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Earth and Environmental Science



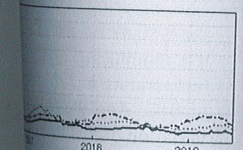
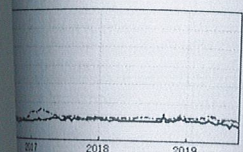
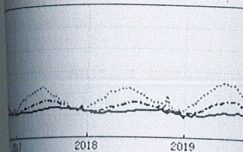
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The Strategy of Passive Ecological Building Design Based on Guangxi's Climate Characteristics —A Case Study on the Garden Art Gallery of the 12th China (Nanning) International Garden Expo

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Abstract. This project is based on the climate characteristics of Guangxi, combined with regional traditional construction methods and vernacular construction materials, and mainly in the light of the passive green building technology system guided by the principle of less manpower and more natures features, which saves early investment and the cost of operation and maintenance, further verifies the effectiveness of the strategy after completion, providing a reference for the development and application of related passive building technology.

1. Introduction

Guangxi is located in the central and southern subtropics of China. The southern part of the Xijiang River Basin where the project bases is adjacent to tropical ocean, featuring a subtropical monsoon climate. Therefore, the temperature is relatively high throughout the year, providing relatively abundant sources of heat and precipitation with an annual average temperature of around 20 °C. From the perspective of topography and geomorphology, its northwest side is close to the edge of the Yunnan-Guizhou Plateau, so the terrain is high in the northwest and low in the southeast. There are many mountains but few plains within the territory, with widespread karst landscapes. Except for a small amount of evaporation, the abundant precipitation mainly flows into the rivers through surface runoff and underground rivers. The large number of rivers in this area has brought a great inflow.

The 12th China International Garden Expo (hereinafter referred to as Garden Expo) is located in Nanning City in the Xijiang River Basin of Guangxi, sitting in the Dingsi Mountain [1] which is 12km southeast of downtown Nanning. With the unique natural environment, rich and colorful national culture and regional advantages of being close to ASEAN, it has made efforts from three aspects [2], namely ecology, culture, and sharing, in line with the planning concept of no mountain flatted, no lake filled, and no tree cut. The Garden Art Museum (renamed as Livable City Hall during the exhibition, and hereinafter referred to as the Art Hall) is the main venue of this year's Garden Expo. It is located in the east entrance area of the Garden Expo Park, south of the visitor center, and has a construction area of 25,600 square meters.

Guangxi's climate is hot and rainy. The complex, alongside with its heat insulation and ventilation performance, determines the comfort of the indoor space. At the same time, the park covers a large area and the venues are far away from each other. The design also features the shade of the outdoor public space, which determines the comfort of the outdoor space.

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The Strategy of Passive Ecological Building Design Based on Guangxi's Climate Characteristics —A Case Study on the Garden Art Gallery of the 12th China (Nanning) International Garden Expo

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The Strategy of Passive Ecological Building Design Based on Guangxi's Climate Characteristics

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1. Introduction

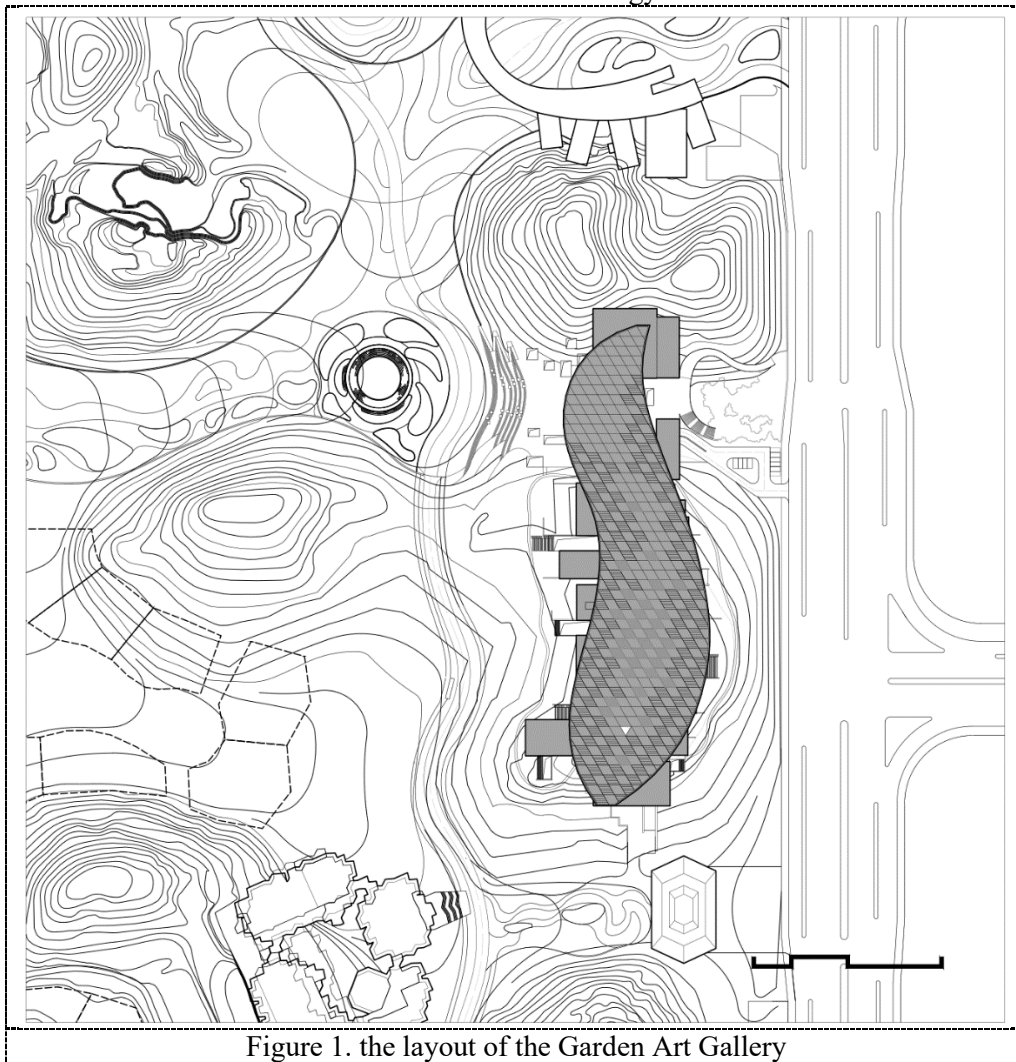
Guangxi is located in the central and southern subtropics of China. The southern part of the Xijiang River Basin where the project bases is adjacent to tropical ocean, featuring a subtropical monsoon climate. Therefore, the temperature is relatively high throughout the year, providing relatively abundant sources of heat and precipitation with an annual average temperature of around 20 °C. From the perspective of topography and geomorphology, its northwest side is close to the edge of the Yunnan-Guizhou Plateau, so the terrain is high in the northwest and low in the southeast. There are many mountains but few plains within the territory, with widespread karst landscapes. Except for a small amount of evaporation, the abundant precipitation mainly flows into the rivers through surface runoff and underground rivers. The large number of rivers in this area has brought a great inflow.

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Based on Guangxi's unique climate characteristics and the requirements on indoor and outdoor environment (shown in Figure 1), the team proposes passive design strategies such as settlement layout, connected profile, the use of soil and local materials from the circumstance of wind and thermal environment. During the construction process and through on-site measurements, in the context of controlling the investment and fully adapting to the climatic characteristics and functional requirements, the team analyzes key indicators of building energy consumption, including building energy consumption, recyclable materials, soil insulation, traditional material walls, settlement ventilation corridors, chimney effects, large-space atriums, etc. In that way, comprehensive tracking and post-evaluation of passive ecological architectural design during the implementation process are achieved, and the results further confirms the effectiveness of the strategy.



