Passive design of green public buildings adapted to cold climate: a case study of China pavilion of the international horticultural exhibition 2019 Beijing China

Quan Jing, Jingwei Li, Liang Li, Meng Jia, Ye Zhou* and Xiangyu Zhao*
China Architecture Design & Research Group, Beijing, 100000, China
*Corresponding author’s e-mail: zhouy0129@126.com; 2021031@cadg.cn

Abstract: This paper took the China Pavilion of the International Horticultural Exhibition 2019 Beijing China as the subject for study. Based on the influence of cold climate on people’s behaviors and their perception of the environment, the paper proposed designs of green public buildings adapting to the cold climate and analyzed the overall functions of green buildings via tests of temperature, humidity, illumination and total energy consumption to verify the ecological features and energy conservancy of the buildings, forming a closed-loop chain of procedures of the green design.

1. Introduction

1.1. Overview
Despite rapid economic and social development of China, environment and energy issues are becoming increasingly prominent these days. At present, the greenhouse gas emissions of China have reached the top of the world. Studies show that the energy consumption of buildings in China accounts for 20.6% of total energy consumption of China, and the number for carbon emission is 19.0% [1]. Therefore, energy conservation of buildings is of great significance for environmental protection and emission reduction.

There have been a number of domestic studies on adaptations of green buildings to climate changes. According to environmental psychology, architectural climatology and conditions of human thermal comfort, Yan (2013) established theories and models of thermal comfort based on regional climate of China. Gao (2013) simulated climate-adaptive patterns of typical residents, with human thermal comfort as the major indicator [2], which revealed the strong adaptability of residents to climate changes [3]. Han (2019) discussed major strategies and approaches to enhance the climate-adaptive features of public buildings from architectural layout, spatial and morphological characteristics, climate-specific design of single space and the performance-oriented external enclosure and space separation [4]. Li (2020) proposed the design of climate-adaptive architecture guided by performance, incorporating architectural layout, sunshade and individual architectural design [5].

The design of climate-adaptive green buildings provides theoretical support for the spatial form, physical construction, spatial performance, and humanistic characteristics of the green buildings, endowing users with a sense of belonging and identity. Compared with green architecture relying on technologies, the climate-adaptive green buildings integrate ecological, geographical and technological factors into the design, featuring energy conservation and environmental protection. This paper took the China Pavilion of the International Horticultural Exhibition 2019 Beijing China, a
building adapting to the cold climate as the subject for study. Based on location, space and technologies, the paper looked at passive features such as ventilation, earth-sheltered insulation, improved lighting, and greening design, and took an innovative study of green public buildings adapting to the cold climate.

1.2. Project background
The China Pavilion of the International Horticultural Exhibition 2019 Beijing China (or China Pavilion) is located in the southwest of Yanqing District, Beijing. The Yanqing District of Beijing is located in the northwest of Beijing, bordering Huairou District in the east, Changping District in the south, Huailai County in Hebei Province in the west, Chicheng County in Hebei Province in the north, about 74 kilometers away from the Deshengmen of Beijing. With a continental monsoon climate, the Yanqing District features a transition between the temperate zone, middle temperate zone, semi-arid zone and semi-humid zone. With the unique climate characteristics, it is cold in winter and cool in summer, with an annual average temperature of 8 ℃. It has the longest sunshine duration and the highest level of solar radiation, with an annual sunshine duration of 2800 hours, making it the area with the richest solar energy resources in Beijing. The wind of the region is mainly directed at the southwest, west and northwest. The region has a low level of precipitation in winter due to dry and cold air from the northwest. In summer, there is abundant rain as a result of warm and humid airflow from the southeast. In spring and autumn, frequent cold air causes fluctuations in the precipitation.

The China Pavilion is the core landscape and a most important architectural venue of the International Horticultural Exhibition 2019 Beijing China. The Chinese Pavilion, entitled "Prosperity and Happiness", symbolizes the combination of ancient agricultural civilization and traditions. By integrating green ecological technologies with the traditional culture of China, it reflects changes of lifestyle in China, and displays the national, cultural and technical characteristics of the country. The China Pavilion covers a total construction area of 23,000 m², including 14,902 m² above ground and 8,098 m² underground. The building consists of the lobby, exhibition hall, multi-function hall, office, VIP reception, viewing platform, underground warehouse of civil defense, equipment room and outdoor terraces. The China Pavilion is a multi-stored civil public building. Based on its coverage, it is categorized as a medium-sized exhibition building.

