Study on Key Technical Route and Construction Mode of Low-Carbon Park

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Abstract. The potential for energy conservation and emission reduction in parks is enormous, promoting the popularization of low-carbon parks is a necessary means to promote the green and low-carbon transformation of energy consumption and achieve China's 'dual carbon' goals. This article summarizes and extracts four main technical routes for building low-carbon parks through research on low-carbon parks and building cases at home and abroad: energy conservation and low-carbon construction of architectural noumenon, proactive energy conservation and operational carbon reduction, internal development of renewable energy, and external green energy input. Horizontal comparison and qualitative analysis of the four technical routes adopted in each typical case, summarizing and proposing eight models and typical application scenarios for building low-carbon parks, providing a theoretical basis and implementation suggestions for low-carbon development of the park.

1 Introduction

According to the 2022 Research Report of China Building Energy Consumption and Carbon Emissions[1], the total carbon emissions of the whole process of building in China in 2020 will be 5.08 billion tons, accounting for more than 50% of the national carbon emissions, which shows that buildings are the main battlefield for realizing the "Dual Carbon" strategy. It is very important to study and implement the goal of "double carbon" in the construction of the park, which is a building group carrying life and production. According to the "2020 Future smart park white paper"[2], more than 90% of urban residents work and live in the parks, more than 80% of GDP and more than 90% of innovation are generated in the parks, and the urban pattern and planning of our country are basically based on the parks as "units". With a large number of parks in China, highly concentrated elements, vigorous development of innovation activities, and low difficulty in collaboration among participants, it is currently the most suitable scene for low-carbon research and practice. It is precisely because of the practicability and huge potential of research in the park that the application value of energy-saving and carbon-reducing technologies in the park has begun to be valued by the industry, and low-carbon parks have become a focus of attention in implementing the goal of "double carbon".

As the most important part of the park, the building's low-carbon and energy-saving construction is an important part of the realization of low-carbon park. In 2019, the national standard "Technical Standard for Near zero Energy Buildings" (GB/T51350-2019)[3] was officially implemented, which is the first time in the world to clarify the definition, boundary and key technical indicators of near-zero energy buildings and zero-energy buildings in the way of national standards. It provides reference for relevant researchers to study the key technology paths of low carbon, near zero carbon and zero carbon buildings. In addition, the comprehensive energy system of the park is a new energy system that adapts to distributed development and meets the diversified energy needs of the park[4][5]. For the park, optimizing the energy structure and reducing the proportion of energy consumption with high carbon emission is also the most direct path to achieve emission reduction[6]-[8].

On the basis of low-carbon buildings and comprehensive energy, the relevant researchers put forward the overall macro technical measures for the realization of low-carbon parks. Zhou et al.[9] put forward the key points of the optimization strategy for planning and design of green low-carbon parks, including the layout of clean energy, the addition of energy storage facilities, carbon capture devices, carbon utilization or carbon storage logistics warehouses, the expansion of green space carbon sink space, and the construction of digital twin smart workshops to track carbon footprint. Yang et al.[10] proposed to realize the construction and application of low-carbon smart parks through the construction of micro-grid energy management system, all-domain sub-metering system, automatic sensing green buildings and digital management service platform. Zang

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et al.[11] put forward four paths to realize smart low-carbon/zero-carbon parks: using green materials in park construction, low-carbon/zero-carbon energy infrastructure, low-carbon/zero-carbon information infrastructure, and low-carbon/zero-carbon production and life. Chen et al.[12] proposed a zero-carbonization implementation path for business office parks by adopting green energy, green buildings, green transportation, green office and green carbon sink.

Low-carbon park is a green development mode that takes overall consideration of carbon emission and sustainable development, and takes the formation of low-carbon industrial clusters as the ultimate development goal[13]. Low-carbon park is a model of park construction and development, which takes "low carbon" as the goal of park construction and development. However, the above relevant studies only focus on the single building, energy system and other related technologies in the park, and lack the "low-carbon model" study of the park.

Therefore, by investigating typical low-carbon parks and building cases at home and abroad, this paper summarizes and abstractes the main technical paths for the construction of low-carbon parks, makes horizontal comparison and qualitative analysis of the technical routes adopted in each typical case, proposes the typical models and application scenarios for the construction of low-carbon parks, and provides theoretical basis and implementation suggestions for the low-carbon development of parks.

