A Simulation Study on the Climate-Adaptive Design of Jiangmen Binjiang Sports Center

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Abstract: Jiangmen Binjiang Sports Center, is the representative of the sports buildings in the sub-tropical area of China. The research is exploring a low-carbon climate adaptive design strategy for sports buildings in the sub-tropics through a case study on whether the design strategy of the Jiangmen Binjiang Sports Center fits in with the sub-tropical climate by means of computer simulation of wind, light and heat of the building.

1. Introduction
The past decades of reform and opening-up have witnessed a rapid growth of China’s economy, along with an unprecedented development of sports industry. Myriad sports buildings have been springing up in the Pearl River Delta in subtropical southeast China where the favorable economic environment, the modern philosophy and the cutting-edge technology converge. With the influx of new technology and philosophy, sports buildings are developing with larger scale, integrated functions, improved space quality, and more comprehensive utilization after the games. For example, Jiangmen Binjiang Sports Center, completed in 2017 with distinctive design features, can be regarded as a microcosm of sports facilities in the Pearl River Delta region.

The climate-adaptive design of sports buildings is at the top of the agenda as China is now advocating energy saving and emission reduction. Taking Jiangmen Binjiang sports center as the research subject, this paper analyzes some climate-adaptive design measures of the building through computer simulation of wind, light and heat environment, promoting the development of subtropical sports buildings in an environmentally friendly way.
2. Background

Jiangmen Binjiang Sports Center was completed in 2017, and occupies 400,000 square meters with a total floor area of 210,000 square meters and a capacity of 25,000 spectators in the stadium. Funded and operated by DBOT of China Resources, Jiangmen Binjiang Sports Center was designed by South China University of Technology.

Jiangmen Binjiang Sports Center is located in the start-up area of Binjiang new district, Jiangmen city. The Tiansha river flows along the west side of the base, and the lakes and ponds on the east side are scattered and extended into the base. The sports center stands beside the water and enjoys a preferable natural environment. In the future, it will become a comprehensive sports and leisure park in Binjiang ecological and livable new district. The base is a rectangular plot with a length of about 1200 meters in the south and north and a width of about 450 meters in the east and west. The layout of the building consists of two areas: the south area with a stadium and a swimming pool, the north area with a gymnasium and an exposition area. Between the north and south areas is the water system landscape. At the north end of the site is Poly International Plaza with multiple functions of commerce, office and hotel.

3. Climatic features and computer simulation

Jiangmen is located in the west of the Pearl River Delta. It is hot and rainy with the prevailing southeast monsoon in summer, and warm in winter. With long sunshine duration throughout the year, the city falls into the subtropical maritime monsoon climate.

The key of the climate-adaptive design of subtropical buildings is preventing heat and reducing temperature, so ventilation, shading, and appropriate use of climate buffer space are the main measures to cope with the hot and humid climate.

To study the climate-adaptive design of buildings, we must start from the analysis on the wind, light and heat environment. Through computer simulation technology that visualizes the thermal environment of the building, the researcher is able to analyze the advantages and disadvantages of the climate-adaptive design measures the building has adopted. (The simulation data in the research are all calculated by Ecotect. The basic weather data are simulated by Guangzhou_CTYW.WEA of Weather Tool.)
4. Ventilation and thermal prevention in the linear layout

Jiangmen Binjiang Sports Center is made up of two areas, with a north-south linear layout. As shown in figure 3, the dominant wind blows towards the building from the southeast in summer, and the windward surface is shaped as a gentle curve so that wind will be directed by the surface to blow northward and westward along the façade. The water system landscape belt in the center of the site separates the buildings into the south and the north by about 300 meters, which forms a high-quality ventilation corridor, allowing more wind to pass through the water and the greenery, and then cool down before blowing to the buildings in the south and north. The exposition part and the gymnasium part of the north area are arranged in the shape of "L", and the secondary entrance square is located inside the corner (figure 4). Due to the shelter of the gymnasium in the southeast, the natural ventilation of the secondary entrance square is weakened. However, there is a second-level pedestrian corridor running through the south and north between the exposition area and the gymnasium, which not only serves for distribution, but also allows the wind from the south to blow through the corridor to the north. In addition, owing to the function of wind orientation of the circular and smooth facade of the stadium and the outer corridor under the eaves in the east of the exposition area, the “leeward” squares with a secondary entrance are able to get some natural wind flow. Therefore, in general, Jiangmen Binjiang sports center has satisfactory wind environment and less wind shadow area.

5. Compact layout for heat reduction

The center is vertically divided into the north area and the south area, and the functional layout of each area features the compact east-west horizontal layout that effectively reduces sun exposure in the building complex. For example, the exposition area on the west side of the complex in the north area provides shading for the secondary entrance square and the gymnasium on the east side. The west and east facades of the buildings in the exposition area are so wide that a large area of belt-shaped shadow falls on the west side of the secondary entrance square in the afternoon, which alleviates the western sun exposure in the square. The stadium is also located to the east of the exposition area, and the shadow of exposition building covers the western interface of the stadium, thus avoiding the direct western sun exposure to the stadium in the afternoon (figure 5).

