Use of Energy-efficient Materials and Sustainable Design Strategy for Large Sports Architecture in Beijing

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ABSTRACT

The sports facility typically requires large open spaces and thus falls into the category of energy-intensive public architecture. The level of energy consumption directly reflects the operation cost of a large sports facility. The future role of architecture design will be critical to help improve energy efficiency by designing sustainably. Through the study of the use of energy-efficient materials in the design and construction phase, this article analyses the trend of using new energy-efficient materials in large sports architecture in Beijing, and discusses the key factors and techniques for selection of those materials. The impact of using energy-efficient materials on large sports architecture on its daily operation is also discussed. Lastly, it proposes a sustainable strategy for large sports architecture, from architectural design to the selection of energy-efficient materials.

INTRODUCTION

As civilizations have evolved, so does the world's need for energy. The question of how to balance economic growth with care for the environment largely revolves around energy. Countries, including China, face the challenge of meeting rising energy needs in ways that are cost-efficient, sustainable and environmentally compatible. Buildings are becoming the heaviest consumers of natural resources in China. The area of public buildings accounts for about a third of the total civil buildings, but they contribute to more than 50% of the total building energy consumption. High-performance green buildings do not represent just an environmentalist vision. They represent opportunities to reduce energy and operation costs.

As typical large public buildings, sports stadium and arena are energy intensive. They have the greatest energy-saving potential and are playing a key role to achieve China's energy conservation goals. After successfully hosting the 2008 Beijing Olympics, China has entered into the "post-Olympic era" as hosting large sports events and building sports complex are becoming "new normal". In the process of design and construction, owners are paying more and more attention to their daily operational needs. Energy efficiency is an important factor which influences the operational costs of large sports buildings.

China's Ministry of Construction has issued a regulation on civil building energy conservation, which prescribes that "Civil building energy conservation refers to the activities of reducing building energy consumption, reasonable and efficient use of energy in the process of the civil buildings' planning, designing, construction and use". As building energy conservation is a systems engineering, this paper mainly discusses the energy conservation and the sustainable development strategy for large sports buildings, from the perspectives of architectural design and energy efficient materials selection.

INTENT AND OBJECTIVES OF APPLIED RESEARCH

This applied research is based on the case study of the 2008 Beijing Olympic Games' competition and training venues. As a delegate of the State General Administration of Sports, author B has been participated in the construction process of the two projects that are analyzed in this paper, and is able to apply the project data in the study. Through the study of the use of energy-efficient materials in the design and construction phase, this article analyses the trend of using new energy-efficient materials in large sports architecture in China, and discusses the key factors and techniques for selection of those materials. The impact of using energy-efficient materials on large sports architecture on its daily operation is also discussed. Lastly, it proposes a sustainable strategy for large sports architecture, from architectural design to selection of energy-efficient materials.

PROCESSES

Beijing Sports University Training Center (Hereinafter referred as BSU Training Center)

Project overview. Beijing Sports University National Team Training Base was invested by the State General Administration of Sports in preparation for the 2008 Olympic Games. It was constructed as a comprehensive training base with the function of national team training, scientific research and education. As a training venue for the national teams, the BSU Training Center's gross floor area is about 29,700 m^2, with a total investment of about 206.6 million Yuan. It is 288 meter long, 72 meter wide and 24 meter high, and is one of the largest comprehensive training venues in China. The ground part of the whole building area is divided into three structural units: the west wing for track and field training center (axis plane size is 72m by 128m); intermediate for taekwondo hall and comprehensive auxiliary facilities (axis plane size 72m by 90m); the east wing for rhythmic gymnastics and trampoline comprehensive training venue (axis plane size 72m by 72m).

Table 1 BSU Training Center's use of energy-efficient materials

Building Part	Material Type	Construction Practice	Measured K Value*	Local Standards
Outer wall	Decorative insulation bearing integrated block	310mm thick insulation block, with 80mm thick polystyrene board insulation layer	$0.45W/m^2 \cdot K$	$0.6W/m^2 \cdot K$
Curtain wall	Broken bridge aluminum alloy glass curtain wall	Broken bridge aluminum alloy, low-e insulating glass, 12mm thick air space,6+12A+6	$2.3W/m^2 \cdot K$	$3.0W/m^2 \cdot K$
Roof	Multi-functional composite metal roofing	Metal roofing, fills in a 100mm thick glass cotton	$0.5W/m^2 \cdot K$	$0.55W/m^2 \cdot K$

***Overall Heat Transfer Coefficient of Building Envelope**

Energy-efficient building materials selection. The architectural design follows the "public building energy conservation design standard" (Beijing local standard DBJ01-621-621), which requires an energy saving level of 65%. It applies the approach of green, energy efficient and environmental friendly in the architectural design and material selection, reasonability designs the thermal performance of building envelope, and reduces building energy consumption. Its shape coefficient of building, overall heat transfer coefficient of building envelope and other indexes meet or exceed the standard limit, which lays a foundation to reduce the cost of daily operations for the venue. The main parts that use energy-efficient building materials include:

1. Energy-saving outer wall. The outer wall heat preservation, to comply with the standard of 65% energy saving, uses decorative insulation bearing integrated block. The size of the block is 310x190x90mm, with an 80-mm thick thermal insulation material for polystyrene insulation board inside. To prevent cracking, workers were required to strictly follow the construction procedures. The block wall's overall heat transfer coefficient of building envelope (K value) was designed as 0.45 W/ ($m^2 \cdot K$). After a review by the specialized institutions upon the completion of the construction, the actual heat transfer coefficient is confirmed to be less than 0.6 W/ ($m^2 \cdot K$), which meets the requirements of the standard of 65% energy saving.

2. Energy-saving windows and doors (curtain wall). The venue's glass curtain wall airtight performance is designed as class Ⅲ. The low-e insulating glass with a radiation rate of less than 0.25 was selected. The hollow glass curtain wall is equipped with a broken bridge aluminum alloy, double-layer, 6mm thick low-e glass and 12mm thick air space. All south to glass windows and glass curtain wall were installed with the set of infrared remote control electric sunshade inside. K value of the glass curtain wall is 2.3 W/ ($m^2 \cdot K$).

3. Energy-saving roofing. The roofing of the venue uses the compound metal insulation board, filled with 100mm thick centrifugal glass cotton. The metal roofing system consists of a magnesium aluminum manganese alloy roof board, insulation,

lining layer, purlin and a sound-absorbing, galvanized steel base plate. K value of the metal roofing is 0.5 W/ (m^2 • K).

Beijing Shooting Range Hall

Project overview. Beijing Shooting Range Hall is the 2008 Olympic Games' shooting competition venue. It consists of a 10m air rifle hall, a 25m pistol pavilion, a 50m target pavilion, training and game rooms, technology rooms and supporting services, with a comprehensive function of training and competition. It serves as the national shooting team's training venue and a major competition venue. The gross floor area of the venue is 45,645 m^2, with a seating capacity of 9,000 audiences. The main structure of the venue is frame-shear wall structure, using the large-span space steel pipe rack and truss roof system.

Figure 1 Photo-realistic of BSU Training Center
Source: http://www.bsu.edu.cn

Figure 2 Photo-realistic of Beijing Shooting Range Hall
Source: http://lvyou.baidu.com/beijingshejiguan

Energy-efficient building materials selection. The architectural design performs the "public building energy conservation design standard" (Beijing local standard DBJ01-621-621), which requires an energy saving level of 65%. The venue design emphasizes the building functions, convenience & economy of use, leveraging the ecological building technology which is mature, reliable, and efficient. Through the use of architectural structure, detailed and appropriate building technology and materials, it enhances the overall quality of the construction. With the goal of being a green building, the venue used precast concrete heat preservation sound insulation wall panels, ecotype double breathing curtain wall, multi-functional composite metal roofing and other energy-saving new technologies. By using these typical energy-saving materials, it can effectively reduce the heat transfer coefficient of the building, and improve the overall thermal insulation performance.

1. Energy-saving outer wall. As a large sports facility, the Beijing Shooting Range Hall pursuits for an architectural style of simple natural atmosphere, as its facade emphasizes on large scale frame and deep seam decorative texture. It uses the outer walls of precast concrete heat preservation sound insulation wall panels, which are good for exterior wall thermal insulation, sound insulation, heat insulation, components and exterior decoration. As regards the construction technology, the first structure pendant was set aside for building structure, pasting 30mm thick extruded polystyrene insulation board on retaining wall surface, and hanging precast concrete wall panels outside. Hanging panels with insulation layer formed about 40mm air between the layers. The air layer is advantageous to the wall heat preservation and sound insulation, which greatly reduces the influence of indoor shooting training and competition to the external environment. At the same time, use of precast concrete heat preservation sound insulation wall panels can save the operational cost without more maintenance investment. By using the energy-saving outer wall system, the exterior wall heat transfer coefficient of the venue is greatly reduced. K value of the venue is significantly lower than the standard requirement of 0.6 W/ (m^2 • K).

2. Energy-saving windows and doors (curtain wall). When the venue was designed, it proposed a creative design of Ecotype double breathing curtain wall, considering the special requirements of sound insulation, viewing and energy saving. The curtain wall system is an externally circulating double curtain wall, with auxiliary external sunshade measures and intelligent control system, combining architectural shading, ventilation, ventilation function into an organic system. It also improves the construction technology for physical comfort. The inner glass wall uses 6 + 12A + 6 toughened hollow low-e glasses, and the outer is with 12-mm toughened glasses. The glass size is 1400 mm x 2500 mm. Calculation shows the ecological breathing curtain wall heat transfer coefficient has decreased to 1.3-1.5 W/m^2.K, which is much better than the public building energy efficiency standards and greatly reduces building energy consumption.