2 Typical low-carbon park project

The research team conducte research and analysis on more than 50 domestic and foreign low-carbon parks and energy-saving building projects, and summarize the main technical routes for the realization of low-carbon parks and buildings. The following seven typical cases are illustrated.

2.1 Low-carbon parks

2.1.1 Apple Park

Apple's new headquarters is located in California, the United States, with a total area of about 175 acres, as shown in Fig. 1, which is a low-carbon technology park dominated by offices. The project officially opened in 2019[14].

Fig.1. Apple Park[14]

The project mainly uses natural ventilation, natural lighting, external shading, plant carbon sink, fresh air heat recovery system, efficient lighting, efficient electrical appliances, radiation terminal, indoor environment monitoring, full fresh air replacement ventilation, solar photovoltaic, biofuel cells and other building energy saving and renewable energy utilization technologies. The building can solve the cold and heat load in the building most of the time through natural ventilation, and the design of natural lighting + task lighting can reduce the lighting power of the station by about 20%.

The peak photovoltaic power generation of the park is about 17kW, which can meet 75% of the daily electricity load, and the California photovoltaic power station supplies the remaining 25% of the energy. At the same time, the building has been connected to the grid, and the surplus electricity can be transmitted by the grid to achieve 100% renewable energy supply[15].

2.1.2 Bay View Campus

Google headquarters Bay View Campus is located in Mountain View, Silicon Valley, California, as shown in Fig. 2, the project covers an area of about 170,000m^2, and officially opened in 2022.

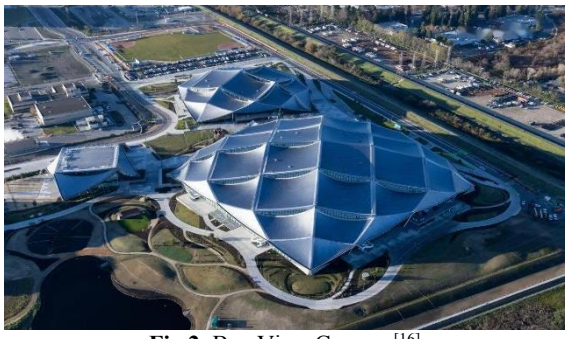

Fig.2. Bay View Campus[16]

The project adopts natural lighting, natural ventilation, automatic shading, green building materials and green construction, indoor and outdoor green landscape, solar photovoltaic, ground source heat pump and other building energy saving and renewable energy utilization technologies.

The 50,000 solar panels in the shape of a dragon scale are installed on the roof of the buildings in the park, which can generate nearly 7MW of electricity, meet about 40% of the energy demand of the park, and reduce nearly 50% of carbon emissions. Meanwhile, green energy companies will provide more than 50% of the electricity to the Google headquarters building, achieving 100% electrification of the park.

2.1.3 EUREF-Campus

Located in the city of Berlin, with an area of 55,000m^2, the EUREF Energy Technology Park is Europe's first zero-carbon smart transformation park, as shown in Fig. 3.

The buildings in the park use high-performance building materials, efficient insulation system, three-layer

doors and windows, shading, intelligent lighting, energy management system, energy storage, solar photovoltaic, wind turbines, ground source heat pump and other building energy saving and renewable energy utilization technologies. At the same time, the park will build charging piles and smart grid systems to reduce carbon emissions in the park.

The park deals to purchase biogas and integrates it into the pipeline network to meet 60% of the heating needs of the EUREF-Campus, while relying on ground source heat pump and photovoltaic power generation technology to achieve 80% to 95% renewable energy utilization.

Fig.3. EUREF-Campus[17]

2.1.4 Sino-German Ecopark

The Sino-German Ecopark is located in the West Coast New District of Qingdao, with a start-up area of 34.92km^2, as shown in Fig. 4. The first phase of the project has been completed in 2021.

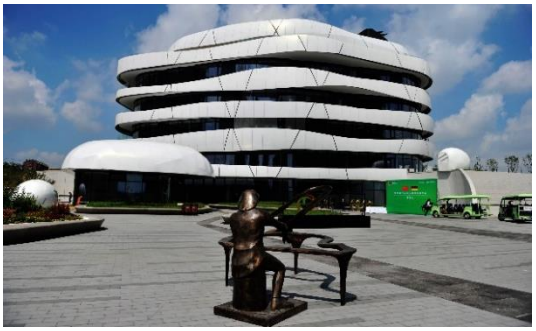

Fig.4. Passive room technology experience center in Sino-German Ecopark
(Picture source: http://www.sgep.cn/index.htm)

The project adopts natural lighting, natural ventilation, efficient building envelope, intelligent lighting, intelligent building, fresh air heat recovery system, terminal radiation, indoor monitoring system, "double carbon" operating system, lithium battery energy storage, solar photovoltaic, wind turbines, ground source heat pump and other building energy saving and renewable energy utilization technologies.