2. Material and Methods

2.1. Strategies of design

2.1.1. Design of indoor ventilation.
Unlike traditional Chinese architecture facing lakes and with mountains at the back, the China Pavilion has a semi-circular structure, which leaves a square on the south side as the entrance to the building. In the north of the building sits the Guirui Lake. An overhead ventilation corridor is located on the central axis of the first floor, and the main entrance is set up in the overhead area, which protects visitors and provides shading and sheltering from wind and rain. The corridor that runs through the north and south presents a complete view of the lake, incorporating water into the design of the building. The southerly wind passes through the above-ground grey space of the overhead floor in summer, and directly introduces the cool air of the Guirui Lake into the building. The air flow would contract sharply and accelerate in the overhead space. The contraction would form a zone of negative pressure, which drives the surrounding air to flow \(^6\), and brings cool air to the building and the south square, thus cooling the entrance. In winter, the northwest wind is blocked by the west side of the building and the terrace, which protect the semi-enclosed space on the south from the cold wind. Also, the earth-sheltered space lies in the terrace, which allows wind to pass through the site, reduces the resistance of the building to the wind, and improves indoor ventilation of the building.

The first floor of the building is earth-sheltered. To increase lighting and settle the design on the traditional Chinese architectural style of the funnel wellhead, a sunken courtyard was designed in the
center of the semi-enclosed square of the building. The space not only increased lighting, but also improved hot-pressing ventilation. Also, it uses water of the landscape to cool down the space in the form of evaporation, thus creating a regional microclimate.

![Figure 1](image1.png)

**Figure 1.** A plane diagram shows how the passive ventilation strategy enhances the secondary predominant wind in summer and withstand the predominant wind in winter.

![Figure 2](image2.png)

**Figure 2.** Sectional ventilation diagram.

### 2.1.2. The earth-sheltered design.
As the oldest form of shelter, earth-sheltered buildings have been used since ancient times. The local Guyaju Caves in Yanqing is the largest cliff-dwelling site discovered in China. The unique architectural form and structure of the building indicates the adaptability to the local climate, which provides inspiration for the earth-sheltered design.
To increase thermal inertia and boost the capacity of heat storage, the designer buried the first floor of the China Pavilion underground, as shown in Figure 3. The passive design of the building in the form of earth shelter not only shows respect for the natural landscape of the site, but also greatly reduces the amount of underground excavation, which is conducive to saving land resources. In addition, the thickness of sheltered earth is directly proportional to the change of indoor temperature. The thicker the sheltered earth, the better the indoor thermal stability. Therefore, the sheltered earth could reduce the outer surface of the building exposed in the air, thus preventing heat exchange between the building and the outside air. The adjustment of the thickness and depth of the sheltered earth could enhance the thermal performance of the enclosure structure, ensuring thermal insulation in winter and summer. The circular structure and earth-sheltered design also reduce the building’s shape coefficient (i.e., the ratio of the surface affected by the external environment against the volume of the building), thus saving energy.

2.1.3. Roof lighting system.
As a semi-arid and semi-humid zone, Yanqing has a low level of precipitation in winter and abundant rain in summer. It is also characterized by frequent cold air and irregular precipitation in spring and autumn. Yanqing is rich in solar energy resources and has a long duration of sunshine. The design of the roof is thus determined by the local climate and lighting conditions.
The arc-shaped plane of China Pavilion provides sufficient illumination for the roof, and the double-slope design of the roof could facilitate the drainage of the building. The gentle slope of the southbound roof fits with the incident angle of light, and is more conducive to receiving light, incorporating photovoltaic solar energy into the design of the building. Without fabric substrate, the transparent ETEF film has a light transmission spectrum similar to that of the glass, with a translucent and semi-reflective appearance. The exhibition hall of flowers and vegetation on the second floor of China Pavilion has a tough demand on lighting and ventilation. Inspired by traditional greenhouse, the enclosure structure consisting of glass and ETFE film was adopted, as shown in Figure 4. The surface of the ETFE film was subjected to spot shading treatment to meet requirements on light transmittance. In addition, the ETFE, with its sound thermal insulation performance, worked together with the glass to form a double-layer roof, the cavity between which was conducive to thermal insulation in winter and ventilation and cooling in summer.

