Environmental Science

http://www.aimspress.com/journal/environmental

AIMS Environmental Science, 6(6): 460–471.
DOI: 10.3934/environsci.2019.6.460
Received: 05 September 2019
Accepted: 12 November 2019
Published: 03 December 2019

Research article

Research on the applicability of passive house technology in areas hot in summer and cold in winter-take Nanjing area as the research object

Shenwei Yu* and Mengqiu Yang

North China Power Engineering Co.,Ltd. of China Power Engineering Consulting Group, Langfang Development Zone, Hebei Province, China

* **Correspondence:** Email: 513184837@qq.com.

Abstract: In this study, to explore the applicability of passive house technology under PHPP assessment standards in Chinese areas hot in summer and cold in winter, Nanjing area was taken as an example, real cases were examines under PHPP assessment standards for passive houses in line with regional climatic differences. The present study focused on four aspects, namely the thermal insulation & heat preservation properties of the external enclosure structure, the mildew-growing temperature of the interior wall, the air-tightness property of the external enclosure structure, as well as the damp-proof performance of buildings. A numeric analysis was conducted using Dest software, and the German PHPP assessment standards for passive houses were eventually found not entirely applicable to Chinese areas hot in summer and hot in winter. Thermal insulation, damp-proof, and vapor-proof properties should be considered when designing passive house projects for such areas. Based on influential factors, this study proposed the climatically-reconstructed design for the external enclosure structure of passive houses and employed Energyplus for demonstration and analysis. Analytical findings suggested that the reconstruction plan is feasible.

Keywords: passive houses technology; areas hot in summer and cold in winter; applicability

1. Introduction

Passive houses [1] have originated from Germany and been developing for nearly three decades. The application thinking is to adjust clean energy (e.g., solar energy and geothermal energy) to maintain indoor comfort without the application of active cooling and heating; it is an effective and energy-conserving form of architecture. The enclosure structure of passive houses exhibits excellent thermal insulation and air-tightness properties. In the meantime, special treatment of the hot & cold bridges, central ventilation, and residue heat collection system in buildings are conducted, thereby effectively reducing energy exchange both in and outside the house. It can satisfy over 90% of indoor heating demands through the local heat source even in cold winter, maximizing the utilization of natural resources. Thus far, numerous passive house projects have been achieved in China. These houses are primarily concentrated in severely cold areas. Nevertheless, most scholars only studied these cases from the perspectives of applying, discussing, introducing, and testing energy-conservation technology of passive houses. For instance, Wang Hongtao delved into the application of energy-conserving technology and analyzed the development trend with relevant demonstration projects [2–5]. Wang Zhaojun et al., together with the Ministry of Housing and Urban-Rural Development, tested the indoor air temperature of passive house projects to explore the indoor environment in winter [6–8]. China enjoys a vast territory, a wide latitudinal span between the north and south, as well as large climatic variations. If the technology relevant to passive houses is applied in China rigidly, its advantages cannot be manifested. Thus, this study studies the climatic characteristics of Chinese areas hot in summer and cold in winter. It makes a qualitative discussion of methods for applying passive houses to areas hot in summer and cold in winter through software simulation and numeric analysis.

2. Interpretation of passive houses based on climatic characteristics

The geographical locations of China and Germany are presented in Figure 1. Germany refers to a federal republic country in Central Europe, with the capital of Berlin. This country primarily has a temperate climate. China is a socialist country in Asia, with the capital of Beijing; it primarily has monsoon climate, temperate continental climate, as well as alpine climate. In comparison, China has more climate types and larger differences between extreme temperatures. It is thus unlikely to introduce PHPP assessment standards for passive houses blindly. Furthermore, the scientific application of relevant technology is worth subsequently studying.

