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RETRACTED: Climate Adaptability Analysis on the Shape of Outpatient Buildings for Different Climate Zones in China Based on Low-Energy Target

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Abstract: Under the impact of COVID-19 and the needs for urban expansion, a large number of outpatient buildings have been rapidly constructed, but the problem of high energy consumption has always been ignored. There is a lack of research on the adaptability of building shape in different climate zones. Many studies have shown that a reasonable shape in the early stage of design can significantly reduce the energy consumption of buildings. Therefore, it helps if architects quickly select a reasonable shape that can effectively reduce energy consumption. This study summarized a number of outpatient building cases in China and proposed three typical building shapes: centralized-type (Shape-1), corridor-type (Shape-2), and courtyard-type (Shape-3). The Design Builder tool was used to simulate and analyze the typical building energy consumption in different climate zones. The simulation results show that Shape-2 (angle: 0°) should be chosen in severe cold zone; Shape-1 (angle: 90°) should be chosen in cold zone; Shape-1 (angle: 0°) should be chosen in hot summer and cold winter zone; Shape-1 (angle: 60°) should be chosen in hot summer and warm winter zone; and Shape-1 or Shape-2 can be chosen in warm zone. The results of this study can provide suggestions for the energy saving design of outpatient buildings in China and other areas with similar conditions. The result can help architects make rapid shape selection in the early stage of design.

Keywords: outpatient buildings; building shape; building energy consumption simulation; climate zones; climate adaptability

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1. Introduction

In the past decade, China's health services and hospital construction have sustained rapid development, with various types of data increasing exponentially (Figure 1). According to the data from China's Bureau of Statistics [1], in 2021, the number of hospitals increased from 21,600 to 37,000, which was about 1.7 times that of 2011, and the total number of hospital beds increased from 3.68 million to 7.48 million, which was about twice that of 2011. However, the high energy consumption of hospital buildings has not been solved. Hospital building is a special building that operates 24 h and provides multifunctional services. The data show that hospital energy consumption is higher than general public buildings [2,3]. Due to the large population, high usage frequency, and high population density, the energy consumption of hospital buildings in China is about 1.5–2 times that of general public buildings and more than twice that of similar hospital buildings in developed countries [4]. In addition, with the increase in the equipment used, the damage to building envelope structure, the lack of operational management, and many other uncertain reasons, the data on energy consumption show a trend of increasing year by year, about 5–10% per year [5]. From the perspective of energy consumption distribution, outpatient buildings and inpatient buildings account for about 30–70% and 25–40%, respectively [6].

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The heating and cooling energy consumption accounts for the largest proportion [7–10]. Therefore, it is very important to reduce the energy consumption of outpatient buildings.

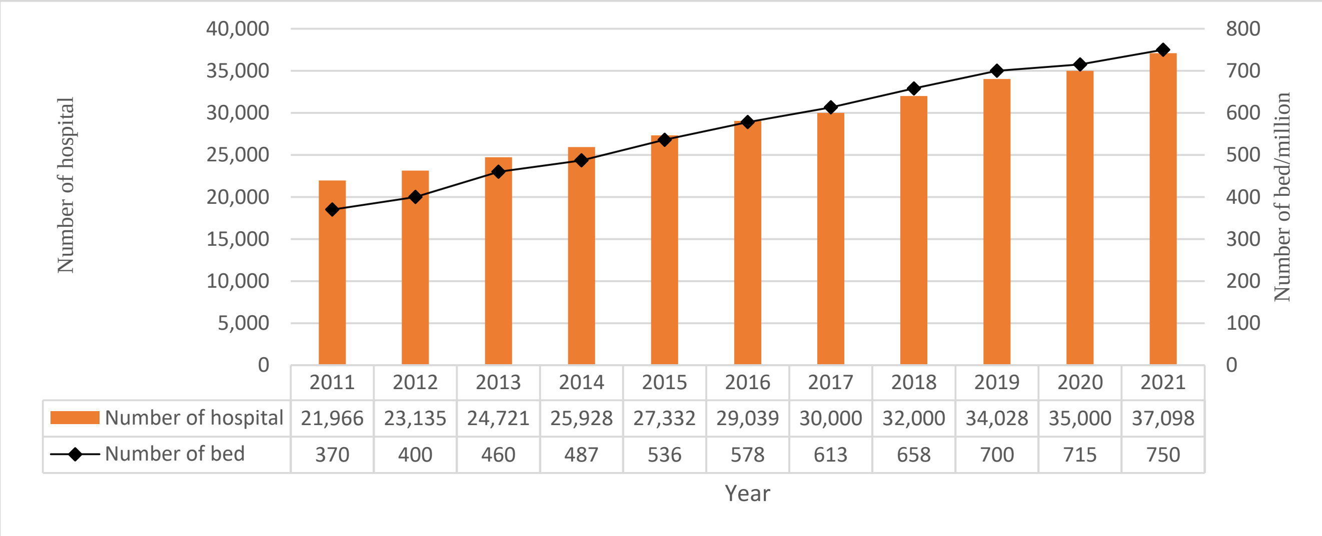


Figure 1. The change in the number of hospitals in China, 2011–2021.