2.1.4 Design of Green Space.
Yanqing has the longest duration of sunshine and the highest level of solar radiation. With an annual sunshine of 2800 hours, it has the richest solar energy resources in Beijing. The site has maintained a sound ecological landscape. To protect recycles and operation of the ecological system and adapt the site to local climate, the designer focused on improving the microenvironment. Several measures have been taken in the design, including making a full use of existing plants and vegetation and reserving trees and forest, which served as the foundation of the ecosystem. Also, the design incorporated local plants and diversity of species to establish plant colonies, paving way for a site with distinct features and well-distinguished seasons. Meanwhile, new and superior plant varieties that fit Yanqing were introduced to extend the green belt. Plants such as pinus bungeana, pinus tabulaeformis, acer truncatum, koelreuteria paniculata, begonia fortunei, peach, mountain peach, sophora japonica, steamed bread willow, elm, and spring blossom were planted, with a shade ratio of 24.16% in the outdoor area, and 70% on the road. The green design and the sheltered earth jointly established a sound environment for the building.

2.2. Test Method
The actual effect of the passive ventilation design on the space thermal environment is determined by testing the temperature and humidity in the grey space. The grey space was divided into the
aboveground and underground earth-sheltered space. The external and internal hourly average temperature was used along with the evaluation standard GB/T50785-2012 for indoor thermal and humid environment of civil buildings [8]. The graphic method was adopted to compare the internal and external conditions of the grey space based on the temperature range of non-artificial cold and heat sources where people are exposed to.

By testing the indoor temperature and humidity of earth-sheltered and non-earth-sheltered rooms, the thermal insulation effects of the sheltering technology were compared and analyzed. The test selected typical weeks of transition season, summer and winter for continuous monitoring, with a sampling interval of 30 minutes. The distribution of temperature measuring points in rooms with and without sheltered earth was the same to test the influence of sheltered earth on the insulation. Both rooms had the same area, with the same orientation and material in wall. The temperature measuring points shall be located at typical positions within (700-1800) mm from the ground. Temperature sensors should not be directly affected by solar radiation or indoor heat sources.

The lighting efficiency of the roof system in the exhibition hall on the second floor was determined by testing the indoor illumination before being evaluated by the standard. The multi-channel illuminance tester was used to test the illuminance of the space under the roof of the second floor, where readings were made at the interval of 10 minutes. According to "Design Standard for Daylighting of Buildings" GB 50033-2013[9], the measured space was divided into measuring points in sequence along the line to measure illuminance. The test results by the multi-channel illuminance meter was recorded, analyzed and compared with the outdoor illuminance.

By testing the temperature and humidity in the microclimate, this paper studied the effect of the green space pattern on the thermal environment. Microclimate could improve outdoor thermal environment in summer. However, its effect in winter was not evaluated in this paper. The typical weeks of transition season and summer were selected for continuous monitoring, with a sampling interval of 30 minutes. The thermal comfort of the microenvironment was estimated by calculating hourly average temperature and type II UTCI index [10]. By comparing the results of the microenvironment with those of the outdoor conditions, we found out the effect of artificial microenvironment on lowering heat stress of human body and the efficiency of the passive design.

3. Results and Discussion

3.1. Test results of ventilation
The hourly average temperatures of the gray space aboveground and the outdoor space from May 23rd to October 3rd of 2019 (transition season and summer) are shown in Figure 5. The hourly average temperature of the grey space in the middle peaks at 27°C without air conditioning, 2.5°C lower than the outdoor temperature.
Figure 5. Comparison of average hourly temperature between the grey space aboveground and the outdoor environment.

The comfort ranges of somatosensory temperature brought by non-artificial cold and heat sources in the hot and humid environment of the grey space aboveground and the outdoor space were compared, as shown in Figure 6. During the test, the grey space aboveground reached the second-level comfort standard for 83% of the time under the condition of pure natural ventilation. The comfortable hours in the grey space aboveground are 295 hours longer, that is, 13% higher than the outdoor conditions.

Figure 6. Comparison of the comfort ranges of somatosensory temperature by non-artificial cold and heat sources in the hot and humid environment of the grey space aboveground and the outdoor space.

