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Research on energy consumption analysis and zero-carbonization transformation of existing universities---- Take the Balitai Campus of Nankai University as an example

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ABSTRACT

With the proposal of China's "dual carbon" strategy, zero-carbon transformation has become an important direction for the development of various industries, and the education field has also issued documents. The scale of construction, the number of students and energy consumption of colleges and universities continue to increase, and the carbon emission remains high. Taking Balitai Campus of Nankai University as an example, this paper starts with the analysis of the energy consumption of the school in recent years, carries out correlation analysis, excavates the main influencing factors of energy consumption, and proposes corresponding zero-carbonization transformation strategies. It adopts the scenario simulation method to analyze the benefits of energy conservation and emission reduction, and marks the relevant requirements of carbon emission indicators of university campuses in cold areas. This achievement is expected to provide a useful reference for existing universities in China to achieve carbon neutrality and provide a reference for the construction of zero-carbon campuses.

Keywords: Existing universities and colleges, Energy consumption analysis, Zero-carbonization transform a-tion

1. INTRODUCTION

Climate change and its impact are a serious problem facing today, and zero-carbon transition has become an important direction for the development of various industries. The zero-carbonization transformation of universities has become a consensus. Reihaneh Aghamolaei et al. proposed that universities play a key role in promoting decarbonization and sustainable development. The sustainable design of Cornell's campus energy system to achieve climate neutrality and 100% renewable energy; Ryan P. Shea et al. found that the transformation of the University of Dayton into a carbon neutral campus would bring huge economic and environmental benefits; Ball State University uses geothermal energy resources to establish a closed-loop regional geothermal energy system, reducing carbon emissions by nearly 50%; Princeton University and the University of Calgary have established campus databases, which show the energy supply of the school and the proportion of campus functions, the age of construction, and the energy consumption per unit area in real time. The low-carbon campus of Tianjin University establishes the top-level management idea and adopts the contract energy management mode to carry out the overall outsourcing of services, which can effectively solve the common problem of high energy consumption. The management system of Jiangnan University implemented 24-hour monitoring and alarm, which saved nearly 100 million yuan of water and electricity expenses for the school; Ruishi Li et al. put forward a new policy for the low-carbon emission campus management of North China University of Water Resources and Electric Power, and formulated comprehensive strategies to reduce carbon emission and improve energy and water conservation.

In July 2021, the Ministry of Education of China issued the Action Plan on Carbon Neutral Scientific and Technological Innovation in Institutions of Higher Learning, which put forward clear requirements for the national strategy of ensuring carbon peak and carbon neutrality in institutions of higher learning. On April 24, 2022, the Ministry of Education issued the notice on Strengthening the Construction of the Carbon Peak

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Carbon neutral higher Education personnel Training System, which clearly pointed out that green low-carbon education and science popularization activities should be widely carried out. As of June 15, 2023, there are 3,072 universities in China, with an estimated number of college students exceeding 38 million. The construction scale, number of students and resource consumption of colleges and universities have increased sharply, energy consumption has increased year by year, and carbon emission has remained high, which has huge potential for energy conservation and emission reduction. According to the statistics of the Ministry of Housing and Urban-Rural Development, the per capita water consumption of colleges and universities is nearly twice that of the average Chinese, and the per capita annual energy consumption is nearly five times that of the average Chinese. Universities to help carbon peak, carbon neutral, zero carbon transformation is imminent. In recent years, most colleges and universities in China have built campus energy consumption monitoring platforms, using energy consumption data and field research to analyze the influencing factors of energy consumption in order to carry out corresponding zero-carbon transformation, which is expected to provide beneficial references for Chinese colleges and universities to achieve carbon neutrality and provide references for zero-carbon campus construction.

2. ANALYSIS OF CURRENT SITUATION OF EXISTING CAMPUS IN BALITAI CAMPUS OF NANKAI UNIVERSITY

The Balitai Campus of Nankai University is an old campus, located in Nankai District, Tianjin, China, where the buildings before 2000 accounted for more than 74%, belonging to the cold area, the solar radiation is relatively rich, belonging to the second class area, the land area of 1.216 million square meters, the total building area of 6774 million square meters, the school energy consumption is mainly for municipal heating, electricity, gas and so on.