The high energy saving potential during the design stage has been repeatedly demonstrated by various scholars. In the design stage, the design parameters have a significant impact on building energy consumption [11], with more than 40% of the building energy saving potential coming from the design stage [12]. Previous research results have shown that the energy saving effect of a reasonable building shape is far better than that of technological measures used in the design stage [13,14]. At present, the research on energy-saving design mainly includes the following directions: (1) Comparative research that focuses on different building shapes under the same climate condition. For example, Ligang, L. et al. [15] showed that, in the same cold climate, the energy consumption variation between different shapes can be as much as 17%. (2) Research studies that focus on the correlation between climatic factors and architectural form design. For example, Yeretzian Ara et al. [16] proposed a method to determine the optimal building shape according to the demand of incoming solar radiation, which was used to improve the design process of building shape in the early stage. Shiliang, W. et al. [17], with the help of the Ladybug Tools, proposed a climate adaptive design method for shading systems in the early stage of the scheme. (3) Research studies that focus on the local design of buildings. Jain, N. et al. [18] achieved the improvement of indoor air quality under the condition of low energy consumption by optimizing the management mode. Haijing, L. et al. [19] simulated seven cities in four thermal climate zones, and the results showed that the influence of shading differed significantly under different scenarios, with the variation range of cooling load proportion being about 45% and that of heat load proportion being about 21%. Asim, N. et al. [20] proposed measures to improve the efficiency of HVAC system by analyzing related factors affecting the selection of HVAV system in the early design stage, so as to reduce the operation energy consumption. 4) Comparative studies that focus on the applicability of energy consumption simulation software in the design stage. For example, Panagiotou Dimitrios, K. et al. [21] compared three different energy consumption prediction tools: Artificial Neural Networks, ANFIS, and LSTM Network, which provided help for the selection of prediction tools in different scenarios.

The above research put forward methods and suggestions for the early energy saving design, which has a great significance for reducing building energy consumption. Most of the research results are based on the analysis of building energy consumption under the same climate condition. China has a vast area, including five climatic zones, and the climatic conditions are quite different. So far, the influence of different climates on the energy consumption of building shape has not been quantified, and there is a lack of comparative research on the energy consumption of different shapes in different climatic zones. In addition, many factors can affect energy consumption in different ways. For example, functional layout, window/wall ratio, shading mode, and other factors are quite different even in the same area, and many studies are not representative enough to be generalized. Therefore, in order to clarify the energy consumption of different shapes under different climate conditions, other building parameters have been kept unchanged in the energy consumption simulation. This paper analyzes the energy consumption of three shapes and compares the differences in energy consumption in five climate zones. Some recommendations are provided for the selection of outpatient building shape in different climate zones. Under the target of reducing energy consumption, it can help architects select a reasonable building shape.

Through the analysis above, it can be found that the initiative of architects plays an irreplaceable role in the process of green building design. Energy consumption simulation is the most effective way to help architects optimize energy saving strategies and understand energy consumption results [22]. Energy consumption simulation is performed simultaneously with the start of architectural design and runs through the whole design process (Figure 2), providing architects with the possibility of energy-saving design optimization at different stages from concept generation to construction drawing design. In addition, with increasing design depth, the accuracy of energy consumption simulation calculation, the constructive feedback, and the attention to detail also increase [23].

