Research on the Construction of Green and Environmental Protection Modern Gymnasium

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Abstract. The lighting and air-conditioning of gymnasium buildings consume huge amounts of energy. How to make full use of natural lighting and natural ventilation is the key issue of energy conservation and environmental protection in gymnasium buildings. The paper focuses on the main energy-saving measures of sports buildings, from the building form factor and window-to-wall ratio, the thermal parameters of the envelope structure, the construction method of the envelope structure, the energy-saving design of the air conditioning system, and the energy-saving design of the building electrical system. Analysing and discussing the water-saving design of buildings and other aspects, it provides beneficial practical experience for the development of sports buildings in the direction of environmental protection and ecology.

Keywords: Green environmental protection, energy saving, modern gymnasium, lighting, air conditioning.

1. Introduction
In the face of the energy crisis, environmental pollution, climate change and other key issues of global concern, and my country is still in the key process of urbanization, facing the important challenge of improving people’s livelihood, vigorously developing "green buildings" in the field of construction has become the common ideas of society and engineering have been put into action. The gymnasium is one of the main public buildings in the city. It has the characteristics of large size, large indoor cooling load, dense personnel, and high air-conditioning quality requirements. The building area is generally more than 10,000m², the ceiling height is more than 10m, and the total cooling load index of the competition hall can reach 230 – 580W/m², it is a tall space building. Compared with a small space building, the airflow organization is more complicated and the energy consumption is higher. However, passive energy-saving technologies in foreign countries and northern my country mainly focus on meeting the heating demand in winter or reducing heating energy consumption. In hot summer and warm winter areas in my country, there is a large demand for cooling throughout the year, and there is no or little heating demand in winter [1]. On the basis of climate adaptability, passive energy-saving technologies adopt the most suitable energy-saving technologies for different climatic conditions to reduce the energy consumption of buildings such as lighting, heating and air conditioning. Therefore, when different passive energy-saving technologies are applied in hot summer and warm winter areas, the impact on building cooling load and building energy consumption is different from the situation when they are applied in buildings abroad or in northern my country.
This paper analyses and studies the significance of the cooling load and building energy consumption of a gymnasium when using five passive energy-saving technologies: external shading, natural ventilation, natural lighting, external wall energy saving, and external window energy saving. The research method adopted is the orthogonal experiment method, and the cooling load and building energy consumption of the gymnasium are simulated and calculated by the orthogonal analysis method throughout the year.

2. Passive building energy saving technology application

2.1. Natural ventilation

The main stadium of the gymnasium is in the form of falling from the north to the south, as shown in Figure 1. This can strengthen the contrast between the positive and negative wind pressure areas and enhance the natural ventilation of the room. The wind pressure distribution on the surface of the main stadium is obtained by CFD simulation. As shown in Figure 1, it can be seen that in this area, when the main wind is directed downwards, a pressure difference of about 3Pa can be formed between the south and east of the windward side of the main hall and the north of the leeward side, creating sufficient power for indoor natural ventilation.

![Figure 1. Wind pressure distribution on the outer surface of the main hall](image)

In terms of the selection of air inlets and outlets, according to the simulation results of building surface wind pressure, ventilation windows can be opened on the south facade and roof in the positive pressure zone to introduce wind into the room, as shown in Figure 2. The air outlet is under the cornice of the north facade, and the air outlet is selected on the high-end side of the inclined roof, so that the hot air rises along the inclined roof and is discharged outside.
Figure 2. Ventilation windows on the south facade of the gymnasium

The upper and lower outer windows of the south facade are the main air inlet channels. The wind speed at the window is close to 0.9 m/s. The seating area under the ventilation window can also obtain ideal natural ventilation. The average wind speed reaches 0.5 m/s, and the personnel can feel it. Air flow; and there is no obvious air inlet channel around the sunken competition venue, forming a "basin effect". The wind speed in this area is relatively low, and the average wind speed is less than 0.2 m/s. The personnel can hardly feel the air flow; in the main hall in the northern area, due to the excessive depth of the stadium and insufficient air flow power, the wind speed attenuation is more obvious. The average wind speed in the northern seating area is also less than 0.2 m/s, and the natural ventilation effect is not significant [2].

