) The annual cumulative heating load of buildings in severe cold areas can be reduced by 75%, and the average reduction rate of cumulative cold and heating load is 70%. The annual cumulative heating load reduction rate of buildings in cold areas is above 50%, and the cumulative cold and heating load can be reduced by 30%-40%. In hot summer and cold winter areas, the annual cumulative heating load reduction can reach 80%, and the cumulative cold and heating load can be reduced by 20%-30%.

2.5.2 Selection of building energy system

Table 2.7 Suggestions on Cold and Heat Source System Configuration in Different Climate Regions

	Severe cold climate zone	Cold climate zone	Hot summer and cold winter climate zone	Hot summer and warm winter climate zone	Mild climate zone
Rural residential building	Central heating+split air conditioning	Heat pump system for cooling and heating	Split air conditioner for cooling and heating	Split air conditioner cooling	Split air conditioner for cooling and heating
4-story residential building	Central heating+split air conditioning	Central heating + split air conditioning	Split air conditioner for cooling and heating	Split air conditioner cooling	Split air conditioner for cooling and heating
8-story residential building	Central heating+split air conditioning	Central heating + split air conditioning	Split air conditioner for cooling and heating	Split air conditioner cooling	Split air conditioner for cooling and heating
15-story residential building	Central heating+split air conditioning	Central heating + split air conditioning	Split air conditioner for cooling and heating	Split air conditioner cooling	Split air conditioner for cooling and heating
Large office buildings	Central heating+heat pump cooling	Solar energy + heat pump cooling and heating	Solar energy+heat pump cooling and heating	Chiller cooling	Heat pump system for cooling and heating
Small office building	Central heating+heat pump cooling	Solar energy + heat pump cooling and heating	Heat pump system for cooling and heating	Chiller cooling	Heat pump system for cooling and heating
Large hotel building	Central heating+heat pump cooling	Solar energy + heat pump cooling and heating	Solar energy+heat pump cooling and heating	Chiller cooling	Heat pump system for cooling and heating
Small hotel building	Central heating+heat pump cooling	Solar energy + heat pump cooling and heating	Heat pump system for cooling and heating	Chiller cooling	Heat pump system for cooling and heating
School building	Central heating+heat pump cooling	Solar energy + heat pump cooling and heating	Heat pump system for cooling and heating	Chiller cooling	Heat pump system for cooling and heating
Shopping mall building	Central heating+heat pump cooling	Solar energy + heat pump cooling and heating	Heat pump system for cooling and heating	Chiller cooling	Heat pump system for cooling and heating

2.5.3 Technical indicator and potential classification of building photovoltaic systems

According to the matching analysis of building photovoltaic system capacity and building energy consumption in different climatic regions in China, the layout of building photovoltaic systems is obtained, and its potential is classified.

1) The inclination angle setting of photovoltaic systems in different climatic regions should be consistent with the local latitude, and the deviation should not exceed 10°. The orientation of each climatic region should be due south, and the deviation should not exceed 30°.

2) The roof photovoltaic system per unit area in severe cold areas, cold areas, hot summer and cold winter areas, hot summer and warm winter areas and mild areas can bear 2.5 m²~4.9 m², 2.7 m²~5.4 m², 2.6 m²~5.2 m², 2.2 m²~4.4 m² and 4.2 m²~8.5 m², and the south facade photovoltaic system per unit area can bear 2 m²~4 m², 2 m²~4 m², 1.6 m²~3.3 m², 1.3 m²~2.6 m², and 2.6 m²~5.3 m² at most.

3) The energy-plus buildings are classified according to the contribution rate of building photovoltaic, as shown in Table 2.10, and the classification standard is:

A (easy to realize): photovoltaic contribution rate > 100%

B (possible to realize): 80% ≤ photovoltaic contribution rate ≤ 100%

C (relatively difficult to achieve): 60% ≤ photovoltaic contribution rate < 80%

D (difficult to achieve): photovoltaic contribution rate < 60%

Table 2.8 Classification of energy-plus buildings with Different Building Types in Different Climate Zones

	Severe cold climate zone	Cold climate zone	Hot summer and cold winter climate zone	Hot summer and warm winter climate zone	Mild climate zone
Rural residential buildings	A	A	A	B	A
4-story residential building	A	A	A	A	A
8-story residential building	B	A	B	C	A
15-story residential building	B	B	B	C	A
Large office buildings	C	C	C	D	A
Small office building	B	B	B	C	A
Large hotel building	C	B	C	D	A
Small hotel building	B	B	B	C	A
School building	B	B	B	C	A
Shopping mall building	D	D	D	D	B

3. Study on indicator system of energy-plus communities

3.1 Typical cases and feasibility study of energy-plus communities

3.1.1 Typical cases of energy-plus communities

(1) Vauban New District in Freiburg, Germany

Freiburg Vauban New District is only 3km away from the main city, with about 5,100 residents. The community includes 59 capacity houses (about 8000 m²) and a "solar boat" with a commercial office area of 6,000m^2, which also meets the energy-plus building standards.

Figure 3.1 Spatial Structure of Vauban New District

1. Co-generation station

Except for micro-energy houses, all residential heating in residential areas is supplied by a co-generation system with innovative sawdust particle combustion technology, and an efficient co-generation plant powered by wood is connected with the heating network in this area. The additional power can meet the demand of 700 households.

2. Utilization of renewable energy

Relying on Freiburg Solar Demonstration Zone, solar photovoltaic and solar water heaters are widely used. At the same time, many innovations have been made in the application of solar energy, including the construction of solar energy single buildings and solar energy communities.

Solar boat is the service center of Freiburg solar energy solutions and the first commercial building in the energy-plus community. It extends more than 125m along a channel and acts as a soundproof board for the building behind it.

(2) Germany Esslingen New West City

A new district covering an area of 10 hectares was built in the center of Esslingen, which was formerly a freight station and an industrial zone, and was built on the basis of its transformation. Since 2012, the nine independent buildings in the new district have provided 560 residential units, accommodating 1,000 - 1,200 residents, in addition to about 66,000 m^2 of commercial space.

1. Photovoltaic building integrated system + water source heat pump

The annual electricity output of photovoltaic equipment is 35% higher than the electricity demand of building operation. Due to the large proportion of users' special electricity consumption in commercial buildings, and the buildings of this project being mostly on four or five floors, the photovoltaic equipment only covers 50% of the annual total electricity demand.

Two-thirds of photovoltaic power is used directly in buildings, half of which is used for building operation, and half is used for special power demand of users. The photovoltaic power delivered to the power grid only accounts for one-third, thus relieving the pressure on the public power grid and further expanding the expansion potential of the building integrated photovoltaic system.

2. Biogas-driven building co-generation system

The natural gas network supplies biogas (produced in surrounding villages and supplied to cities) and about 10% hydrogen (produced by centralized electrolysis powered by solar energy). This kind of "green natural gas" is converted into heat by a distributed building co-generation system. In addition, the electric heat pump can be used to replace the building co-generation system to provide heating in winter and cooling in summer. Most of the photovoltaic power generation on the roof and facade of a building is directly used for the building itself.

(3) German residential community Stuttgart-Heumaden

The block consists of 7 multi-storey point houses, with a total of 82 residential units and a living area of about 8,400 m^2. The design goal of this project is to reach the capacity standard and realize a high self-use ratio of renewable energy to generate electricity. Through electric load management and the use of electric vehicles, the proportion of self-used electricity can reach more than 30%.

1. Photovoltaic equipment combined with distributed/central batteries to supply power

The photovoltaic hybrid collector (550 m^2) provides solar heat for the regeneration of ice storage, and also produces 75kW of electricity. The solar energy system design of the building, especially the integration design of photovoltaic panels on the roof and facade, has been completed as early as the initial stage of the scheme. In order to meet the capacity standard, in addition to reducing the heat demand and electricity demand, the solar energy utilization area should also be maximized from the energy point of view.

Solar power generation is preferred for building operation, supplying power for household appliances and heat pumps. The surplus is used for electric transportation. Through electrochemical storage, the proportion of photovoltaic self-used power increased from less than 1/5 to more than 50%. According to the plan, each building is provided with a lead/gel battery or a lithium/lithium ion battery with a storage capacity of 35kW•h or 100kW•h, and a centralized vanadium/redox flow battery with a capacity of 200/400 kW•h.

Figure 3.2 Power Supply-Combination of Photovoltaic Equipment and Decentralized/Central Cells

(4) Wildpoldsried Town, Germany

Wildpoldsried is a small town in Bavaria, southern Germany, with a total area of 21 square kilometers. The town uses wind power generation, solar power generation and biomass power generation facilities to produce 43 million kWh of electricity, while the local residents need only 6.2 million kWh of electricity for transportation and life. The energy production is 7 times its consumption, and the annual income reaches 5.7 million US dollars.

1. Renewable energy utilization

The renewable energy resources in Wildpoldsried include 11 wind turbines, a biomass power generation facility based on local farmers' bio-waste, three small hydropower systems and a solar thermal energy collection system of over 2,100 square meters. These make the town and its 2,600 residents independent of the power grid, and the community can also transmit the surplus energy to the power grid. The town is leading the way in renewable energy transformation in German residential communities. In addition to five biogas plants, 4,983 kW photovoltaic power generation equipment, 11 wind turbines and hydropower systems, the town also has several municipal and residential biomass heating systems and a solar energy system of 2,100 square meters. Five private houses are heated by the geothermal system, and passive house design is adopted in some new buildings. Electric cars have also been put into use.

2. District heating

All public buildings, 120 private houses and 4 companies are connected to the district heating system. The biomass of this system comes from the waste wood of the local forest, which generates 8.2 MMBtu of heat every year. Most photovoltaic systems in the town are located in private houses. About 200 households have rooftop solar energy. Nine municipal buildings, including primary schools, recycling facilities and sports centers, are also equipped with photovoltaic systems. According to the fixed price 20-year power purchase agreement (PPA), the electricity generated by solar, wind, and biomass is sold to AÜW.

3. Smart grid

From 2011 to 2013, the town cooperated with universities and Siemens to carry out a plan, focusing on the implementation of smart grid technology, including monitoring systems and energy storage facilities. In the follow-up plan from 2014 to 2018, the stability and operation management of distributed power grid were monitored.

The key of smart grid is a self-organizing automation system named SOEASY, which can balance the relationship between supply and demand to keep the grid stable. SOEASY will consider weather, electricity price, power quality and other factors when deciding whether to send electricity into the grid or storage. One way to help balance the power grid is to use electric vehicles to store excess energy.

(5) Nanjing Jiangbei New District Industrial Technology Research and Innovation Park

Jiangbei New District of Nanjing, approved by the State Council on 27 June 2015, has become the 13th national new district in China. The new district is located in the northwest of Nanjing's main city, bordering Laoshan National Forest Park in Liuhe District in the north and the Yangtze River in the south, facing Nanjing city across the river. The talent apartment project has obtained a three-star green building and a three-star health building identification certificate. Among them, the No.3 building (the future building) adopts the fabricated composite structure (fabricated steel frame + cast-in-place concrete shear wall structure), which is the first residential building with fabricated composite structure in Jiangsu Province.

The community service center of Building No.12 adopts a prefabricated wooden structure, which is the first zero-carbon building with a wooden structure in Jiangsu Province, achieving the goal of zero energy consumption and zero carbon emission in the whole life cycle. The community service center takes "Energy Mountain" as the design concept, adopts wood structure + photovoltaic power generation system, and realizes zero energy consumption and zero carbon emission of the whole building. It is the first prefabricated wood structure zero carbon building in China, and it is also a passive building project with ultra-low energy consumption in the provincial housing and construction hall.

1. Passive optimization

Passive optimization can be achieved by fully reducing the demand of building environment control and the influence of outdoor environment on buildings, such as controlling the floor height as much as possible, reducing the energy consumption waste caused by space, and improving the airflow organization. Also, move areas with low thermal comfort requirements, such as toilets, equipment rooms and stairwells, to the northwest outward area to form a thermal buffer space. Design photovoltaic component shading, greening shading, building self-shading, grid shading, and perform performance-based design on grid parameters.