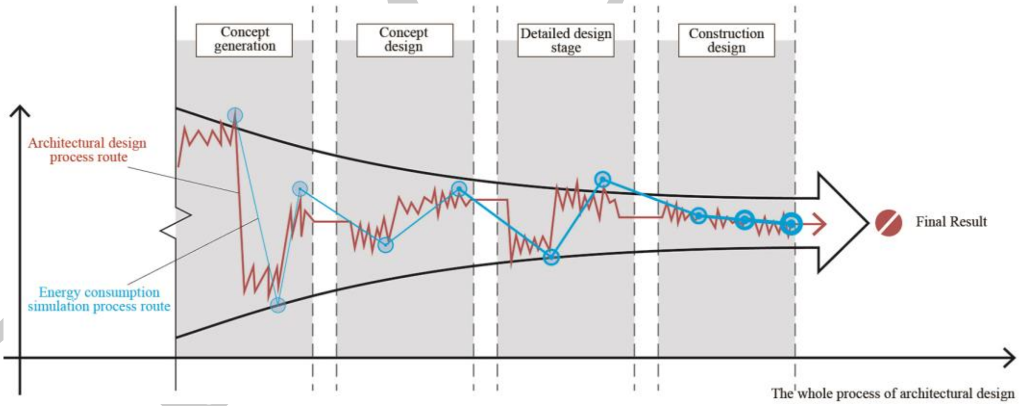


Figure 2. The synergetic relationship between energy simulation and architectural design.

2. Methodology

To study the climate adaptability of general outpatient buildings, the adopted methodology is as follows:

Firstly, according to the literature and case survey, classify the outpatient buildings and then establish the typical models for energy simulation. Secondly, select the appropriate simulation software and set the parameters, and identify the research objects and targets (heating and cooling energy consumption). Finally, analyze the simulation results, clearly identifying the reasonable building shape for different climate zones.

In the whole process of analysis (Figure 3), a key problem is how to build a typical model and set the simulation parameters.

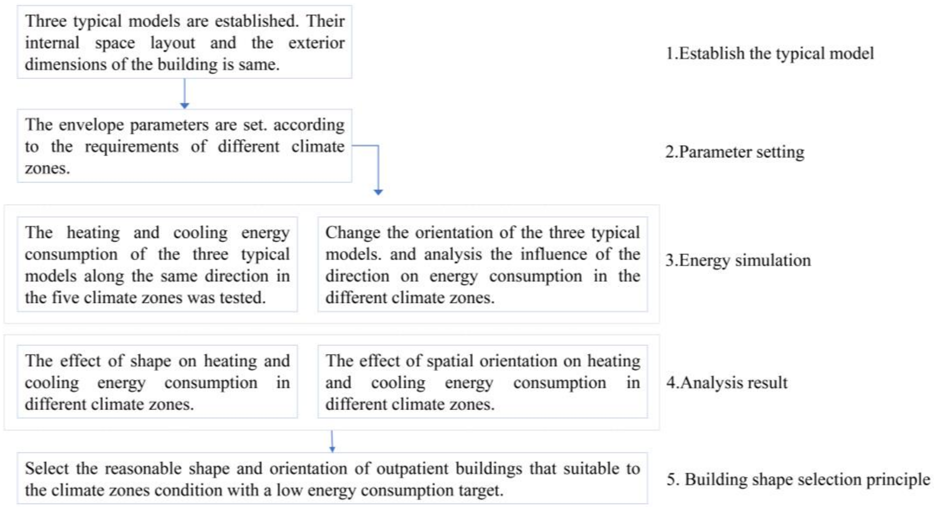


Figure 3. Procedure of building shape simulation.

2.1. Building a Typical Model

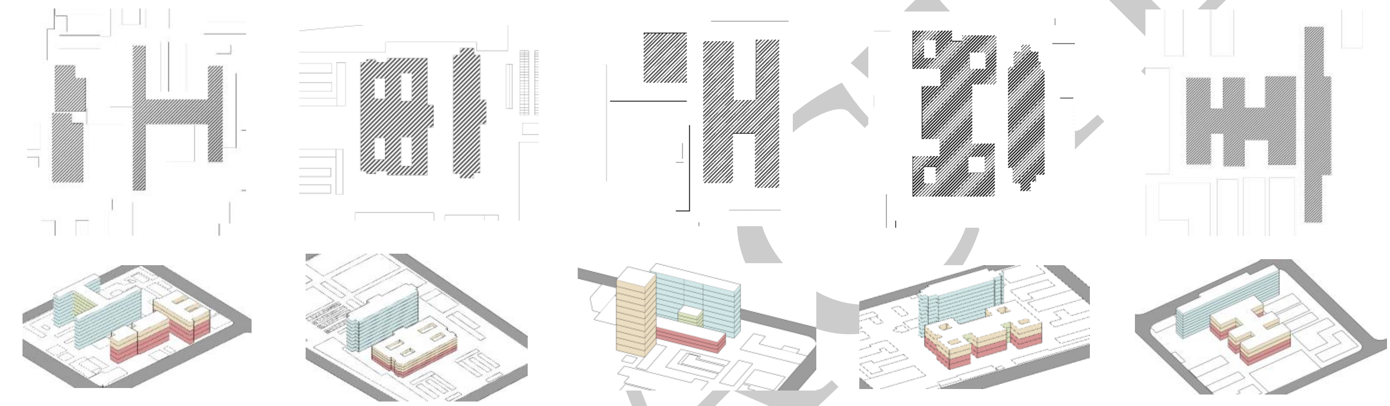
In order to understand the development and change process of outpatient building shape, the relevant research literature was statistically analyzed (Table 1) and summarized from the aspects of country, time, analytical method, and content. According to the results of the literature review, the following conclusions can be made: (1) Due to the special functional characteristics of outpatient buildings [24], the building shape in different areas are similar. (2) There is little change in building shape in different periods, and the types are relatively fixed. (3) The types of building shape gradually decrease, and the main types are centralized-type, corridor-type, and courtyard-type, which provide the basic conditions to establish a typical model. The above conclusions provide a priori condition for the establishment of a typical model and are conducive to enhancing the persuasiveness of the conclusions.