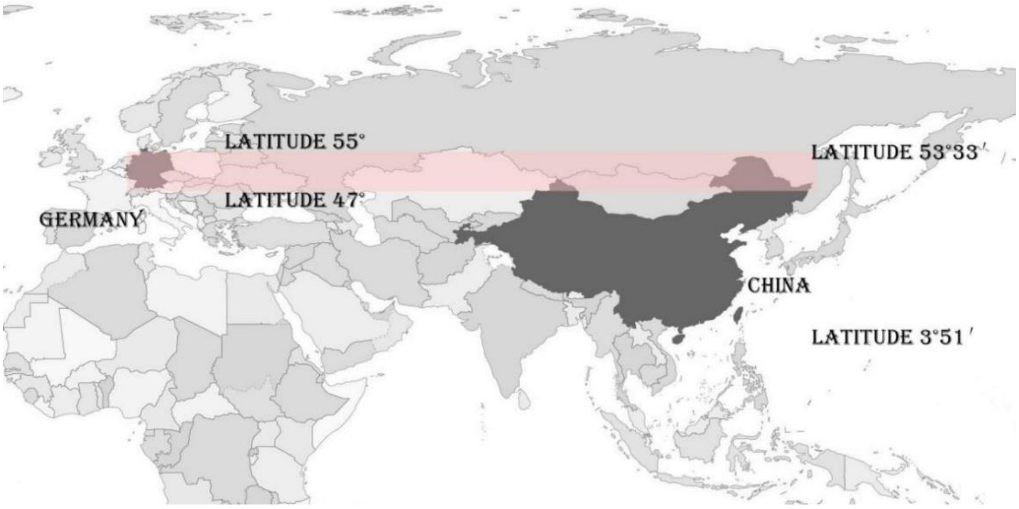


Figure 1. Analysis of differences between geographical locations.

The Chinese areas hot in summer and cold in winter (hereinafter referred to as HSCW areas) refer to the partial areas of 14 provinces (municipalities), covering Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, as well as Guizhou. These areas have a large thermal division area, and their climatic characteristics differ from those of the German climate. Germany has a moist winter and a large rainfall, with an average daily temperature of 0–5 °C. The summer is dry and cool at the average daily temperature of 20–28 °C. The Chinese HSCW areas have a humid, cold winter and a scorching summer, with the average daily temperature of −5–10 °C and raining and hotness in the identical period [9]. In terms of the monthly temperature and humidity in Germany, the designs of passive houses primarily consider architectural thermal insulation. The designs for passive houses in Chinese HSCW areas should rigorously consider the impact from architectural thermal insulation and environmental humidity on the design to ensure the thermal insulation performances of buildings. According to the mentioned reasons, the PHPP assessment standards for passive houses are not entirely applicable to countries with a large latitudinal and longitudinal span. Besides, the high temperature and high humidity characteristics of HSCW areas will inevitably affect the thermal comfort of passive houses.

3. PHPP indicators for passive houses based on parameter analysis

Nanjing was taken as the typical representative city. In this study, a theoretical analysis was conducted given the data and research achievements of the master’s dissertation [10]. Nanjing is located in the HSCW areas of the thermal division zone. Its summer is stuffy and rainy, while its winter is humid and cold. In the meantime, the D-23 residential public service project, a typical case of passive houses with ultra-low energy consumption in Beijing Municipality, was studied to analyze whether the building applies to Nanjing under the PHPP assessment indicators for passive houses [11].

3.1. Overview on passive house project

The passive ultra-low energy project, undertaken by the Technology Development Center of Beijing Uni. Construction Group Co., Ltd, is one of the first batches of architectural projects for the demonstration projects of ultra-low energy consumption in Beijing Municipality. The project adopted six energy-conservation technologies according to its characteristics, namely high-performance enclosure structure thermal insulation, high-performance windows with three pieces of glass and two argon layers, the exquisite processing with no heat bridge nodes, complete architecture air-tightness layer, central ventilation system with high-efficient heat recovery, and renewable energy utilization of GSHP (Ground Source Heat Pump). The project has now been completed and passed the air-tightness test. The basic information of the project is listed in Table 1 as follows:

Table 1. Overview on D-23 residential public service project—an architectural engineering case for passive houses with ultra-low energy consumption in Beijing Municipality.