The installed capacity of distributed PV in the park reaches 16MW, and the energy supply area is nearly 1,000,000 m^2. The construction of passive houses in the first phase of the Sino-German Ecopark totaled 400,000m^2, which is expected to save 1,300,000kWh of primary energy consumption and reduce carbon emissions by 664tons per year.

2.2 Low-carbon buildings

2.2.1 Rocky Mountain Insititute's New Innovation Center

Rocky Mountain Institute's new Innovation Center is located in Colorado, USA, with a construction area of 1450m^2, as shown in Fig. 5. It has been completed and put into operation in 2022, accommodating 50 employees daily.

The building adopts efficient building envelope, natural lighting, natural ventilation, external shading, glare control, indoor sound insulation, thermal storage floor, landscape green plants, fresh air heat recovery system, efficient electrical appliances, efficient lighting, energy control system, solar photovoltaic, lithium battery energy storage and other building energy saving and renewable energy utilization technologies.

The building is equipped with 83kW solar photovoltaic panels to meet the energy needs of 123%~148% of the building. Compared with conventional buildings, heating energy consumption is reduced by 84%, ventilation energy consumption is reduced by 96%, and lighting energy consumption is reduced by 73%.

Fig.5. Rocky Mountain Insititute's New Innovation Center[18]

2.2.2 NREL Research Support Facility

National Renewable Energy Lab (NREL) Research Support Facility is located in Colorado, USA, with an area of 17,000m^2 and a construction area of 203,45m^2, as shown in Fig. 6. The project was completed in 2011 as a green office building.

Fig.6. NREL Research Support Facility
(Picture source: http://www.nrel.gov/)

The project adopts efficient building envelope, electric color glass, natural lighting, natural ventilation, active external shading, green carbon sink, thermal storage floor, fresh air heat recovery system, efficient electrical appliances, radiation terminal, indoor environment monitoring, intelligent lighting, evaporative cooling technology, full fresh air displacement ventilation design, solar photovoltaic, photothermal, ground source heat pump, biofuel cell, biomass boiler and other building energy saving and renewable The energy utilization technology reduces the design target of building energy intensity to 110.57kWh/(m^2·a).

Through solar photovoltaic, photothermal utilization, and biomass boiler hot water system, it can provide 2238MWh of energy for the building every year, accounting for about 30% of the total energy consumption of the building. The actual monitored energy consumption of the project in 2017-2018 is 78.75kWh/(m^2·a), which is 74.4% energy-saving compared with the general office buildings with the same level of use.

2.2.3 CABR Near Zero Energy Demonstration Bbuilding

The near-zero energy demonstration building of China Academy of Building Research (CABR) is located in Beijing, with a construction area of 4025m^2 and its main functions are office and conference, as shown in Fig. 7. The project was officially completed and put into use in 2014.

Fig.7. CABR Near Zero Energy Demonstration Building[19]

The project adopts high efficiency envelope, natural lighting, natural ventilation, adjustable central shading, roof greening, fresh air heat recovery system, efficient electrical appliances, efficient lighting, radiation terminal, indoor environment monitoring, full fresh air displacement ventilation, energy management platform, energy storage, solar photovoltaic, solar collector, ground source heat pump and other building energy saving and renewable energy utilization technologies.

The building energy saving rate is greater than 80%, the building energy consumption level is 25kWh/m^2·a, and the renewable energy utilization rate is 45%.

3 Technology routes of Low carbon park

Through the analysis of typical low-carbon park and building projects at home and abroad, the main technical routes of low-carbon parks can be summarized, including: energy conservation and low-carbon construction of architectural noumenon, proactive energy conservation and operational carbon reduction, internal development of renewable energy, and external green energy input, as shown in Fig. 8. At the same time, the horizontal comparison and qualitative analysis of the four technical routes are carried out, and Table 1 is obtained.