2.2. Energy-saving measures and system design of air-conditioning systems

2.2.1. Energy-saving measures. The first is to use the underground heat pump system and the surface water heat pump system to jointly provide cooling and heating. The use of natural energy has significant environmental benefits, low pollutant emissions, and its energy saving and emission reduction benefits are very obvious. The system does not require an outdoor unit or cooling tower, therefore, there is no outdoor environmental noise problem and will not affect the appearance of the building. The second is that the envelope structure of the air-conditioned room adopts better thermal insulation measures to reduce cold and heat losses. The third is to divide the air-conditioning system and form according to the use function of each room, in order to achieve flexibility in operation, and set up a heat recovery device, and each floor is equipped with a centralized exhaust system, which is discharged after energy recovery, which achieves a good energy saving purpose. The fourth is that the end of the air-conditioning system adopts variable water operation, and the circulating water pump adopts frequency conversion control to reduce the energy consumption of transportation. In order to make full use of the natural adjustment ability of outdoor air, the all-air system can adjust the minimum fresh air to the fresh air according to the change of indoor and outdoor temperature in the transition season to achieve the purpose of energy saving. The fresh air exhaust system is equipped with a heat recovery device [3]. The indoor carbon dioxide monitoring device controls the fresh air volume to reduce the heat and cold of the air conditioner. Fifth, there are automatic control systems for air conditioning and ventilation, and direct digital DDC control systems are used to maximize energy-saving operation. All cold and hot equipment and air-conditioning cold and hot water pipes and air ducts laid in non-air-conditioning parts or areas have adopted better heat preservation (cold) measures. The heat preservation (cold) materials are high-efficiency and energy-saving products to minimize cold Heat loss.

2.2.2. Air-conditioning energy-saving optimization control system. This paper adds an air-conditioning energy-saving optimization control system based on the original air-conditioning system, which realizes the optimized control of the air-conditioning equipment in the plate heat exchanger, and can classify and
adjust the air-conditioning terminal equipment according to different requirements such as stadium events and holidays to meet From the cold source to the end, energy-saving optimized operation and refined control requirements. The entire control system is divided into three layers: remote monitoring layer, field control layer, and equipment layer. The control system block diagram is shown as in Fig. 3.

**Figure 3.** Block diagram of air conditioning energy saving optimization control system

The role of the remote monitoring layer is to remotely monitor the main operating parameters of the air-conditioning system through the remote monitoring centre, remotely optimize settings, remote fault alarms, and remote operations. The main task of the on-site control layer is to monitor the operating status and operating parameters of the air-conditioning system in real time, establish the connection between the air-conditioning equipment, and control the coordination between the equipment, including the data acquisition server, the PLC control cabinet between the plate heat exchangers, and the terminal PLC. The control cabinet and the terminal fan coil intelligent node device designed based on the LonWorks power carrier technology [4]. The main task of the equipment layer is to collect the operating parameters of the air conditioning system, receive and execute control instructions from the field control layer, including temperature sensors, humidity sensors, flow sensors, differential pressure transmitters, cold water pump inverters, and plate heat exchangers. Side flow regulating valve, secondary side flow regulating valve of plate heat exchanger, air-conditioning unit electric regulating valve, fan coil cold water electric two-way valve, fan coil fan wind speed switch position, etc.

3. **Orthogonal experiment of energy saving and environmental protection factors**

3.1. **Factor analysis**

External shading level. The form of external shading is widely used horizontal shading. The performance of external shading is expressed by the protruding length of the horizontal shading. The protruding lengths of the 3 horizontal fingers of the external shading are 0.5, 1.0, and 1.5m respectively.

Natural ventilation level. In the case of natural ventilation, the indoor temperature that meets the thermal comfort of the human body can be increased. Research suggests that the temperature of a naturally ventilated indoor comfort zone can be 16 to 29°C. Therefore, the indoor thermal comfort temperature in the cooling season is taken as 28°C in this paper.
Natural lighting levels. Natural lighting means that during working hours in the gymnasium, when the daylight illuminance of the office area (Division 4 on each floor) is greater than or equal to 300lx, turn down or turn off the lighting fixtures, and the natural lighting meets the illuminance requirements; when the illuminance is less than 300lx, the insufficient part is caused by the lighting fixtures supplement. The natural lighting level is expressed by the natural lighting area ratio of the office area (the ratio of the area occupied by the lighting fixtures with adjustable illuminance in the area to the total area). The three levels of natural lighting refer to the natural lighting area ratio of 30%, 55%, 80%.