Architectural property	Rehabilitation center for people with disabilities	Floor height	12m
Construction area	Ground: 3, floors: 1719m^2	Shape factor	0.29
	Underground: 1 floor; 800 m^2	Structural form	Frame structure
Application indicators for enclosure structure technology			
Position	Material	Thickness	Heat transmission coefficient
Outer wall	Rock wool band	300 mm	0.14 W/(m^2·K)
Roof	XPS	300 mm	0.11 W/(m^2·K)
Floor	XPS	250 mm	0.13 W/(m^2·K)
Application indicators for energy-conservation window technology			
Energy-conservation windows	PVC windows with 3 glass layers and 2 argon layers 5 Low−E+18Ar+5+18Ar+5Low−E Insulating glass with warmth edges; PVC window frames. The windows are built in walls, with air-tight adhesive tapes sealing all cracks. The windows are opened inwardly and downwardly.		
Overall heat transmission coefficient	0.8 W/(m^2·K)	SHGC	≥0.45
Air-tightness Level	Level 8	Water tightness level	Level VI
Wind-resistance property	Level 9	Installation position	In the thermal insulation layer
Indicators of efficient heat recovery & central ventilation system			
Central ventilation group	Total heat recovery & central ventilation system	Temperature exchange rate	≥75%
Enthalpy exchange efficiency	≥70%	Filtration efficiency	>90%
Fan consumption power of heat recovery device per unit air volume	<0.45W/(m^3/h)		
Application of renewable energy			
Geothermal energy	Geothermal heat pump group		

3.2. Thermal functions of external envelop structure

The performances of the external envelop structure are primarily dependent of the composition materials and thickness of walls. The assessment indicator refers to the overall heat transmission coefficient. The higher the heat transmission coefficient, the worse the thermal performances walls will exhibit. If walls exhibit a poor heat transmission coefficient, during the heating period, the temperature on the surface of external walls can drop below the mildew-growing temperature. As a result, dews can occur on wall surfaces and cause mildew, thereby affecting indoor air quality and reduce the level of health and comfort. The International Energy Agency defines the critical value of mildew germination at the relative humidity of 80%. The German PHI proposed methods to calculate mildew-growing temperatures in walls. Its calculation formula is expressed as follows: [2]

$$P_{sat}(\theta_i) * RH_1 = P_s * RH_2 \tag{1}$$

In the Eq 1, $P_{sat}(\theta_i)$ denotes the saturated vapor pressure at the mildew-growing temperature; RH_1 refers to the critical value of mildew germination and has the value of 80%; P_s indicates the saturated vapor pressure at the environmental temperature; RH_2 represents the relative humidity in the current environment. $P_{sat}(\theta_i)$ can be calculated by Eq 1. In the meantime, the corresponding mildew temperature θ_i can be found from the table of saturated vapor pressure. The temperatures unfavorable for mildew in and outside walls in Beijing and Nanjing can be calculated using the mentioned method. All calculation results of parameters are listed in Table 2.

Table 2. Analysis of mildew growing temperatures of external walls in Nanjing and Beijing.

Location	Season	Indoor temperature (Tested)	Indoor relative humidity (Tested)	Poor mildew growing temperature (Calculated)
Beijing	Winter	18–20 °C	20–40%	6.95 °C
	Summer	20–26 °C	40–70%	21.11 °C
Nanjing	Winter	10–15 °C	40–70%	12.98 °C
	Summer	28–31 °C	70–90%	32.8 °C

According to the mentioned calculation results, the mildew growing temperature on the interior surface of the external walls is lower than the normal indoor temperature in summer and winter in Beijing. Thus, vapor will not turn into dews. In contrast, during the fluctuations of indoor temperatures in Nanjing, the mildew growing temperature on the interior surface of external walls takes place. As affected by high temperature and humidity in summer, the mildew growing temperature reaches over the indoor temperature. Moreover, vapor may lead to the formation of dews and cause mildew on wall surfaces in both winter and summer, thereby affecting the sanitation of the indoor environment, causing safety hazards, and jeopardizing residents' mental and physical health.