2. Passive ecological strategy I -Settlement Layout

Guangxi's complex and changeable topography and climate environment have spawned a representative local settlement culture, which is a valuable human settlement environment heritage. It strengthens the ventilation of the interior and surrounding environment of the settlement building through the layout of the building group, and becomes an important source of inspiration to the passive wind environment design of the art museum. [3]

Different from the precedented mode where the large space includes the smaller one, which is commonly seen in building space organization of large or medium-sized exhibition, the design of the art museum combines the superior natural climate conditions in Nanning, Guangxi to decentralize the

large exhibition space and organize it in a settlement manner, which is conducive to exhibitions with different themes, and more spatial experience. Different spatial images such as street, alley, square, courtyard, slope, ditch, and connected bridge are formed in the settlement to create a spatial atmosphere with traditional local characteristics and optimize the outdoor space through the layout.

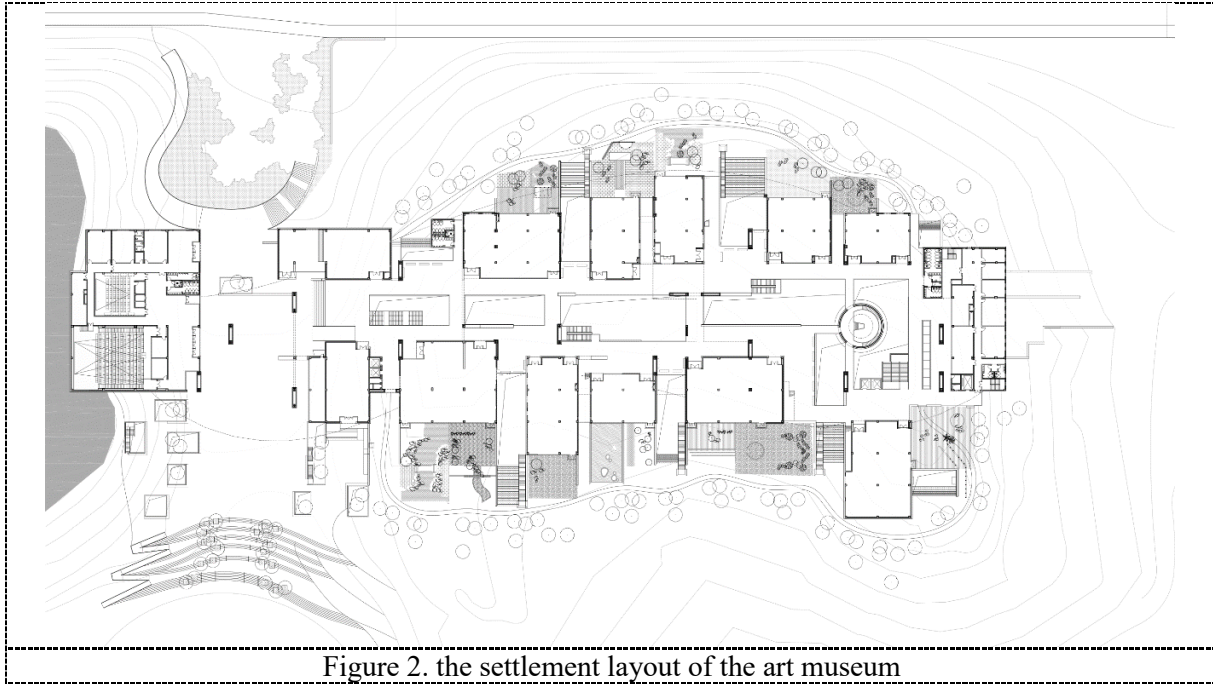


Figure 2. the settlement layout of the art museum

The art museum connects its exhibition halls which are the only places where air-conditioning is used through semi-outdoor public space. The mountain mass cut in the middle forms north-south sunken pathways which create a regional microclimate and ventilation corridors (Figure 3), together with the settlement building blocks, sunken courtyards, inner street canals, landscape cylinders, and streamlined canopies, forming a local temperature difference and air pressure difference, and realizing efficient natural ventilation and airflow guidance. The settlement-style small exhibition halls plus the semi-outdoor shared space which effectively organizes the microclimate is a way to organize exhibition space which follows the local climate, showing the wisdom contained in the passive ecological design which is tradition and simple.

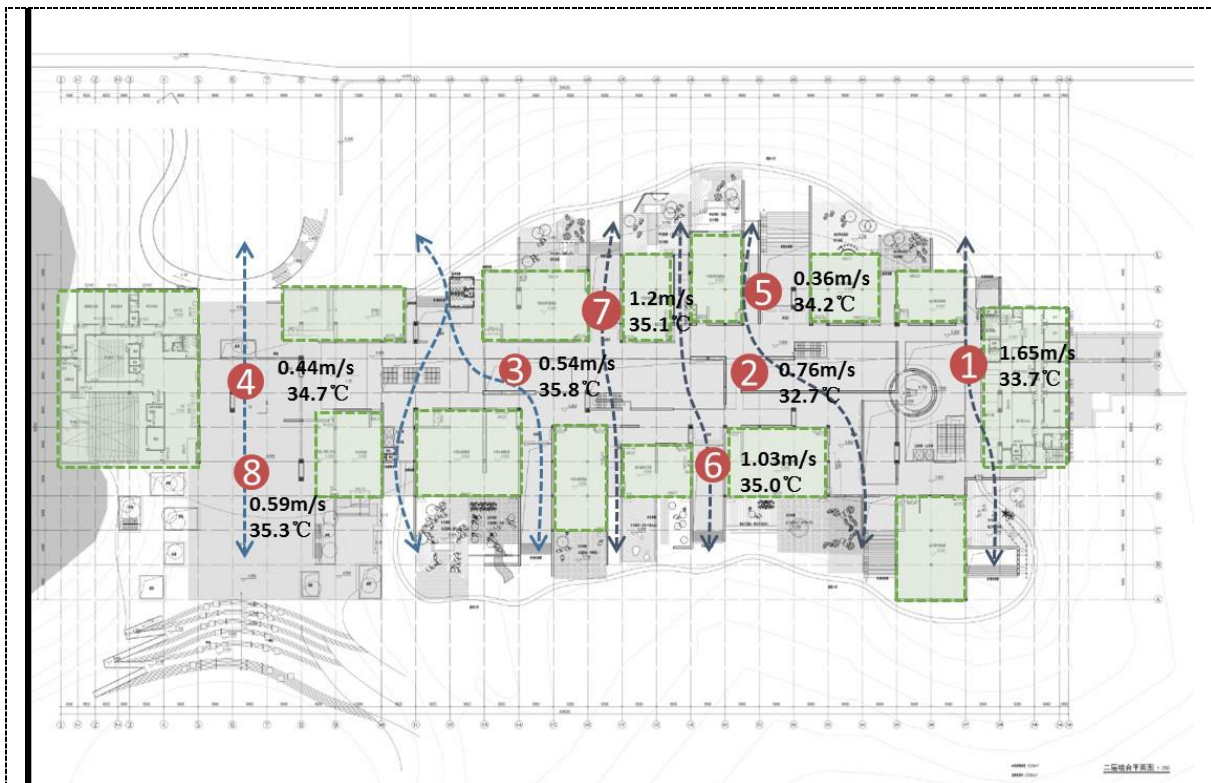


Figure 3. the effects of ventilation corridors(test time-1:15PM) [4]

In order to verify the influence of the ventilation corridors on the temperature distribution in the project, a typical ventilation corridor is selected and the temperature distribution in the surrounding space is tested with a thermal imager. As shown in Figure 4, the temperature in the wind corridor is 22.3°C, and 23.5°C near the wind corridor, which means the temperature in the wind corridor is about 1.2°C lower than the surrounding temperature, and about 10.1°C lower than the top. The design of the wind corridor significantly reduces the surrounding temperature and improves the human comfort.