From May 23rd to October 3rd of 2019, differences in the hourly average temperature between grey space underground (sinking water courtyard) and the outdoor space are shown in Figure 7.
Without air conditioning, the hourly average temperature of the grey space underground (sinking water courtyard) peaked at 25°C, which was 4.5°C lower than that of the outdoor conditions.

![Average Hourly Temperature in the Grey Space](image1)

![Average Hourly Temperature in the Outdoor Space](image2)

Figure 7. Comparison of average hourly temperature between the grey space underground (sinking water courtyard) and the outdoor environment.

See Figure 8 for comparison of the comfortable ranges of somatosensory temperature in thermal and humid environment with non-artificial cold and heat sources in the grey space underground (sinking water courtyard) and the outdoor space. The interior grey space underground kept a total of 2807 hours in the Level 2 comfort zone. During the test, the grey space underground stayed in the comfort zone for 93% of the time. The external temperature of the space stayed in the Level 2 comfort zone for a total of 2225 hours, 582 hours fewer than that of the internal space, or a percentage of 26%.

![Comfort Zone Grey Space Underground (Sinking Water Courtyard)](image3)

![Comfort Zone Outdoor Space](image4)

Figure 8. Comparison of the comfort ranges of somatosensory temperature in thermal and humid environment with non-artificial cold and heat sources in the grey space underground (sinking water courtyard) and the outdoor space.

The test of the average temperature and comfort time of the gray space underground (sinking water
and the gray space aboveground shows that a sound design of natural ventilation and shading can effectively lower indoor temperature and create a more comfortable indoor environment in transition season and summer.

3.2. Test results of sheltered earth and heat insulation

See Figure 9 for comparison of daily average temperature of sheltered room, unsheltered room and the outdoor temperature. In the transition season and summer, there is only slight difference due to the use of air conditioning. However, the average indoor temperature of the sheltered room remains slightly lower than that of the unsheltered one.

![Comparison of daily average temperature of sheltered room, unsheltered room and the outdoor space in transition season and summer.](image)

Figure 9. Comparison of daily average temperature of sheltered room, unsheltered room and the outdoor space in transition season and summer.

Select the day with the highest outdoor daily average temperature during the test period as the typical day. Figure 10 compares the typical daily hourly average temperatures between the sheltered and unsheltered rooms. During the non-operation period from 0:00 to 8:00 and 20:00 to 23:00, the temperature of the sheltered room is about 0.3 to 0.8°C lower than that of the unsheltered room.

The proper earth-sheltered design could significantly lower the temperature of the sheltered room compared with the unsheltered one during the non-operation period.
3.3. Test results of the roof lighting system
The natural lighting illuminance under the exhibition hall on the second floor of China Pavilion in summer was tested, as shown in Figure 11. During the test, the illuminance value of each point was greater than 300 lx, far exceeding the standard value.

![Figure 11. Analysis of illuminance at the exhibition hall on the second floor in summer.](image)

See Figure 12 for the test results of winter illuminance in the exhibition hall on the second floor of China pavilion. During the test, the outdoor was in a cloudy condition. At 13:00 pm, the outdoor illumination was 3600 lx. The illuminance value of each point was greater than 300 lx, far exceeding the illuminance value required by the standard.
A sound design of natural lighting and shading supplies the exhibition hall with sufficient natural lighting during the operation period, without the need for additional artificial lighting.

3.4. Test results of the green space pattern

From May 23 to October 3 of 2019, a number of measuring points were set up in the China Pavilion, which recorded temperature and humidity in the transition season and summer for a total of 3193 hours in 133 days. During the test, the average hourly temperature inside and outside the microenvironment is shown in Figure 13, with the interior of the landscape lower than the exterior in terms of temperature. The temperature hit the bottom at 5:00 am, when the internal temperature was 17.5°C and the external temperature was 18.3°C, with an average difference of 0.8°C. The room temperature peaked during 13:00 pm and 16:00 pm. The outdoor temperature reached the peak of 30.3°C at 14:00. The temperature in the microenvironment reached the peak of 28.5°C at 17:00. The peak temperature of the microenvironment was 3 hours later than the outdoor temperature, with a difference of 1.8°C.

