Research on Evaluation Index of Energy Efficiency Design of Multi-level Sports Complex Based on Synergistic Effect

Siwen Guo\textsuperscript{1,2}, Qiuju Mao\textsuperscript{1,3} and Jiamin Zou\textsuperscript{1}

\textsuperscript{1} College of Architecture and Urban Planning, Tongji University, 1239 Siping Road, Yangpu District, Shanghai, China
\textsuperscript{2} Shenyang Jianzhu University, No.9, Hunnan East Road, Hunnan New District, Shenyang, Liaoning, China
\textsuperscript{3} Guizhou Architectural Design Research Institute Co. 28 Lincheng West Road, Guanshanhu District, Guiyang, Guizhou, China

Email: g.siwen@163.com

Abstract. Transforming the single-storey large space of traditional sports buildings into vertical extension space of multi-level venues, the multi-level sports complex achieves efficient use of resources by introducing a combination of recreation and social functions. Analyzing the key design points of the cascade-type gymnasium based on relevant criteria and standards of evaluating sports buildings, this paper establishes a multi-layer evaluation system to achieve synergistic energy efficiency design. It also provides a reference for expanding the efficient design of sports complexes.

1. Introduction
By 2013, the total number of sports venues per ten thousand people in China has nearly doubled vs 2003. In 2015, the number of sports venues in China was approximately 1.88 million, and the national stadium area reached 2.53 billion square meters. Large stadiums and gymnasiums, as essential building types, possess three characteristics: large initial investment, high operating costs and large energy consumption. The multi-level sports complex can greatly save enormous space and alleviate the pressure of high-density environment in city.

2. Multi-level sports complex
Superimposing multiple sports (site) spaces and other related functional spaces in the vertical direction, the multi-level sports complex takes advantage of large-span construction technology to transform the single large space of traditional sports buildings into multi-layer composites. For example, Zhonghe Sports Center, located in New Taipei City, provides public facilities for a range of sports activities including badminton, basketball, rock climbing and hockey. "Lacking spatial and visual qualities is often the aftermath or syndromes of this building type, particularly in the metropolitan cities of Taiwan," said the architect. (figure 1)
In the first half of the 20th century, developed countries such as European countries, America, and Japan began to study large-span buildings with overlapped multi-layer space. From the perspectives of urban development, economic planning, and sports space, they explored multi-storey large spaces and began to design small community multi-storey gymnasiums with commercial functions. Furthermore, there are more than 10 thesis studying in training halls, college gymnasiums, and hybrid structures of multi-level large-span building. A comparatively new research, From single to compound: research on the design of multilevel gymnasium based on national fitness, by Professor LU in 2018 from HIT China, analyzes the key design points of the cascade-type gymnasium based on the in-depth study of the function and technology of the laminated spaces[1]. Skyworld Arena, a 3.80ha sports complex, just completed in Malaysia, is a good reference. There are also many evaluation criteria of sports building.(Table 1)

| Standard                                                                 | Standard number       | Country |
|------------------------------------------------------------------------|-----------------------|---------|
| Design Code for Sports Building                                        | JGJ 31-2003           | China   |
| Specification for acoustical design and measurement of gymnasium and stadium | JGI/T 131-2012        | China   |
| Standard for lighting design and test of sports venues                 | JGJ 153-2016          | China   |
| Technical specification for intelligent system engineering of sports building | JGI/T 179-2009        | China   |
| Code for electrical design of sports buildings                          | JGJ 354-2014          | China   |
| Standard Specification for Helmets Used for Recreational Snow Sports   | ASTM F2040-2018       | USA     |
| Developing Sustainable Sports Facilities. A Toolkit for the Development of a Sustainable Community Sports Hub | OHSIS ZBH 368-2008    | USA     |
| Sports lighting-Part: Daylighting                                      | DIN 67526-3-2018      | Germany |
| Sports halls. Halls and rooms for sports and multi-purpose use. Part 1: Planning principles | DIN 18032-1-2014     | Germany |
| Sports halls-Martial arts halls-Design, layout and use                  | NF P90-209-2016       | France  |

The existing research usually limits its discussion to the concepts around feasibility, such as space combination and technical difficulties, while systematic research on the energy efficiency design of the cascading sports complex from the view of synergistic effect is limited.
3. Construction of energy efficiency evaluation system for multi-level sports complex

3.1 Energy efficiency design based on synergistic effect
Synergetics is to study various systems, composed of a large number of subsystems under certain conditions, through the synergy between subsystems, in a macro ordered state, form a self-organizing structure mechanism with certain functions. The system evolution mechanism is called order parameter. For this research, the functional structure construction principle, the overall goal, the combined effect, and the functional compatibility play the role of order parameters, thus promoting the optimization of the system.

Sports complexes should apply appropriate ecological technologies under environmentally sustainable development design concepts. Since the multi-level sports complex also consumes a lot of energy, it is helpful to simplify the energy efficiency index and thus test the “greenness” under different schemes by considering the physical performance of different sub-venues and the energy efficiency of the structural system.[2]

3.2 Establish the evaluation model
The energy efficiency design evaluation index model of the multi-level sports complex is divided into the target layer, the criterion layer and the index layer. The target layer refers to the evaluation of the multi-level sports complex in terms of synergetics energy efficiency design. The criterion layer classifies each element according to relevant sports building codes and standards, and has guidance. The indexes explain the index layer into detailed design elements [3][4][5].

