Study on the application of solar power generation in gymnasiums

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Abstract. To accelerate the promotion of green and low-carbon development, the development of green buildings, new energy development into the "14th Five-Year" planning recommendations, in the global climate change, energy shortage situation, solar power generation as a clean and renewable energy, in today's society has received more and more attention. Drived by China's successful hosting of the 29th Summer Olympic Games in 2008 and its bid for the 2022 Winter Olympic Games in 2015, there has been a boom in the construction of sports venues and facilities across the country. Study on the present situation of the application of solar power in the stadium hall has carried on the system analysis and research.

1. Introduction
Since the beginning of the 21st century, facing the urgent situation of global warming, the transformation of energy structure to green and low carbon has become a common consensus of all countries in the world, and renewable energy such as wind power and solar power has shown a booming situation. In 2020, the sudden COVID-19 outbreak and low oil prices will have a profound impact on the oil and gas industry and will accelerate the transition to low-carbon energy. China is formulating the low-carbon and green development of the "14th Five-Year Plan" and the medium and long term energy development plan, the use of solar power in stadiums has become one of the effective ways to solve the contradiction between energy and economic development

2. Research methods

2.1. Literature survey
In the writing process of this paper, I consulted a large number of literature materials, including relevant books and works, master and doctoral theses, journals and newspapers, professional websites, etc., and the literature collection is not limited to the direction of sports and architectural design, but a wide range of subjects such as economics, behavioral science, sports science, sociology and so on.

2.2. Typical example analysis
Through the study and analysis of excellent examples at home and abroad, the author explores the successful points that can be used for reference and learning, and concludes and summarizes them for further promotion. Find out the practical problems that need to be improved, learn from experience and
lessons, and analyze and study them to get solutions; through the research of new ideas and new technologies in various disciplines, we can find a breakthrough.

2.3. Inductive deductive method

This paper mainly collates and makes a comparative analysis of the representative newly-built small and medium-sized gymnasiums in the past 10 years, and draws a conclusion through the study of these actual data and cases, so as to avoid the theoretical emptiness.

3. Research results and analysis

3.1. International energy and environmental situation

Since 1980, global climate change has intensified, and energy consumption has become an urgent and important environmental issue. In 2006, the International Energy Agency (IEA) predicted that global demand for energy would increase by more than 50% between 2006 and 2030. Analysis of relevant statistical data shows that if the current rate of exploitation continues, the world's energy resources, such as oil, gas, coal and uranium, will be rapidly exhausted, leaving only reserves of 45, 61, 230 and 71 years at the current rate of exploitation, while China's reserves are 15, 30, 81 and 50 years [1].

![Figure 1. Changes of primary energy consumption structure in China from 1994 to 2019](source: BP Statistical Yearbook of World Energy 2020)

3.2. The distribution of solar energy in China

The area of solar energy resources in China is large, accounting for more than 2/3 of the total area of the country (Figure 4-36, Table 4-3). The annual solar radiation in China is about 1050-2450 kWh/(m² • a), which is equivalent to about 1.7 trillion tons of standard coal. In the case of good radiation, the electricity of a 1m² building needs about 1m² of photovoltaic area to provide it [3], which can be achieved in dense urban areas. However, large public buildings such as sports buildings have advantages in photovoltaic power generation due to their wide land area and large roof.

![Figure 2. Distribution of solar energy resources in China](source: BP Statistical Yearbook of World Energy 2020)
In terms of the total amount of solar energy, China has abundant solar energy resources, and the western solar energy resources are better than the eastern solar energy resources. In addition to Xinjiang and Tibet, the solar energy resources in the north of China are better than those in the south. From the extreme value, the Qinghai-Tibet Plateau is the highest value center of solar energy resources in China, while the eastern Sichuan Basin and Guizhou are the areas with the most deficiency of solar energy resources. From the perspective of scope of various provinces, the potential of solar energy resource itself using gap between provinces is very big, Tibet, Qinghai, Inner Mongolia and other provinces of Sichuan basin, Guizhou times above, in addition to Anhui, Henan, the rest of the provinces within the solar energy gap is bigger also, especially in Sichuan is most obvious, its western solar energy resource potential is 2 times more than the east.