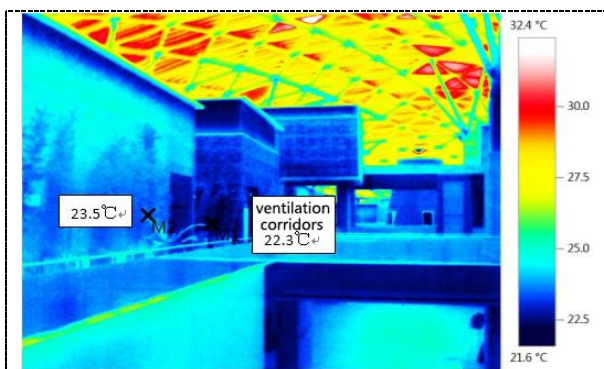


Figure 4. the temperature distribution of ventilation corridors through thermal imaging

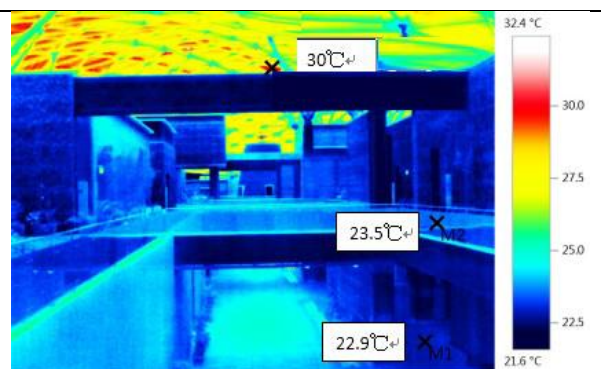


Figure 5. Hourly average temperature in the courtyard and outdoor of the Garden Art Museum from May to June

Figure 5 shows the hourly average temperature comparison between the first floor-courtyard of the Garden Art Museum, and the outdoor from May to June. In the case of high outdoor temperature, thanks for the good ventilation and shading design of the indoor courtyard, the internal temperature is

significantly lower than the outdoor temperature, and the maximum temperature difference is about 4°C, which provides a good thermal environment for tourists.

3. Passive ecological strategy II -Connected Profile

Traditional dwellings optimize the living environment under the eaves through rolling roofs, which inspires the introduction of a mountain-shaped steel structure called sky curtain (Figure 6) to cover the public rest space between the exhibition halls, avoiding sunlight and rainfall as a whole. In the outdoor hall without air conditioning (Figure 7), the energy consumption of the large space is reduced to a minimum. Three-dimensional ventilation corridors are created in the cross-section of traditional residential buildings to form a local temperature difference and air pressure difference, and realize efficient natural ventilation and airflow guidance to optimize the microclimate together (Figure 8).

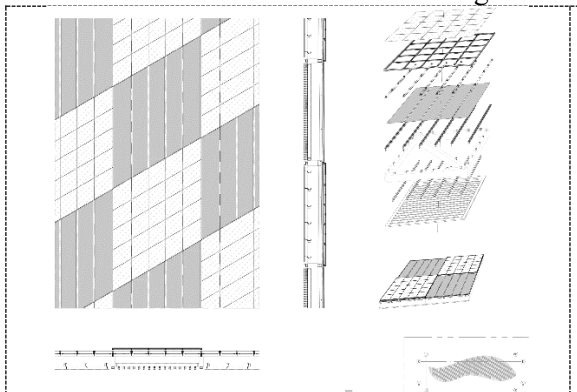


Figure 6. Structural nodes of sky curtain, the steel structure



Figure 7. the real view of the outdoor hall of the art museum

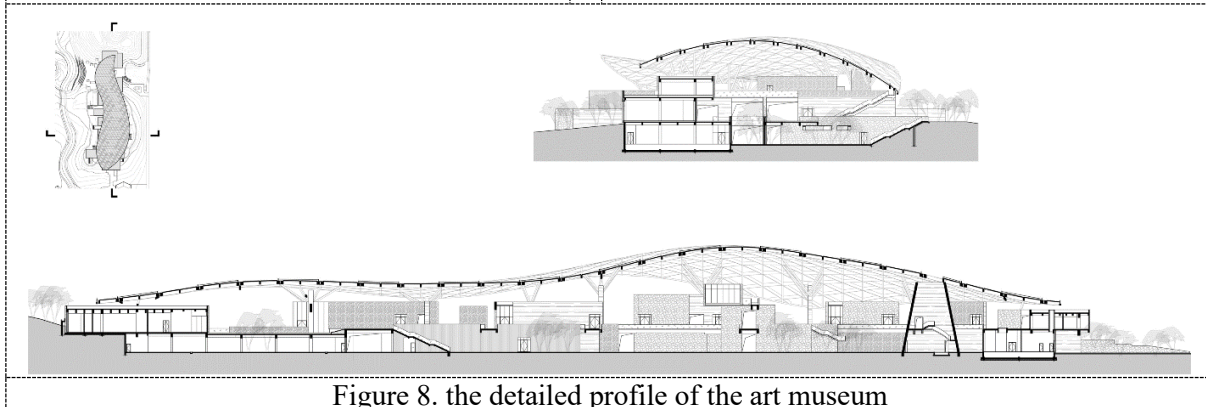


Figure 8. the detailed profile of the art museum

After testing the wind speed and temperature of the vertical distribution points inside the building, as shown in Figure 9, the wind speed on the first floor is between 0.27m/s and 2.5m/s, and the air flows from the exhibition halls on the first floor to the wind gallery on the second floor through the skylights above, and the wind mainly flows upward to the south. Secondly, the chimney effect inside the building is obvious, and the wind speed gradually reduces from bottom to top, which effectively improves the indoor comfort and air quality in the soil-covered area of the first floor, and at the same time makes the ventilation effect in the adjacent exhibition halls obvious, reaching 0.3m/s.

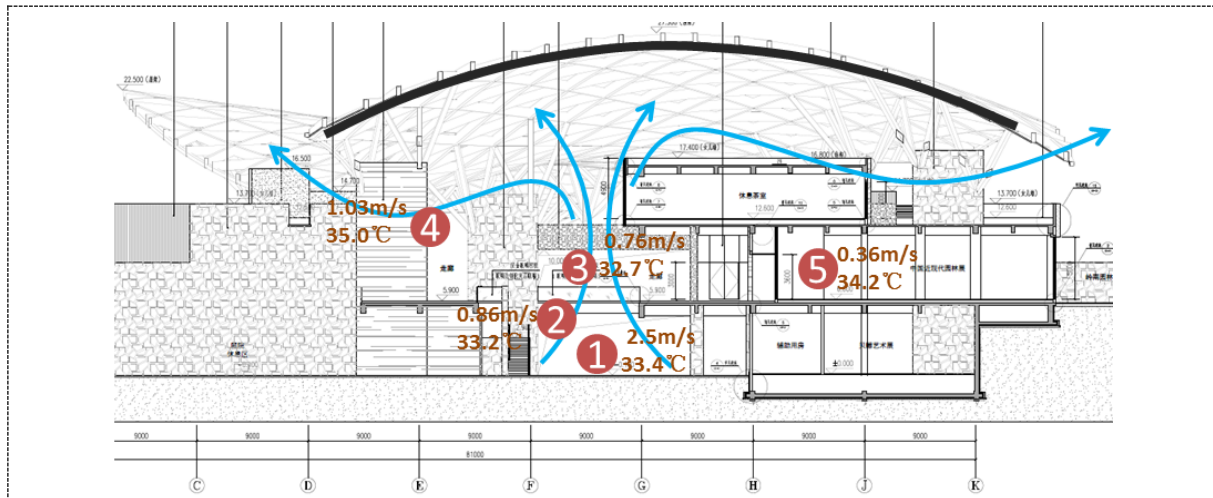


Figure 9. Schematic diagram of measuring points for chimney effect(test time-1:15PM) [4]

The Drum Tower, which works as the gathering venue, is the activity center of the local villages in Guangxi. In response, the circular landscape tube in the building forms the climax and condensing of the public space sequence. The exterior of the 18-meter-high landscape tube is a plain wall plastered with ecological mud, and the interior is a tall vertical green wall decorated with shade-loving plants which usually grow in local rock caves, directly leading to the top. This indoor space is also supplemented by a drip irrigation system, and a pool at the bottom connected to the water system of the inner streets. Active air-conditioning equipment is used to optimize the internal environment of the landscape tube through the passive pull-out effect (Figure 11).