2.1 Analysis of current energy consumption in Balitai Campus of Nankai University

In terms of the overall energy consumption of the campus, the carbon sources of the Balitai campus are mainly electricity, heat and natural gas consumption. Due to the COVID-19 epidemic, the data in recent years are not representative. The energy consumption data of Balitai Campus from 2017 to 2019 are obtained, as shown in Table 1. From 2017 to 2019, the energy consumption and total energy consumption showed a gradual upward trend. In terms of power consumption, the annual average growth rate from 2017 to 2019 was 13.23%; In terms of natural gas, the use of natural gas in the three years from 2017 to 2019 changed steadily, and the use of natural gas in 2018 was about 200,000 cubic meters higher than in other years. From the perspective of comprehensive energy consumption, the proportion of municipal heat in annual energy use is about 60%, followed by electricity accounting for about 30%, the third is natural gas, accounting for about 8%, and gasoline and diesel account for a very small proportion.

Table 1 Energy consumption structure of Balitai Campus of Nankai University from 2017 to 2019

Time	Building area（m^2）	Students	Electricity (kWh)	Natural gas(m^3)	Municipal heat(GJ)	Total energy consumption(tce)	Water consumption(m^3)
2017	677400	17011	43047200	994100	314285	17354.21	158.84
2018	677400	16811	43620800	1208200	326983	18143.17	150.78
2019	677400	17175	48741700	959900	333446	18662.75	134.53

2.2 Analysis on current planning situation of Nankai University Balitai campus

In terms of building operation, Balitai Campus includes a total of 129 individual buildings, including the second main building, provincial building, sea ice building, Fansun Building, comprehensive laboratory building, student activity center, sports center, etc., of which 74.4% were buildings before 2000, 22.5% were buildings from 2000 to 2010, and 3.1% were buildings after 2010. Building energy efficiency renovation work demand is high, the workload is also large, is being phased passive transformation. There are four types of building roof, namely flat roof, double slope roof, thin shell roof and arch roof. The student dormitory has a large demand for hot water and a flat roof; Part of the family courtyard (North Village, Southwest village) has a double slope roof, and the rest has a flat roof; Most of the other functional buildings have flat roofs and the demand for hot water is smaller than the dormitory. Siyuan Hall is China's key cultural relics protection unit, it is not suitable to install rooftop photovoltaic, other building roof conditions can be installed photovoltaic.

In terms of energy supply, according to the survey, Balitai Campus has good geothermal resources. The existing biological station and natatorium of the College of Life Sciences use ground source heat pump for clean heating, the two main buildings use water source heat pump for heating, the bath park uses air source heat pump for domestic hot water, and the administrative office building and provincial building provide multi-connection central air conditioning and municipal heat heating. The winter heating of the other buildings is municipal central heating, which provides hot water after heat exchange station.

2.3 Analysis of influencing factors and key points of transformation of energy consumption in Balitai Campus of Nankai University

Nankai University attaches great importance to campus energy conservation, has set up the university energy Management Committee and built an energy consumption supervision platform. Monitoring and management of campus energy use, using these data to comprehensively analyze the influencing factors of building energy consumption, that is, to find the key point of zero-carbonization transformation. The energy consumption data of Balitai Campus of Nankai University was collected and combined with the current situation investigation, and the factors affecting energy consumption were summarized, which mainly included the following aspects: building area, building age, average building layers (height), number of users, time of use, green land rate, proportion of primary energy, heating and cooling methods, peak traffic congestion caused by narrow road cross section, etc. The data of energy consumption and some quantifiable influence factors are collected, and then the correlation between each influence factor and energy consumption is obtained to determine the main influence factors. Through correlation analysis, the positive correlation between building area, building age and number of users and energy consumption is higher, the negative correlation between using time and energy consumption is higher, and the correlation between average building floors (height) and energy consumption is lower. According to the analysis of correlation degree, it is determined that the building area, the number of users and the use time are the main influencing factors of power consumption.