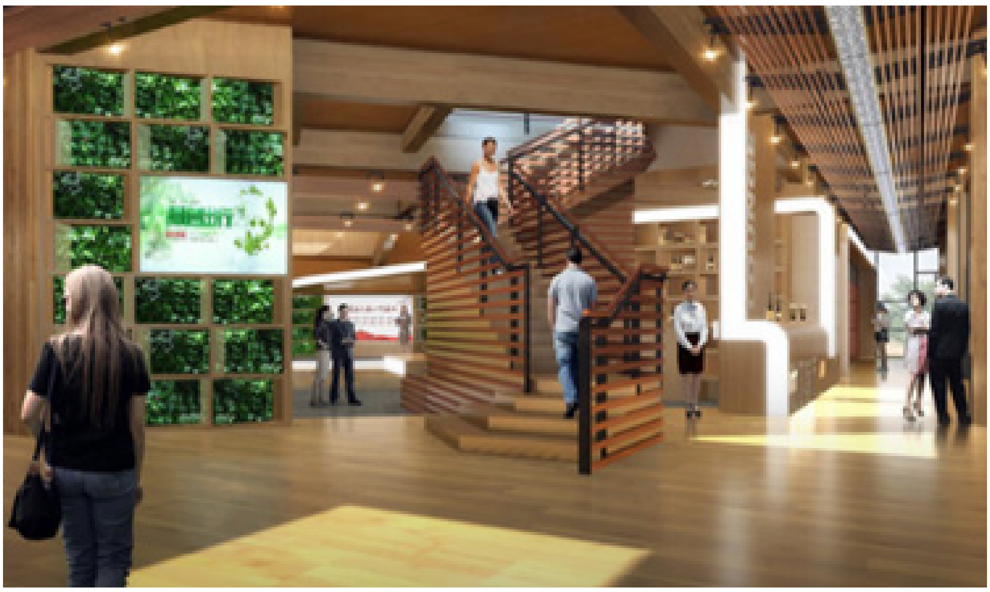


Figure 3.3 Natural lighting

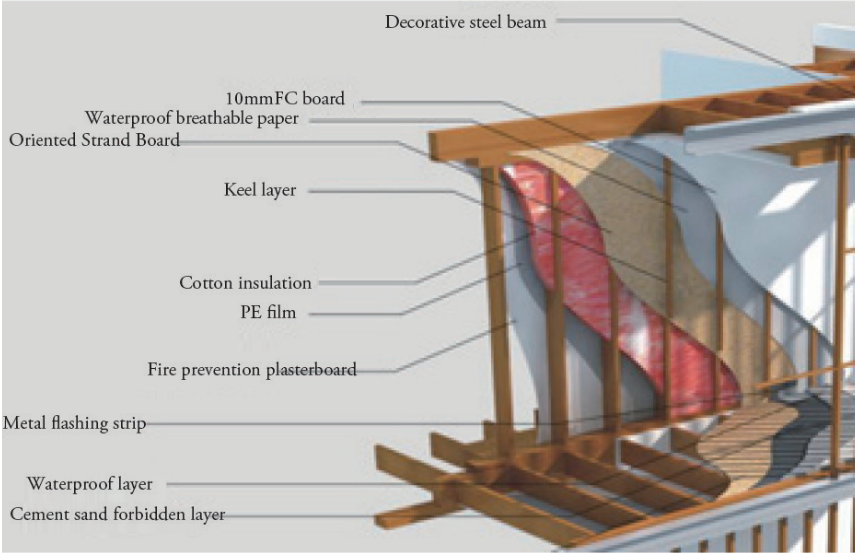


Figure 3.4 Thermal Engineering of Envelope

2. Active and efficient

The DC VRF air conditioner is adopted, which has the advantages of small-size, decentralization, high adjustability, and high energy efficiency under partial load to realize DC power supply. Total heat recovery fresh air is concentrated in layers, enthalpy efficiency is over 65%, and PM2.5 filtration efficiency is over 95%. Fresh air units are incorporated into the building energy management system and linked with the indoor air monitoring system.

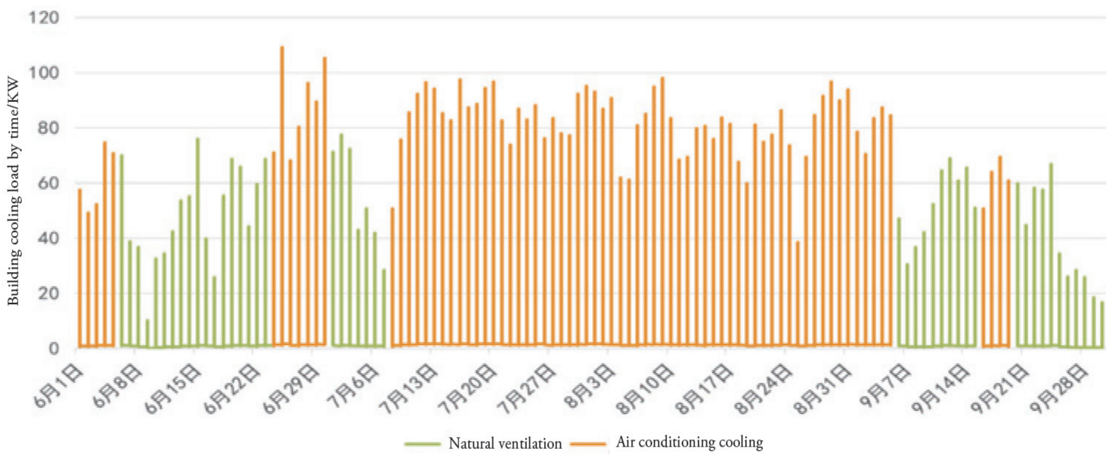


Figure 3.5 Strengthen natural ventilation to bear the load

Three inclined roofs at the top of the photovoltaic roof building form the architectural form of artificial hills, and solar panels are arranged on the inclined roofs in combination with roof wooden racks. At the same time, the roof of the building attracts people from the ground to go upstairs through ramps and steps, and the whole building is like an "energy mountain", positively interacting with the city. The expected annual average power generation is 269,000 KWh.

This project adopts the DC building design, combined with a photovoltaic roof, to establish distributed DC microgrid. This is the first demonstration project combining DC microgrid with a residential community in China. With the help of DC power supply and distribution and energy storage technology, the local consumption of renewable energy is realized, the AC-DC conversion times and conversion losses are reduced, and intelligent operation management improves the system energy efficiency.

(6) Suzhou Wuzhong Taihu New City Startup Area

Suzhou Taihu New City is the first city in Jiangsu to obtain the three-star design logo of national green ecological city. It is an important part of the urban development strategy of “one core and four cities” of Suzhou Municipal Party Committee and Municipal Government, as well as an important opportunity for Suzhou to move towards “Taihu Lake Era”. The energy center project covers an area of 40 mu (Chinese area unit, c.a. 0.0247acre), with a building area of about 29,000 m^2 and a total investment of about 480 million yuan. The designed cooling and heating scale of the project is 2.05 million m^2.

Figure 3.6 Location of Start-up Area in Taihu New City

Table 3.1 Main Energy Indicators of Taihu New City in Wuzhong

<table>
<tr><th colspan="2" rowspan="3">Indicator item</th><th rowspan="3">Indicator attribute</th><th colspan="4">Planning indicators (%)</th></tr>
<tr><th colspan="2">Near future to 2020</th><th colspan="2">Long term to 2030</th></tr>
<tr><th>Taihu new city</th><th>Start-up area</th><th>Taihu new city</th><th>Start-up area</th></tr>
<tr><td colspan="2">Replacement rate of renewable energy in new buildings</td><td>Guiding</td><td>≥3</td><td>≥3.5</td><td>≥3.5</td><td>≥4</td></tr>
<tr><td rowspan="3">building energy conservation</td><td>Proportion of two-star and above green buildings in new buildings</td><td>Controllable</td><td>≥45</td><td>≥50</td><td>≥50</td><td>≥55</td></tr>
<tr><td>Proportion of three-star green buildings in new buildings</td><td>Guiding</td><td>≥10</td><td>≥10</td><td>≥10</td><td>≥10</td></tr>
<tr><td>Cold and heat source forms of new buildings</td><td>Controllable</td><td colspan="4">COP or IPLV value of cold and heat sources should not be lower than the requirement of increasing proportion in plot index compared with “design standard for energy efficiency of public buildings” (GB 50189), and the planned cold and heat sources or other cold and heat sources with equivalent energy efficiency should be selected</td></tr>
</table>

Municipal energy conservation	Efficient urban lighting Usage rate of LED lamps	Controllable	≥95	≥95	≥95	≥95
	Municipal water pump performance	Controllable	Energy-saving evaluation value of energy efficiency limit value and energy-saving evaluation value of clean water centrifugal pump (GB 19762-2007)			
	Municipal fan performance	Controllable	The ventilator energy efficiency limit value and energy saving evaluation value (GB 19761-2009) energy saving evaluation value			
	Performance of other municipal equipment	Controllable	Code for design of energy efficiency of public buildings (GB 50189-2015) Energy saving evaluation value or level 2 or above standard			

1. System scheme

Suzhou is rich in natural gas. In order to make efficient use of natural gas and clean energy, the gas co-generation technology can be adopted in this area, and the high-efficiency electric refrigeration unit and energy storage technology can be used for balance.

2. Pipeline design

The primary side cooling parameter is 5.5℃ /12℃ , and the primary side heating parameter is 80℃ /50℃ . Each building and high-rise building adopts secondary heat exchange. The energy supply buildings in the land served by the energy center are all public buildings, totaling 2,053,900 m^2. The total area of public buildings in the start-up area of Taihu New City in Wuzhong is 4,864,200 m^2. The public building area covered by the CCHP system in the regional energy center accounts for 42.2% of the total public building area in the urban area.

The regional intelligent energy dispatching system is established. According to the characteristics of the functional system and energy consumption of the user-side, the energy demand analysis and simulation are carried out by monitoring the operational data of the energy system in real time. The group control strategy of the computer room is adopted to adjust the operation combination, start-stop time and operation parameters of equipment in real time.

(7) Demonstration of Zero Carbon Park -- Suzhou Tongli New Energy Town

State Grid Jiangsu Electric Power and Suzhou Municipal People's Government decided to jointly build an integrated energy service center on the north side of Tongli Ancient Town, which is about 800m north of Tongli Ancient Town and covers an area of 53 mu.

Figure 3.7 Suzhou Tongli New Energy Town

1. Energy supply

a) **Multi-energy complementary comprehensive utilization project**

With distributed energy sources such as photovoltaic, wind turbines and geothermal energy in the service center area, equipped with energy storage and charging piles, etc., as typical templates, the regional micro-energy network is promoted and established.

b) **High temperature phase change photo-thermal power generation**

The core devices include two sets of 100 square meters butterfly solar concentrating and collecting systems, 300 kWh high temperature phase change heat storage system, and 10 kW steam turbine co-generation system. Under normal operating conditions, there are two working modes: photo-thermal heat storage and exothermic power generation. The comprehensive energy utilization efficiency can reach 36.41%, and the efficiency can be further improved to 43.5% with the subsequent addition of refrigeration system.

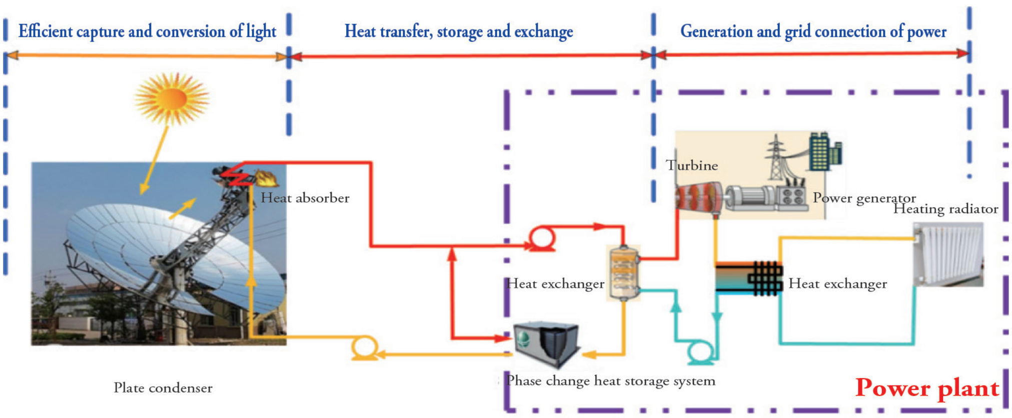


Figure 3.8 Schematic diagram of high temperature phase change photothermal power

c) **Compressed air energy storage**

Large-scale energy storage technology is the core technology of energy internet to complete efficient transmission and intelligent allocation of new energy. Compressed air energy storage technology has the advantages of large energy storage capacity, low cost, long life, no pollution and no geographical restrictions, which can effectively solve the problems of large-scale consumption of new energy, peak shaving and valley filling. The device has a variety of service modes, such as cooling in summer, heating in winter and air supply with high cleanliness. The plant can provide 500 kWh electricity for the park, with a cooling capacity of about 2.9 GJ/day in summer and a heating capacity of about 4.4 GJ/day in winter, meeting the heating and cooling requirements of 2,500 square meters of users, and the comprehensive efficiency of the system is 67%.

d) **Prefabricated cabin energy storage system**

It consists of two sets of hybrid energy storage systems:

20 kW× 15 seconds super capacitor energy storage and 200 kW× 2 hours lithium battery

80 kW× 15 seconds super capacitor energy storage and 400 kW× 2 hours lithium battery.