3. Energy-saving roofing. The Beijing Shooting Range Hall chose bem aluminum roofing system. Its metal roofing uses 0.9-mm thick aluminum manganese magnesium alloy plate, featured with light weight, high hardness and flexibility, corrosion resistant and maintenance-free. Roof construction bottom-up is ranged by: plate, aluminum foil, insulation cotton, purlin bracket, purlin, roofing and roof panel. Fire prevention, heat preservation cotton was adopted to achieve preferable centrifugal glass cotton insulation performance, and the thickness reaches 150 mm. By adding a layer at the bottom of the glass cotton insulation moisture-proof aluminum plus fascia, the roofing heat preservation performance is greatly improved. K value of the metal roofing is decreased to about 0.38 W/m^2, K.

Table 2 Beijing Shooting Range Hall's using of energy-efficient materials

Building Part	Material Type	Construction Practice	Measured K Value*	Local Standards
Outer wall	Precast concrete heat preservation sound insulation wall panels	Building structure reserve structure is hanged, retaining wall surface paste 30 mm thick extruded polystyrene insulation board, dry hanging outside of precast concrete wall panels, hangs panels with insulation layer formed between about 40mm air between the layers	<0.6W/m^2 • K	0.6W/m^2 • K
Curtain wall	Ecotype double breathing curtain wall	Inner wall of glass use 6 + 12A + 6 toughened hollow low-e glass, the outer with 12mm toughened glass	1.3-1.5W/m^2 • K	3.0W/m^2 • K
Roof	Multi-functional composite metal roofing	Metal roofing uses double metal plate, two layer board adopted the good fireproof and heat insulation performance between centrifugal glass wool, thickness of 150mm	0.38W/m^2 • K	0.55W/m^2 • K

***Overall Heat Transfer Coefficient of Building Envelope**

Survey of energy consumption in daily operations for the two venues

As a comprehensive training venue project, the Beijing sports university training center was completed by the end of 2007 in preparation for the Olympic Games in 2008.The Beijing Shooting Range Hall, which was completed in 2007, hosted the test event to stage the games in August 2007 and the Olympic Games official competition in 2008. The two venues are subordinate to the State Sport General Administration. The owners are respectively the Beijing Sports University and the Archery Shooting Sports Management Center under the State General Administration of Sports. After the 2008 Olympic Games, the two owners are responsible for the daily operations of the facilities. In this paper, the daily operational energy consumption levels of the two venues in 2008-2010 were investigated and analyzed. The comparative datas are from a research on quota of operation energy consumption for venues and accessory facilities by the State General Administration of Sports. The energy consumption values are set in accordance with the unified running time, which is 8 hours per day, 6 days per week(according to the training character of sports teams),and 12 months per year.

1. Electric power energy consumption spending

BSU Training Center's power energy consumption in 2008-2010 is 2643,300 kWh, 2651,913 kWh, and 2613,600 kWh respectively. The average annual electricity consumption of the venue is about 2.64 million kWh. Beijing Shooting Range Hall's power energy consumption in 2008-2010 is 2181,470 kWh, 2226,619 kWh and 2224,712 kWh respectively. The average annual electricity consumption of the venue is about 2.21 million kWh.

2. Energy consumption analysis

Training venues' energy consumption level is higher than the competition venues, due to the higher proportion of large space, and less accessory occupancy. Beijing Shooting Range Hall's annual power consumption in construction square meters is 48.4 kWh/m^2•a. BSU Training Center's annual power consumption in construction square meters is 88.9 kWh/m^2•a. Beijing Shooting Range Hall's annual heat/gas energy consumption in construction square meters is 21.3 m^3 / m^2•a. BSU Training Center's annual heat/gas energy consumption in construction square meters is 105.4 m^3 / m^2•a.

3. Comparison with the similar venues of the State General Administration of Sports

To analyze the energy saving performance, we choose some similar venues for comparison, which are subordinate to the

State Sport General Administration. The sample venues were all newly built or renovated for the 2008 Beijing Olympics, with the gross floor area of more than 20,000 m^2, and the highest ceiling height of more than 16 meters. We take the whole architecture as the research object, including the arena, stands and accessory functional rooms. The electric power energy consumption of BSU Training Center and Beijing Shooting Range Hall, are in the middle range of the group of similar venues, and both are lower than the quota standard set by the State Sport General Administration.