To sum up, when carrying out the zero-

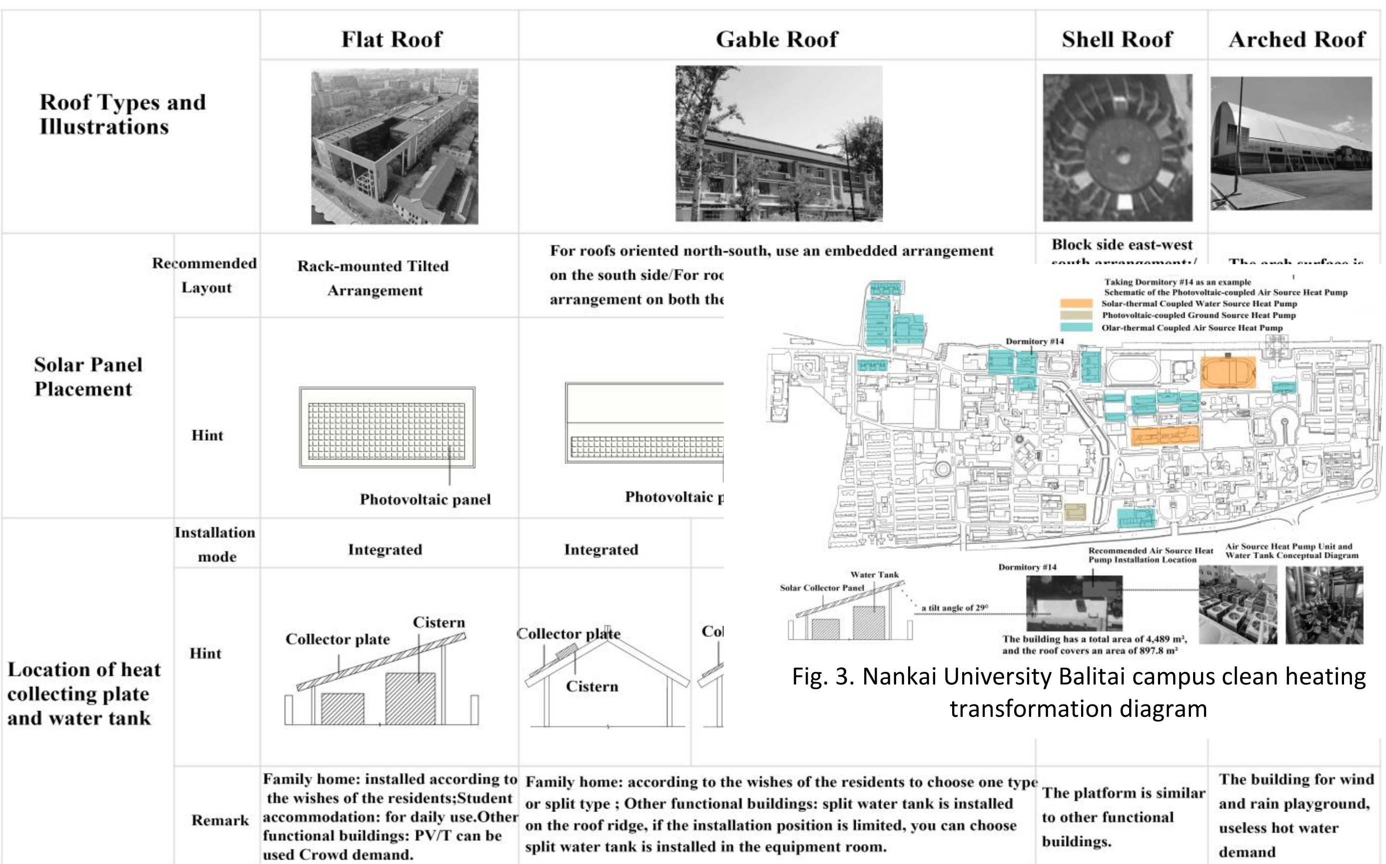

Fig. 3. Nankai University Balitai campus clean heating transformation diagram

Fig. 1. Illustration of photovoltaic building renovation of Balitai Campus of Nankai University

carbonization transformation of Nankai University Balitai Campus, it is necessary to fully consider the bearable transformation intensity of the building transformation under the influence of the long age of some buildings, the use time of the users, whether the supply and demand relationship of heating and cooling is consistent with the use of the building, the surrounding environment of clean heating and cooling, whether the roof conditions of the building are suitable for photovoltaic, the configuration of campus green plants, and the reuse of water.