3.1 Energy conservation and low-carbon construction of architectural noumenon

Energy conservation and low-carbon construction of architectural noumenon technology emphasizes the direct use of the natural conditions of the site, through the optimization of planning and architectural design, the building can meet the requirements of heating, cooling and lighting of part of the building under the operation mode of non-mechanical, no energy consumption or less energy consumption, so as to achieve the purpose of reducing building carbon emission. Including the use of efficient building envelope, shading, natural lighting, natural ventilation and green carbon sinks and other means.

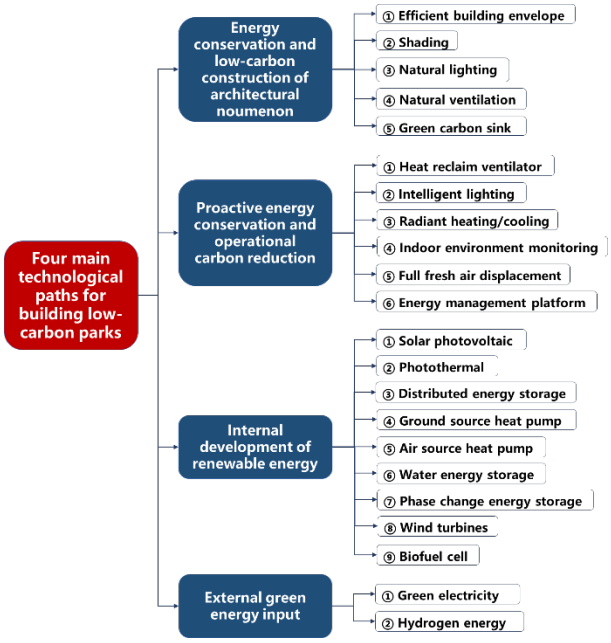

Fig.8. Four main technological paths for building low-carbon parks

Efficient building envelope is one of the key technologies to realize passive house building and ultra-low, near-zero energy building. Efficient building envelope emphasizes high standard insulation design for external walls, roofs, parapet walls, partition walls, floors, underground foundations, and others. Studies have shown that the use of external insulation system is 30% lower than the use of sandwich insulation carbon emissions. At the same time, the efficient building envelope should pay attention to the design of the detailed joints of the cold and hot bridges and the air tightness measures.

Shading has a significant effect on reducing building heat and cold load and improving indoor comfort. When

selecting the performance of the shading device, it is necessary to consider the needs of the building for shading in summer, obtaining heat in winter and natural lighting.

Natural ventilation technology enables indoor cooling through the planning and design of buildings, thereby reducing the energy use of building mechanical ventilation equipment. This kind of reasonable technical design means to deal with the relationship between the building and the natural environment has become the development trend of low-carbon building design.

With the development of passive houses and ultra-low and near-zero energy consumption building systems, energy conservation and low-carbon construction of architectural noumenon technology in buildings will play an increasingly important role.

Table 1. Quantitative analysis of typical low-carbon projects at home and abroad

No.	Name	Energy conservation and low-carbon construction of architectural noumenon	Proactive energy conservation and operational carbon reduction	Internal development of renewable energy	External green energy input	The effect of energy saving and carbon reduction
1	Apple Park	Natural ventilation meets 70% of the building's heating and cooling requirements	Reduced lighting power by 20%	Meet 75% of the building's energy needs	Meet 25% of the building's energy needs	Zero energy consumption
2	Bay View Campus		100% electrification	Meet 40% of the building's energy needs	Meet 50% of the building's energy needs	Neat-zero energy consumption
3	EUREF-Campus			Meet 80%~95% of the building's energy needs	Purchase biogas	Near-zero carbon
4	Sino-German Ecopark	Millions of square meters of passive room, the annual carbon reduction of 46,000 tons, more than 92% energy saving than general office buildings				Low-carbon
5	Rocky Mountain Insititute's new Innovation Center		Compared with conventional buildings, energy consumption for heating is reduced by 84%, air conditioning by 100%, ventilation by 96% and lighting by 73%	Meet 123% ~ 148% of the building's energy needs		Produce enenrgy, negative carbon
6	NREL Research Support Facility	74.4% energy-saving compared with the general office buildings		Meet 30% of the building's energy needs		Neat-zero energy consumption
7	CABR Near Zero Energy Demonstration Bbuilding	The envelope reduces building energy consumption by 47.8%	Reduced lighting power by 20%	Renewable energy utilization rate reached 45%		Neat-zero energy consumption

3.2 Proactive energy conservation and operational carbon reduction

The core of proactive energy conservation and operational carbon reduction technology refers to reducing energy consumption by improving the efficiency of energy use systems, mainly including heat reclaim ventilator, intelligent lighting, radiation terminal, indoor environment monitoring, full fresh air displacement ventilation and energy management and control platforms.