Furthermore, cyclical heat transmission laws can be found outdoors in HSCW areas in summer. Thus, the thermal insulation performances of external enclosure structures of buildings should be considered rigorously. The thermal storage coefficient and thermal inertia index of wall materials are two critical indicators in the assessment of the thermal insulation performances of architectural enclosure structures. As impacted by the identical temperature wave, the higher the thermal storage coefficient and thermal inertia index, the more the stable thermal performances walls will exhibit. Besides, the more obvious the attenuation to cyclical temperature waves, the better the indoor comfort will be. For this reason, thermal insulation designs should be made by combining the physical characteristics and formulas of relevant materials and the formulas of (2), (3), and (4) [12].

$$V_0 = 0.9\mathrm{e}^{\frac{\sum D}{\sqrt{2}}} * \frac{S_1+\alpha_i}{S_1+Y_1} * \frac{S_2+Y_1}{S_2+Y_2} * \frac{Y_2+\alpha_e}{\alpha_e} \tag{2}$$

$$S = \mathrm{b}\sqrt{\frac{2\pi}{T}} \tag{3}$$

$$D = RS = \mathrm{d}\sqrt{\frac{2\pi}{T\mathrm{a}}} \tag{4}$$

In Eq 2, V_0 denotes the attenuation of thermal insulation materials; D represents the thermal inertia index of materials and $D = R{\cdot}S$; S refers to the thermal storage coefficient of the material; α_i and α_e denote the thermal exchange coefficients of the interior and outer surfaces, respectively; Y indicates the heat storage coefficient of the exterior surface. In Eqs 3 and 4, a denotes the coefficient of thermal diffusion (m^2/s); b represents the thermal penetration coefficient ($\mathrm{J}/(\mathrm{m}^2{\cdot}{}^\circ\mathrm{C}{\cdot}\mathrm{S}^{0.5})$); d indicates the thickness of the material layer.

3.3. Air-tightness level of passive houses

The average wind speed in Beijing is 3.4 m/s in winter and 1.5m/s in summer. The average wind speed in Nanjing is 2.7 m/s in winter and 2.4 m/s in summer. In the meantime, the HSCW areas differ from cold areas, since there are fewer temperature differences in winter. Accordingly, there are differences between the requirements to hinder cold wind penetration in passive houses. For the designs of passive houses in HSCW areas, the application demands for architecture in summer should be considered. Also, the overall air tightness level of architecture should be down-regulated appropriately to organize effective natural ventilation.

3.4. Damp-proof designs of passive houses

The German PHPP assessment standards for passive houses involve no architectural damp-proof designs. As affected by regional differences, nevertheless, the average annual humidity of Nanjing ranges from 60% to 90%. If the architectural enclosure structure is in a highly humid environment for a long time, its heat transmission coefficient will be affected. Taking the aerated concrete building blocks that are commonly used in Nanjing as an example, long-term exposure to environment humidity down-regulates the heat transmission coefficient, and the correction factor of heat transmission is nearly 1.132 [13]. If improperly used, the thermal performances of the architectural external enclosure structure are noticeably lower than the ideal design value. Accordingly, the design for the external enclosure structure of HSCW areas should rigorously consider the anti-proof and air-tightness designs for walls.

In brief, the direct application of German PHPP assessment indicators for passive houses to the passive house design project in Nanjing may cause a range of problems. Thus, specific problems should be analyzed, and design strategies should be optimized in practical application.

4. A Study on the applicability of PHPP assessment indicators for passive houses in Nanjing

4.1. Numeric simulation analysis

Two working conditions were simulated according to the energy consumption analysis of Dest software: The PHPP assessment indicators for passive houses are used to simulate energy consumption for ultra-low energy consumption houses and work out the information related to working condition A (Table 3). Next, this system is applied to Nanjing for simulation, get the working condition B (Table 3), and analyze differences between energy consumption.

Table 3. Simulation of energy consumption working conditions for passive houses.