3. ZERO CARBONIZATION TRANSFORMATION OF BALITAI CAMPUS OF NANKAI UNIVERSITY

3.1 Building low carbon transformation

Balitai Campus has various building types and different roof forms. In the integrated design of photovoltaic buildings, corresponding designs need to be made for different types of roof forms, as shown in Figure 1.

According to the floor area data provided by Balitai Campus, the roof area of the building of Balitai Campus is calculated and corrected by extracting the building outline through online map and ENVI software, as shown in Figure 2. By removing part of the old first-floor building and the floor area of the bottom building, the roof can be installed with a photovoltaic area of about 104,000 m^2, and the optimal installation Angle is 29°. The installed number of 62338 photovoltaic panels, the installed capacity is 19,948.16 kWp, and the Solar PV software is used to simulate photovoltaic power generation, and the annual power generation is about 25242.64MWh. According to the power consumption data of Balitai Campus from 2017 to 2019, photovoltaic power generation accounted for 58.64% of the electricity consumption in 2017, 57.87% in 2018, and 51.79% in 2019, with the relatively stable electricity cost of 0.505 yuan /kWh as the standard calculation in recent years, about 12.747 million yuan of electricity can be saved every year.

Fig. 2. Online maps and ENVI software extract the building outline

3.2 Clean heating renovation

Most of the buildings in Balitai Campus are municipal heating, so the focus of clean heating is to combine the load and use characteristics of each building, and carry out clean heating transformation according to local conditions, as shown in Figure 3. Two of the main building water source heat pump due to the aging of the heating effect is not good, consider replacing the new equipment; Biological experimental station, sports center ground source heat pump heating; Boling Tower for cooling tower and municipal heat supply; The administrative office building and the provincial building (Mathematics center) have a long service life for the central air conditioning multi-connection, which often fails. It is suggested that the whole photothermal coupled air source heat pump should be replaced to achieve the expected goal. The air source heat pump in the bath park has a good heating effect. The remaining buildings provide municipal central heating in winter, and the heat exchange station provides hot water, among which the dormitory is considered to install an air source heat pump coupled with light heat and water tank for heating.

It is suggested that the newly installed heat pump combined with the green layout of the building site can effectively alleviate the noise pollution generated by the operation of the heat pump unit, so as not to interfere with the work, study and rest of the staff and students.

Taking 14# dormitory as an example, the average daily hot water usage is 9.92 tons, the number of collector installations is 24 groups, the single collector lighting area is 8.4m^2, the solar guarantee rate is designed to be 50%, the annual energy efficiency COP of air source heat pump is 3.2, and the consumption of water pump operation and winter electric tracking zone accounts for about 5% of the entire system.[8]

Among them, according to formula (3), the energy saving estimate of the air source heat pump system is as follows:

$$Q_k = cm\triangle t \quad (1)$$

Where, Q_k is the heat load, KJ; c is the specific heat capacity of water, which is 4.2×10^3J/ (kg • ℃); m is the mass of water, kg; $\triangle t$ is the temperature change of water, ℃.

It can be calculated that the heat load is 937440KJ, that is 260.4kWh, and the annual electricity saving is 22378kWh.

Among them, according to formula (2), the energy saving estimate of solar hot water system is as follows:

$$Q_t = A_c \cdot J_t \cdot h_{cd} \cdot (1 - h_L) \quad (2)$$

Where: Q_t refers to the heat of the solar heat collection system, kJ; A_c is the collector lighting area, m^2; J_t is the annual average daily radiation amount of total solar radiation on the lighting surface of Tianjin, kJ/m^2·d; h_{cd} is the collector efficiency; h_L is the heat loss rate of pipeline and water storage tank is 0.2.

It can be calculated that the actual annual average daily heat of the solar heat collection system is 919.7MJ, that is, 260.7kWh, and 71690.34kWh of electricity can be saved every year.