The fresh air heat recovery system uses exhaust air to preheat fresh air in winter and precool fresh air in summer, which can reduce energy consumption caused by treating fresh air, and is an effective means of building energy saving and carbon reduction, as shown in Fig. 9. Studies have shown that the emission reduction of buildings in Beijing, Shanghai and Guangzhou using fresh air heat recovery system only in summer can reach 14%~23%. In addition, the overall energy saving and economic benefits of using fresh air heat recovery system in cold regions are higher than those in other climate regions[20].

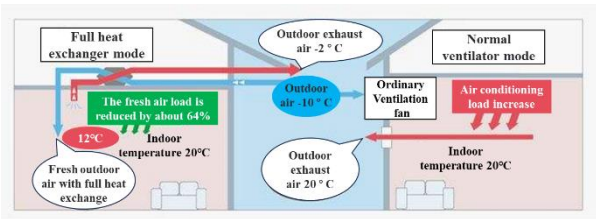

Fig.9. Working principle of fresh air heat recovery system (winter)

Intelligent control and energy-saving lamps should be used for lighting in the park. Common forms of intelligent lighting include light soft start, timing control, brightness intensity adjustment, scene setting, etc., so as to reduce lighting energy consumption and carbon emissions. Intelligent lighting system is usually used with LED lighting, LED lighting has developed rapidly in recent years, is one of the highest luminous efficiency lighting sources, compared with ordinary lighting can save 80%, has been widely used in green buildings, ultra-low energy consumption buildings.

Indoor heating and ventilation terminials of buildings are usually in the form of radiators, fan coils, all-air systems, active cold beams, radiant ceilings/floors, etc. Radiant terminal help reduce energy grade requirements, increase load flexibility, and increase comfort levels.

However, the radiant terminial has high investment and high dehumidification control requirements, so the radiant terminial can be used for partial application demonstration in the low-carbon construction process of the park.

In order to realize intelligent energy monitoring and fine management, improve the operation efficiency and intelligent management level of the park, an integrated energy management system should be built in the park. The system should be fully compatible with heating, air conditioning, lighting, water supply and drainage, power transmission and distribution monitoring, fire alarm, traffic and parking management and other subsystems. It can realize the functions of forecast, supervision, diagnosis, early warning, regulation and optimization of park energy consumption, so as to save park energy consumption and reduce park carbon emissions.

3.3 Internal development of renewable energy

The field of building and park is an important scene for the application of renewable energy, and renewable energy technology is also one of the key technologies to achieve low carbon in building and park. Priority should be given to solar thermal system, ground source heat pump, air source heat pump, etc. The power supply system should give priority to photovoltaic and wind power.

As the most important forms of renewable energy utilization in the park, solar photovoltaic and photothermal utilization are the most important technical ways to reduce carbon emissions in the park. Photovoltaic construction is the most important part of meeting the energy demand of the park, realizing the electrification of the park and building a low-carbon park. The low-carbon park proposes to make full use of the building roof and facade for the installation of photovoltaic modules, encourage self-adoption, and coupled with the energy storage system design to adjust the asynchronism of photovoltaic power generation and load demand, as well as the volatility and uncertainty of solar photovoltaic power generation, so as to improve the effective utilization rate of building photovoltaic power generation. With the continuous improvement of photovoltaic cell power generation efficiency, and the continuous decline of photovoltaic module prices with the advancement of industrialization, photovoltaic construction will become the most direct and effective technical measures to achieve low-carbon parks.

Fossil energy is the main energy for building heating, and the carbon emissions of winter heating in the park account for more than 20% of the total carbon emissions in the park. Therefore, the joint use of clean energy and electric energy according to local conditions is in line with the characteristics of China's resource endowment, and is the only way to re-electrification in the field of heating and cooling. Heat pump is an efficient and low-carbon energy supply method that elevates heat from low temperature to high temperature, and is the best way to efficiently convert electricity into heat, as shown in Fig. 10. As an efficient renewable energy utilization method, heat pump plays an important role in reducing carbon emissions of park heating. The heat source of the heat pump can be divided into air, surface water, groundwater, soil, solar energy, sewage, waste gas, etc.