Figure 13. Comparison of the average hourly temperature inside and outside the microenvironment.
A period of continuous outdoor high temperature was selected to analyze the UTCI difference between indoor microenvironment and the outdoor environment. The outdoor daily average temperature during the test period was ranked in ascending order, where outdoor temperature above the average temperature during the test period was selected and the 50th percentile was taken as the critical value [11]. The day with the outdoor daily average temperature above the critical value was selected as a typical day to calculate the UTCI of the outdoor environment and the microenvironment of the day. The UTCI values of the outdoor environment and the microenvironment are shown in Table 1.

| Date     | Mean ventilation rate (m/s) | Mean radiant temperature | Average daily temperature | Average daily humidity | UTCI Mean radiant temperature | Average daily humidity | Average daily humidity | UTCI |
|----------|-----------------------------|--------------------------|---------------------------|----------------------|-------------------------------|-----------------------|------------------------|------|
| May 23   | 2.08                        | 27.28                    | 26.09                     | 24.62                | 23.8                          | 28.36                 | 27.18                  | 23.72 | 25       |
| June 10  | 3.08                        | 26.65                    | 25.37                     | 38.58                | 22.4                          | 26.65                 | 26.37                  | 38.58 | 23.3     |
| June 11  | 2.08                        | 27.01                    | 25.85                     | 56.09                | 25.2                          | 27.01                 | 26.85                  | 56.09 | 26.2     |
| June 14  | 2.67                        | 27.07                    | 25.99                     | 47.76                | 24.1                          | 27.07                 | 26.99                  | 47.76 | 25.1     |
| June 18  | 2.00                        | 26.63                    | 25.86                     | 74.68                | 26.6                          | 26.63                 | 26.86                  | 74.68 | 27.6     |
| June 19  | 2.50                        | 26.80                    | 25.77                     | 69.57                | 25.5                          | 26.80                 | 26.77                  | 69.57 | 26.5     |
| June 20  | 1.83                        | 27.86                    | 26.73                     | 62.06                | 27                            | 27.86                 | 27.73                  | 62.06 | 28       |
| June 22  | 4.08                        | 28.67                    | 27.75                     | 33.05                | 23.9                          | 28.67                 | 28.75                  | 33.05 | 24.9     |
| June 23  | 2.75                        | 28.91                    | 28.10                     | 44.43                | 26.3                          | 28.91                 | 29.10                  | 44.43 | 27.3     |
| June 24  | 1.58                        | 29.15                    | 28.63                     | 43.95                | 28                            | 29.15                 | 29.63                  | 43.95 | 29       |
| June 25  | 1.58                        | 27.20                    | 26.25                     | 45.42                | 25.5                          | 27.20                 | 27.25                  | 45.42 | 26.5     |
| June 28  | 2.42                        | 25.89                    | 25.12                     | 70.47                | 24.8                          | 25.89                 | 26.12                  | 70.47 | 25.8     |
| July 1   | 1.50                        | 26.81                    | 25.56                     | 41.02                | 24.6                          | 26.81                 | 26.56                  | 41.02 | 25.6     |