Energy-saving level of external walls. The external wall energy saving is measured by the heat transfer coefficient of the external wall. The three levels of external wall energy saving refer to the external wall heat transfer coefficient of 1.493, 0.974, and 0.755W/(m²·K).

3.2. Orthogonal experiment

3.2.1. Visually analyse the calculation results. The intuitive analysis results of the passive energy-saving technology on the total cooling load of the stadium and the annual building energy consumption per unit area are shown in Table 1. The significant sequence of the passive energy-saving technology's influence on the cooling load of the gymnasium is: external shading>natural lighting>natural ventilation>outer window energy saving>external wall energy saving [5]. Table 1 shows that the significant sequence of the impact of passive energy-saving technologies on the energy consumption of gymnasium buildings is as follows: natural lighting> external shading> energy saving of external windows> natural ventilation> energy saving of external walls.

| Table 1. Intuitive analysis and calculation results of the impact of passive energy-saving technologies on the annual building energy consumption per unit area |
|---------------------------------|----|----|----|----|----|
|                                 | A  | B  | C  | D  | E  |
| Level 1 mean                   | 66.97 | 66.44 | 68.84 | 65.86 | 66.2 | 66.18 |
| Level 2 mean                   | 65.96 | 66.06 | 66.16 | 66.17 | 66.44 | 66.21 |
| Level 3 mean                   | 65.47 | 65.89 | 63.39 | 66.37 | 65.76 | 66.01 |
| Very bad                       | 1.51 | 0.55 | 5.45 | 0.5 | 0.68 | 0.21 |

3.2.2. Analysis of variance calculation results. Use SPSS 22.0 software to carry out the variance analysis of the influence of passive energy-saving technology on the annual total cooling load of the gymnasium and the annual building energy consumption per unit area (significance level α = 0.05). The results are shown in Table 2.

| Table 2. Variance analysis of the influence of passive energy-saving technologies on the total annual cooling load |
|---------------------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|------------------|
| Type III sum of squares                                      | Degree of freedom               | Mean square error               | F                              |
| External shading (A)                                         | 6509962638                      | 2                              | 3254981319                     | 73.13                          |
| Natural ventilation (B)                                     | 3247285280                      | 2                              | 1623642640                     | 36.48                          |
| Natural lighting (C)                                        | 5653352115                      | 2                              | 2826676057                     | 63.51                          |
| Energy saving of exterior wall (D)                          | 1824601424                      | 2                              | 912300712                      | 20.49                          |
| Energy saving outside window (E)                            | 2326395884                      | 2                              | 1163197942                     | 26.13                          |
| error                                                        | 311541039                       | 7                              | 44505862.8                     |                                |
Mean Square Error Although the top two significant factors affecting the cooling load of the
gymnasium and building energy consumption are external shading and natural lighting, the order of
significance is different. The most significant factor affecting the cooling load is external shading,
followed by natural lighting. This is because the climate is hot in summer and warm in winter, the solar
irradiance is large, and the cooling load caused by the heat of the solar radiation from the outer window
accounts for a large proportion of the total cooling load [6]. The application of natural lighting
technology can reduce the power consumption of lighting fixtures, thereby reducing the cooling load
caused by lighting. However, relatively speaking, the lighting cooling load accounts for a small
proportion of the total cooling load. For stadiums in areas with hot summers and warm winters, the focus
of reducing the cooling load is to reduce the cooling load caused by solar radiation through the outer
windows, so the influence of the outer shading is the most significant. The most significant impact on
building energy consumption is natural lighting, and the second is external shading. This is because
building energy consumption includes three parts: lighting power consumption, equipment power
consumption, and cooling and air conditioning power consumption. Passive energy-saving technology
can reduce the power consumption of lighting and refrigeration and air conditioning, thereby reducing
building energy consumption.

4. Conclusion
In the design process of the stadium building, various forms of passive energy-saving technologies are
considered, for example, openings are set on the main windward and leeward sides of the building to
make full use of natural ventilation and reduce the opening time of air conditioning equipment; on the
facade of the building Reasonably open windows and scientifically design sun-shading components to
make full use of natural lighting, while blocking direct light to prevent glare; in the selection process of
enclosure structure materials, in addition to the heat transfer coefficient, the thermal inertia index of the
material should also be considered to reduce The internal surface temperature fluctuates, reducing the
adverse effects of roof heat and cold radiation on personnel thermal comfort.

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