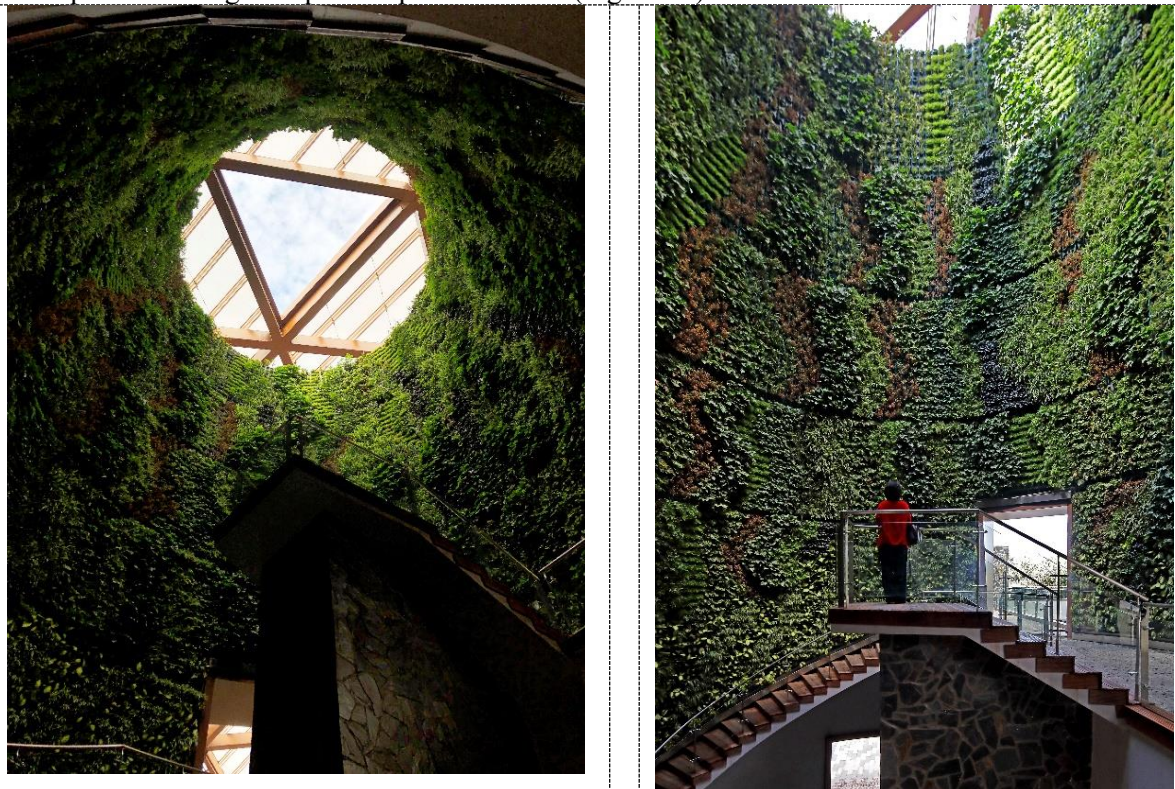


Figure 10. the real view of the Garden Art Gallery

4. Passive ecological strategy III-Soil Covering

On the basis of summing up the previous experience of garden art exhibitions, the design utilizes the original topography to reduce the building's pressure on the natural environment.

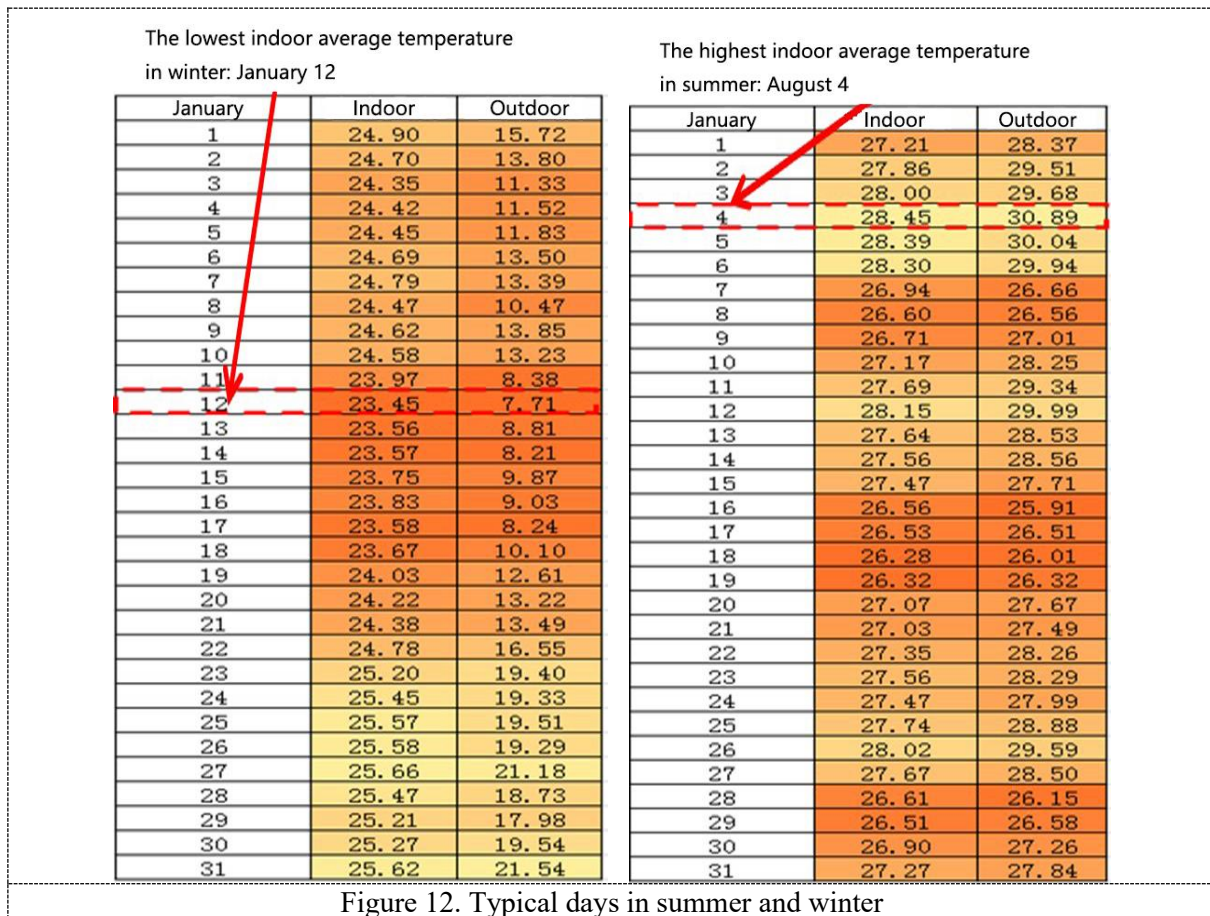
To continue the planning concept of integrated buildings conforming to nature, the south side of the mountain is slotted to embed the exhibition hall on the first floor in the mountain, forming an earth-sheltered building. Meanwhile, the hollow between the two mountains is developed as a semi-outdoor parking garage, and the second floor of the exhibition hall is divided and then connected through the inner streets, further hiding the volume of buildings.