| July 3   | 2.42                        | 28.58                    | 28.00                     | 51.38                | 27                            | 28.58                 | 29.00                  | 51.38 | 28       |
| July 4   | 1.00                        | 25.92                    | 25.38                     | 45.25                | 24.9                          | 25.92                 | 26.38                  | 45.25 | 25.9     |
| July 12  | 1.92                        | 25.76                    | 25.45                     | 68.54                | 25.6                          | 25.76                 | 26.45                  | 68.54 | 26.6     |
| July 13  | 0.58                        | 26.96                    | 26.02                     | 71.65                | 27.8                          | 26.96                 | 27.02                  | 71.65 | 28.8     |
| July 14  | 1.67                        | 28.58                    | 27.44                     | 56.96                | 27.6                          | 28.58                 | 28.44                  | 56.96 | 28.6     |
| July 15  | 1.75                        | 27.78                    | 26.82                     | 69.14                | 27.7                          | 27.78                 | 27.82                  | 69.14 | 28.7     |
| July 18  | 2.00                        | 27.21                    | 25.88                     | 81.85                | 27.4                          | 27.50                 | 26.18                  | 81.85 | 27.8     |
| July 20  | 2.67                        | 27.10                    | 25.93                     | 96.89                | 28.1                          | 27.86                 | 26.70                  | 85.61 | 28       |
| July 21  | 2.75                        | 29.99                    | 29.00                     | 70.36                | 29.7                          | 30.83                 | 29.91                  | 66.12 | 30.4     |
| July 23  | 2.67                        | 28.68                    | 27.55                     | 77.91                | 28.4                          | 28.87                 | 27.75                  | 70.95 | 28.1     |
| July 24  | 2.25                        | 29.35                    | 28.73                     | 81.68                | 30.9                          | 29.69                 | 29.07                  | 72.51 | 30.4     |
| July 25  | 2.58                        | 27.52                    | 27.12                     | 65.84                | 26.7                          | 27.81                 | 27.41                  | 59.76 | 26.6     |
| Date      | 5/23  | 5/30  | 6/13 | 6/20 | 6/27 | 7/4   | 7/11  | 7/18  | 7/25 | 8/1  | 8/8  | 8/15 | 8/22 | 8/29 | 9/5  |
|-----------|-------|-------|------|------|------|-------|-------|-------|------|-----|-----|------|------|------|-----|
| July 26   | 1.92  | 29.74 | 29.11| 70.78| 30.6 | 30.46 | 29.83 | 64.58 | 30.6 | 30.46| 29.83| 64.58 | 30.6  | 29.83| 64.58|
| July 27   | 1.58  | 28.94 | 28.63| 76.40| 30.8 | 30.30 | 30.00 | 68.74 | 31.8 | 63.49| 30.8 | 30.30 | 30.00 | 68.74| 31.8 |
| July 30   | 2.33  | 27.25 | 26.45| 72.72| 26.8 | 27.66 | 26.86 | 67.79 | 26.5 | 63.49| 26.8 | 27.66 | 26.86 | 67.79 | 26.5 |
| July 31   | 0.58  | 28.18 | 27.49| 63.49| 28.8 | 28.70 | 28.02 | 56.17 | 28.8 | 63.49| 28.8 | 28.70 | 28.02 | 56.17 | 28.8 |
| August 1  | 2.33  | 26.00 | 25.18| 68.98| 24.9 | 27.93 | 27.13 | 61.61 | 26.8 | 63.49| 24.9 | 27.93 | 27.13 | 61.61 | 26.8 |
| August 7  | 2.67  | 26.60 | 25.78| 90.75| 27.1 | 27.18 | 26.37 | 78.77 | 26.8 | 90.75| 27.1 | 27.18 | 26.37 | 78.77 | 26.8 |
| August 8  | 1.75  | 27.07 | 25.89| 85.78| 28   | 28.05 | 26.88 | 74.10 | 28.2 | 85.78| 28   | 28.05 | 26.88 | 74.10 | 28.2 |
| September 7 | 2.08 | 26.82 | 25.98| 55.37| 25.2 | 28.01 | 27.18 | 53.70 | 26.6 | 55.37| 25.2 | 28.01 | 27.18 | 53.70 | 26.6 |
| September 8 | 2.50 | 27.39 | 26.51| 51.68| 25.2 | 28.82 | 27.95 | 49.85 | 26.8 | 51.68| 25.2 | 28.82 | 27.95 | 49.85 | 26.8 |