Electric energy storage technology is an important component and key supporting technology of the smart grid, renewable energy system and energy internet, which can be widely used in different links of power system and assume different roles and functions.

2. Energy allocation

a) **Micronetwork router**

As the hub of AC/DC hybrid distributed energy system, it is composed of four-port power electronic transformer and coordinated operation control system, which faces multiple microgrids and realizes energy routing and coordinated control among multiple microgrids through port energy regulation and information interaction.

b) **Coordinated control system of source network load and storage**

With the construction idea of “regional cooperation and complementarity, microgrid distribution self-discipline, and two-way terminal interaction”, the coordinated operation control of source-network-load-storage and the complementary operation control of cold-heat-electricity multi-energy flow in Tongli Integrated Energy Service Center realize the safe, reliable, economical, efficient and green operation of the regional power grid and build an integrated energy service center with low carbon at the source end.

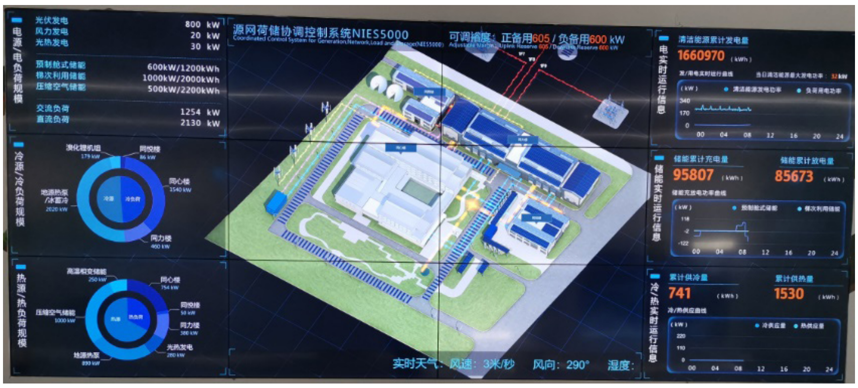


Figure 3.9 Load-storage coordination control system of source network

3.1.2 Applicability analysis of energy-plus community in Jiangsu Province

(1) Summary and comparison of Chinese and German cases

Table 3.2 Summary of Cases

Project	Utilization of renewable energy	Replacement rate of renewable energy	Key technology	Reference standard
Vauban New District, Freiburg, Germany	Solar energy, wind energy, biomass, surface water heat energy, shallow geothermal energy	100%	Photovoltaic building integration, wood combustion co-generation	EnEV2016, DGNB (Germany)
Germany Esslingen new west city	Solar energy, biomass, surface water heat energy	100%	Keywords photovoltaic building integration, water source heat pump, phase change heat storage, biogas co-generation, electrolytic hydrogen production	
German residential community Stuttgart-Heumaden	Solar energy, biomass	100%	Photovoltaic building integration, phase change heat storage	
Nanjing Jiangbei new area industry technology research and innovation park	Solar energy, surface water heat energy, sewage heat energy	10%	Heat source tower heat pump, sewage source heat pump, water storage and heat storage, air conditioning waste heat recovery, cooling tower free cooling	Assessment standard for green building
Suzhou Wuzhong Taihu New City Startup Area	Solar energy, shallow geothermal energy	4.33%	Natural gas co-generation, ground source heat pump, waste heat recovery, thermal control	

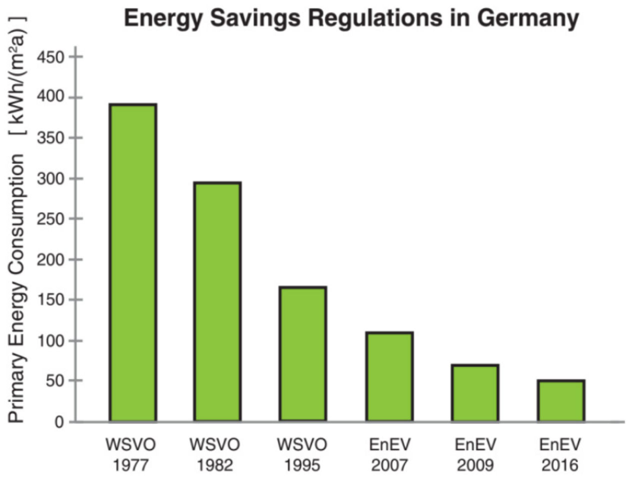


Figure 3.10 Development process of German energy saving standards (primary energy consumption)

All three projects in Germany are energy-plus communities, which meet the requirement of 100% utilization of renewable energy. In 2016, EnEV (German Energy Conservation Code), which came into effect on 1 January 2016, the requirements of buildings and their energy standards, were revised. This regulation reduces the maximum annual primary energy demand of new buildings by 25%.

(2) Conditions for developing energy-plus communities in Jiangsu Province

Jiangsu is located on the eastern coast of the Chinese mainland, with a mild climate and distinct seasons. Most of the southern part of Jiangsu is in a hot summer and cold winter area, while a few of the northern parts are in cold areas, with abundant solar energy resources and with rich wind energy resources in coastal areas. The terrain is flat, the landform is composed of plains, waters and low mountains and hills, and the utilization conditions for shallow geothermal energy are good. The province spans across the Yangtze River and the Yellow River, with numerous lakes and vertical and horizontal water systems, making it easy to utilize the heat energy of surface water sources. Jiangsu Province has superior natural geographical conditions and great potential for renewable energy utilization, which provides natural resources for the development and construction of energy-plus communities.

(3) Reference and development

The first batch of energy-plus buildings have been built in Germany, and their practicability has been proved. First, single-family houses and collective houses, and then extended to schools and non-residential buildings. In terms of the energy-plus community, the typical pilot projects in the case of the present study will become the new standard of sustainable cities. Research projects such as “Energy-plus Building” and “Energy Efficiency City” will promote further development of capacity standards, shorten the innovation cycle and accelerate the marketization process in Germany.

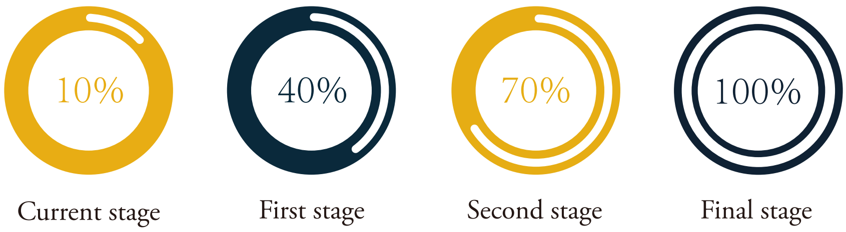


Figure 3.11 "Small Step Run" Path Map of Renewable Energy Utilization Rate in Jiangsu Productivity Community

In view of the actual situation in Jiangsu Province, it can be divided into three stages. The first stage is the exploration period. With reference to the construction experience of the existing green ecological city, the building envelope and heating and cooling system are improved and optimized, the ground source heat pump+photovoltaic system is reasonably selected, the primary energy consumption is reduced, and the community renewable energy utilization rate is increased to 40%. At the same time, the construction technology applicable to productive buildings is studied, the corresponding construction technology and method are improved, and scientific and technological innovation is actively carried out, and pilot demonstrations are carried out.

The second stage is the market cultivation period. In this stage, the annual energy demand is fully considered, and technologies such as photovoltaic building integration are continuously developed in combination with regional climate characteristics. Under economically suitable conditions, consumer terminals and systems are networked in combination with use strategies to further explore renewable energy utilization potential.

The third stage is the mature stage, in which the relevant implementation rules and management measures are issued, the evaluation and audit requirements are clearly defined, and the specific implementation of pilot demonstration projects is guided and standardized.

3.2 Research on control indicators of energy-plus community

3.2.1 Control indicator system of energy-plus community

The establishment of a productivity community/control indicator system emphasizes the requirement of high-standard access from planning and construction. Based on forward-looking and operability, six types of first-level indicators and 20 second-level indicators are set, covering the whole process of community planning, construction and operation management. Among them, the binding indicator is the indicator of energy-plus community which must meet the requirements of target reference value, and the guiding indicator is the indicator of productivity community which can determine the target reference value according to its own situation.

Table 3.3 Productivity Community/Control Indicator System

Primary indicator	Secondary indicator		Indicator property	Target reference value
Energy supply and demand	Average energy demand of community		Binding	≤60kWh/m^2•a
	Energy demand of residential buildings		Guiding	≤45kWh/m^2•a[16]1
	Public build	Energy demand of office buildings	Guiding	≤45kWh/m^2•a ②
		Energy demand of school buildings	Guiding	≤70kWh/m^2•a ③
		Energy demand of commercial buildings	Guiding	≤120kWh/m^2•a ④
		Energy demand of hotel buildings	Guiding	≤60kWh/m^2•a ⑤
		Energy demand of hospital buildings	Guiding	≤110kWh/m^2•a ⑥
	Energy output (capacity)		Binding	≥66kWh/m^2•a
Green building	One-star compliance rate of green buildings in newly built buildings		Binding	100%[17] ⑦
	Two-star compliance rate of green buildings in newly built residential buildings		Guiding	30% ⑧
	Two-star compliance rate of green buildings in newly built residential buildings		Guiding	50% ⑨
	Technical parameters of new building		Binding	All technical parameters meet the requirements of "Technical Standard for Near Zero Energy Consumption Build-ings" (GBT 51350-2019)
Energy system	Replacement rate of renewable energy		Binding	≥100%
	Coverage rate of photovoltaic and photothermal utilization of solar energy on building roof		Guiding	≥80%[18] ⑩
	Proportion of solar photovoltaic self-use electricity		Guiding	≥80%[19] ⑪
	Utilization ratio of renewable energy air condition-ing		Guiding	≥80%
	Proportion of renewable energy street lamps		Guiding	≥80%[18] ⑫
	Energy household metering rate		Binding	100%[18] ① 2
Municipal facilities	Utilization rate of high-efficiency LED lamps for municipal lighting		Binding	100%[17] ②
	Municipal water pump performance		Binding	Energy saving evaluation value ③ of En-ergy Efficiency Limit Value and Energy Saving Evaluation Value of Clean Water Centrifugal Pump (GB 19762-2007)

①、②、③、④、⑤、⑥：It is increased by 20% based on the requirements of Technical Standard for Near Zero Energy Consumption Buildings (GBT 51350-2019)
⑦、⑧、⑨：It has been improved on the basis of the requirements of the Evaluation Standard for Green Ecological City (GBT 51255-2017)
⑩：It has been improved on the basis of the requirements of "Guidelines for Pilot Construction of Low Carbon Communities"
⑪：According to the implementation plan of the national distributed photovoltaic power generation application demonstration zone in 2013
⑫：according to the requirements of "guide to pilot construction of low-carbon community"

	Municipal fan performance	Binding	Energy-saving evaluation value ④ of "Limited Value of Fan Energy Efficiency and Energy-saving Evaluation Value" (GB 19761-2009)
	Performance of other municipal equipment	Binding	Energy-saving evaluation value of design standard for energy efficiency of public buildings (GB 50189-2015) or grade ii or above standard ⑤
Operation management	Intelligent monitoring and control system	Binding	Have
	Urban energy consumption information supervision system	Guiding	Have [30] ⑥
Green life	Cultural propaganda of productivity community	Binding	Have ⑦
	Popularization rate of energy-saving appliances	Binding	≥80% ⑧

3.2.2 Analysis of control indicator system of energy-plus community

(1) Primary energy

In total, 100% of the energy consumption of the energy-plus community is met by renewable energy, and the available methods include passive building energy-saving measures, active equipment energy-saving technologies, and renewable energy technologies such as solar energy and geothermal energy, etc. Reducing primary energy consumption and increasing primary energy output are the inevitable requirements of energy-plus communities. Considering energy supply security, the primary energy output is taken as 110% of the consumption.

(2) Green building

According to the requirements of related indicators of energy-plus communities, the proportion and standard requirements of green buildings in pilot communities shall be strictly implemented from the whole process of design, material selection and construction. Local climatic conditions should be taken into consideration to adopt passive design strategy and make maximum use of natural lighting and ventilation. Active energy-saving technology should be made full use of to improve energy consumption of building HVAC equipment. Renewable energy utilization technology should be selected reasonably to achieve integration and synchronous design of renewable energy utilization system and buildings, prolong the service life of buildings, and reduce their energy consumption.