At the same time, the exposition part of the stadium is a climate buffer space with good thermal insulation for the stadium. The west side of the exposition area heats up after being exposed to the western sunshine. The heat radiation needs to pass through the exposition space before penetrating
into the gymnasium. The deep exposition space and the strong thermal inertness prevents the infiltration of thermal radiation. In addition, the perforating platform between the exposition area and the gymnasium, as well as the outer corridor with grille on the east facade of the exposition, are wind passageways. These passageways have good air convection under the Venturi effect (as shown in FIG. 4)), which can take away some radiation heat timely from the environment. Therefore, the compact layout, supplemented by the measures such as climate buffer space and ventilation corridor, offers a comfortable external space for the complex in the north area.

6. Ventilation and shading of the second-level pedestrian platform

To meet the function of spectating, many sports buildings have a second-level walking platform for the spectators to gather and disperse. Good platform design can make the external environment of a building ventilated and cool, such as the pedestrian platform in the south area of Jiangmen Binjiang sports center. The south area has a compact architectural layout, with a hollow second-level pedestrian platform connecting the east stadium with the west swimming pool and the affiliated venues. It can be clearly seen from the ventilation simulation (figure 6 and figure 7) that the platform boasts a good ventilation environment. The gently curved facade of the buildings in the south area enables the wind to blow smoothly along the building interface. The summer wind blows into the platform from the space between the south side of the site, the natatorium and the affiliated venues, flowing northward along the ventilation corridors enclosed by the building interfaces on both sides, and blow out from the north side of the building complex to the central water system. In addition, the platform is equipped with a hollow patio, so that the air flow above and below the platform is connected, and the air volume increases. As a result, the pedestrian platform in the south area makes the convection ventilation run through the whole building complex to create a preferable natural ventilation environment. At the same time, as shown in figure 8, the stadium is on the west side of the building complex in the south area. The shadow area in the afternoon basically covers the footpath platform, so that the platform space is fully shaded in the hot summer afternoon. Moreover, the second-level platform is not only the gathering and distribution space of the audience, but also the awning of the ground floor. Besides, the hollow patio creates a more comfortable wind and light space for the ground floor.

Therefore, the design of the second-level pedestrian platform in the south area not only satisfies the basic function, but also serves for ventilation and shading, which is a good climate-adaptive design measure.

7. The stand descending from west to east that performs the function and applies climate-adaptive design

The comprehensive utilization of the stadium after the game is one of the key issues in the design. In recent years, with the rapid development of China's cultural and sports industry, undertaking large-scale commercial performances has become another important post-game utilization of stadiums. In order to offer better functional support for speculating, many new stadiums adopt asymmetric auditorium layout that features the more and higher seats on one side than the other side, in order to deal with a variety of use.
The stadium of Jiangmen Binjiang Sports Center adopts the layout of the asymmetric stand descending from west to east for the comprehensive post-game utilization. At the same time, because the east stand of the stadium faces west, the problem of westwen sun exposure is much more serious than that of the west stand against the west. The stand descending from west to east means more seats on the west side than on the seat side. Fewer seats in the east stand means fewer seats suffering from the western sun exposure (figure 10).

As far as wind environment is concerned, as shown in figure 6 and figure 14, on the left side of the stadium, the ventilation of the stand descending from west to east is apparently advantageous. The dominant wind in summer is the southeast wind, and the relatively low east stand in the upper wind area allows more wind to blow into the arena and the west stand. The higher awning on the west side would capture more southeast wind to blow towards the stands. Additionally, the stands on both north and south side of the stadium adopt the design of no balcony and no awning. These low stands create two large openings in the closed "bowl-shaped" stands, allowing natural wind to flow smoothly in the stadium. All of these measures contribute to an excellent ventilation environment in the stadium.

Therefore, the asymmetric stand that descends from west to east in the stadium of Jiangmen Binjiang Sports Center performs the basic functions, reduces the western sun exposure and improves ventilation. It is a good climate-adaptive design measure for subtropical sports buildings.

8. Natural ventilation and lighting indoors

Considering the requirements of static wind and even illumination for the high-standard competition, the indoor thermal environment of Jiangmen Binjiang Sports Center was designed by combining natural ventilation and daylighting with air conditioning and artificial lighting. Take the gymnasium in the north area as an example. As far as its wind environment is concerned, the bottom of the competition hall is surrounded by many auxiliary functional rooms that hinder the convection of natural wind. The entrances placed at the corner of the venue are provided with wide passageways leading to the outdoor space. These passageways will introduce a small amount of natural wind into the competition hall and form a breeze in a limited area (see the gymnasium section at the lower right corner of figure 4). When a high-standard game takes place, the doors and windows will be closed so that the venue will not be disturbed by the natural wind. In the stand area at the upper area of the competition hall, the natural wind environment is much better than that at the bottom of the hall due to
the reduction of enclosed space and more inlet air. In addition, the large high windows at the top of the venue form the chimney effect (figure 15 and 16). Natural wind enters the site from the entrance of the stand and spirals towards the roof with low wind pressure, which creates breeze in the stand area. In terms of the light environment (figure 11), the large high windows offer the even natural lighting. However, simulation of direct sunshine at 3-6 p.m. in the summer afternoons (figure 12) show that during this period with lower angle of the sun, some areas on the east side of the site are exposed to direct sunlight that may cause glare interference to the players on the pitch. Therefore, when the game is held during this period of time, curtains and other shading measures should be appropriately adopted to avoid direct glare in the site.