In the same way, the 16 dormitories on the Balitai campus can be renovated for clean heating, which can save 1985590kWh per year, and the electricity cost can be saved by about 1.003 million yuan per year based on the relatively stable electricity cost of 0.505 yuan /kWh in recent years.

3.3 Spatial layout optimization

Balitai campus road is mostly a board section (two-way two lanes), although there is a certain amount of traffic interference, but the speed is low, covers the smallest area, investment province, and is safer in the old school area where people and vehicles mix. The roads in the old campus are narrow and there are a variety of cross-sectional roads, some of which cannot meet the travel needs of students. At the same time, the number of motor vehicles and non-motor vehicles has increased greatly, and the problem of students seizing the road with motor vehicles has appeared. Some roads have strong traffic capacity, so the greening landscape can be considered to improve. In the process of road cross section optimization, road widening or greening landscape enhancement should be carried out, as shown in Figure 4.

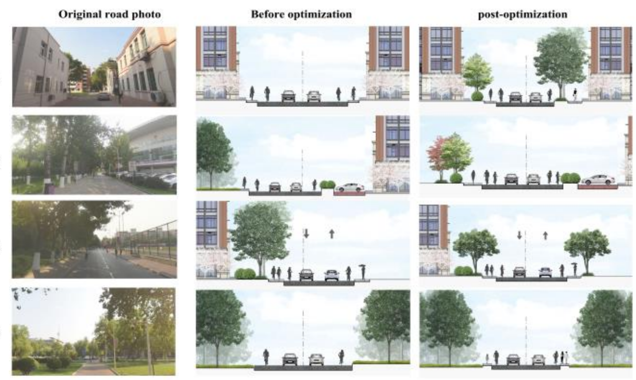

Fig. 4. Nankai University Balitai campus road cross section optimization diagram

Campus lush ecological vegetation, green shading effect is good. Emphasize the use of rainwater to supply green watering, in order to achieve the goal of water saving. The green layout has continuity, mostly on both sides of roads and rivers. Greening diversity allocation was optimized based on the principle of giving priority to localized plants and strong carbon sequestration ability, and rainwater reuse was carried out for greening watering, as shown in Figure 5.

Balitai campus dormitory distribution is relatively dispersed, to ensure that the student dormitory toilet flushing all use of water requirements, it is appropriate

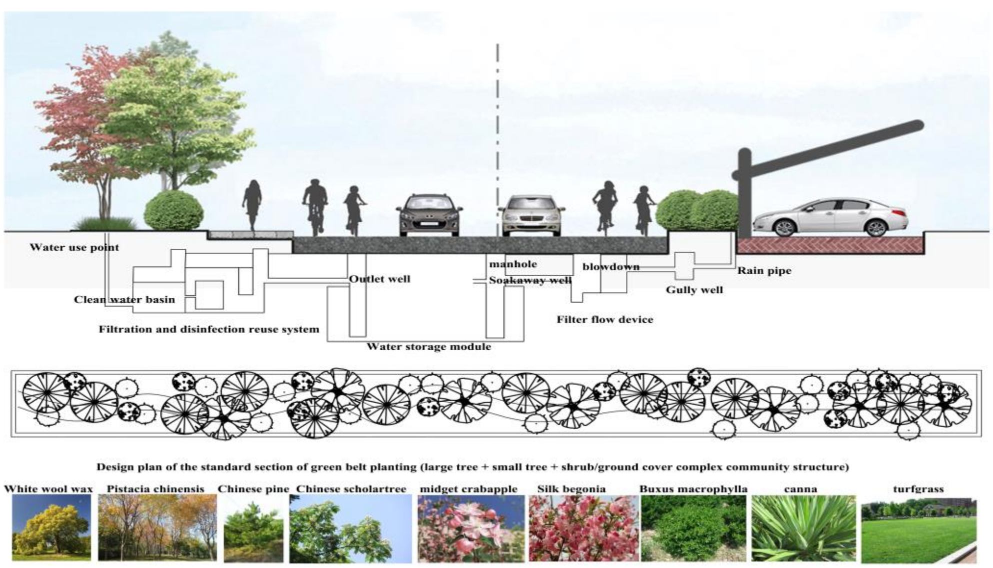

Fig. 5. Illustration of green layout optimization and rainwater reuse in Balitai Campus of Nankai University