(3) Energy system

Renewable energy utilization facilities. Encourage pilot communities rich in renewable energy, and actively build renewable energy utilization facilities such as solar photovoltaic, solar photothermal, ground source heat pump, surface water source heat pump, and biomass power generation. Solar street lamps and wind-solar complementary street lamps are used, photovoltaic power generation systems are build in bus station sheds, bicycle sheds and parking lot sheds. Geothermal energy and water heat are encouraged to use for centralized cooling and heating, and the construction of smart microgrid systems is also encouraged.

4. Main technical measures

4.1 Energy-saving technology of outer building envelope

4.1.1 Heat insulation technologies of non-transparent outer building envelope

(1) External wall insulation technology

The external insulation system performance and insulation material performance of energy-plus buildings must meet the requirements of near-zero energy consumption building technical standards (shown in Table 4.1).

Table 4.1 Average Heat Transfer Coefficient Indicators of Building External Wall

Building type	Enclosure structure parts	Heat transfer coefficient K(W/ (m·K))				
		Severe cold area	Cold area	Hot summer and cold winter area	Hot summer and warm winter area	Mild area
Residential building	External wall	0.10~0.15	0.15~0.20	0.15~0.40	0.30~0.80	0.20~0.80
Public building	External wall	0.10~0.25	0.10~0.30	0.15~0.40	0.30~0.80	0.20~0.80

Data source: near-zero energy consumption building technical standard GB/T 51350-2019

In order to ensure the durability, safety and reliability of the external wall insulation system, the external wall insulation technology must choose high-quality insulation materials that meet the performance requirements specified in the standard; equipped with effective accessories, such as window connection lines, dripping lines, corner protection lines, expansion joint lines, anchor bolts of thermal insulation bridges, sealing strips for water sealing, etc., to improve the thermal insulation, waterproof and vapor permeability and connection safety of the external insulation system. Reasonable structural design and fine construction are needed for key joint parts, such as fire isolation belt, outer wall of building basement, scattered water parts, building expansion joints and so on.

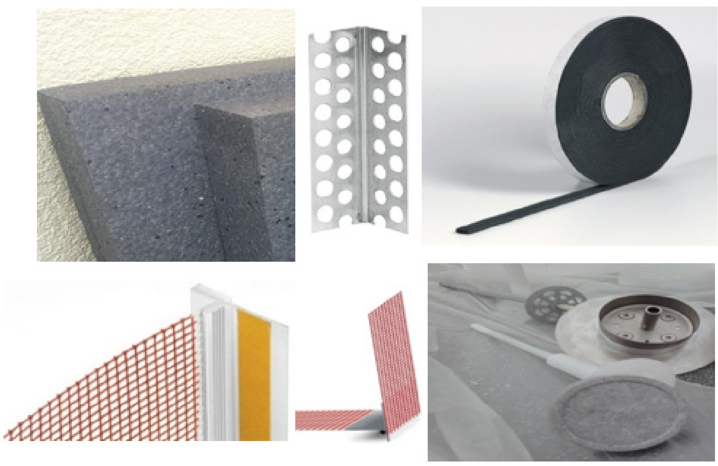


Figure 4.1 Materials and Components of External Wall Insulation System

Figure 4.2 Structure of Fireproof Isolation Belt

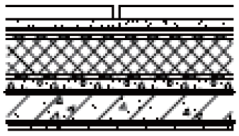
(2) Roof waterproof and thermal insulation technology

The roof waterproof and thermal insulation systems of ordinary energy-saving buildings in China are mostly inverted roof systems, which lack steam a barrier, so the dry-wet mixed operation of multiple jobs under the condition of a large indoor and outdoor temperature gradient in winter may cause condensed water to accumulate in the thermal insulation layer, which will affect the thermal performance of the insulation layer. The roof performance indicators of energy-plus buildings should meet the requirements of the near-zero energy consumption building technical standard (GB/T 51350-2019), and the roof waterproof and thermal insulation technology should adopt the system of surface waterproof layer + bottom waterproof layer + thermal insulation layer + waterproof and steam insulation layer + slope-finding layer + base material.

Table 4.2 Average heat transfer coefficient indicators of building roof

Build type	Enclosure structure parts	Heat transfer coefficient K(W/ (m·K))				
		Severe cold area	Cold area	Hot summer and cold winter area	Hot summer and warm winter area	Mild area
Residential building	roofing	0.10~0.15	0.10~0.20	0.15~0.35	0.25~0.40	0.20~0.40
Public building	roofing	0.10~0.20	0.10~0.30	0.15~0.35	0.30~0.60	0.20~0.60

Data source: near-zero energy consumption building technical standard GB/T 51350-2019



a) Paving block material, wiping seam with dry cement
b) 25 thick coarse sand cushions
c) 4 thick PE surface glass fiber reinforced polyester tire modified asphalt waterproofing membrane
d) 3 thick PE surface glass fiber tire modified asphalt self-adhesive waterproofing membrane
e) Insulation board (polyurethane adhesive paste)
f) Self-adhesive modified asphalt steam insulation coil with glass fiber tire on thick alkali-resistant aluminum foil surface
g) Adhesive bitumen primer
h) The thinnest 30-thick LC5.0 lightweight aggregate concrete 2% slope-finding layer
i) Reinforced concrete roof board

Figure 4.3 Roof structure of reinforced concrete structure

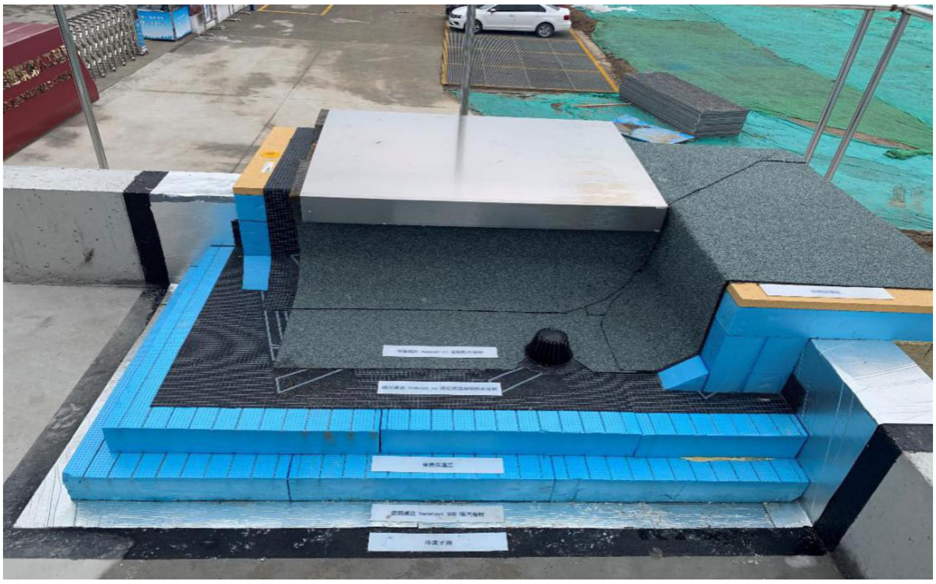


Figure 4.4 Roof Node Structure

4.1.2 Energy-efficient external door and window system integration technology

(1) External door and window technology

External doors and windows are the weakest link in heat preservation, waterproof and air-tightness of building envelope, so it is very important to adopt high-efficiency external doors and windows to improve building energy efficiency. Performance indicators of external windows of energy-plus buildings must meet the requirements of near-zero energy consumption building technical standard (GB/T 51350-2019) (shown in Table 4.3).

①：It has been improved on the basis of the requirements of the Guide to Pilot Construction of Low Carbon Communities
②：It has been improved on the basis of the requirements of "Evaluation Standard for Green Ecological City" (GBT 51255-2017)
③、④、⑤：It is determined according to the requirements of Evaluation Standard of Green Ecological City (GBT 51255-2017)
⑥、⑦、⑧：determined according to the requirements of "Guidelines for Pilot Construction of Low Carbon Communities"

Table 4.3 Heat transfer coefficient (K) and solar heat gain coefficient (SHGC) of external windows (including transparent curtain walls) of buildings with near zero energy consumption

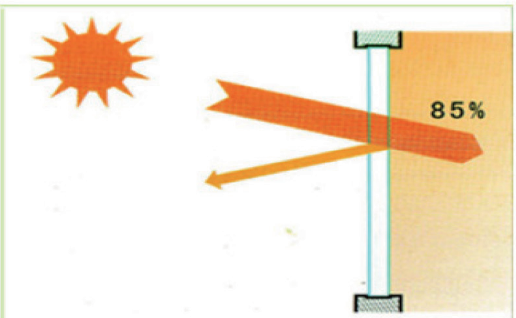
Building type	Performance parameter		Severe cold area	Cold area	Hot summer and cold winter area	Hot summer and warm winter area	Mild area
residential building	Heat transfer coefficient k (W/m²K)		≤1.0	≤1.2	≤2.0	≤2.5	≤2.0
	Solar heat gain coefficient SHGC	winter	≥0.45	≥0.45	≥0.40	-	≥0.40
		summer	≤0.30	≤0.30	≤0.30	≤0.15	≤0.30
public building	Heat transfer coefficient k (W/m²K)		≤1.2	≤1.5	≤2.2	≤2.8	≤2.2
	Solar heat gain coefficient SHGC	winter	≥0.45	≥0.45	≥0.40	-	-
		summer	≤0.30	≤0.30	≤0.15	≤0.15	≤0.30

Data source: near-zero energy consumption building technical standard GB/T 51350-2019

Note: The solar heat gain coefficient is the comprehensive solar heat gain coefficient including shading (excluding internal shading).

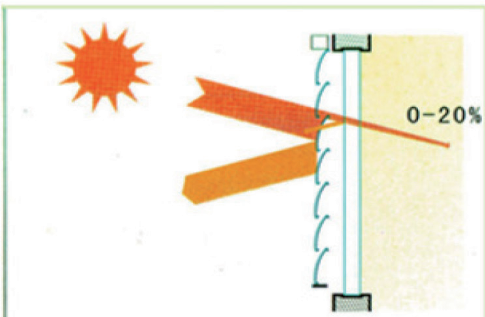
(2) External shading technology

Building external shading can prevent harmful direct sunlight, reduce the incoming solar radiation heat, prevent indoor overheating in summer, and reduce energy consumption of air conditioning. Using external shading can save more than 25% of air conditioning energy and 10% of heating energy.



The sunlight passes through the glass window, and 85% of the sunlight radiates directly into the room, which is easy to form greenhouse effect, and glare will affect indoor work and life.

Sunshade facilities are not installed



The sunlight is reflected and filtered by the outdoor blinds, and only about 20% of the sunlight is radiated indoors, which can prevent glare and freely adjust the light.

Install the outer sunshade blinds

Figure 4.5 Comparative analysis of building external shading to improve indoor thermal environment and light environment

4.1.3 Thermal break technology

Building a thermal bridge can be divided into a geometric thermal bridge, a structural thermal bridge and a systematic thermal bridge, in which geometric thermal bridge usually refers to the part with outer surface area larger than inner surface area, such as the exposed corner of external walls. Structural thermal bridge refers to the nodes with unconventional design, such as overhanging, protruding and penetrating. Thermal break technology is to strengthen thermal insulation for potential structural and systematic thermal bridges in building envelope to reduce heat flux. Special design of thermal break should follow the following principles:

a) Avoidance rule: try not to damage or penetrate the outer envelope structure;

b) Breakdown rule: when the pipeline needs to pass through the external envelope, it should ensure that the insulation at the penetration part is continuous and free of voids;

c) Continuity rule: at the joint of building components, the insulation layer should be continuous without gap;

d) Geometric rule: avoid the change of geometric structure and reduce the heat dissipation area.

4.1.4 Technology of improving building airtightness

The air-tightness of a building is the ability of a building to prevent air infiltration in a closed state. Usually, the air-tightness of a building is tested by differential pressure experiment, and is characterized by the air exchange rate N_{50}, i.e., the air exchange rate under the indoor and outdoor differential pressure of 50Pa.

The advantages of improving the air-tightness of buildings are as follows: 1) reducing the cold and heat loss of buildings through the gaps of enclosure structure, improving the effect of building heat preservation and insulation, thus significantly reducing the energy consumption demand of buildings; 2) avoiding mildew, condensation and damage of building components due to moisture invasion; 3) improving living comfort and quality, reducing “through flow” and the impact of outdoor noise and air pollution on indoor environmental quality.

4.2 Heat recovery technology

4.2.1 High-efficiency heat recovery technology of fresh air system

The heat recovery technology of a fresh air system is to recover the energy of the exhaust air in the fresh air system and preheats the fresh air. A fresh air heat recovery system is divided into total heat recovery system and sensible heat recovery system. The sensible heat recovery efficiency of a fresh air system is not less than 75%, and the total heat recovery efficiency is not less than 60%. The fresh air system is set with three-gear air volume adjustment. In severe winter, when the temperature reaches -15℃ , anti-freezing and anti-frost devices shall be provided to ensure that the air inlet does not freeze. Indoor intake air filtration equipment shall be at least F7, and exhaust air filtration shall be at least F4. Electricity consumption of fresh air system should be ≤ 0.45W.h/m3.