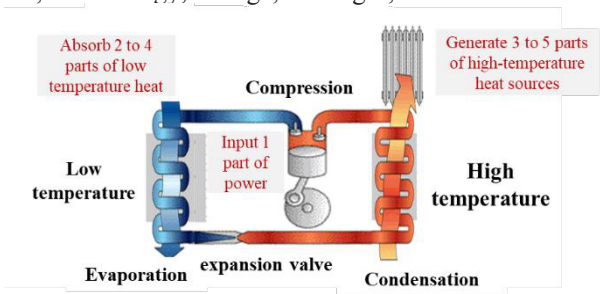

Fig.10. Heat pump system

The initial investment of the heat pump system is not much different from the cost of municipal heating, but the operating cost is much lower than that of municipal heating, showing excellent economy. In addition, a heat pump unit is combined with an energy storage system to form a heat pump energy storage system. By controlling energy storage and discharge, the time transfer of cold and heat source energy production and actual cold and hot energy use can be realized, and the flexible power consumption and peak power load of the heat pump system can be effectively transferred, further improving the economy and utilization efficiency of the system.

Due to the limitation of the park site, the smaller turning radius of the vertical axis wind turbine has better application potential in the park than that of the horizontal axis wind turbine. In areas with good wind energy conditions and far from the grid, it can supply lighting, electrical appliances, communication equipment and other electricity.

3.4 External green energy input

Compared with energy-saving buildings, low-carbon buildings emphasize more on the use of electricity, so it is necessary to consider the cancellation of gas and the realization of gas to electricity, in order to reduce or zero all kinds of direct carbon emissions. Therefore, for parks with sufficient renewable resources, solar energy and wind energy can be fully utilized to generate electricity to meet the demand of the parks. For parks lacking renewable resources, external green energy can be introduced to achieve low carbon goals. The external green energy input is mainly green electricity trading, and the main sources of green electricity are solar energy, wind energy, biomass, geothermal energy, hydrogen energy and so on.

When importing electricity from the external network, the low-carbon park should consider the power composition of the grid at different times, use more electricity and store more electricity when the proportion of wind power is large, use less electricity when the external network is dominated by coal power peaking, and use its own energy storage facilities to release energy storage to reduce the dependence on the external grid.

The development of green electricity market plays an important role in realizing low carbon in parks with

limited renewable resources. However, the implementation of the green electricity trading mechanism in the past period of time has also exposed some problems, including the imperfect green electricity pricing mechanism, the popularization of multi-year green electricity trading, and the demand for cross-province and cross-region trading can not be met. Therefore, the future development of the green electricity market is proposed from the above perspectives to better release the potential of green electricity trading and promote the realization of low-carbon parks.

4 Low-carbon park construction

By analyzing the characteristics of the above technical measures, this paper puts forward eight different modes of building low-carbon parks, as shown in Table 2 below.

By further comparing the technical measures applied in the typical low-carbon park construction mode, the typical application scenarios of different modes are summarized as shown in Table 3 below, and carbon emission analysis is carried out for each scenario.

Table 2. Construction modes of typical low-carbon parks

Modes	Names	Energy conservation and low-carbon construction of architectural noumenon	Proactive energy conservation and operational carbon reduction	Internal development of renewable energy	External green energy input
Mode A	Original insulated type	●	●		
Mode B	New energy development type			●	
Mode C	Passive architecture type	●	●		
Mode D	Internal and external combination type	●		●	
Mode E	Comprehensive low-carbon type	●	●	●	
Mode F	Existing building renovation type		●	●	●
Mode G	High density building type	●	●		●
Mode H	Integrated zero carbon type	●	●	●	●

Table 3. Application scenarios of typical low-carbon park modes

Modes	Typical applications scenario	Conments
Mode A	Reconstruction of northern residential community	Focus on energy conservation of architectural noumenon
Mode B	Rural residential building green energy	No focus on net carbon emissions
Mode C	Passive house construction	Focus on building energy efficiency improvement
Mode D	Villa community construction	De-emphasizing operational optimization
Mode E	New construction of comprehensive low-carbon park	Lay emphasis on the overall operation effect
Mode F	Renovation of special climate zones	Energy conservation of architectural noumenon meets the basic requirements, and further upgraded
Mode G	High density commercial building	The use of renewable energy in the park is limited
Mode H	New comprehensive zero-carbon demonstration zone	Can participate in market trading

Mode A: Adopt the technical route of energy conservation and low-carbon construction of architectural noumenon, mainly through strengthening the external wall insulation performance, replacing the external window and other architectural noumenon energy saving means to reduce building energy consumption, and achieve the goal of reducing the cumulative building heating and cooling load by more than 40% in cold areas. This model is mostly suitable for energy saving renovation of residential communities in northern China.