Table 1. Literature review of outpatient building research.

Country	Scholar	Time	Research Direction	Shape Type Mentioned/Analyzed
China	Huang Xiqiu et al. [25]	2001	Building density	(1) Centralized-type; (2) corridor-type; and (3) decentralized-type.
China	Ma Jin et al. [26]	2009	Building layout	(1) Corridor-type; (2) street-type; (3) courtyard-type; and (4) combination-type.
China	Zhang Shizhi et al. [27]	2015	Building layout	(1) Courtyard-type; (2) street-type; (3) centralized-type; and (4) semi centralized-type.
Germany	Ines Verena Arnolds et al. [28]	2017	Pathway design	(1) Street-type; (2) courtyard-type; and (3) semi centralized-type.
China	Sun Bing et al. [29]	2018	Building layout	(1) street-type; (2) covered courtyard-type; (3) alley-type; and (4) plate-type.
The United States	Jennifer I. Lather et al. [30]	2019	Building shape	(1) Covered courtyard-type; (2) vertical combined-type; and (3) street-type.
China	Wu Shaopeng et al. [31]	2019	Building density	(1) Streets-type; (2) courtyard-type; and (3) plate-type.
UK	Joshua Caplan et al. [32]	2020	Social distance	(1) Centralized-type; (2) semi centralized-type; (3) street-type; and (4) decentralized-type.
Indonesia	Sri Hartuti Wahyuningrum et al. [33]	2020	Efficiency of space using.	(1) Decentralized-type, and (2) centralized-type.
China	Zhao Chao Wang [34]	2021	Pathway design	(1) Centralized-type, and (2) corridor-type.

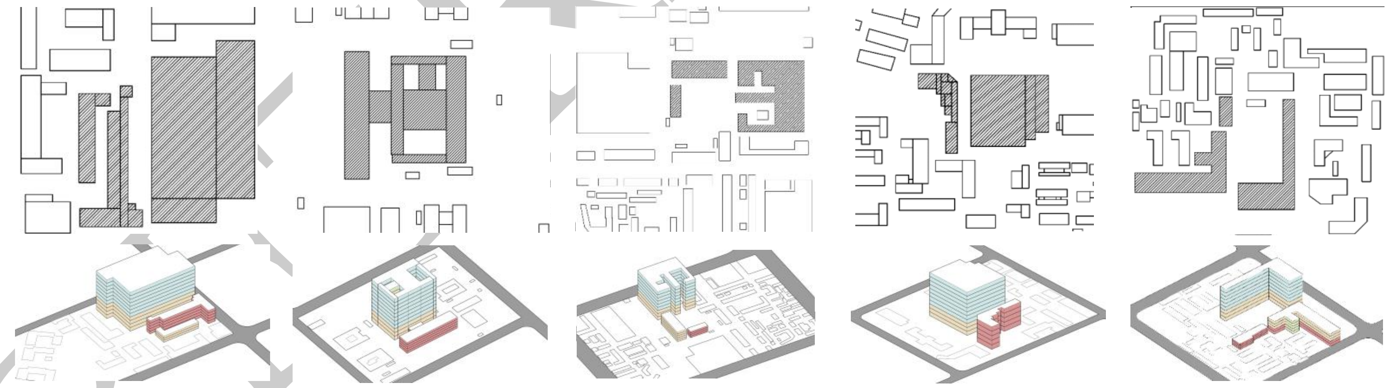
At the same time, in order to further understand the classification of general outpatient buildings in China, this paper collects case information from different climate regions in China, including regional location and building shape (Table 2). It can be seen from Table 2 that outpatient building shapes in each climate zone are different. The results show the following: (1) The early outpatient building shape was scattered and chaotic. There is a need for expansion and energy saving reconstruction. This phenomenon might be caused by the limitations of site condition, but it also indicates that the building shape did not consider energy saving design. Therefore, these cases are not representative. (2) The sample buildings built in recent years show a certain similarity, and the classification of building shape is relatively clear. According to the building block relationship, it can be roughly divided into centralized-type, corridor-type, courtyard-type, and plate-type. These shapes can provide the original data for the establishment of a typical model.