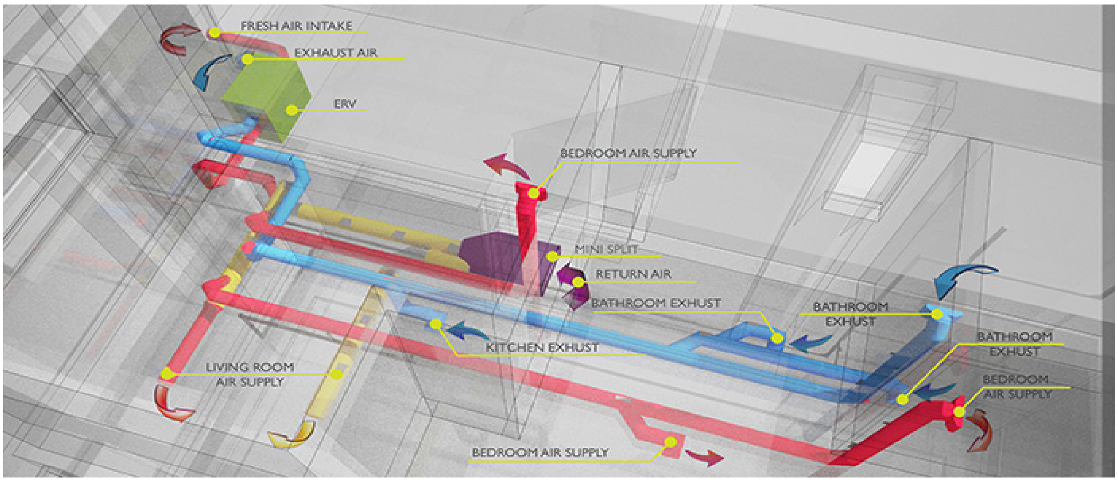


Figure 4.6 Schematic diagram of fresh air heat recovery technology

4.2.2 Condensing heat recovery technology

Air-conditioning condensing heat recovery system refers to an air-conditioning system that adds heat recovery equipment, including heat recoverers (shell-and-tube, plate-type and sleeve-type condensers, etc.) and heat storage devices (heat storage tanks or phase change material heat storage tanks) to recover the condensing waste heat of air-conditioning in summer and directly or indirectly produce process hot water or domestic hot water. After adopting a heat recovery device, the total energy consumption of an air conditioner can be saved by about 20%.

4.3 Renewable energy technology

4.3.1 Solar photothermal utilization technology

(1) Solar domestic hot water technology

Solar domestic hot water is a technology that converts solar energy into heat energy and conducts it to the water in the water tank. According to the types of auxiliary energy, it can be divided into three types: no auxiliary heat source, electric auxiliary heat and gas auxiliary heat, among which electric auxiliary heat is the commonest. According to the different structure of the collector, it can be divided into vacuum tube type and flat plate type.

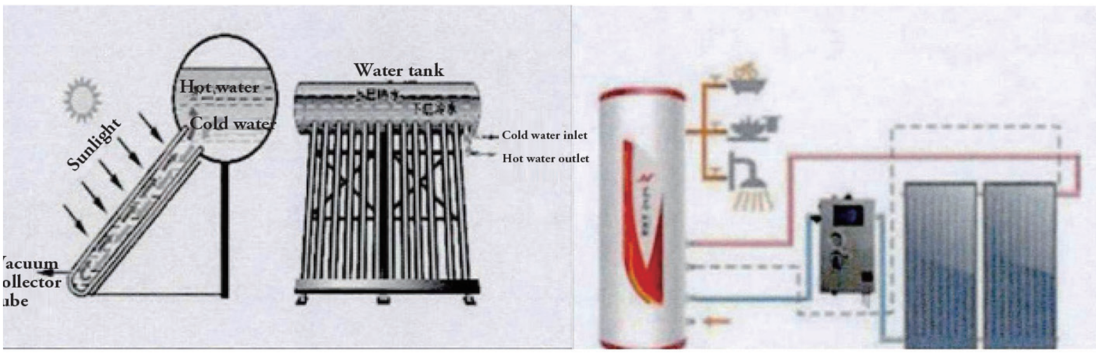


Figure 4.7 Solar domestic hot water technology

(2) Solar heating technology

Solar heating is a technology that uses solar collectors to collect solar radiation and convert it into thermal energy for heating. The solar energy heating system collects solar radiation energy through solar collectors and converts it into thermal energy, which is sent to the room for heating through heat dissipation components.

(3) Solar energy air conditioning technology

There are many kinds of the solar energy air conditioning technology, mainly absorption refrigeration and photoelectric conversion electric energy driven refrigeration. The more mature technology is lithium bromide -- water-based absorption refrigeration. The heat source temperature of solar refrigeration and air conditioning is high, and the collector needs to keep efficient operation at high working temperature, so the thermal performance indicator of the collector is high, and the product performance of only a few large backbone enterprises in China can meet the requirements. Because of its small scale of industrialization, there are only a few pilot demonstration projects in China.

(4) Passive solar greenhouse technology

Passive solar greenhouse technology mainly uses the principle of "greenhouse effect", which allows sunlight to enter the room through the south-facing glass (heat collecting surface) of the building, absorbs solar energy by heat storage bodies such as bricks, adobes, stones, etc., and then converts it into heat. After three processes of heat collection, storage and preservation, the heat remains in the building. The technology has many forms including direct collection type, heat collection and storage wall type, additional sunlight room type, and convection loop type, etc.

4.3.2 Solar photovoltaic power generation technology

During the day, solar energy is converted into DC power by photovoltaic modules, and DC power can be converted into sine wave current with the same frequency and phase as the power grid by inverter, which can be directly used for building energy-using equipment, and can also be incorporated into municipal power grid for unified transmission and distribution or into power storage devices. Solar photovoltaic power generation technology is currently the most cost-effective and direct renewable energy type for building capacity.

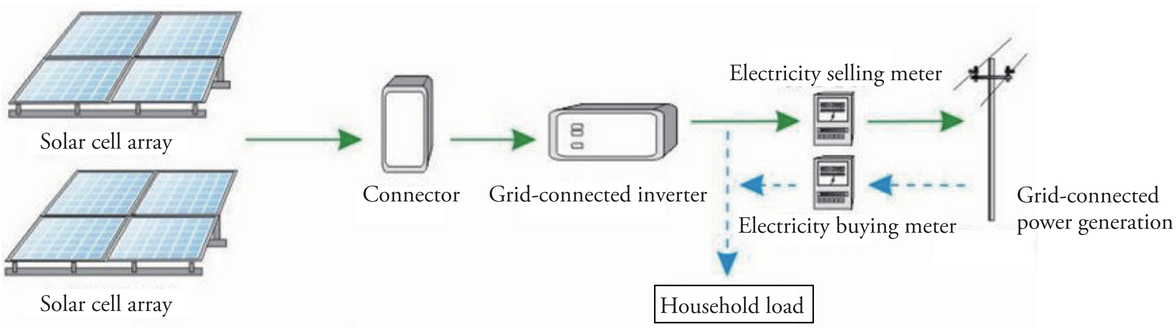
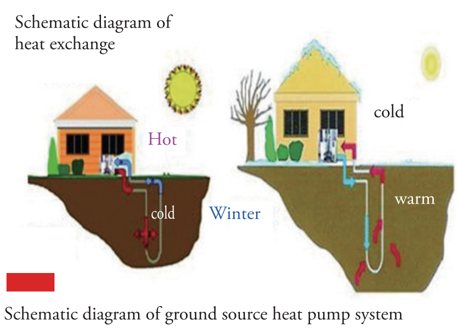


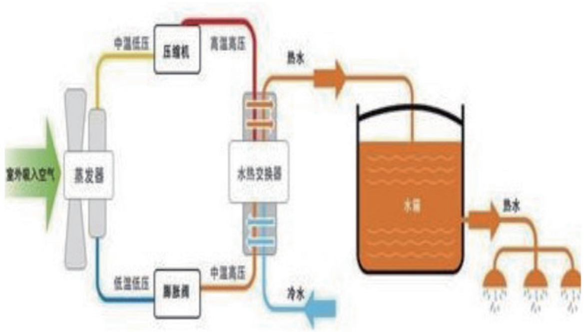
Figure 4.8 Schematic diagram of solar photovoltaic power generation principle

4.3.3 Heat pump technology

Heat pump technology is an energy-saving technology that uses a small amount of energy to drive the heat pump unit, and uses the low-temperature heat in the natural environment (such as air, soil, water) after absorbing, compressing and heating up by the working medium in the heat pump system. Since the 1970s, with the emergence of “energy crisis”, the heat pump industry has been highly valued by countries all over the world because of its ability to save energy and replace conventional energy. New heat pump technologies are emerging one after another, and the application scope of heat pump is expanding constantly. It is widely used in hot water, heating and industrial fields, and plays an active role in energy saving and environmental protection.



Ground source heat pump



Air source heat pump

Figure 4.9 Schematic diagram of different heat pump technologies

4.3.4 Utilization technology of geothermal energy in medium-deep layers

Medium-deep geothermal technology is to use underground hot water or thermal energy of rock and soil to supply heat by directly extracting hot water or indirectly utilizing it. According to resource temperature, burial depth and occurrence state, the distribution depth and occurrence state of geothermal energy in medium-deep layers are shown in the following table.

Table 4.6 Distribution Depth and Occurrence State of Geothermal Energy in Medium-deep Layers

Type	Distribution depth	Temperature range	Occurrence state
Medium-deep geothermal energy	200-3000m	90-200℃	Geothermal resources with groundwater as the main carrier

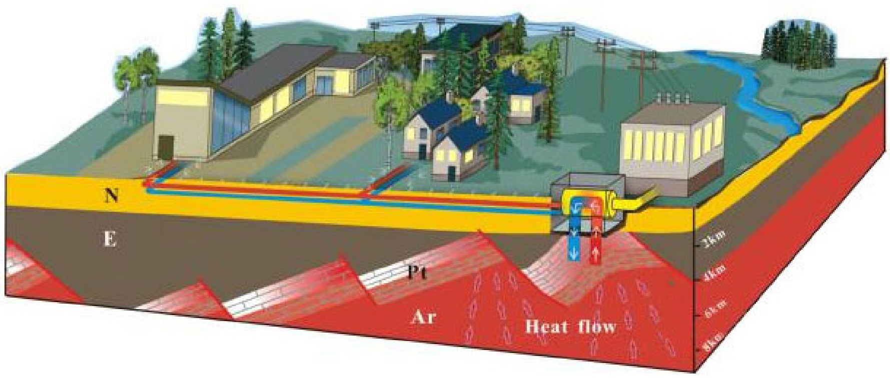


Figure 4.10 Technology of drilling wells and taking heat in middle and deep geothermal fields

4.3.5 Biomass energy utilization technology

Biomass energy utilization technology is divided into five categories: forestry resources, agricultural resources, domestic sewage and industrial organic wastewater, municipal solid waste and livestock manure. The materials can be used for heat supply by direct combustion in boiler, pyrolysis gasification or burning after becoming biogas. At present, the main biomass utilization in China includes biomass gasification technology and solid compression granulation technology.

In recent years, biomass power generation has developed rapidly and made new breakthroughs in technology, showing a good growth trend in the fields of biomass power generation in agriculture and forestry, waste incineration, biomass power generation to co-generation and so on.

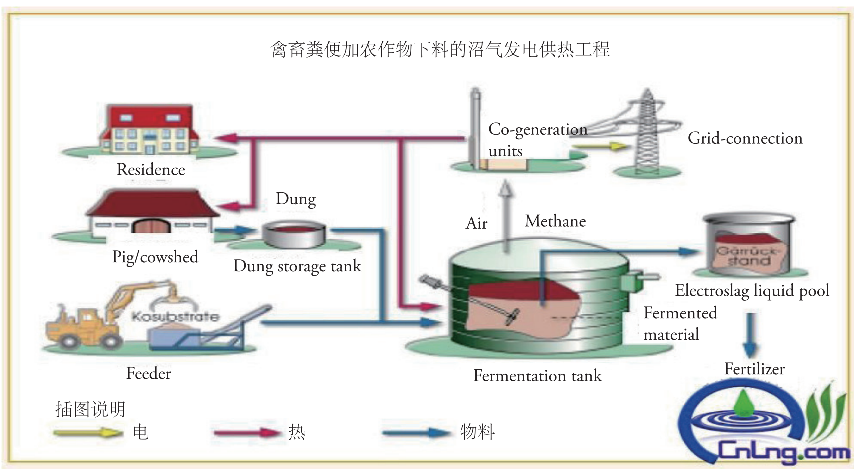


Figure 4.11 Schematic diagram of biomass power generation principle

4.3.6 Wind technology

At present, the energy consumption structure of buildings tends to be mainly electric energy. As green power, wind power generation is an important technical measure to apply electric energy in energy-plus buildings, which is conducive to reducing the energy consumption of building heating, air conditioning and domestic hot water, and fundamentally addressing problems such as fossil energy supply pressure and air pollution emission caused by building energy consumption.