3.3 Clarify the indexes

3.3.1. Physical performance. In a multi-level venue, the thermal comfort requirements of different types are different and affect each other. Factors such as wind, light and thermal environment of different sub venues need to be considered and adapted separately in order to satisfy the comfort standards of each venue with high efficiency. The adjacent venues should avoid the heating loss through the partition or floor, and the public space connection between the venues can serve as an effective physical environment buffer or barrier. At the same time, it is necessary to control the equipments of each site separately, and fully consider the maximum load of the environment and reasonably predicting the usage mode.[6]

3.3.2 Functional layout. The multi-level sports complex is more diversified in terms of functional layout than traditional sports buildings. The scale of the building, the number of building layers, the type and size of sports venues, and the height requirements should be considered when forming a reasonable layout. Analyzing the internal and external constraints of the functional structure enables the designer to understand the ways in which different parts of the building should be combined, and their respective suitable scale. This includes the layout of different levels and the number of indoor venues. In addition to providing sports-related functions, sports complexes often include commercial facilities such as sports training, sports lottery sales, monopoly of sports goods sale, and sports-themed catering. They mutually reach a rational combination to form a complementary and efficient use of the space[7].

3.3.3 Structure system. The stacked large-span structure system shares common characteristics with multi-level and long-span structures. Its stress performance under stress is similar to these two structures but more complicated. The types of structure should be selected according to different functions and spaces. Emphasis ought to be placed on the performances, such as the seismic performance and the ability to resist continuous collapse in the event of accidental loads, as well as special studies on the comfort analysis of buildings. The cascading structure system is generally a superposition of large space structure systems[8]. It is necessary to conduct a research from the perspective of economic cost and functional fit to form a structure system database and provide technical support for the application of the sports complex[9]. (Table 2)
Table 2. Evaluation index table of energy efficiency design of multi-level sports complex.

| Target layer | Criterion layer | Index layer | Index connotation |
|--------------|-----------------|-------------|-------------------|
| Energy efficiency design of multi-level sports complex based on synergistic effect | Physical performance (U1) | Multi-venue lighting environment (V1-1) | Daylight, lighting |
| | | Multi-venue wind environment (V1-2) | Ventilation, mechanical air supply, wind control |
| | | Multi-venue thermal environment (V1-3) | Thermal comfort, humidity, temperature |
| | | Public space transition (V1-4) | Heat transfer buffer, sound insulation |
| | | Surrounding ecological environment (V1-5) | Site microclimate |
| Functional layout (U2) | Construction scale (V2-1) | Regional population, frequency of use, openness |
| | | Venue type and size (V2-2) | Intensive design |
| | | Sports layout (V2-3) | Venue layout |
| | | Other layout (V2-4) | Multifunctional operation of ancillary space |
| Structure system (U3) | Rational and advanced structure (V3-1) | Seismic performance, resist continuous collapse |
| | | Economical material (V3-2) | Recycled materials |

3.4 Establish the weight of indexes

The indexes of designing multi-level sports complex are sophisticated and cover a wide range of parameters. The energy efficiency synergetic design of the complex is also a system involving multi-objective decision making problems. The indexes of the complex design a set of qualitative preparation plans, which assign and weight the index of the plan layer to converts the original divergent subjective qualitative judgment into a quantitative judgment matrix. This establishes a "qualitative-quantitative-qualitative" connection between the final design target and the design elements. By using the Delph method to compare the indexes, starting from the criterion layer of the hierarchical model, this research compares the different influencing factors of the hierarchy with the importance of the basic criteria in the previous level. The scale method is used to numerically identify the comparison results, quantifies the importance, in order to get the relative importance between each two indexes, then construct the judgment matrix. According to the formed weight index system, the synergy effect of energy efficiency design for the same target can be achieved [9].

4. Conclusions

The multi-level sports complex is growing larger and more complex, shares many similar attributes with sports buildings and urban complexes. Based on the design method of sports buildings, this research
obtains the design index and weight database by using the analytic hierarchy process to connect the relationship between the design strategy layer and the criterion layer. It enables people to evolve from competitive functions to fitness functions, and even to social functions, thereby accelerating the construction of a shared commercial sports platform.

5. References

[1] Shiliang Lu. From single to compound: research on the design of multilevel gymnasium based on national fitness, Urbanism and Architecture, Volume 13, 2017, pp112-115

[2] Jonathan Mallie, Expansive Workflows: Downstream Coordination in the Design of Sporting Facilities, Architectural Design, Volume 87, 2017, pp 68-73

[3] M.Turrin, E.van den Ham, A.Kilian, S.Sariyildiz, Integrated design of a large span roof: a parametric investigation on structural morphology, thermal comfort and daylight, Proceeding of ICCBE 2010, International Conference, Nottingham UK, 2010

[4] Ministry of Construction, PRC. Industry Criteria JGJ/T 131-2012: Specification for acoustical design and measurement of gymnasium and stadium (2012)

[5] Ministry of Construction, PRC. Industry Criteria JGJ 153-2016: Standard for lighting design and test of sports venues (2016)

[6] Ministry of Construction, PRC. Industry Criteria JGJ/T 179-2009: Technical specification for intelligent system engineering of sports building (2009)

[7] Ministry of Construction, PRC. Industry Criteria JGJ 354-2014: Code for electrical design of sports buildings (2014)

[8] Heiselberg P, Brohus H, Hesselholt A, et al. Application of sensitivity analysis in design of sustainable buildings. Renewable Energy, 2009, 34: 2030-2036.

[9] Green Olympic Building Research Group, Assessment System for Green Building of Beijing Olympic, China Architecture & Building Press, 2003:73-76