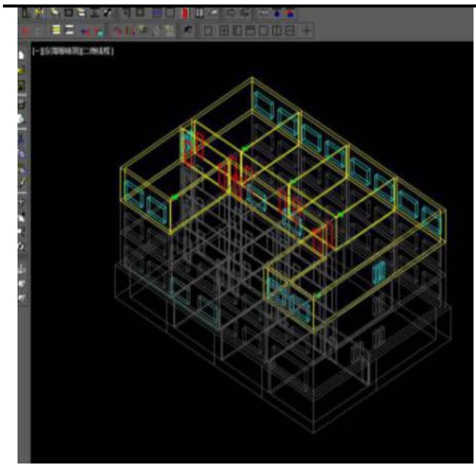
	Type	Work condition A	Work condition B
	Geographical position	Beijing	Nanjing
	Annual maximum heat load	81.68 kW	57.97 kw
	Annual maximum cooling load	121.24 kW	108.41 kW
	Annual accumulative heat load	150191.13 kw·h	101779.65 kw·h
	Annual accumulative cooling load	74364.94 kw·h	121520.20 kw·h
	Heat load index in heating period	19.91 W/m^2	14.75 W/m^2
Construct model and set parameters through dest	Cooling load indicator in AC season	14.18 W/m^2	22.59W/m^2

Table 3 suggests that there are significant differences between the energy consumption of passive houses in Nanjing and Beijing under the identical PHPP indicator. The buildings in Nanjing have a lower sum of heat and cooling load, as primarily reflected in the low requirements for heating rather than centralized heating in winter. Besides, the cooling load and indicator requirement in the AC season of Nanjing are much higher than those of Beijing. Thus, it is suggested that the architectural comfort of Nanjing in summer is more unacceptable. Figure 2 can prove this opinion. According to the hourly AC loads in two regions, Nanjing exhibits a higher cooling load, a longer time cycle, and the identical cooling and heat load. The following conclusion can be drawn: The passive houses in Nanjing should combine heat preservation and thermal insulation in winter. In the meantime, the thermal insulation design should be better than heat preservation design. It is widely different from the PHPP assessment indicators for passive houses. Accordingly, the German PHPP assessment indicator of passive houses should not be taken as the referential basis for designing passive houses with ultra-low energy consumption in this region

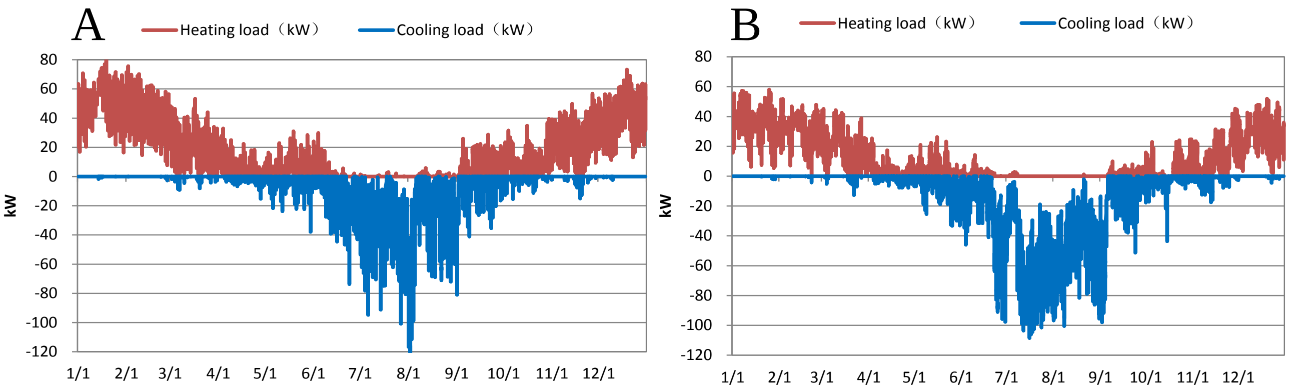


Figure 2. Hourly AC load of buildings. A: Hourly AC load of passive houses in Beijing; B: Hourly AC load of passive houses in Nanjing.

4.2. Regionally optimal designs for passive houses

The wall structure sample of passive houses is illustrated in Figure 3a, primarily consisting of nine construction layers, including the mixed mortar, aerated concrete building blocks, interface mortar, binder, rock wool bar, binder leveling layer, anti-breaking mortar grid cloth, flexible base coating, as well as flexible coating. The comprehensive heat inertia indexes of this wall were calculated, respectively; all calculated parameters are listed in Table 4.