4.4 Microgrid and energy storage technology

4.4.1 Microgrid technology

Microgrid technology is a small-scale power generation and distribution system that organically combines distributed power and load, and effectively aggregates monitoring and protection devices. It can effectively adjust the power of equipment and optimize the system reasonably, thus effectively improving the quality and reliability of the whole photovoltaic power generation[22-23].

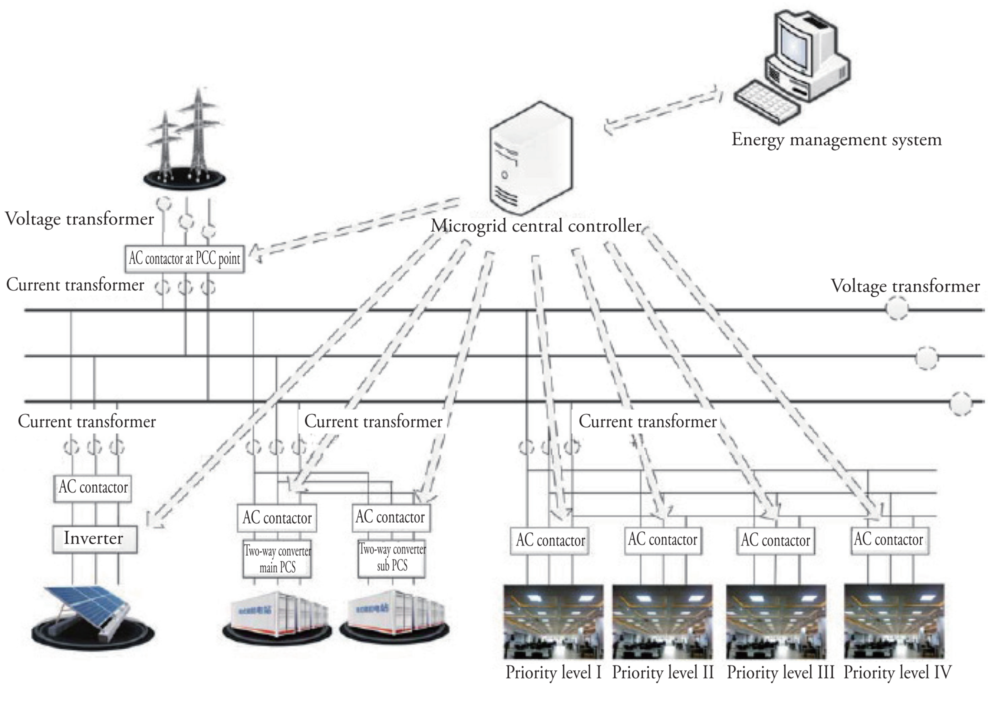


Figure 4.12 Topology of Storage Microgrid

4.4.2 Energy storage technology

Energy storage technology mainly refers to the storage of electric energy. With the development of science and technology, by constructing an energy storage system, the clean and low-carbon substitution of traditional energy system on the supply side and the consumption side can be successfully realized, and the problems of peak shaving, transmission and consumption caused by the large-scale development of renewable energy can be solved. According to the conversion form of electric energy, energy storage can be divided into physical, electrochemical and electromagnetic energy storage.

Table 4.7 Types of Energy Storage Technologies

Energy storage type	Technology name
Physical energy storage	Solar energy storage, pumped storage, etc.
Electrochemical energy storage	Lead battery, lithium ion battery, flow battery, etc.
Electromagnetic energy storage	Super capacitors, superconducting energy storage, etc.

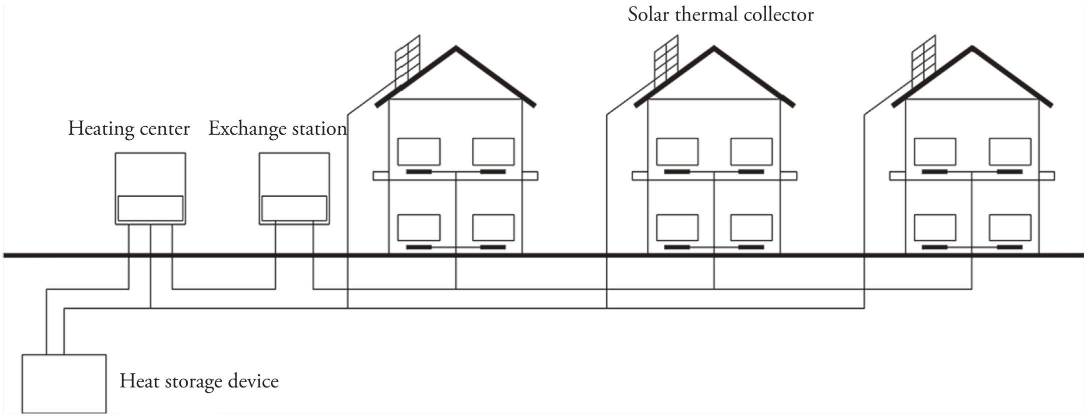


Figure 4.13 Schematic diagram of solar central heating system with cross-season heat storage

4.5 Micro thermal climate and ventilation technology in block

4.5.1 Urban planning and layout

Reasonable planning and layout of blocks can improve the thermal environment and thermal comfort of blocks. Based on the natural ventilation and sunshine conditions in summer, the influences of land use layout, architectural layout and design, road traffic system and green landscape system on the thermal environment of the block should be considered comprehensively.

Layout of land use:

(1) Arrange ventilation corridors

Urban ventilation corridor can improve the wind speed, guide the wind direction correctly, dilute the pollutants in the city and speed up their outflow from the city, so that the wind in the city can move smoothly and conveniently. At the same time, using the low temperature in the suburbs and the high temperature produced by the heat island effect in the city to form cold and hot air convection can not only reduce the heat island effect in the city, but also accelerate the emission of pollutants over the city. Although the urban ventilation corridor plays a small role in improving the overall regional climate, it plays a significant role in improving the urban internal air, reducing urban pollution and improving the city's own regulation capacity.

(2) Control the building density

Too dense or too scattered building density is not conducive to alleviating the heat island effect. The most suitable building density should be selected through design and the contradictions should be coordinated so as to realize the optimization of street shape.

4.5.2 Design of spatial interface

Roof

As the "fifth facade", the roof can not only beautify the environment and save land, but also have positive significance for improving the microclimate of the block.

Planting and greening on the roof allow plants to absorb a lot of solar radiation to lower the temperature of the roof surface, at the same time, it can also reduce air pollution and greenhouse gas emissions.

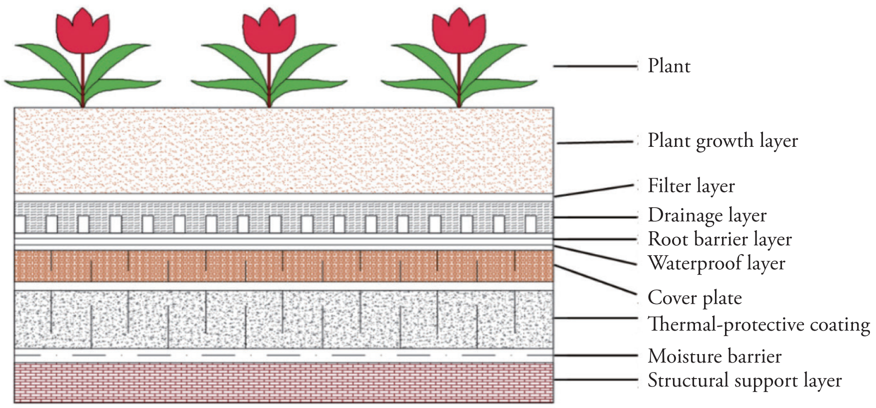


Figure 4.14 Schematic diagram of green roof

Building facade

Local materials, traditional techniques or new materials and techniques can be used in building facades to reduce heat exchange between buildings and outdoor environment and improve outdoor thermal environment. To improve the thermal resistance of household window materials, it should reduce the heat loss through the window frame by selecting plastic window frames with low thermal conductivity, select suitable glass varieties and strengthen the air-tightness of windows. Then, adjustable movable sunshades can be set to reduce the solar radiation heat in summer.

4.6 Regional energy comprehensive utilization and management technology

4.6.1 Background and role of regional energy planning

Under the guidance of the concepts of "smart growth" and "new urbanism", developed countries put forward that energy planning must be made in advance in urban development, and projects trying to establish cooling and heating systems such as co-generation and ground source heat pump need more detailed energy planning.

4.6.2 Principles and main tasks of regional energy planning

Energy planning should adhere to the following four principles: first, the choice of energy should adhere to the principle of adapting to local conditions and promote the maximum use of renewable energy and clean energy; second, energy planning and municipal facilities planning should be considered as a whole to maximize infrastructure functions; third, the efficiency of energy utilization should be maximized through the cascade utilization of energy; fourth, building energy should be matched with energy system to maximize economic benefits.

Table 4.8 Contents of Regional Energy Planning of Different Spatial Types in British Cities

Space type	Project type	Energy planning response
Urban center	Mixed use, public and commercial buildings	Large-scale combined thermoelectric system and solar and photoelectric system
Marginal zone	Universities and hospitals. Emerging residential areas, mixed utilization and development	County heating system, community renewable technology (solar thermal collector, etc.)
Inner city district	Housing renovation, mixed housing	Community-scale separate building energy system
Industrial area	——	Large energy production project
Suburbs	——	Micro energy production technology
Large-scale new urban extension and settle-ment area	Ecological town plan, growth area plan	Low-carbon and decentralized energy production
A rural area	——	Medium and large wind power generation system, biofuel sup-ply chain, marine energy production

4.6.3 Regional distributed energy cascade utilization technology

(1) Solar co-generation technology

The Trough solar organic Rankine cycle system can be built into small power stations, which is beneficial to reduce the construction cost and is very suitable for distributed energy. In order to further improve the energy efficiency of distributed solar energy system, the researchers put forward various types of co-generation system with cascade utilization of solar energy. Because of the random fluctuation and instability of solar energy, solar co-generation system must be integrated with heat storage system or other fossil energy sources to achieve the stability of energy supply. However, at present, the cost of solar heat collection is high, and the heat storage technology is immature, so the solar co-generation technology does not have a demonstration role. In the future, with the maturity of solar heat collection technology and heat storage technology, and the decline of related equipment costs, solar co-generation technology will have broad prospects.

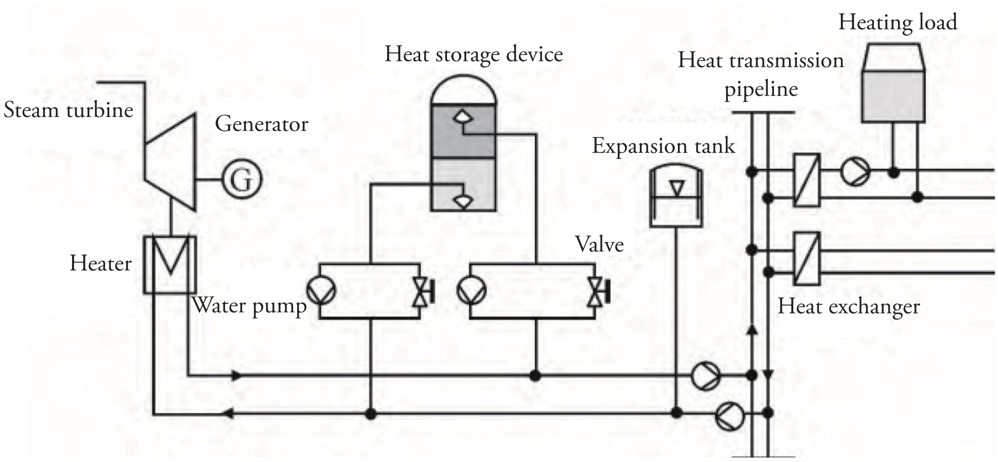


Figure 4.15 Co-generation system diagram with heat storage system

Figure 4.15 shows the co-generation system with heat storage system. When heat is being stored, hot water in the water supply pipe of the heat network enters the heat storage tank from the upper area, and cold water with the same quality is discharged from the bottom of the heat storage tank. When heat is being released, the water flows in the opposite direction. By controlling the mass and flow of inflow/outflow water, the system can ensure the reliable operation of the heat storage device, prevent the mixing of hot and cold water layers in the heat storage tank, and maintain the stability of the transition layer.