Mode B: Adopt the technical route of internal development of renewable energy, which is mostly suitable for parks or counties and towns that use solar photovoltaic panels to generate power to improve the utilization of renewable energy, and realize the green energy use of rural residents' buildings by not changing the form and function of the building itself. This model usually focuses on regional comprehensive carbon emissions, instead of building energy efficiency and net carbon emissions.

Mode C: Adopt the technical route of energy conservation and low-carbon construction of architectural noumenon+proactive energy conservation and operational carbon reduction, mainly through various energy-saving technologies to construct the best building envelope and indoor environment, improve building energy efficiency, and minimize the building's heating and cooling demand, which is mostly suitable for the construction of passive residential buildings. Relevant researchers have proposed that improving building energy efficiency to ultra-low energy building energy efficiency can reduce the equivalent carbon emissions of all types of residential buildings in various climate zones by 10% ~38% compared with the “General Code for Energy Efficiency and Renewable Energy Application in Buildings” (GB55015-2021), and reduce the carbon emission intensity of public buildings by more than 30%~40% compared with the benchmark buildings[21].

Mode D: The technical route of energy conservation and low-carbon construction of architectural noumenon+internal development of renewable energy is adopted. When the energy conservation and low-carbon construction of architectural noumenon meets the requirements, the optimization effect of building

operation is not emphasized, and the villa buildings and residential communities that can install distributed energy such as solar photovoltaic are mainly targeted.

Mode E: Adopt the technical route of energy conservation and low-carbon construction of architectural noumenon+proactive energy conservation and operational carbon reduction+internal development of renewable energy, which is suitable for new comprehensive near-zero carbon parks that pay attention to the overall operation effect of buildings. Compared with mode C, mode E not only improves building energy efficiency, but also further increases the proportion of renewable energy application in the park. At the same time, research shows that if the building reaches the near-zero-energy building energy efficiency index and further increases the building renewable energy application, the carbon reduction rate of the benchmark building can be increased by 15%[22].

Mode F: Adopt the technical route of proactive energy conservation and operational carbon reduction+internal development of renewable energy+external green energy input. It is mainly aimed at the low-carbon transformation of existing public buildings or parks in special climate zones. For example, in mild areas, the building has met the requirements of basic energy conservation, but further improving the performance of the building envelope has no obvious effect on the energy conservation and low-carbon construction of architectural noumenon, so this model can be adopted.

Mode G: Adopt the technical route of energy conservation and low-carbon construction of architectural noumenon+proactive energy conservation and operational carbon reduction+external green energy input, which is mainly suitable for high-density commercial buildings with poor renewable resources in the park, and achieve the low-carbon energy saving goal of the park through green electricity trading.

Mode H: Adopt the technical route of energy conservation and low-carbon construction of architectural noumenon+proactive energy conservation and operational carbon reduction+internal development of renewable energy +external green energy input, so that the net carbon emission of the park meets certain indicator requirements, and the comprehensive carbon emission is less than or equal to zero. This model is suitable for new office industrial parks with good renewable resource conditions, and is the most comprehensive technical model for building a new zero-carbon comprehensive demonstration zone.

5 Conclusions

Through the investigation of low-carbon parks and building projects at home and abroad, this paper summarizes and refines four main technical routes for building low-carbon parks: energy conservation and low-carbon construction of architectural noumenon, proactive energy conservation and operational carbon reduction, internal development of renewable energy, and external green energy input. Horizontal comparison and qualitative analysis were carried out on the four technical routes adopted by each typical project, and eight modes of building low-carbon parks were summarized and proposed. By analyzing the characteristics of different technical measures, the scope of application and typical application scenarios of each mode were obtained, providing theoretical basis and implementation suggestions for low-carbon development of parks.