### Table 1. The theoretical content of solar energy resources in each province in mainland of China

| Province (city, autonomous region) | Theoretical implication (gigajoules) | Province (city, autonomous region) | Theoretical implication (gigajoules) |
|-----------------------------------|--------------------------------------|-----------------------------------|--------------------------------------|
| Beijing                           | 950.4                                | Guangdong                         | 8665.2                               |
| Tianjin                           | 583.2                                | Hainan                            | 1713.6                               |
| Hebei                             | 10389.6                              | Guangxi                           | 10227.6                              |
| Shanxi                            | 8294.4                               | Sichuan chongqing                 | 26496                                |
| Inner Mongolia                    | 63918                                | Yunnan                            | 20786.4                              |
| Shanghai                          | 277.2                                | Guizhou                           | 6818.4                               |
| Jiangsu                           | 5954.4                               | Tibet                             | 84981.6                              |
| Zhejiang                          | 4636.8                               | Shaanxi                           | 9363.6                               |
| Anhui                             | 6120                                 | Gansu                             | 24120                                |
| Fujian                            | 5619.6                               | Qinghai                           | 49176                                |
| Jiangxi                           | 7351.2                               | Ningxia                           | 3927.6                               |
| Shandong                          | 7891.2                               | Xinjiang                          | 97416                                |
| Henan                             | 7869.6                               | Liaoning                          | 7426.8                               |
| Hubei                             | 8049.6                               | Ji Lin                            | 8953.2                               |
| Hunan                             | 8906.4                               | Heilongjiang                      | 21495.6                              |
| A total of                        | 528361.2                             | Provinicial average               | 17612.1                              |

### 3.3. Technical characteristics of solar power generation

#### 3.3.1. Solar power generation

Solar energy from every second is about 3.88 x 1023 kW, which reaches the earth is only one in 2.2 billion m, amount of solar energy reaching the earth's surface in a year is about 21 trillion kW, development also has 21 billion kW, 1% is the main energy in the world has proven reserves of 10000 times, far more than biomass 100 million kW, 378 million kW hydropower, wind power 378 million kW. The conversion efficiency of solar energy is high, which is 15%-20% of crystalline silicon, 10-30 times of edible biological conversion efficiency, 50-100 times of corn ethanol conversion efficiency, and 15-20 times of input and output of new power station construction and operation. Solar energy can be used locally, without transmission cost, and is tax-free energy [1].

At the same time, solar energy is a kind of clean energy, which produces almost no pollution and waste when it is developed and utilized. 3KW solar power generation system is equivalent to reducing CO2 emissions: 540 kg/a, oil: 729 L/a, conversion forest area: 5544 m2. The carbon emission of 1kW of solar photovoltaic power generation is 0, 6 g of wind power, 20 g of hydropower, 181 g of natural gas, 204g of oil and 304g of coal. Therefore, solar energy is a kind of clean energy, has a significant effect of emission reduction.

### 3.4. Development status of solar power generation in China

Solar-thermal power generation is one of the main methods of solar energy utilization, along with the advance of solar-thermal power generation technology in China and the continuous improvement of the related industry system, the advantages of solar power gradually, together with the people environmental
protection consciousness enhancement, gradually increased demand for clean energy, solar power began to rapid growth. China generated 23.5 billion kilowatt-hours of solar power in 2014 and 223.8 billion kilowatt-hours in 2019.

![Figure 3. China's solar power generation capacity (unit: Million kilowatt hour)](image1)

![Figure 4. China's installed capacity of solar power generation (unit: kilowatts)](image2)

With the strong support of national policies for solar power generation projects, solar power generation projects in China are in full swing and developing rapidly. In China, the northwest has good sunshine conditions, and solar power generation projects are mostly concentrated in Qinghai, Tibet, Xinjiang, Gansu, Ningxia, Inner Mongolia and other regions. In 2014, China's installed solar power capacity was 24.86 million kw, and in 2019, China's installed solar power capacity was 204.38 million kw.

3.5. During the 14th Five-Year Plan period, the state plans for solar power generation resources

Before the central government made overall planning for the 14th Five-Year New Energy Plan, many provinces had already made plans for the development of new energy during the 14th Five-Year Plan period. According to public information, incomplete statistics, at least 15 provinces have disclosed their new energy installed scale plans in various ways during the "14th Five-Year" period, and the cumulative new installed scale of 15 provinces has reached 219.99GW. In 2019, China installed 204 million kilowatts of solar power and is expected to put into production 30 million kilowatts in 2020. During the 14th Five-Year Plan period, it is planned to put into production 320 million kilowatts. By 2025, the installed solar power capacity is planned to reach 560 million kilowatts, with an annual increase of over 60 million kilowatts. In 2025, distributed photovoltaic power will account for 33.3%, and installed power in the western and northern regions will account for 55.9%.
Liu Jimao, founder of Sunlight, said: "The 14th Five-Year Plan of each province has been introduced successively. Photovoltaic, light + energy storage, water scenery, solar and other new energy sources have been included in the 14th Five-Year Plan of many provinces. Among them, Xizang, Shaanxi and Gansu Jiujian laid emphasis on wind-solar energy storage; Jilin, Liaoning, Hebei and Guangdong proposed to develop hydrogen energy; Jiangsu and Sichuan developed water-light complementary energy. "Photovoltaic and wind power are the main force of the action to reach the peak of carbon emissions. In the next few years, national policies will guarantee the bottom line and sustainable development. The development direction of new energy is to reduce cost and increase efficiency.