Figure 14 compares the UTCI values of the microenvironment and outdoor environment. Table 1 and Figure 14 indicate that on typical scorching days in summer, the heat stress of human body in the microenvironment is about 1°C lower than that in the outdoor environment.

Tests show that the microenvironment with green space can improve the outdoor thermal comfort of human body in summer.

3.5. Test results of energy consumption

According to the Standard for Energy Consumption of Civil Buildings, the energy consumption of public buildings with central heating system in severely cold and cold areas could be divided into non-heating energy consumption and heating energy consumption [12]. The non-heating energy consumption includes consumption by air conditioning, ventilation, lighting, domestic hot water, elevators, office equipment, the hot water circulating pump of the heating system, and the fan of the heating system.

The energy consumption involved in this project mainly includes electricity, cold and heat energy sources. The electric energy is mainly used for lighting, elevators, and the fresh air system. The natural
gas is used for boiler heating, and the cold and heat energy for air conditioning and hot water. The water consumption is due to shower, toilet, kitchen and so on.

The annual power consumption of China Pavilion from April 2019 to March 2020 was 1375120kWh, equivalent to 59.79 kW·h/ (m²·a).

The Energy Consumption Standard for Civil Buildings (GB/ T51161-2016) poses no restrictions on exhibition buildings. However, as the buildings have similar spatial characteristics, pedestrian flow and energy consumption patterns to shopping malls, this project can be compared with the Class A shopping malls in cold areas specified by the Energy Consumption Standard for Civil Buildings.

| Characteristics of space | Shopping mall | Exhibition building |
|--------------------------|---------------|---------------------|
| Space for flow of people: the corridor is used to connect shops and the exhibition hall and keep the smooth flow of people. | Space for display: The spatial functions and artistic display of commodities attract visitors and customers. Variable space: The variable space separate and connect the space horizontally, and enrich the space for business and exhibition. |

| Characteristics of flow | Shopping mall | Exhibition building |
|------------------------|---------------|---------------------|
| Similar operation duration, daily and hourly flow of people, and population density. |

| Characteristics of energy consumption | Shopping mall | Exhibition building |
|---------------------------------------|---------------|---------------------|
| The coverage of a single shop in the shopping center is similar to that of a single exhibition hall in the exhibition building, with similar flow of people and indoor cooling and heating loads. | Both buildings are for display, with similar lighting power density Except necessary display equipment and computer, there are few other indoor electrical equipment. The air-conditioning system is similar, with the VRV as the dominant air-conditioning system |

From April 2019 to October 2019, the China Pavilion was in normal operation, and received a large number of tourists. The period from October 2019 to March 2020 was the off-season for tourists. According to Figure 13, the annual non-heating energy consumption of China Pavilion from April 2019 to March 2020 was lower than the standard constraint value and the guiding value.

Table 3. Constraint value and the guiding value of the non-heating energy consumption index of commercial buildings.

| Building types | Severe cold and cold regions | Hot summer and warm winter zone | Hot summer and cold winter region | Temperate zone |
|----------------|-----------------------------|--------------------------------|----------------------------------|----------------|
| Type A         | Constraint value | Guiding value | Constraint value | Guiding value | Constraint value | Guiding value | Constraint value | Guiding value |
| General 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             |
| General shop   | 60                       | 45                   | 90                       | 70                      | 85               | 65              | 55                  | 40             |
| restaurant     | 55                       | 40                   | 90                       | 70                      | 85               | 65              | 55                  | 40             |
In conclusion, the results showed that the climate-adaptive green design enabled the China Pavilion to lower the total energy consumption below the guiding value, proving the efficiency of the design in energy conservancy.

4. Conclusion
This paper studied the layout of the construction site, the passive design of functional space of architecture, and the enclosure structure and material of the roof and walls in the cultural and ecological context based on the cold climate of the Beijing-Tianjin-Hebei region. This paper evaluated the energy consumption and comfort level of the building through tests of the physical environment, indoor and outdoor environment, and energy consumption, and validated passive designs of improved ventilation, earth-sheltered insulation, enhanced illumination and green space. The energy consumption of China Pavilion is below the Energy Consumption Standard for Civil Buildings (GBT 51161-2016), which indicates that the design can not only improve comfort, but also adapt to local climate conditions, thus effectively reducing energy consumption and meeting the standard.

The designs and feedback proposed in this study included: 1) a proper layout of buildings to improve ventilation in summer and block wind in winter. Meanwhile, a yard could be added to the design of the sheltered earth, underground space or large space with poor ventilation to form thermal pressure ventilation. The test results showed that this strategy has effectively improved the spatial and physical environment of the building. 2) The sheltered earth could be applied to space with low lighting requirement and high standard on the physical environment. The results showed that the design had a sound performance in heat insulation in summer and winter, thus effectively reducing energy consumption of the building. 3) The roof system with glass and ETFE film was used in the space with a tough demand on lighting. The results showed that the roof design greatly reduced artificial lighting, thus lowering energy consumption of the building. 4) Green spaces like grass, shrubs and trees should be properly arranged on the site or in combination with the earth-sheltered design. The results showed that the green space improved the comfort of the microenvironment.

Based on the above strategies and feedback, this research takes human perception as the basic requirement and forms a process path that starts with evaluation and ends with feedback, thereby promoting the formation of a closed-loop chain of green design methods and processes.

Acknowledgments
This project, entitled Design and Demonstration of Green Public Buildings Adapting to Cold Climate, is a subject of the New Design and Demonstration of Regional Climate-adapted Green Public Buildings (2017YFC0702300), which is supported by the National Key R&D Program.

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