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References

1. China Association of Building Energy Efficiency, 2022 research report of China building energy consumption and carbon emissions. Chongqing, 2022.
2. Huawei Technologies Company Limited, 2020 Future smart park white paper. Beijing, 2020.
3. China Academy of Building Research. Technical standard for near zero energy buildings:GB/T 51350-2019. Beijing, China building industry press, 2019.
4. Jordan Jalving, Jaffer Ghouse, Nicole Cortes, Xian Gao, et al. Beyond price taker: Conceptual design and optimization of integrated energy systems using machine learning market surrogates. Applied Energy, 2023, 351: 121767.
5. Xue Yixun, Guo Qinglai, Sun Hongbin, Shen Xinwei, et al. Comprehensive energy utilization rate for park-level integrated energy system. Electric Power Automation Equipment, 2017, 37 (6): 117-123.
6. Jonas Timmerman, Lieven Vandevelde, Greet Van Eetvelde. Towards low carbon business park energy systems: Classification of techno-economic energy models. Energy, 2014, 75 : 68-80.
7. Yin Yongguang, Wang Jinxuan, Zhou Min, Yang Chunfang. Discussion on park energy planning based on “Dual Carbon” policy. Construction science and technology, 2022, (19): 62-64.
8. Lu Liu, Qin Zhijun. Low-carbon planning for park-level integrated energy system considering optimal construction time sequence and hydrogen energy facility. Energy Reports, 2023, 9(7): 554-566.
9. Zhou Youmei, Lei Hao. Optimization strategy of industrial park planning and design from the perspective of double carbon. Architecture & Culture, 2023, (04): 8-10.
10. Yang Zhe, Fang Jiong, Chen Tiantian, Fan Yubo, et al. The construction and application practice of low-carbon smart parks under the dual carbon goal. Innovative Practice in Management of Chinese Power Enterprises. 2023(3): 169-171.
11. Zang Sheng, Zhao Bo. Exploration and practice of smart low-carbon or zero carbon parks. Jiangsu Construction, 2022, (06): 1-3.

12. Chen Xiaolin, Zhang Tiqiang, Zhang Yuning. Research on the implementation path of zero-carbon business office parks under the background of double carbon. Sichuan Chemical Industry,2022,(05):56-58.
13. Liu Lirong, Li Xin, Li Xinyuan, Liu Yong. Planning control path and method on the low-carbon industrial parks based on concept of industrial cluster. Journal of Guangxi University(Natural Science Edition), 2014, 39(04): 933-940.
14. Yue Hengyu, Tang Xiao, Jia Hongkun. Jobs' posthumous work, gathering cutting-edge architectural techniques, Apple Park's inspiration for the development of the construction industry. (2022-06-03).[EB/OL].https://baijiahao.baidu.com /s?id=1734536791386680080&wfr=spider&for=pc.
15. Lv Yanjie, Zhang Shicong, Xu Wei, James Connelly. Best practices and incentive policies for zero energy buildings in the united states. Building Energy Efficiency,2020,48(03):22-30.
16. Official google.org Blog. Reducing our carbon footprint with the direct purchase of renewable energy.(2010-7-20).[EB/OL]http://blog.google.org /2010/07/reducing-our-carbon-footprint-with_35. html.
17. He Jijiang. Germany's energy transformation (4. Berlin EUREF zero carbon energy technology park). China-nengyuan.com, (2018-04-25). [EB/OL] https://www.sohu.com/a/229474663_100049846.
18. Cris McClurg, Iain Campbell. Rocky mountain institute’s new innovation center: a net zero energy building. Eco-City and Green Building, 2016, (02): 78-85.
19. Zhang Shicong, Li Huai, Chen Qidong. Tracking research on operation energy consumption of CABR nearly-zero energy demonstration building. Construction science and technology, 2019, (18): 39-44.
20. Zhang Wen, Nie Jinzhe. Study on applicability of heat recovery ventilation system in typical buildings in different climate regions of China. Building Scenice,2022,(08):194-200.
21. Zhang Shicong, Wang Ke, Yang Xinyan, Xu Wei. Research on carbon emission control index of low-carbon, nearly zero-carbon and zero-carbon residential building. Building Science, 2023,39(02): 11-19.
22. Zhang Shicong, Wang Ke, Xu Wei. Research on carbon emission control index of low-carbon, nearly zero-carbon and zero-carbon public building. Building Science,2023,39(02):1-10.