9. Data Analysis on the simulation of thermal environment

Ecotect simulation software can be used to simulate the thermal environment of buildings. The data about the temperature, heat conduction and spatial comfort can generally describe the climate adaptability of the simulated subjects. Although the accuracy of simulation data for complex subjects is limited at present, the simulation technology could shed some light on the climate adaptability research on the buildings.

For example, the charts are the thermal environment simulation results of the buildings in the north area of Jiangmen Binjiang Sports Center (hereinafter referred to as "the north area buildings"). Figures 17 and 18 are the simulation results of the temperature change of the indoor buildings without air conditioning intervention. Given the comfortable temperature of 23.5-27.6 °C, the temperature in the north area buildings falls into the comfort zone during more than a quarter of the time all the year round, and the indoor temperature on the hottest day is steady with lower fluctuation and not excessively high; figure 19 shows the uncomfortable temperature of each month, which is a value describing the degree of indoor comfortable temperature. Without air conditioning and heating equipment, when the indoor average temperature in a certain hour is 1°C higher than that of comfort zone, the uncomfortable temperature degrees of the hour
is overheating 1°C•h (red). For all north area buildings, the uncomfortable temperature degree from June to September is overheating 2.9 k°C•h accumulatively. Calculated by the standard that the buildings are running 14 hours from 7 a.m. to 9 p.m. every day from June to September, the temperature should go down to 1.73 °C by air conditioning, and the value is lower than the average among the buildings of the same kind, which shows its good general thermal environment.

In addition, figure 20 shows the percentage of the heat gains in different forms. The green section is the heat gains from natural ventilation, which reflects the overall ventilation of buildings. Generally, the value about the percentage of heat gains from natural ventilation for most buildings is 10% - 40%, while that for the north area buildings is as high as 49% for two reasons: on the one hand, there are a lot of ventilated corridor in the outer space; on the other hand, the complex curvilinear surface of the building and the large space of the exposition area affect the thermal simulation calculation of Ecotect, resulting in abnormally high value. The passive adaptation index in figure 21 is generated by calculating the uncomfortable temperature difference and the number of days within the set period of time to describe the overall climatic adaptability of the building. The value of the north area buildings is 0.63, which is better than the average level of similar buildings.

Therefore, according to the thermal environment simulation data, the thermal environment of north area buildings is better than the average level of similar buildings. These data, from the perspective of thermal environment, support the research findings on the climate-adaptive measure adopted by the north area buildings. But it is clear that simulation, after all, is not field measurement, and the simulation software has its own limitations, so the data could not be completely accurate, and only support the qualitative research and serve as a reference in the argument. The data would be of greater research value by taking into account the actual situation analysis, and some abnormal data need to be corrected or ruled out.

10. Conclusion

The researcher is committed to establishing a preliminary database on the climate-adaptive design methods applied by the sports buildings in the subtropical region of China through systematic simulation studies on wind, light and heat environment of about 20 major sports buildings in the Pearl River Delta. Jiangmen Binjiang Sports Center is a distinctive case among all, features a series of design techniques to respond to the wet and humid climate of the subtropics. In addition, computer technology is of great importance to facilitate architects by visualizing the design measures.

China's sports industry is undergoing rapid growth, and more sports buildings will be built in the future. As people are increasingly aware of the environmental problems, energy saving and emission reduction in sports buildings becomes an urgent issue. More research on the climate-adaptive design through simulation technology should be conducted in order to promote the sustainable development of the buildings and eventually achieve the goal of reducing emission in the Paris Agreement in the near future.

References
[1] Norbert Lechner. Heating, Cooling, Lighting: Design Methods for Architects. New Jersey: John Wiley & Sons Inc, 2001.
[2] G.Z. Brown, Mark DeKey. SUN, WIND & LIGHT: ARCHITECTURAL DESIGN STRATEGIES. New Jersey: John Wiley & Sons Inc, 2001.
[3] Ken Yeang. A Manual for Ecological Design. New Jersey: John Wiley & Sons Inc, 2006.
[4] Lin Qibiao. ya-re-dai-jian-zhu[Subtropical architecture]. Guangzhou: Guangdong Science & Technology Press LTD, 1997.
[5] Yang Liu.jian-zhu-qi-hou-xue[BIOCLIMATIC ARCHITECTURE]. Beijing: China Architecture & Building Press, 2010.
[6] Lin Xiande.lv-se-jian-zhu[Green building: ecology, energy saving, waste reduction, health]. Beijing: China Architecture & Building Press, 2011.
[7] Li xinmin. di tan shi jiao xia jiang men bin jiang ti yu zhong xin ti yu chang you yong guan she ji ce lue[Design strategies of natatorium & stadium in Jiangmen Sports Center under the low-carbon concept]. Guangzhou: south China university of technology,2015.