Table 4. Heat unertia indicator and attenuation of walls.

Types of materials	Material heat storage coefficient (S) W/(m^2·K)	Material thickness (mm)	Heat transmission coefficient(W/m·K)	Material heat inertial index (D)
Mixed mortar	10.63	15	0.87	0.18
Aerated concrete mortar	3.60	200	0.2	3.61
Water-proof construction	3.30	10	0.17	0.194
Air tightness layer	3.30	10	0.17	0.194
rock cotton bar	0.60	300	0.05	3.6

According to the parameter calculation of Table 4, the heat inertia index *D* of the wall sample was approximately 7.75. The calculation formula of attenuation *Vo* (only considering the relationship between the subject structure and thermal insulation position) is written as (5):

$$V_0 = 0.9e^{\frac{\sum D}{\sqrt{2}}} * \frac{S_1+\alpha_i}{S_1+Y_1} * \frac{S_2+Y_1}{S_2+Y_2} * \frac{Y_2+\alpha_e}{\alpha_e} \tag{5}$$

In Eq 5, S_1 denotes the heat storage coefficient of wall materials; Y_1 refers to the heat storage coefficient of wall materials. If $D \geq 1$, $S_1 \approx Y_1$; $S2$ represents the heat storage coefficient of the thermal insulation material of rock wool bars. Y_2 indicates the surface heat storage coefficient of thermal insulation materials. α_i is 8.7 W/m^2·K, and α_e is 19.0 W/m^2·K. Specific parameters are substituted to obtain Eq 6 for the attenuation of simple harmonic waves of the external thermal-insulation walls:

$$V_0 = 1.76 * \frac{(S_2 + 8.7) * (S_1 + S_2) * (S_1 + 19.0)}{S_1 * S_2} \tag{6}$$

By building the thermal insulation layer inside, $V_0^{\angle}$ is expressed as:

$$V_0^{\angle} = 1.76 * \frac{(S_1 + 8.7) * (S_1 + S_2) * (S_2 + 19.0)}{S_1 * S_2} \tag{7}$$

According to the *Design Specifications for Thermal Designs of Civil Architecture* [14], $S_1 = n \cdot S_2$. n is about 6, leading to the Eq 8 below:

$$V_0 - V_0^{\angle} = -k * \frac{n+1}{n} \tag{8}$$

In Eq 8, k denotes the parameter and depends on the differences between the thermal storage coefficients of materials. In this study, the value of k was about 90.64, and the difference between attenuation to temperature waves was nearly 105.75. It is suggested that the calculation results of Eq 8 were constantly lesser than 0. The following conclusion could be drawn: If the composition layers of walls are the identical, the external walls with internal thermal insulation will exhibit better thermal insulation performances than walls with external heat preservation. It is therefore more reasonable to adopt internal thermal insulation for the walls of passive houses in HSCW areas.