The architectural layout breaks how the indoor space is displayed, uses the hillsides on the east and west as exhibition gardens, together with earth-covered buildings, to form an exhibition means where there is one museum pairing with one garden, which integrates exhibition, sightseeing, and travel (Figure 11).

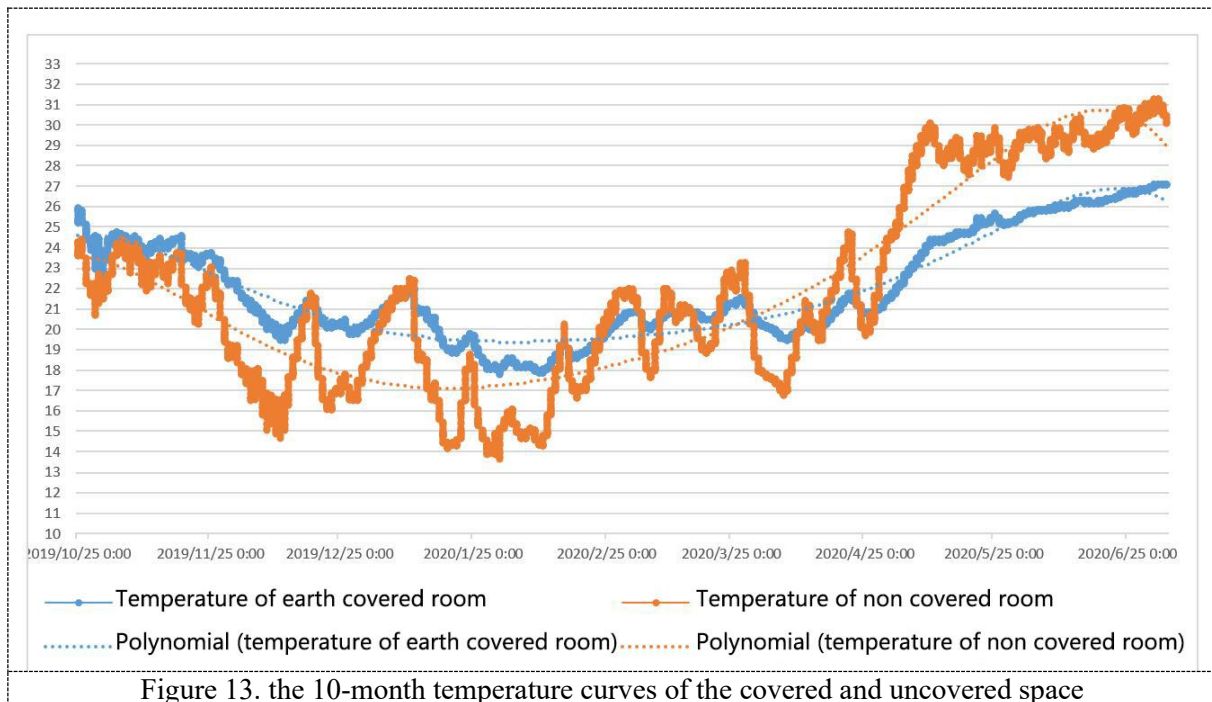


Figure 11. the real view of the Garden Art Gallery

Regarding the soil-sheltered design, the optimization of energy consumption is divided into three steps: the first step is to shorten the summer cooling time on the first floor of the exhibition hall by 2 hours, from 9:00-24:00 to 11:00-24:00; secondly, to cancel the winter heating in all exhibition halls on the basis of shortening the air conditioning time; next is to increase the COP of all air conditioning from 3.3 to 5.5. During the operation period, a comparative test was carried out on the thermal insulation effect of the garden art museum. The team finds, through the simulation of the passive green design technology of the soil covering, that the soil has a significant thermal insulation effect on the Garden Art Museum (Figure 12).

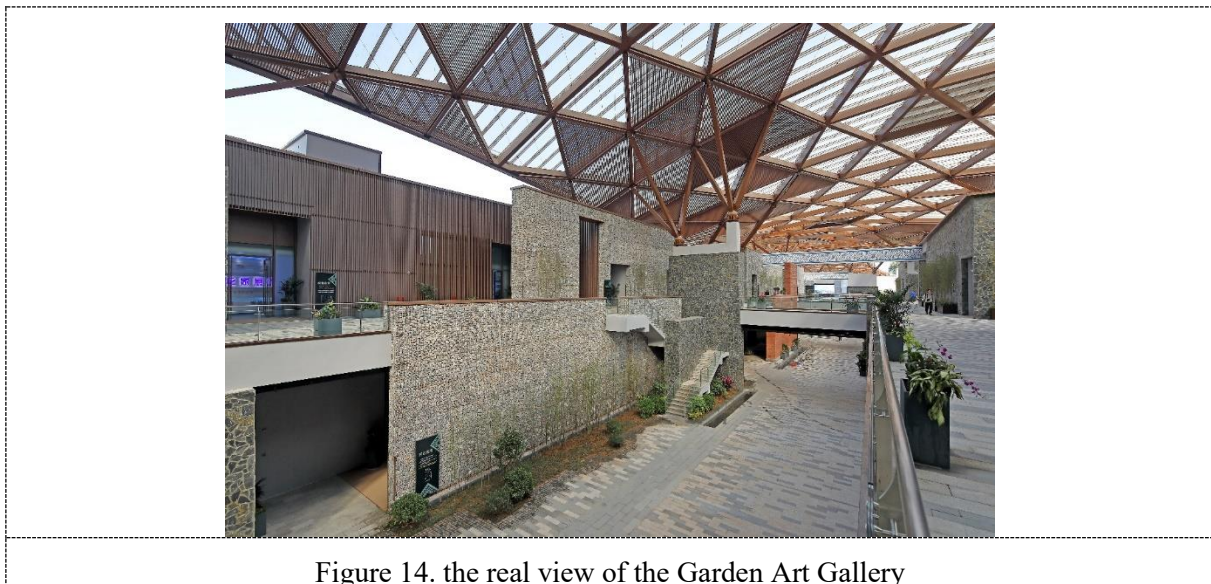


The thermal insulation effect of the soil covering is verified as Figure 13 compares the temperature curve lines between the soil-covered room and the non-covered room from October 2019 to July 2020. The diagram shows that in the winter from November to January, the indoor temperature of the soil-covered room is significantly higher than that of the non-covered room, with a maximum difference of 3°C. From April to July in the summer, the temperature of the covered room was significantly lower than that of the non-covered room, with a maximum temperature difference of 3°C. This shows that the passive design technique of covering soil has a significant thermal insulation effect in winter and a significant thermal insulation effect in summer, which effectively reduces the load of indoor air conditioning and improves the thermal comfort environment of the human body.



5. Passive Ecological Strategy IV- Native Materials

The design of the Garden Art Museum wants to use natural and local materials as much as possible to present the expression of the building (Figure 14). On the one hand, it extracts and translates distinctive building materials from local traditional buildings, such as rammed earth, rubble, and wood; on the other hand, it puts the waste generated during the construction of the park to in the right place, and use raw materials like gravel and red clay to constitute buildings' facades such as the gabion wall.