(2) Distributed CCHP technology of biomass[20]

Biomass CCHP system has many application forms, which can effectively meet the principle of energy cascade utilization. By integrating cooling, heating and power, and giving full play to the role of medium-and-low-temperature waste heat, it can improve the energy utilization rate of the whole system. Biomass gasification technology is the core technology of biomass gasification CCHP system. At present, biomass gasification needs a large amount of heat, and high energy consumption has always restricted the development of biomass gasification. Therefore, it is necessary to improve the process and find a way to comprehensively utilize biomass energy with high efficiency and low energy consumption. In addition, there are few types of gasifiers, while the types of gasifiers affect the composition and quality of gas. Therefore, it is necessary to design new gasifiers, so as to obtain high-grade fuel gas and facilitate continuous and stable feeding.

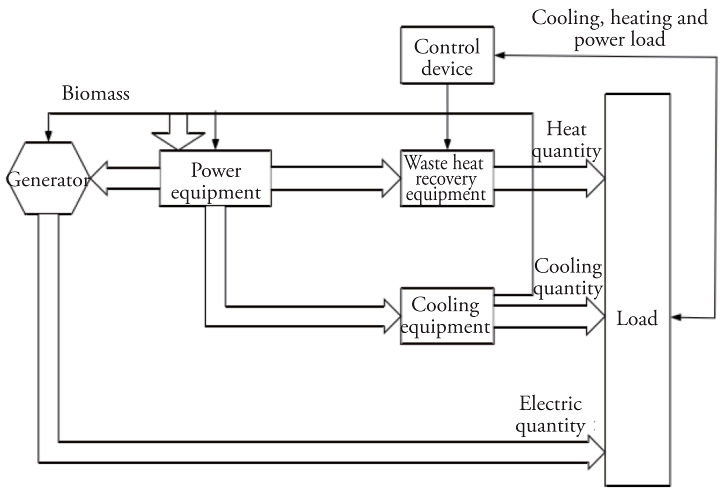


Figure 4.16 Schematic diagram of distributed biomass energy co-generation system

4.6.4 Multi-energy complementary and comprehensive utilization technology

(1) Solar photovoltaic and photo-thermal integration

The integration of solar photovoltaic and photo-thermal (PV/T) can reduce the working temperature of solar cells and improve the photoelectric conversion efficiency, at the same time, obtain part of the heat energy and greatly improve the utilization rate of solar energy. PV/T technology is still in the initial stage of development, and the technology is not mature, so there are some defects in the existing design schemes.

Table 4.9 Applicability of Solar Photovoltaic and Photo-thermal Integration Area

Climatic region	Solar energy resource-rich belt	Solar energy resources are abundant	Solar energy resource-rich belt	General belt of solar energy resources
Mild area	Suitable	Suitable	Relatively suitable	Not suitable
Hot summer and warm winter area	Suitable	Suitable	Relatively suitable	Not suitable
Hot summer and cold winter area	Suitable	suitable	Relatively suitable	Not suitable
Cold area	Suitable	Suitable	Relatively suitable	Not suitable
Severe cold area	Suitable	Suitable	Relatively suitable	Not suitable

(2) Solar energy and ground source heat pump coupled heating system

Series mode

There are two series modes: in the first series mode, the circulating medium first flows through the ground heat exchanger and then enters the solar collector, as shown in the following figure. In this case, the solar collector can reheat the circulating medium heated by the ground heat exchanger, and then directly deliver the high-temperature medium to the fan coil system for heating so as to achieve the purpose of direct heating without starting the heat pump.

The second series mode is opposite to the first mode, in which the circulating medium first flows through the solar collector and then enters the ground heat exchanger. When the sunshine is sufficient and the heat supply capacity of solar collectors is greater than the building heating load, this operation mode can transfer surplus solar heat energy to underground soil and improve the recovery speed of soil temperature.

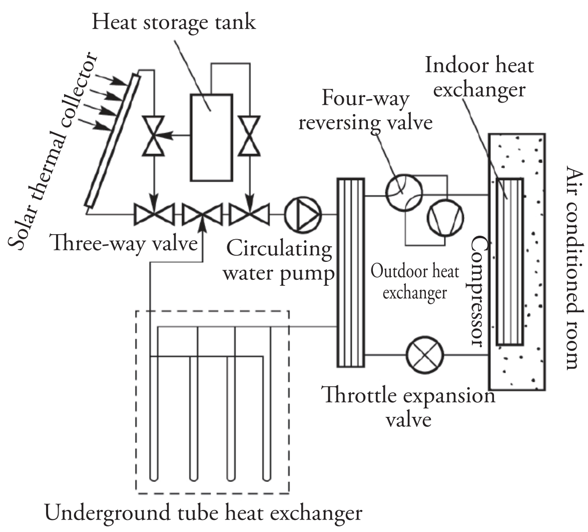


Figure 4.17 Solar-ground source heat pump combined heating system

Parallel mode

The Parallel system is mainly used in hot summer and cold winter areas where groundwater temperature is higher than 15℃ and solar energy is abundant. Solar energy only plays an auxiliary role, and the heat collected by solar energy system is directly sent into air-conditioned rooms for heating, or partially used as domestic hot water. The characteristic of parallel system is that it cannot be complemented or replaced, and the total energy is the sum of solar energy and geothermal energy absorbed from soil.

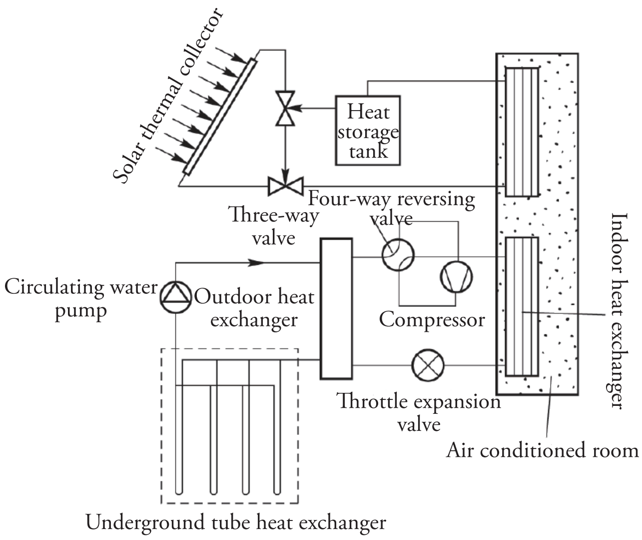


Figure 4.18 Schematic diagram of parallel solar-ground source heat pump combined energy supply system

4.9 Conclusions

1) Energy-plus buildings need to greatly reduce the energy consumption demand of building body on the basis of appropriate cost. At the beginning of design, the climate zone, building function and building location should be taken into consideration, and natural ventilation, lighting and solar heat should be utilized to reduce building energy demand by fully optimizing building orientation, window-wall ratio and room layout. In the case of economic rationality, the performance of building envelope should be improved to the maximum extent.

2) China's traditional energy-saving buildings pay insufficient attention to thermal break technology and air-tightness technology, and lack sufficient measures, components and materials to reduce the impact of building thermal bridges on energy consumption and improve building air-tightness. With the popularization of ultra-low energy consumption buildings and near-zero energy consumption buildings in China, these two technologies have been paid more and more attention to and become the essential technologies of architecture.

3) The fresh air system with high-efficiency heat recovery is an appropriate technology necessary to reduce building energy consumption loss and maintain healthy indoor air quality in ultra-low energy consumption buildings, near-zero energy consumption buildings and energy-plus buildings in unsuitable window-opening seasons like winter and summer, and it is suitable for different climatic regions and building types. With the great improvement of the performance requirements of the fresh air system in energy-efficient buildings, the fresh air system technology in China is also undergoing rapid transformation and upgrading, with the emphasis on the localization of research and development of polymer heat exchange cores, the improvement of intelligent control and sterilization function.

4) Energy-plus building is based on high-energy-efficient building body, and on this basis, the application of renewable energy can be fully utilized. According to resource conditions, measures should be adjusted to local conditions, and complement each other so as to improve energy utilization efficiency.

5) In terms of technology, energy-plus buildings should give priority to the system of combining solar photovoltaic power generation with energy storage devices to achieve self-sufficiency in electricity, and apply solar photo-thermal and heat pump technologies to solve the demand for building heating and domestic hot water. The focus of energy-plus community should be on energy storage conversion and intelligent microgrid construction. It is suggested to give priority to the application of microgrid technology to build controllable units composed of load and power supply, and form an integrated operation mode of "source-grid-load-storage". In areas where conditions permit, a certain proportion of renewable power will be consumed by using surplus wind and photovoltaic power, so as to achieve the regional productivity target.

5. Analysis of industrial support and development

5.1 Industrial support for energy efficiency improvement technology of building envelope

From 2009 to 2019, China has carried out about 6.5 million square meters of ultra-low energy consumption and near-zero energy consumption building demonstrations in 14 provinces and cities in four climatic regions. Since 2016, 16 provinces, municipalities directly under the Central Government, autonomous regions and prefecture-level cities across the country have successively issued economic incentive policies, providing financial incentives, floor area ratio rewards, and rising prices for ultra-low energy consumption buildings. With the gradual popularization of ultra-low energy consumption and near-zero energy consumption buildings in China supported by policies, the near-zero energy consumption building industry has gradually grown and strengthened, providing favorable industrial support for the future development of energy-plus buildings.

According to the "Selection Catalogue of Passive Low Energy Consumption Building Products" issued by the "Passive Low Energy Consumption Building Industry Technology Innovation Alliance" of the Science and Technology and Industrialization Development Center of the Ministry of Housing and Urban-Rural Development in 2016, the number of suppliers of high-performance energy-saving technologies for buildings with near zero energy consumption increased from 51 enterprises in the first batch in 2016 to 136 in 2019, and the number of enterprises more than doubled in 4 years (shown in Figure 5.1). The types of enterprises include external wall insulation, external doors and windows, waterproof system, sunshade, sealing materials, and fresh air conditioning system, etc.

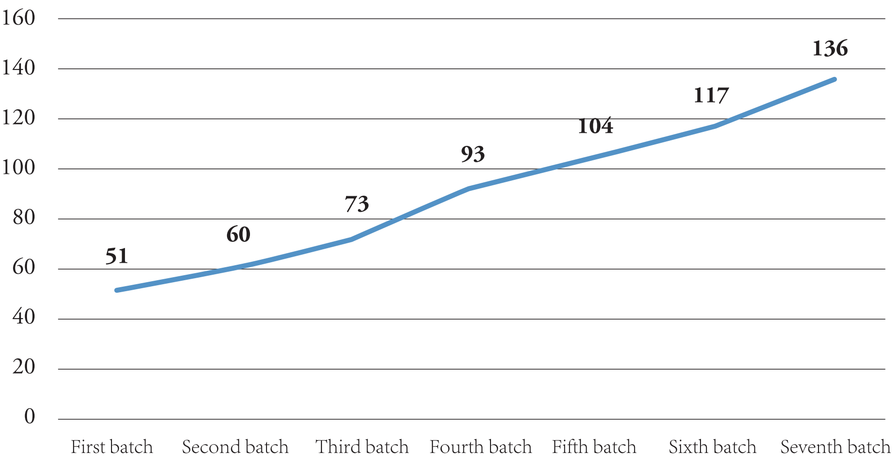


Figure 5.1 Number of Manufacturers in Product Catalogue

In the published supplier catalogue, state-owned enterprises account for more than 90%, among which the enterprises with faster development speed are external doors and windows and auxiliary materials, external insulation system suppliers and fresh air and HVAC equipment suppliers. Among them, in 2019, the number of enterprises of external door and window systems and sectional and auxiliary materials doubled compared with that in 2016.