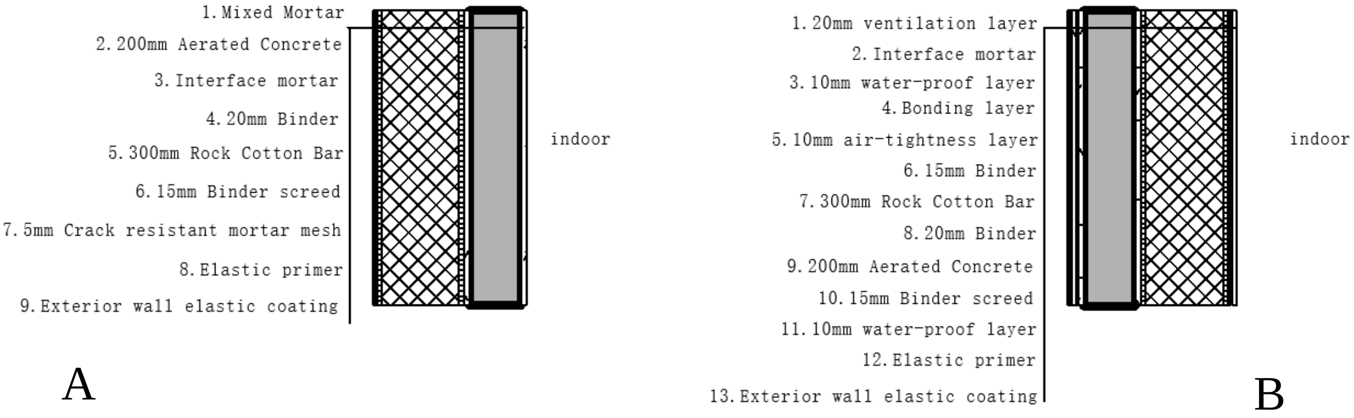


Figure 3. External wall sample of passive houses. A: The wall structure sample of passive houses; B: Reconstructed external wall structure of passive houses.

The damp-proof and air-tightness designs are indispensable for the in-built heat preservation system. Thus, a water-proof layer consisting of SBS modified asphalt membrane was set both inside and outside the wall. In the meantime, to keep the heat preservation layer dry, a vertical vapor barrier layer was set on the interior end. Besides, a vapor barrier layer could be set to address mildew growing on the interior surface of the external wall. It was set given the following requirements: (1) Hydrophobic materials are adopted to make it difficult for vapor to form dews on the wall surface; (2) The wall cellular is made to form several cavities and increase the area for walls to contact indoor air.

On one hand, it enhances the convection evaporation capacity of walls to prevent dews and mildew growing. On the other hand, evaporation should absorb heat from the architectural environment, which positively impacts the indoor environment. The reconstructed external wall structure of passive walls is illustrated in Figure 3b.

4.3. Strategy demonstration

A research unit of 6m*6m*6m was performed using Energyplus. It was split into four thermal zones. In the meantime, relevant information was set with IDF-Editor: (1) Construction site: Beijing/Nanjing; (2) Type: Medical building; (3) The category of energy consumption was simulated: annual heating and cooling; (4) Materials of architectural walls (Figure 3 and Table 4); (5) Construction windows (Table 1); (6) Typical days of construction calculation: winter solstice and autumnal solstice; (7) Normal construction time: 8:00–17:30; (8) Number of people in the house; (9) The design temperature was 26 °C in summer and 20 °C in winter. The outdoor design temperature refers to regional climatic data. The construction layer of the envelope structure was taken as the only parameter to simulate the energy consumption during architectural operation and to delve into the reconstruction strategy. All simulation results are listed in Table 5.

Table 5. Parameters of demonstrating the passive house strategy.

Type of energy consumption	Beijing	Nanjing	Nanjing (Reconstructed)
Total site energy	63880.23 kWh	55880.36 kWh	53794.47 kWh
Total source energy	199480.42 kWh	156015.84 kWh	149697.70 kWh
Site energy per area	443.61 kWh/m^2	388.06 kWh/m^2	373.57 kWh/m^2
Source energy per area	1385.28 kWh/m^2	1083.44 kWh/m^2	1039.57 kWh/m^2

The data listed in Table 5 suggest that HSCW areas exhibit lower architectural energy consumption than alpine areas under the identical PHPP assessment standards for passive houses. The difference in energy consumption is primarily attributed to lower heating energy consumption in HSCW areas. By comparing the differences in architectural energy consumption of passive houses before and after reconstructing the applicability of passive houses, it was reported that the external envelop structure with internal thermal insulation exhibited low energy consumption. This finding is primarily because the reconstruction facilitates the attenuation of architectural walls to cyclical temperatures, enhances the thermal insulation properties of architectures, and lowers the architectural cooling load in summer. In brief, the internal heat preservation system should be adopted for passive houses in HSCW areas.

5. Conclusions

Based on climatic differences, this paper studied whether the German PHPP assessment standards apply to HSCW areas in China. The following conclusions were drawn by relevant simulations, comparisons, and analyses.