Table 2. Case survey of outpatient buildings in different climate zones of China.



BeiJing City	Binzhou, Shandong province	Jinan, Shandong province	Xi'an, Shaanxi province	Xi'an, Shaanxi province
Combined-type	Centralized-type	Plate-type	Centralized-type	Corridor-type

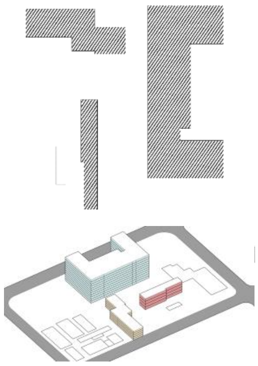
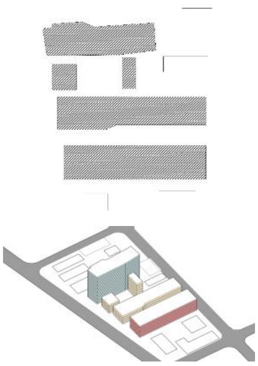
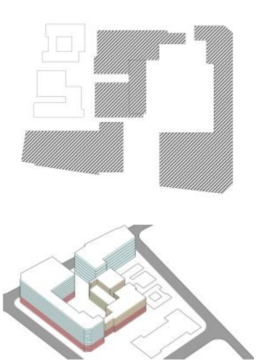
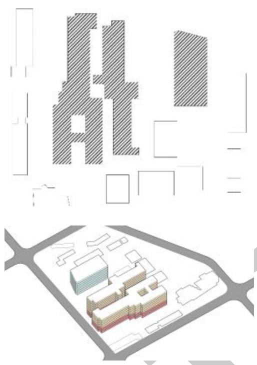
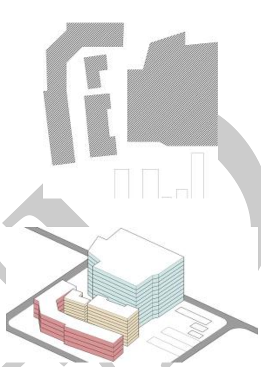
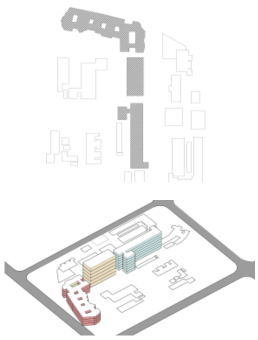
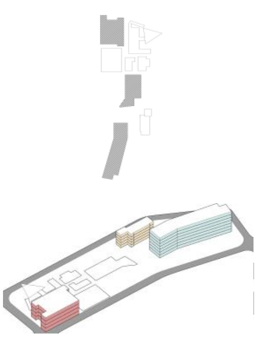
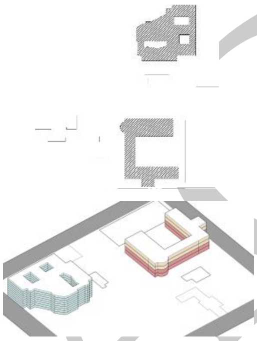
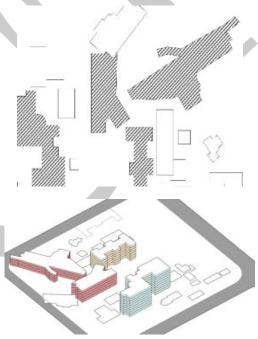
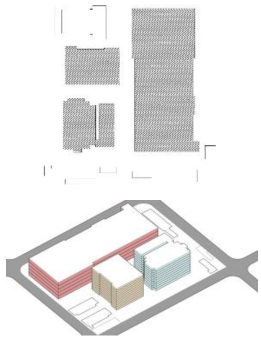
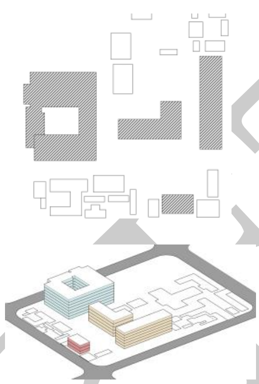
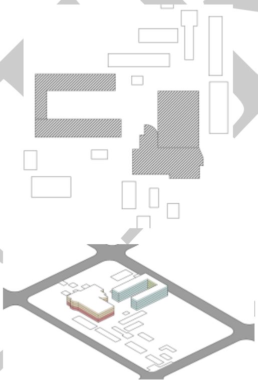
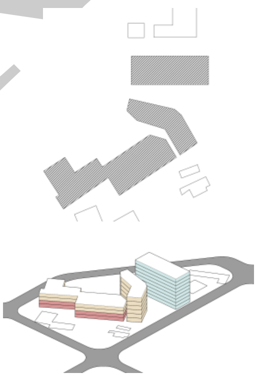
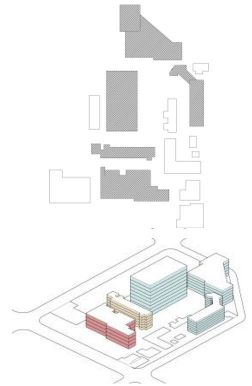
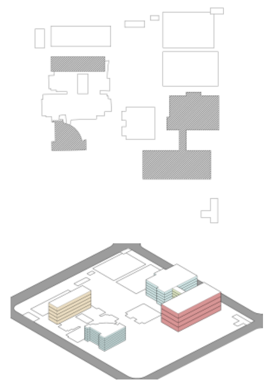
Building shape of cold zone samples