### Table 2. Planning and Distribution of Solar Power Generation Installation in the Fourteenth Five-Year Plan Period (Unit: 10,000 GW)

| Category/Area | The year in 2019 | The year in 2025 |
|---------------|------------------|------------------|
|               | capacity | Accounted for | capacity | Accounted for |
| Installed in total | 20418 | — | 56083 | — |
| Centralized photovoltaic | 14093 | 69.0% | 37147 | 66.2% |
| Heat | 44 | 0.2% | 936 | 1.7% |
| Distributed photovoltaic | 6281 | 30.8% | 18000 | 32.1% |
| Regional distribution | | | | |
| West, North central | 12112 | 59.2% | 31058 | 55.9% |
| | 8356 | 40.8% | 24525 | 44.1% |

### Table 3. Comparison of overall sports venues between the "Sixth Census" and the "Fifth Census"

| Indicators | Unit | Fifth site survey | Sixth site survey | The growth rate of |
|------------|------|-------------------|------------------|--------------------|
| The total number of sports venues in China | Ten thousand | 85.01 | 169.46 | 99.34% |
| The total area of sports venues in China | Million square meters | 22.50 | 39.82 | 76.98% |
| The total construction area of national sports venues | Million square meters | 0.75 | 2.59 | 245.33% |
| Total area of sports venues in China | Million square meters | 13.30 | 19.92 | 49.77% |
| Per capita sports field area | Square meters | 1.03 | 1.46 | 41.75% |
| The number of sports fields per 10,000 people | a | 6.58 | 12.45 | 89.21% |

According to the Sixth National Sports Grounds Survey (excluding Hong Kong, Macao and Taiwan regions), there were 1.6946 million sports venues in various systems, industries and forms of ownership, with a total land area of 3.982 billion square meters, a total construction area of 259 million square meters and a total field area of 1.992 billion square meters. With the total population of 1.361 billion people in the Chinese mainland at the end of 2013, the per capita sports field area is 1.46 square meters, and the number of sports fields is 12.45 for every 10,000 people. From 2004 to 2014, the number of sports venues nationwide increased by 844,500, with a growth rate of 99.34%. The per capita area of sports venues increased by 0.43 square meters, with a growth rate of 41.75%. The number of sports venues per 10,000 people increased by 5.87, with a growth rate of 89.12% [3].
3.7. Necessity of developing the application of solar power in stadiums
Hydroelectric power is the earliest traction power used in the construction of stadiums in China. However, stadiums are of large volume, high energy consumption and high carbon emissions, which are one of the important sources of energy conservation and emission reduction in cities. With the arrival of the era of low-carbon economy, the demand for low-carbon design of stadiums is more intense. Although solar energy has good energy saving and environmental protection benefits, the current generation mode still relies on traditional fossil fuels such as coal, oil and gas as the main energy source, and solar electricity usually accounts for only 0.7% of the total installed capacity. The construction and application of large-scale solar power stations in China is still some time away. But given the worsening climate, it is also imperative to use solar power to achieve effective energy saving and emission reduction targets.

3.8. Application of solar power generation in stadiums
The stadium building has a large roof and a south facing facade, which allows the installation of a large number of solar photovoltaic power generation systems without taking up additional ground space. A larger grid-connected solar photovoltaic power station has a power generation capacity of about 1MW. According to the survey, an area of about 10000m² is needed to install photovoltaic modules on the roof to achieve this power [72]. In addition to the basic role of shelter, the roof of the stadium is also an important part of the building image of the stadium itself. The integrated design of solar photovoltaic panels and gymnasium not only uses the energy generated by solar energy in the gymnasium, such as air conditioning and lighting, but also forms a beautiful building form controlled by architects, and conveys the concept of low-carbon life to the public. Table 4 lists some sports venues that have used solar power generation technology in recent years. It can be seen that more and more sports venues have joined the use of solar photovoltaic power generation technology as an important choice to reduce their energy consumption and carbon emissions.