(1) The mildew-growing temperature on the interior surface of external walls in Nanjing areas is 12.98 °C in summer and 32.8 °C in winter, both of which follow the fluctuation range of environmental temperatures, probably causing dews and mildew.

(2) Nanjing areas are impacted by the temperature, humidity, wind speed, and vapor in the environment. The thermal insulation, air-tightness, and anti-proof properties of buildings should be

overall reconsidered. It is accordingly fully suggested that the passive house technology under PHPP assessment standards do not fit this thermal zone.

(3) The results of calculation analysis suggests that indoor heat preservation structure should be adopted for the external walls of passive houses in Nanjing areas. In this mode, compared with walls with external thermal insulation structures, external architectural walls display a better attenuation to cyclical temperature waves. The difference between attenuation is approximately 105.75, suggesting that internal heat preservation is better to maintain the stability of the heat environment in buildings.

(4) The applicability reconstruction of passive houses in Nanjing areas primarily optimizes the enclosure structure by building the heat preservation layer and adding the water-proof layer, air-tightness layer, as well as ventilation layer. Moreover, model demonstration and analysis were conducted using Energyplus. It was reported that the reconstructed buildings displayed a significantly declined energy consumption. It is suggested that passive houses technology can apply to passive house designs in Nanjing areas. Nevertheless, these standards are not the referential basis for optimal energy conservation. Such standards require a regional study. Apart from making houses passive, efforts should be made to substantially reduce architectural energy consumption, develop the optimal regional solution for passive houses technology under PHPP standards, and truly adapt passive houses to Chinese conditions.

Acknowledgments

This project is supported by Innovation fund for postgraduates of Hebei institute of architectural engineering.

Conflict of interest

The authors declare no conflict of interest.

References

1. John B (2019) Passive House Canada actively pursues Eastern Canada growth. *Daily Commercial News* 92: 150.
2. Wang HT, Liu YJ (2016) A discussion about Zhongde Energy Conservation Demonstration Project of Shenyang Jianzhu University. *Constr Budget* 12: 50–52.
3. Wang CL, Chu HL, Wang HT (2016) A study on the heat transmission coefficient of external walls in passive buildings with ultra-low energy consumption. *Building Ener Eff* 44: 65–67.
4. Wan CL, Wang HT, Shan B, et al. (2015) A testing analysis of the performances of external windows in passive houses with ultra-low energy consumption. *Building Technol* 19: 34–36.
5. Wang HT, Hou P, Weng D (2013) China Society for Environmental Sciences, Collection of Outstanding Papers of Environmental Protection for Puhua of Academic Annual Conference of CSES [C]. China Society for Environmental Sciences.
6. Ji YC, Wang ZJ, Su XW (2019) A study on the heat exchange performance experiment of radiating floor slabs of passive houses in extremely cold regions. *Gas & Heat* 39: 16–22.
7. Wang ZJ, Ji YC, Xue QW, et al. (2018) A study on the indoor environment of passive houses in ultra-low energy consumption in winter of extremely cold areas. *HAVC* 48: 66–70.

8. Wangn ZJ, Xue QW, Yu ZY, et al. (2017) A test and analysis of heat exchange efficiency of passive houses with ultra-low energy consumption in extremely cold areas. *Building Sci* 33: 21–25.
9. Nanjing Bureau of Statistics (2010) Nanjing Statistical Yearbook, Beijing: China Statistics Press.
10. Yu SW (2019) A study on the architectural energy conservation and reconstruction strategies based on BIM technology. Hubei University of Architecture.
11. Cai Q, Zhang ZR, Xie F, et al. (2017) D-23 residential public service project-an engineering case of architectural projects with ultra-low energy consumption in Beijing. *Const Sci Technol* 17: 39–41.
12. Liu JP (2009) Construction physics. 4 Eds. Beijing: China Building Industry Press.
13. Yu SW, Wang JK (2018) A study on the heat transmission coefficient of aerated concrete building blocks under the moisture state. *J Bohai Univ (Natural Sciences)* 39: 309–314.
14. China Academy of Building Research (2016) Design Specifications for Thermal Engineering of Civilian Buildings. Beijing: China Building Industry Press, 1–75.