Harbin, Heilongjiang province	Hohhot, Inner Mongoria IM province	Changchun, Jilin Province	Shenyang, Liaoning Province	Urumqi City, Xinjiang Uygur Autonomous Region
Combined-type	Plate-type	Decentralized-type	Vertical combined-type	Plate-type

Building shape of severe cold zone samples

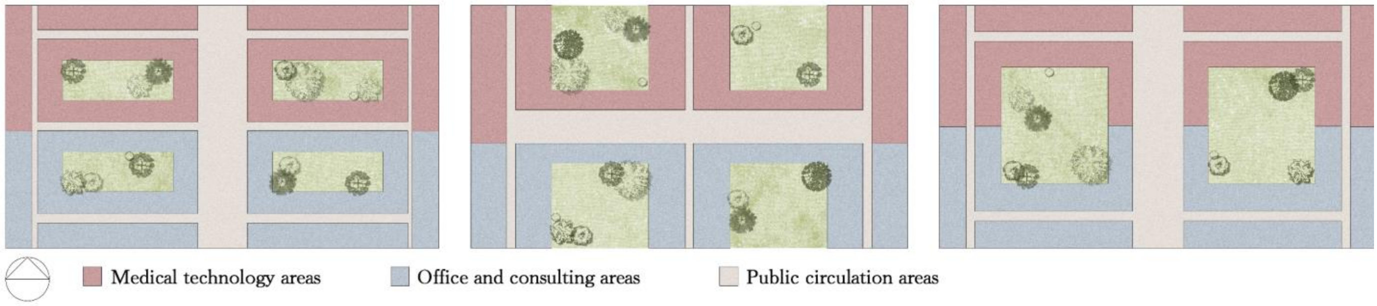
Table 2. *Cont.*

				
Chengdu, Sichuan Province Plate-type	Guilin, Guangxi Province Plate-type	Nanjing, Jiangsu Province Semi centralized-type	Shanghai Semi centralized-type	Changsha, Hunan Province Street-type
Building shape of hot summer and cold winter zone samples				
				
Guangzhou, Guangdong Province Centralized-type	Haikou, Hainan Province Centralized-type	Putian, Fujian Province Corridor-type	Xiamen, Fujian Province Decentralized-type	Shenzhen Centralized-type
Building shape of hot summer and warm winter zone samples				
				
Dali, Yunnan Province Plate-type	Guiyang, Guizhou Province Centralized-type	Guiyang, Guizhou Province Street-type	Kunming, Yunnan Province Centralized-type	Kunming, Yunnan Province Centralized-type
Building shape of warm zone samples				

Note: Outpatient building: the red part. Inpatient building: the blue part. Medical technology building: the yellow part.