to independently set up closed water treatment station, and carry out the corresponding pipeline layout, in order to use water flushing. According to the "Building water Design Standard" GB50336-2018, the location of the campus water treatment station should not be less than 15m away from public buildings and residences. According to formula (3) and (4), the calculation is as follows:

$$Q_c = \sum Q \times F \times N / 1000 \quad (3)$$

$$Q_z = (0.25 \sim 0.35)\, Q_c \quad (4)$$

Among them, Qc is the highest daily flushing water consumption (m^3/d); Q is the water consumption quota for water supply [L/(person ·d)], and the per capita water consumption quota for colleges and universities in Tianjin is 50 tons /(person · year), equivalent to about 137m^3/ (person ·d); F is the proportion of flushing water to domestic water (%), the F value of dormitory is 30% according to the design standard of building water GB50336-2018; N is the number of users (people), the number of residential students in Balitai Campus is about 14,000; Qz is intermediate water reserves.

It can be concluded that the maximum daily flushing water consumption of the dormitory on Nankai University's Balitai Campus is about 580m^3, and the water treatment station runs continuously, and the maximum water transfer reserve is 202m^3. The water consumption of the natatorium on Nankai University's Balitai Campus and the dormitory in the East District fully meet the water demand of the water treatment, and there is no need for water balance. The establishment of 300m^3/ day of reclaimed water treatment station can meet the requirements of using reclaimed water for flushing toilets in student dormitories. The average daily water supply of the bath park is 300 tons. The original reclaimed water treatment station next to the bath park is rebuilt and expanded, and the average annual yield of reclaimed water is about 110,000 tons, which can completely replace tap water for non-riverside afforestation irrigation in the school district, as shown in Figure 6.

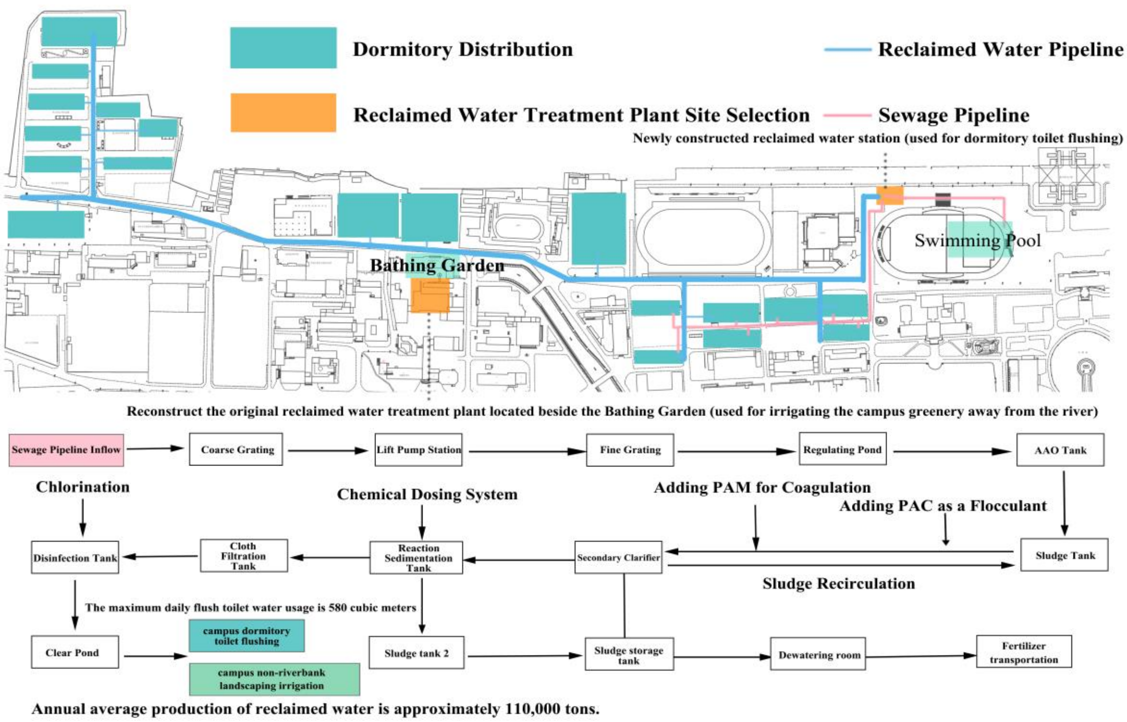

Fig. 6. Nankai University Balitai campus water treatment station site selection and water reuse diagram