Table 3 Energy consumption comparison with the similar venues of the State General Administration of Sports (Excluding the heating energy consumption)

Item	Project Name	Average Electric power energy consumption (kWh / m^2•a)	Gross floor area(m^2)
Training venue （ceiling height more than 16 meters）	BSU Training Center	88.9	29700
	Comprehensive Training Venue of National Olympic Sports Center	69.6	27000
Competition venue （ceiling height more than 16 meters）	Beijing Shooting Range Hall	48.4	45645
	Laoshan Cycling Velodrome	102.0	38000
	National Olympic Sports Center Gymnasium	40.1	32410

From another perspective, we compare the two venues with the Sports and Cultural Center in Shenzhen Overseas Chinese Town, which is among the first buildings that have been certified as the National Three-Star Green Building. The compared building was built in Oct, 2008, with a gross floor area of 5130 m^2, and building height of 15 meters. The annual operation energy consumption intensity of the building is 50.35 kWh/(m^2 • a). Although the building scale of BSU Training Center and Beijing Shooting Range Hall is much larger than this green building, their operation energy consumption intensity is close.

4．Comparison with Chinese large public buildings' current energy consumption

According to a research of Building Energy Research Center of Tsinghua University in 2009, the Chinese large public buildings' current energy consumption are 70-300kWh/(m^2 • a) (excluding the heating energy consumption). The researched large public buildings are central air conditioning and having a building area of more than 20,000 m^2.

The Building Energy Research Center of Tsinghua University also suggested a reference energy consumption index for new-built large public buildings in Beijing in 2010. The index for public office buildings is 72 kWh/(m^2 • a). The index for business office buildings is 105 kWh/(m^2 • a). The index for hotels is 141 kWh/(m^2 • a). The index for large shopping mall is 210 kWh/(m^2 • a). However, they didn't give a suggestion for large sports buildings.

Compared with the above existing data, the energy consumption level of Beijing Shooting Range Hall and BSU training center is significantly lower than that of most of the large public buildings.

OUTCOMES

New trend in the application of energy-efficient building materials

Energy-efficient building materials refer to the building materials with low energy consumption in daily operations and in the process of building, by changing the nature of the materials to achieve the goal of building energy efficiency. The significance of applying energy-efficient materials is that while meeting the architectural space or the thermal environment of thermal equipment, it can help save the energy to a great extent. China is paying an increasing attention to the building energy efficiency and the implementation of corresponding energy saving standards and norms, and the rapid development of building energy saving materials. From the case study of Beijing Shooting Range Hall and BSU Training Center, we can find that the evolvement of applying a single energy saving material to the development of multifunctional composite materials and an energy saving system is becoming a new trend in the application of energy-saving materials. For example, the BSU Training Center's decorative insulation bearing integrated block, Beijing Shooting Range Hall's precast concrete heat preservation sound insulation wall panels etc, are all applying the composite materials to form a comprehensive system of energy conservation.

Key parts and techniques for selection of energy-efficient materials

For large sports architecture, the thermal performance of building surrounding structure is very important to the building's energy efficiency performance. According to the spatial characteristics of the large-scale sports building, the key parts of energy conservation and material selection are outer walls, doors and windows (curtain wall) and roofs. Key techniques are the integrated system structure, processing hot bridge and cold bridge, through improving the structure of heat preservation and insulation system to achieve good energy saving performance.

The energy saving performance

Both Beijing Shooting Range Hall and BSU Training Center are large sports buildings. Beijing Shooting Range Hall has a total length of 420 meters, while Beijing Sports University training center has a total length of 288 meters. Both venues are more than 20-meter high. Through using energy-efficient architectural design and materials in the key parts, the two venues achieved good energy saving performance, significantly lower than the energy consumption level of most of the large public buildings in Beijing. The venues are the models of the green Olympic buildings.

INFERENCES AND CONCLUSION

Sustainable architecture is a future trend. The energy conservation potential for large sports buildings is tremendous, so they should be guided under the energy efficient and environmentally friendly sustainable development strategy. The key is to implement sustainable architectural design methods and to select energy-efficient materials in the process of construction.

Sustainable building design

We should start the research from the angle of ecological sustainability, and achieve the goal of sports building energy saving, water saving and material saving design strategy, through the use of appropriate technology. Considering the domestic situations, we should work out a strategy of reducing total life cycle cost from three aspects: the initial cost, maintenance cost and update cost control. Based on principles of intensive construction, we can explore sports building design strategy of low cost and low loss which addresses the current situation of China.

Energy conservation and material selection

The main energy conservation goal of large sports building is to consume as less energy and resources as possible, in the meanwhile minimizing the impact on environment and ecology, and providing the users with a healthy and comfortable building environment. Choosing energy-saving materials in the process of design and construction, and implementing building energy efficiency standards, is an important approach to realize the energy conservation goals and promote the sustainable development concept of the large sports building. Through the reasonable design and selection of energy-efficient materials, we can gain great energy efficient performance in the long run in exchange of a smaller building cost increase at present.

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