Based on the two ideas mentioned above, a set of exterior walls using four different materials is designed, and they are gabion, rammed earth, rubble, and wooden grille. These walls with different expressions are not simply divided according to the volume of the settlement, but are designed in a form of composition. The building space is divided by walls made of different materials interspersing and

interlacing with each other (Figure 15). In the actual measurement of the thermal insulation effect, walls made of three typical vernacular materials-rubble, rammed earth, and gabion (Figure 16 and Figure 17) are selected while the cement wall is taken as a control group.

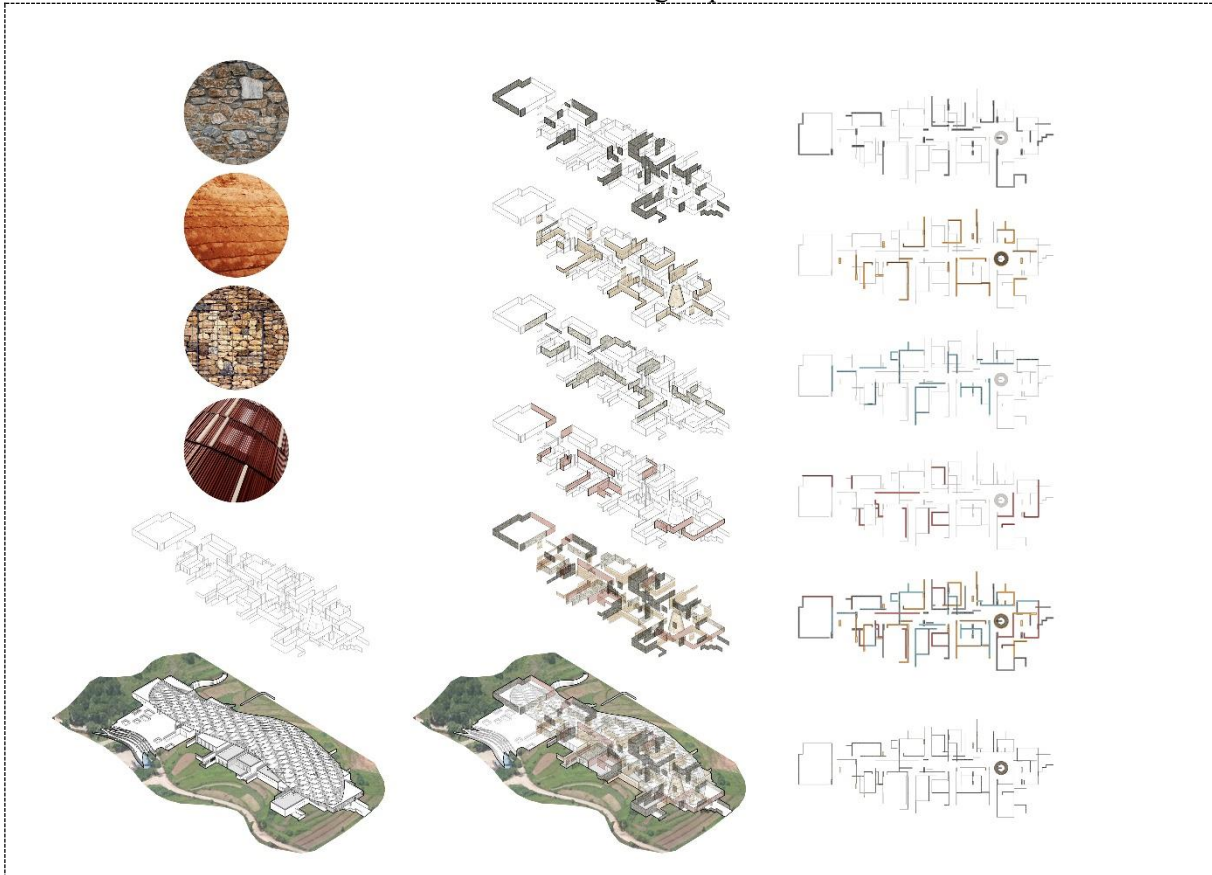


Figure 15. the reconstruction, organization and distribution of local materials used in the Garden Art Gallery



Figure 16. the gabion wall, rammed earth wall and rubble wall during construction