In terms of afforestation allocation optimization and rainwater reuse, according to the carbon sequestration model of ecological green space [8], the annual carbon sequestration amount of standard forest land is taken as the standard value, and the land area of different ecological green space types is converted into the area of standard forest land. The conversion coefficient of standard forest land for dredge forest land is 0.55, and that of standard forest land for grassland is 0.38. The annual carbon fixation amount of this kind of ecological green space is calculated and summed. After optimizing the greening configuration of Balitai campus, the total annual carbon fixation amount is at least 5.12t/a, which has certain social and environmental benefits. In terms of road cross section optimization, road widening or greening landscape upgrading can effectively alleviate peak congestion on campus according to existing road conditions. In terms of water reuse, the annual water saving is about 200,000 tons, but the carbon emission reduction benefit is poor. It is expected to save 1.2 million yuan per year.

4. BENEFIT ANALYSIS OF CAMPUS ENERGY SAVING AND CARBON REDUCTION BASED ON SCENARIO SIMULATION

Under the premise of ensuring the application of feasible carbon reduction technologies, various influencing factors are systematically considered, and the contribution of different transformation strategies to energy conservation and emissiozn reduction is analyzed with energy conservation as the goal, as shown in Figure 7, which provides the possibility of selection and optimization of zero-carbon transformation schemes.

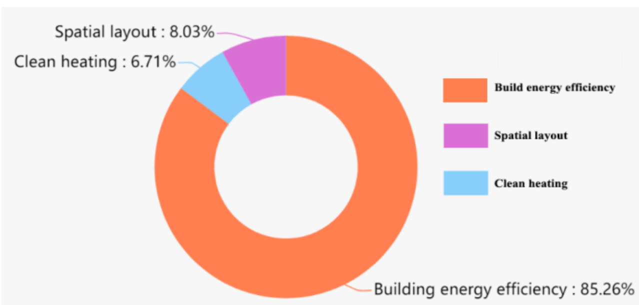

Fig. 7. Contribution rate of different transformation strategies to energy conservation and emission reduction

After the zero-carbon transformation, as shown in Table 2, based on 2017, the carbon reduction rate of Balitai Campus of Nankai University was 73.3%, the per capita carbon emission was reduced to 291.24 kg CO_2/(person ·a), and the water saving was 11.76 m^3/(person ·a), which has reached the near-zero-carbon regional standard requirements.

5. *PERORATION*

The zero-carbonization transformation of existing colleges and universities is the concrete interpretation of the "two-carbon" strategy in the campus spatial scale. Based on correlation analysis, the main influencing factors of energy consumption are explored, and zero carbon transformation strategies corresponding to building low-carbon transformation, clean heating transformation, and spatial layout optimization are proposed. The relevant carbon indicators are analyzed based on scenario simulation method, and the results show that Nankai University Balitai Campus meets the near-zero carbon regional standard requirements. The research results can provide useful reference for existing universities in China to achieve carbon neutrality, which not only helps to reduce their carbon emissions, but also sets up near-zero carbon campus demonstration in terms of sustainable energy utilization. Further studies can be conducted on existing universities with different regional characteristics and different development stages in combination with local and economic characteristics.

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Table 2 Comparison of indicators before and after zero-carbonization transformation of Balitai Campus of Nankai University

Energy type	Units	The year 2017	The year 2018	The year 2019	Amount of change after transformation
Per capita carbon emissions	kg CO_2（p·a）	1091.85	1078.92	1086.32	-800.61
Per capita water consumption	m^3/（p·a）	93.37	89.69	78.33	-11.76

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