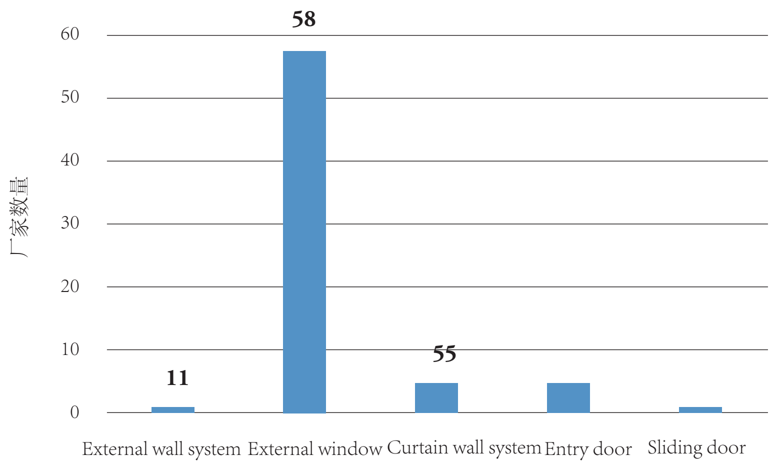


Figure 5.2 Distribution of Chinese manufacturers of PHI certified components

From the perspective of climate zone and regional distribution, the suppliers of technology products for building envelope with near-zero energy consumption are mainly concentrated in Beijing, Tianjin, Hebei and Shandong in cold climate zone, Shanghai and Jiangsu in hot summer and cold winter zone. This is closely related to the large number of demonstration projects of near-zero energy consumption buildings in these areas and the strong policy support. At the same time, these areas are relatively developed in domestic economy, and there are a number of competitive industrial clusters and leading enterprises in the fields of building materials, door and window systems, etc.

5.2 Industrial support for renewable energy technology

(1) Solar photo-thermal industry

The solar energy industry has matured, forming an industrial system of raw material processing, product developing and manufacturing, engineering design and marketing services, and at the same time driving the development of related industries such as glass, metal, thermal insulation materials and vacuum equipment. There are also some achievements secured in the scientific and technological aspect.

(2) Solar photovoltaic industry

In the past ten years, the development of solar photovoltaic power generation industry has undergone several major adjustments, but its production scale has been the first in the world for 12 consecutive years since 2007, and its application scale has been the first in the world.

(3) Heat pump industry

Thanks to the demand for clean energy heating in northern China, the products of air source heat pump units have been growing in recent three years. With the continuous improvement of technology, the products have a wider application range and can operate in a low temperature environment around -30 ℃ . Therefore, in the northern "coal to electricity" market, low-temperature air-source heat pump products can get rapid development, and some have introduced variable-frequency air-source heat pump units, which have been well applied. However, due to the different climatic conditions in the northern region and the differences in product technical strength, the low-temperature module products produced by some manufacturers cannot achieve good heating effect.

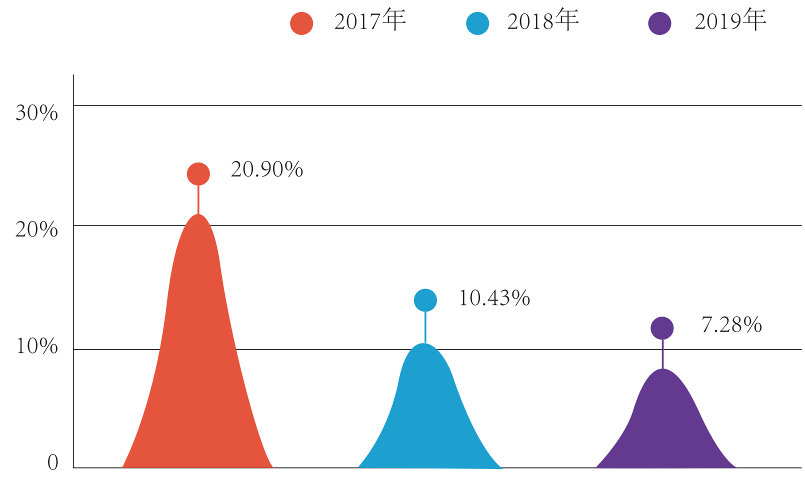


Figure 5.3 Market Share Growth of Air Source Heat Pump Units in 2017-2019

Among them, the number of air source heat pump water heaters has been increasing, and the concentration has also been increasing. Domestic production enterprises mainly include: traditional air-conditioning enterprises, professional air source heat pump water heater enterprises, electric water heater enterprises, solar water heater enterprises and gas water heater enterprises.

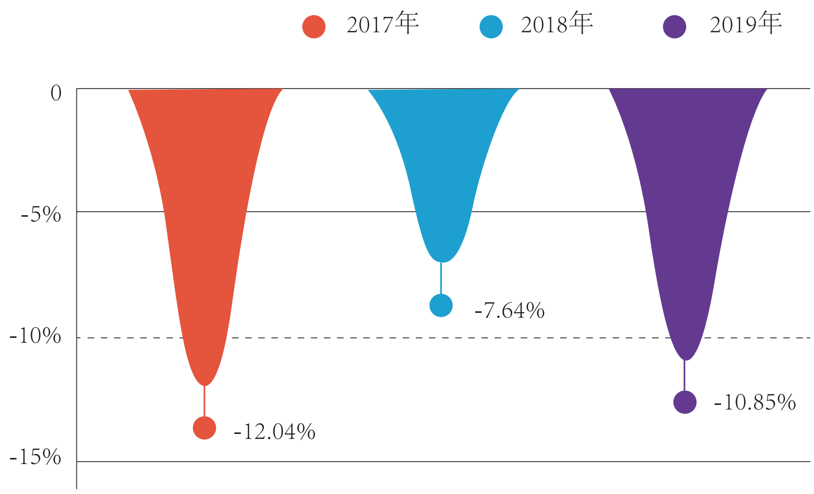


Figure 5.4 Market Share Growth of Water Ground Source Heat Pump Units in 2017-2019

6. Policy recommendations

6.1 Overall policy recommendations

6.1.1 Strengthen the top-level design and guide by region

Further strengthen the top-level design of the development of energy-plus buildings and energy-plus communities in China, and incorporate the research on the development of energy-plus buildings and cities into China's medium-and-long-term strategic planning for scientific and technological development, and special planning for building energy efficiency and green building development. While making maximum use of renewable energy, due to problems such as high cost, multiple techniques, and difficult operation, capacity houses and cities should start with pilot demonstration, determine priority areas and building types, development goals and implementation paths according to the differences of climate conditions, economic development level, technology development level and industrial maturity in different regions of China, sum up demonstration experience and achievements, and gradually explore a set of road for building capacity houses and communities suitable for China's current situation.

6.1.2 Strengthen technical research and innovation

Promote the basic theoretical research and innovation of energy-plus building and energy-plus community based on China's national conditions. Implement major research and development projects related to technological innovation in major national scientific and technological projects, national key research and development plans, and major scientific infrastructure construction. Actively carry out international scientific and technological cooperation and exchanges, learn from the research and practice of energy transformation and integration in European countries, carry out joint technical research in energy-plus building and energy-plus community, and promote the introduction, absorption, transformation and innovation of foreign innovative technologies.

6.1.3 Improve the standard system and standardize the construction and operation of energy-plus buildings and energy-plus communities

Based on the suitability and feasibility study of energy-plus building and energy-plus community, the definition, boundary, technical parameters and technical path of energy-plus building and energy-plus community should be determined. On the basis of demonstration, timely summarize the experiences of construction, operation and control strategies of energy-plus buildings and energy-plus communities, form a technical system suitable for different climatic regions, building characteristics, construction methods and residents' living habits in China, gradually establish and improve technical guidelines and standard documents covering the whole process of design, construction, acceptance, inspection, operation and maintenance and evaluation of energy-plus buildings, and standardize the design, construction and operation quality of energy-plus buildings. Gradually establish technical guidelines for planning, design, construction, operation and evaluation of energy-plus communities to guide the construction and operation of energy-plus communities. Accelerate the standardization of innovative technology products in energy-plus buildings and energy-plus communities.

6.1.4 Improve the construction of system and mechanism to stimulate market vitality

Establish and improve supporting incentive policies to encourage the development of energy-plus buildings, incorporate energy-plus buildings into the scope of subsidies for green buildings and ultra-low energy consumption buildings in various places, and appropriately raise subsidy standards for energy-plus buildings. Expand the target group of financial direct subsidies, encourage subsidies for users to purchase high-performance buildings, such as providing direct subsidies or preferential loans to buyers, and stimulate user demand to promote supply-side reform. Reward and support the R&D units, as well as design, construction and training units of buildings with near zero energy consumption. Establish a dynamic green supplier catalogue of buildings with near zero energy consumption, and give financial or tax preference to suppliers in the catalogue.

6.1.5 Cultivate and expand the emerging industries of buildings with near zero energy consumption

The technologies and products of near-zero energy consumption buildings are the strong support of the suitability technology of energy-plus buildings and energy-plus communities. With the large-scale popularization of ultra-low energy consumption buildings and near-zero energy consumption buildings in China, related industries are gradually maturing. Therefore, it is necessary to encourage all localities to introduce special industrial planning and industrial support policies for ultra-low and near-zero energy consumption buildings, or to bring the ultra-low and near-zero energy consumption construction industries into the medium-and-long-term planning of local green industries. With near-zero energy consumption buildings, energy-plus buildings and energy-plus communities as the technical core, cultivate green recycling emerging industries, improve the industrial chain, fill shortcomings, and drive the linkage development of the upper, middle and lower reaches of the industrial chain and the scale expansion of related industries.

6.1.6 Strengthen education, publicity, and personnel training

Strengthen education and popularization of professional knowledge, raise the awareness of the government, industry and the public on the significance and importance of energy-plus buildings and energy-plus communities, reach consensus from top to bottom, and jointly promote the development of energy-plus buildings and the transformation of energy integration. Increase the publicity of capacity technologies and products, and support the industry to carry out series of capacity design competitions and demonstration projects such as capacity families, communities, hospitals and schools.

6.2 Supporting policy recommendations in different climatic regions

6.2.1 Severly cold and cold areas

Based on the climate characteristics of severly cold and cold areas, the following policy recommendations are given:

1) Introduce incentive policies for production enterprises of parts and components related to energy-plus buildings: strengthen financial support for leading enterprises, promote the rapid development of linkage industries, and provide technology, support and economic encouragement for R&D, operation and maintenance of special parts of energy-plus buildings such as thermal insulation materials, waterproof materials, passive doors, passive windows, external sunshade systems, energy and environment all-in-one machines and new energy materials, so as to lay a solid foundation for the formation of integrated system technology industrial clusters of energy-plus buildings.

2) Introduce incentive policies for the improvement and rapid development of the energy-plus building market: based on the climate characteristics and natural conditions in severe cold and cold areas, take analyzing different market needs as the focus, and implement classified policies, focusing on the development and promotion of energy-saving, economical, comfortable, healthy, capacity, assembly and intelligent ultra-low energy consumption buildings, exploring the production and consumption patterns of buildings through multiple paths, giving play to the multiplier and leading effect of ultra-low energy consumption buildings, so as to stimulate greater market demand and driving more rapid industrial development.

6.2.2 Hot summer and cold winter areas

At present, in hot summer and cold winter areas, only the implementation schemes or regulations of green buildings have been promulgated, and there is no targeted energy-plus building policy. Based on the climate characteristics of the region, the policy recommendations are given as follows:

1) Introduce incentive policies for pilot demonstration of energy-plus buildings: on the basis of promoting green buildings and green ecological zones, carry out pilot demonstration projects of energy-plus buildings, select suitable land for regional planning by district people's governments or specific regional committees, encourage construction units to rely on basic energy-plus buildings, and strengthen research and development of energy-plus building technologies, standards and products in consideration of climatic conditions, resource conditions and geographical location, so as to promote the demonstration application of energy-plus buildings.

2) Introduce incentive policies for renewable energy utilization in line with climate characteristics: new public buildings majorly invested by governments, large public buildings and other public or residential buildings such as schools and hospitals should adopt renewable energy application systems and meet the requirements for comprehensive utilization of renewable energy. The design and installation of renewable energy application system in newly-built civil buildings should adapt to the energy consumption level of buildings and coordinate with the appearance of buildings.

6.2.3 Hot summer and warm winter areas

For hot summer and warm winter areas with air-conditioning energy consumption as the main factor, the technical system of energy-plus buildings in this climatic area should be put forward based on the climate characteristics, energy-saving strategies, technical measures and conventional energy-saving practices.

1) Introduce and issue the incentive policy of technical guidelines for energy-plus buildings applicable to hot summer and warm winter areas: for air conditioning and refrigeration energy consumption in hot summer and warm winter areas, improve China's current national standard, establish an ultra-low energy consumption technical system in hot summer and warm winter areas in China based on the current building energy efficiency design standard system, and establish residential and public building energy consumption indicators mainly based on cooling capacity. Establish a reasonable value range for maintaining structural insulation performance, replace building air-tightness indicators with natural ventilation (fresh air volume), and extend and develop the technical guidelines combining with the regional characteristics of hot summer and warm winter areas in a targeted manner.

2) Introduce special funds and technical support policies for energy-plus buildings: local governments and urban and rural construction bureaus shall, in combination with local actual development of energy-plus buildings, issue clear regulations on the support scope, subsidy methods, fund review, etc., and bring energy-plus buildings into the scope of special subsidy funds for building energy conservation to provide support.

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