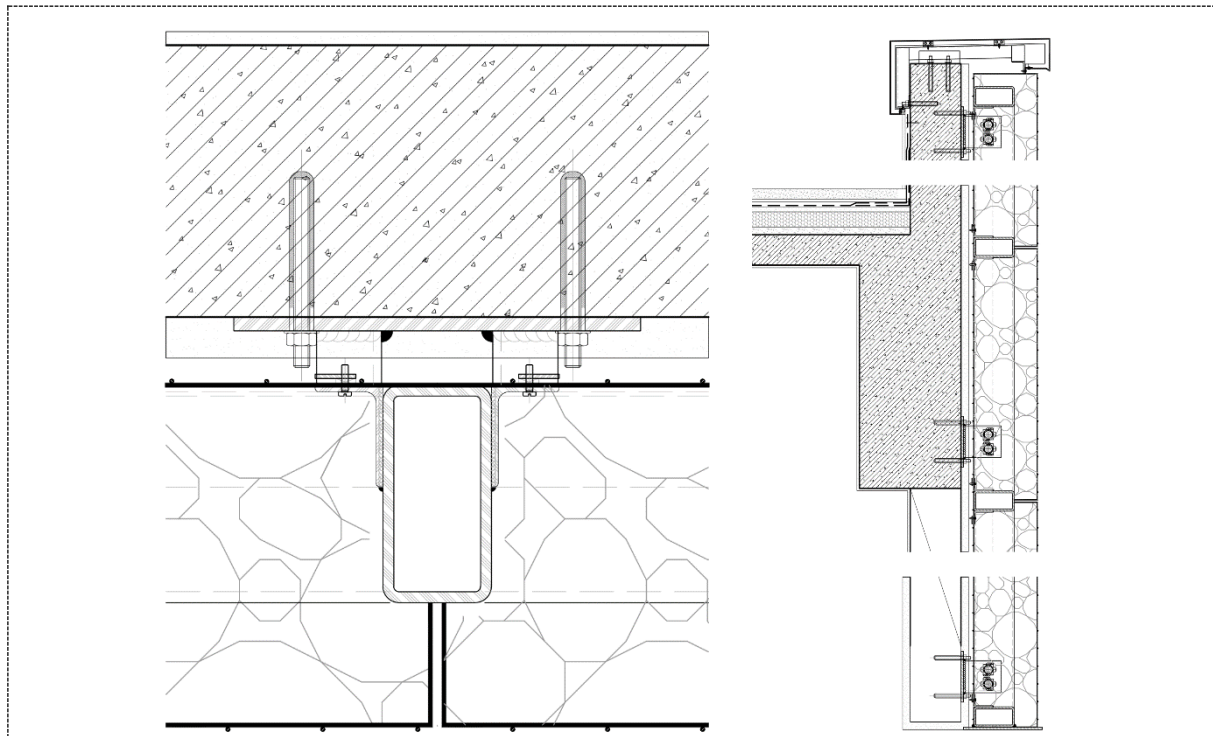


Figure 17. Construction nodes of the gabion wall

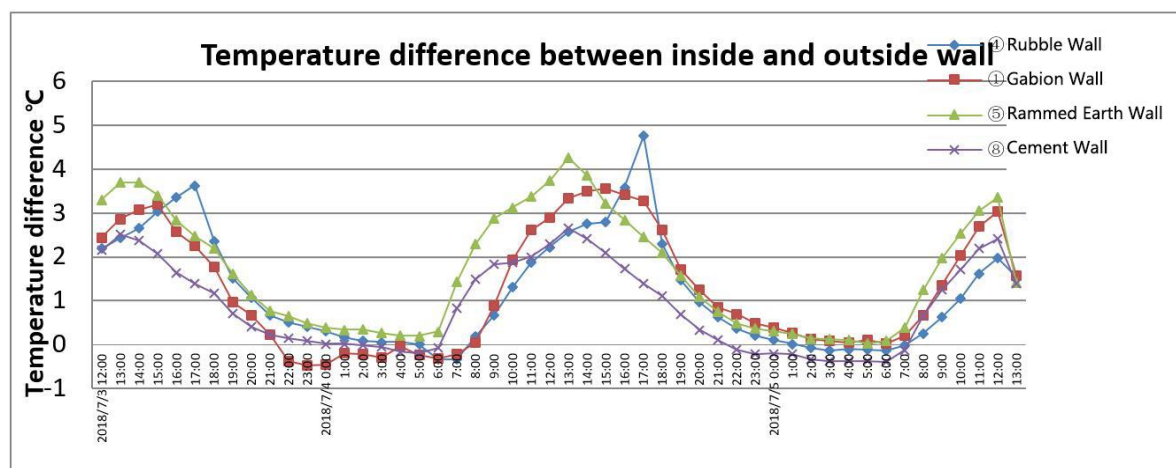


Figure 18. the temperature difference between the inner and outer walls of different walls [4]

Through the actual measurement of the effect after completion, it can be noticed that the use of traditional materials has good thermal insulation performance, and the gabion wall works the best among the four tested walls (Figure 18). During the test period, the indoor temperature of the exhibition hall based on traditional material walls is lower than that of the cement wall, with the average indoor temperature of each exhibition hall lower than 32°C, which is higher than the outdoor high temperature of up to 45°C. The traditional passive wall has effective shading and heat insulation effect. It is also found that the difference between the outer walls of the four types of walls is basically the same, and the inner walls of the gabion wall has the smallest gap, showing that the gabion wall has the best thermal insulation delay performance and the wall heat transfer is the most stable, proving that the gabion wall has the smallest temperature fluctuation of the inner wall, and the best heat insulation, followed by rubble walls, rammed earth walls, and finally cement walls.

All walls are analyzed in terms of heat transfer delay and attenuation, as shown in Figure 19. When the temperature of the outer side of the gabion wall reaches the highest, another 60 minutes are required for the inner wall to be the same, and in the cases of the rammed earth wall and cement wall, 20 minutes are needed respectively, and then 5 minutes for the rubble wall. As for the attenuation of the maximum temperature of the outer wall, the gabion wall decreases by 3.0°C, the rammed earth wall by 3.3°C, the rubble wall by 2.8°C, and the cement wall by 2.2°C.

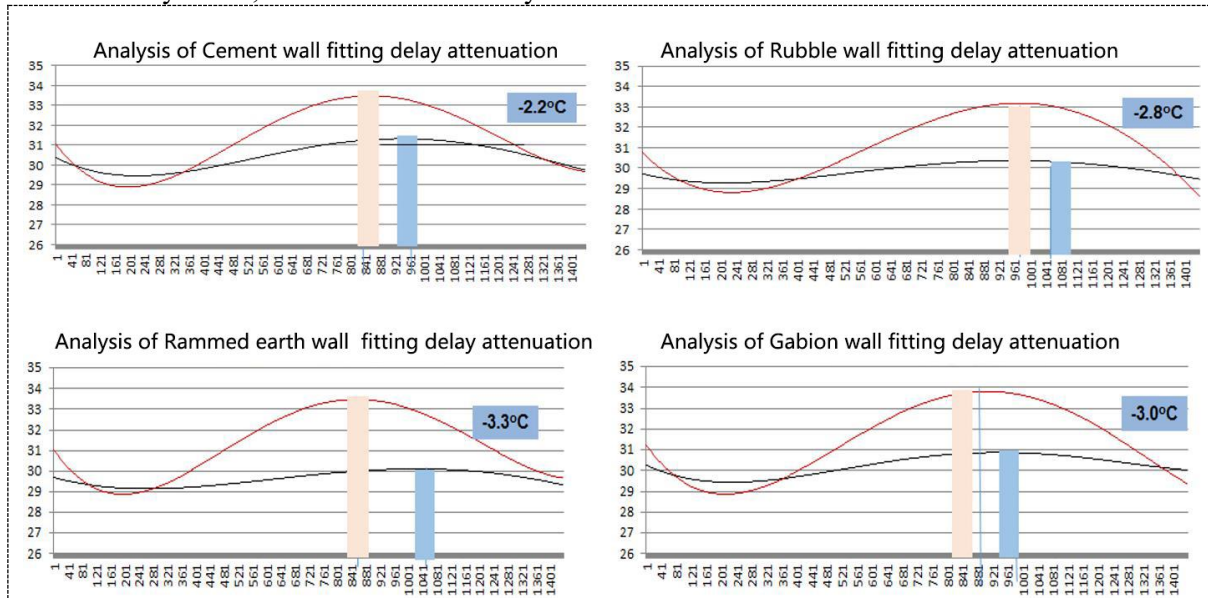


Figure 19. the fitting delay and attenuation of the inner and outer walls of different walls

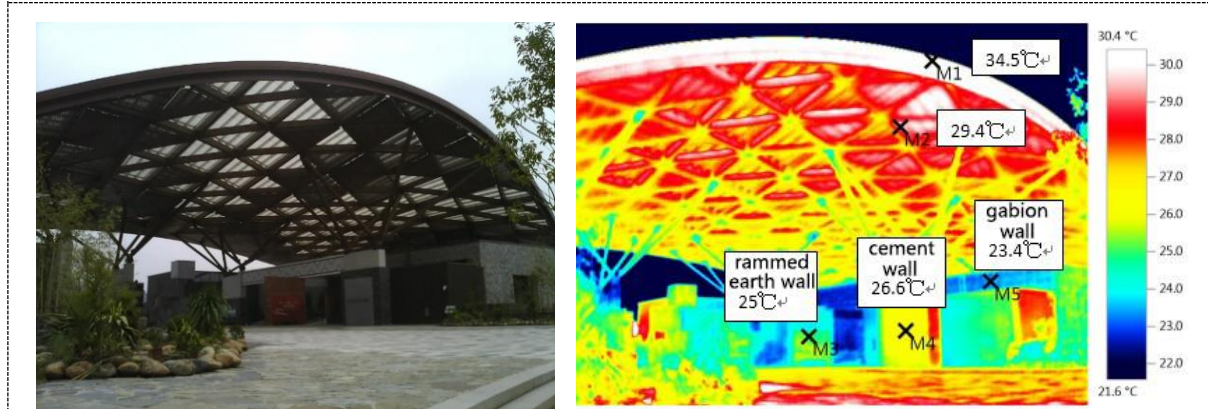


Figure 20. Thermal imaging of temperature distribution inside and outside different walls

For walls of different materials, thermal imager is used to test the surface temperature distribution. As shown in Figure 20, when the outdoor temperature is 34.5°C and the inner surface temperature of the project ceiling is 29.4°C, the surface temperature is 25°C, 26.6°C and 23.4°C among the rammed earth wall, the cement wall, and the gabion wall. The temperature difference between the inside and outside of the ceiling of the project, the rammed earth wall, the cement wall, and the gabion wall is 5.1°C, 4.4°C, 2.8°C and 6°C respectively. It is noted that the gabion wall has the lowest surface temperature, but the largest temperature difference from the inner surface of the project ceiling as it is least affected by the external temperature and has the best thermal insulation performance.