| Field building name | Venue | Where the time | Accommodate the number of accommodative units | Cover area /M² | power installation | Annual output/kwh | Theoretic annual CO₂ emission reduction /t | note |
|---------------------|-------|----------------|---------------------------------------------|---------------|------------------|-----------------|------------------------------------------|------|
| George Tech Natatorium | Transylvania, USA | — | 2856 | 3000 | BAPV | 400000 | 384 | — |
| St. Jacob's Park Vandellof Stadium New York Football Field | Basel, Switzerland 2001 | 38512 | 1012 | 1200 | 200KW BAPV | 260000 | 249 | — |
| Bernier, Switzerland 2005 | 32000 | 7930 | 12000 | 1.35MW BAPV | 130000 | 1247 | Used for club practice and competition |
| Fort New York | 48548 | 758 | 1000 | 140kw BAPV | — | — | — |
| The Fritz Walter Stadium | Kaiserslautern, Germany 2006 | 49780 | 8500 | 10000 | 1.38MW BAPV | — | — | After the completion of the production capacity for four consecutive months beyond the design of 30% |
| AT&T ballpark | San Francisco, USA | — | — | 1000 | 120KW BAPV | — | — | Driven by a huge scoreboard |

Table 4. List of stadiums using solar power technology
| Stadium Name       | Location                | Year of Installation | Peak Power (W) | Type of Solar Power | Additional Information                                                                 |
|-------------------|-------------------------|----------------------|----------------|---------------------|-----------------------------------------------------------------------------------------|
| Pituacu Stadium   | Salvador, Brazil, 2009  | 34000                | 170K W         | BAPV                | The solar panels were subscribed to by the public during the season, these stores can be used by up to 40 families |
| Muggle Solar Arena| Baden-Wurttemberg, Germany | 24000              | 2200 W         | BAPV                | The solar panels were subscribed to by the public during the season, these stores can be used by up to 40 families |
| Bentgotty Stadium | Verona, Italy           | 40000                | 1MW            | BAPV                | It provides 70 percent of the electricity needed for sporting events and sends it back to the grid the rest of the time |
| Kaohsiung Stadium | Taiwan, China 2009      | 40000                | 1.4MW          | BAPV                | It provides 70 percent of the electricity needed for sporting events and sends it back to the grid the rest of the time |
| Weser Stadium     | Bremen, Germany 2011    | 42358                | 1.75MW         | BVPV+BIPV           | Public venues used during the day or back to the power grid, lit at night LED ring |
| Metlife Stadium   | New York, USA 2012      | 82000                | 350K W         | BAPV                | About 5% of the total electricity consumption It is used for lighting the parking lot of 20,000 square meters below |
| Lincoln Financial Stadium | Pennsylvania, USA 2011 | —                    | 2500 W         | BAPV                | About 5% of the total electricity consumption It is used for lighting the parking lot of 20,000 square meters below |
| Staples Center    | Los Angeles, USA 2008   | —                    | 1727 W         | BAPV                | About 5% of the total electricity consumption It is used for lighting the parking lot of 20,000 square meters below |
| National stadium  | Beijing, China 2008     | 18000                | 1000 W         | BVPV+BIPV           | About 5% of the total electricity consumption It is used for lighting the parking lot of 20,000 square meters below |
| HEBI City Stadium | HEBI, China 2011        | —                    | 2300 W         | BAPV                | Daily office, street lighting Meet its own and the surrounding middle school 2/3 of the year |
| Dagang Sports Centre | Zhejiang, China 2012   | 6167                 | 9781 W         | BAPV+BIPV           | Daily office, street lighting Meet its own and the surrounding middle school 2/3 of the year |

Note: The time in the table is mainly for the installation and use of solar integrated devices

4. Conclusion
With the global energy crisis and environmental problems becoming more and more severe, the energy conservation and emission reduction design of stadiums and gymnasiums, as large energy users, has attracted more and more attention. With its large size, high energy consumption and high carbon emissions, the stadium is one of the important sources of urban energy conservation and emission reduction. With the arrival of the "14th Five-Year Plan", the development and utilization of new energy has been put on the national planning, and the low-carbon design demand of the stadium is more intense. Solar power generation should be vigorously developed in the construction of stadiums. At present, the application of solar power generation in stadiums is relatively rare, and the research and development
process is still in the initial stage. Considering the cost and the nature of being affected by force majeure factors such as natural climate, it still has some technical difficulties if it is to be applied to a large number of sports buildings immediately. At present, it is more suitable for large stadiums. Even so, the technology still has room for further development and is not ready for large-scale commercialization. Despite the difficulties, it is still worth looking forward to considering its overall improvement and optimization effect on the domestic energy conservation and environmental protection field.

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