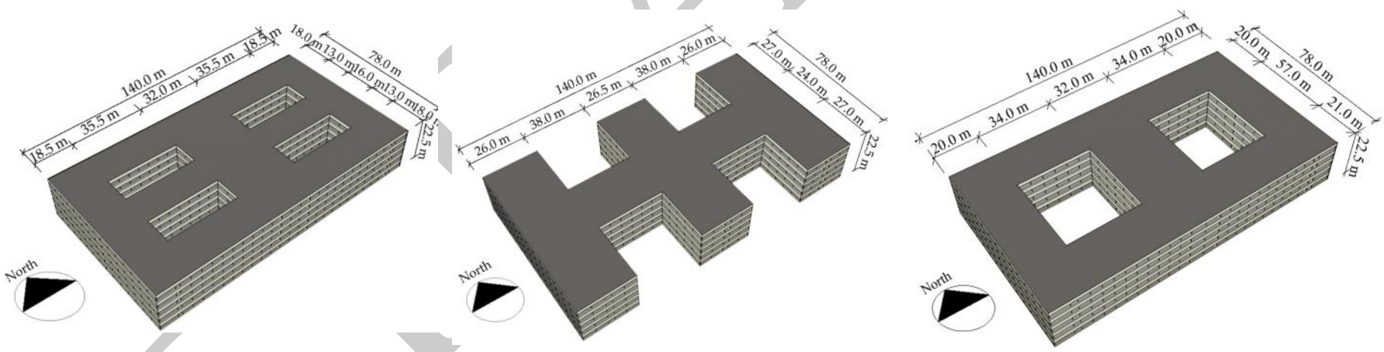
The following principles should be considered in the establishment of a typical model: (1) Combined with the literature review results in Table 1, the samples in Table 2 are screened to remove the invalid samples of a relatively old age. (2) A typical model should be established according to sample classification. Simplify the typical model shape to make it representative. (3) The shape of a typical model should meet the functional requirements of outpatient buildings. In order to ensure that the simulation results of the three typical models are comparable, their plane layouts are consistent. It includes three parts: medical technology area, office area, and public transport area.

According to the above principles, three typical models are established for the simulation analysis (Figures 4 and 5). The specific information is as follows: (1) Centralized-type (Shape-1): the shape of the building is close to a square, there is no or small opening space, and the contact area with air is small (Figure 5a). (2) Corridor-type (Shape-2): a main corridor connects each functional block, forming an open outdoor space between the blocks, which has a large contact area with air (Figure 5b). (3) Courtyard-type (Shape-3): there is the presence of one or two big outdoor spaces inside the building. All rooms are arranged around the courtyard, and the contact area with outdoor air is moderate (Figure 5c).



(**a**) Shape-1 (**b**) Shape-2 (**c**) Shape-3

Figure 4. The plane layout of three typical models: (**a**) centralized-type; (**b**) corridor-type; and (**c**) courtyard-type.



(**a**) Shape-1 (**b**) Shape-2 (**c**) Shape-3

Figure 5. The basic information of three typical models: (**a**) centralized-type; (**b**) corridor-type; and (**c**) courtyard-type.

2.2. Model Establishment Principle and Simulation Environment Setting

This study focuses on the correlation between building shape change and energy consumption in different climate zones. There are many factors that affect building energy consumption. In order to ensure the accuracy of the simulation results under the influence of a single factor of building shape, the typical model should follow the following principles: (1) In the same climate zone environment, the model's shape coefficient, window–wall ratio, and outer boundary parameters should remain unchanged. (2) The typical model should conform to the mainstream outpatient building types in most areas according to the survey results. (3) Combined with the sample survey results, the outer contours of the three models are set as rectangles, and the basic information results are consistent (Figure 5). (Contour size: 140.0 m × 78.0 m, height: 4.5 m, the number of layers: 5 layers, body size coefficient: 0.3, window to wall ratio: 0.4).

Because of the vast territory, distinct latitude, and different environmental conditions, the climate varies greatly in the different regions of China. Different climatic conditions lead to varying energy-saving requirements for buildings. From the perspective of building thermal design, the "Thermal design code for civil buildings" (GB50176-2016) divides the Chinese building climate into five zones [35]. In this paper, according to the case investigation, a typical city is selected from the five climate zones for energy consumption simulation (Figure 6). (Climate data from EnergyPlus: https://energyplus.net/weather, accessed on 21 September 2022).