In summary, it can be concluded that the gabion wall performs the best, and the temperature of its inner wall is least affected by the temperature fluctuation of the outer wall, featuring the largest delay in heat transfer.

6. Conclusion

Exhibition buildings have no corresponding energy consumption standard requirements according to *the Energy Consumption Standards for Civil Buildings* (GB/T51161-2016), but given their characteristics of space, pedestrian flow, and energy consumption which are all similar to general shopping malls (Table 1), the project can be compared with the energy consumption standard limits for general shopping malls in the cold area listed in category A of *the Civil Building Energy Standards* (Table 2).

Table 1. Similarities between exhibition buildings and general shopping malls

Features	General shopping malls	Exhibition buildings
Space	For human flow: to use aisles to connect each store and exhibition hall in series to keep people flowing. For exhibition: to display exhibits and commodities through the spatial and artistic function to attract tourists and customers. For changes: to use cabinets and shelves to horizontally divide and connect space, which features obvious spatial continuity and brings abundant changes to commercial and exhibition spaces.	
Human flow	Similar business hours, daily and hourly traffic changes, and personnel density.	
Energy consumption	The area of a single store in the shopping center is similar to that of an exhibition hall in the exhibition building, which brings the similar human flow, and similar indoor heating and cooling loads. All have display requirements, and similar lighting power density. Not much indoor electrical equipment apart from necessary display facilities and computers. Similar air-conditioning equipment with VRV air-conditioning systems more often used.	

Table 2. Constraints and guide values of non-heating energy consumption indicators for shopping malls

Building classification	Severe and cold area		Hot summer and cold winter area		Hot summer and warm winter		Temperate areas		
	Constraint value	Bootstrap value	Constraint value	Bootstrap value	Constraint value	Bootstrap value	Constraint value	Bootstrap value	
Class A	General department store	80	60	130	110	120	100	80	65
	General shopping center	80	60	130	110	120	100	80	65
	General supermarket	110	90	150	120	135	105	85	70
	Restaurant	60	45	90	70	85	65	55	40
	General shops	55	40	90	70	85	65	55	40
Class B	Large department stores	140	100	200	170	245	190	90	70
	Shopping Mall	175	135	260	210	300	245	90	70
	Supermarket	170	120	225	180	290	240	100	80

The research team work with the operation staff of the project to complete the reading and collection of energy consumption data. The monthly energy consumption data of the Art Museum from July 2019 to July 2020 is shown in Figure 21. From July to October 2019 had witnessed a peak of passenger flow,

during which the museum consumed a lot of electricity. From November 2019, the passenger flow had gradually decreased, and shortly after the outbreak of the epidemic in 2020, the park had ceased operations and only maintains basic energy consumption.

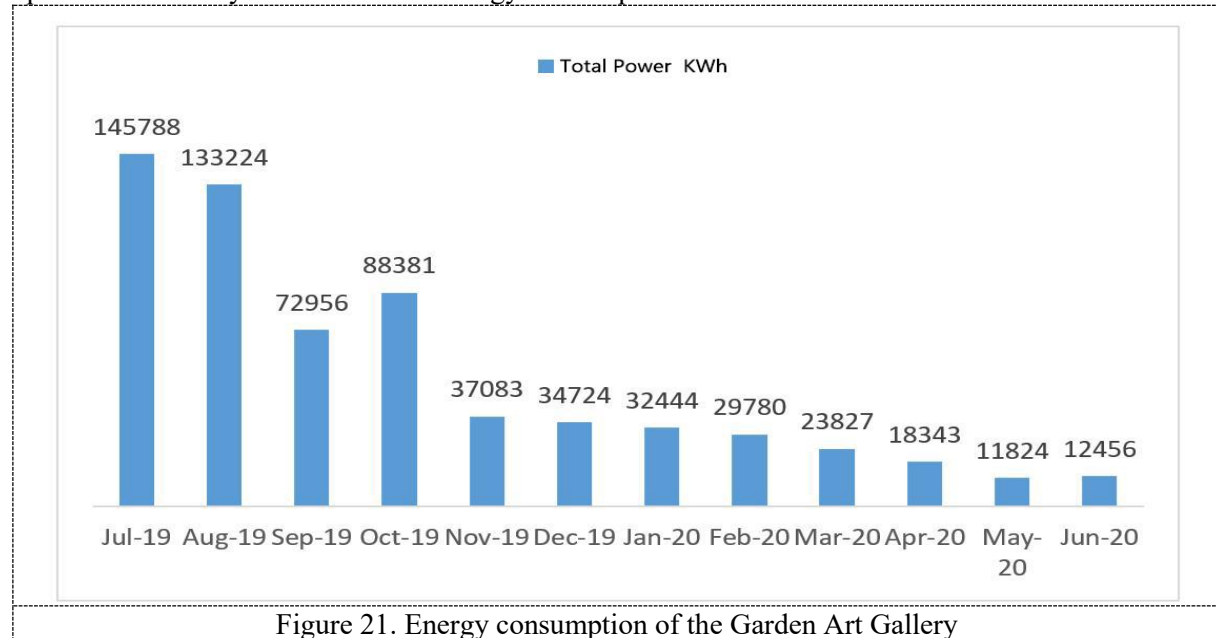


Figure 21. Energy consumption of the Garden Art Gallery

Table 3 shows the monthly energy consumption indicators of the Garden Art Museum throughout the year. It is calculated that the total annual energy consumption is 24.74 KWh/m² which is lower than the standard limit value and the guide number, reflecting good energy-saving characteristics. Given the venues will basically be out of operation after November 2019 and the 2020 epidemic's influence, the data needs to be revised for energy consumption data through the use of meteorological parameters, combined with the on-site investigation and evaluation of energy-using equipment and *the Civil Building Energy Consumption Standard*.

Table 3 Monthly energy consumption indicators of art museums throughout the year

Date	Total Wattage (KWh)	Total Gross Floor Area	Energy consumption index (KWh/m ²)
2019.7	145788	25900	5.63
2019.8	133224	25900	5.14
2019.9	72956	25900	2.82
2019.10	88381	25900	3.41
2019.11	37083	25900	1.43
2019.12	34724	25900	1.34
2020.1	32444	25900	1.25
2020.2	29780	25900	1.15
2020.3	23827	25900	0.92
2020.4	18343	25900	0.71
2020.5	11824	25900	0.46
2020.6	12456	25900	0.48
Total			
energy consumption	640830	25900	24.74

7. Conclusion

On December 6, 018, Nanning Garden Expo officially opened. It lasted 205 days and received more than 1.8 million tourists. From the perspective of the usage after the opening of the park, the expected planning and design effects have been basically achieved, and have also been praised by all sectors of the society. All aspects from overall planning, design details, construction quality, ecological construction to local materials have been highly praised.

It has come to an end as an exhibition, but will continue to be wonderful. Permanently retained as a comprehensive urban park, it will continue to be open to customers and become a permanent ecological wealth in the development of Nanning. It will also be incorporated into the management system as an urban park and green space, in strict accordance with regulations and standards to strengthen supervision and inspection, and create a public green space with unique landmark significance and a symbol of ecological civilization.

Nanning Municipal Government has also established a post-expo operation and management agent to improve the service quality. On the basis of the exhibition gardens left over by the exhibition, more seasonal ornamental flowers and trees will be planted for beautiful views in all seasons. Besides, organically combining people's livelihood and well-being with the ecological environment, more high-quality cultural themed activities will be hold to improve the taste of popular culture and garden culture, and ensure that residents can enjoy long-term happiness and wonderful ecosystem.

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