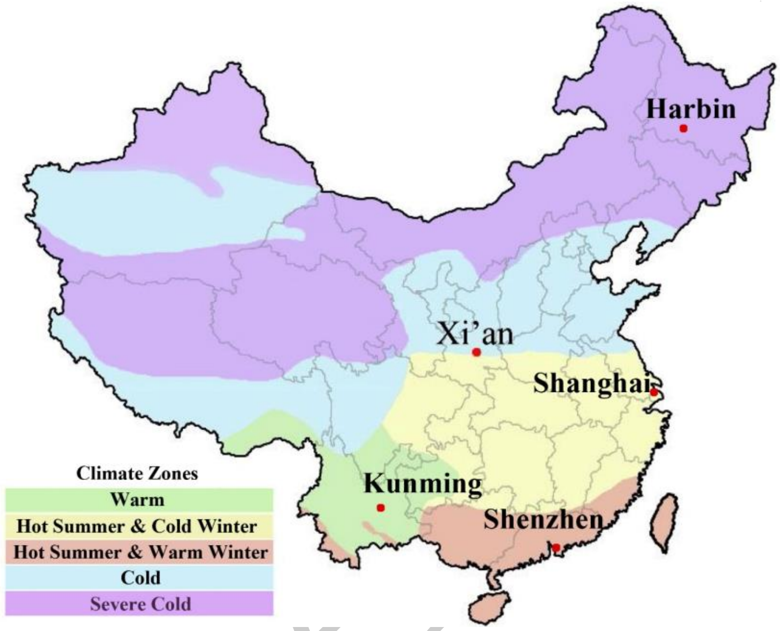


Figure 6. Five typical cities in five climate zones in this study. Data are obtained from the "Standard of climatic regionalization for architecture" (GB 50178-93).

2.3. Simulation Tool and Methods

In this study, the Design Builder simulation tool was used to dynamically simulate the three typical models. The effectiveness of the Design Builder tool in building energy consumption simulation has been verified [36,37]. The Design Builder tool contains an authoritative database of meteorological parameters, including specific design meteorological parameters and simulated meteorological parameters in the winter and summer. The proposed typical model considers the simulation of heating and cooling energy consumption separately in cities in different climate regions. The specific process can be divided into four steps: establishment of a typical model → parameter setting → simulation → analysis of results. The detailed evaluation method is described below (Figure 3).

3. Parameter Setting of Simulation Tool

Correct parameter setting is a prerequisite to ensure the validity and accuracy of simulation results [38]. The selection of the Design Builder function panel should be targeted according to the simulation objective. This paper is mainly focused on the cooling and heating energy consumption. Therefore, personnel activity, envelope structure, and air conditioning system are the main parameters that should be considered. The template for the parameters of hospital buildings is preset in the Design Builder and includes personnel activity schedule, winter and summer temperature settings, lighting standards, air conditioning system operating schedule, fresh air volume standards, etc. However, the above parameters are in British standards, which do not conform to the actual operation of Chinese hospitals. Therefore, these parameters need to be reset according to the investigation and specification requirements.

3.1. The Simulated Meteorological Parameter Setting

The setting of meteorological parameters directly affects the simulation results of energy consumption. In order to calculate building energy consumption more accurately, this paper sets the main meteorological parameters of the five selected cities (Table 3) (Data from the "China Meteorological Data Service Centre", http://data.cma.cn, accessed on 2 December 2022). Other data use the meteorological parameters built in DB. Table 3 shows that the climate of different cities is quite different. Therefore, it is necessary to choose the architectural shape reasonably.

Table 3. Meteorological parameters of five selected cities.

				Summer		
		Harbin	**Xi'an**	**Shanghai**	**Shenzhen**	**Kunming**
Mean solar irradiance (W/m^2) (July)	S	75.4	93.5	76.4	58.9	61.2
	W(E)	31.9	151.8	151.6	145.1	148.3
	N	25.3	72.0	67.4	81.1	86.0
	H	145.8	312.0	315.4	304.9	310.9
Mean wind speed (m/s)		3.2	1.7	3.8	3.2	2.1
Mean temperature of coldest month (°C)		22.8	26.4	27.8	28.4	19.8
				Winter		
Mean solar irradiance (W/m^2) (January)	S	128.9	104.4	136.2	215.8	193.3
	W(E)	49.7	59.2	63.7	73.8	84.5
	N	28.0	42.8	53.1	40.3	46.6
	H	697	91.4	103.9	183.7	128.2
Mean wind speed (m/s)		3.6	1.7	3.0	2.2	2.5
Mean temperature of coldest month (°C)		−19.4	−0.9	3.5	13.3	7.7

3.2. Personnel Activity Parameter Setting

Moreover, personnel activity is a main factor affecting the energy consumption of outpatient buildings. Therefore, this parameter should be set according to the design standards and usage of Chinese hospitals (Table 4). According to the survey results, the operation time of outpatient buildings is generally 8:30–17:30, and rest is 1–2 h at noon (Figure 7). At the same time, the frequency of personnel activities in different periods is quite different. The peak time distribution of the number of patients in the morning and afternoon is 9:00–10:00 and 14:30–16:00, respectively, and the number of patients in other periods is small [39]. In order to ensure the comparability of the simulation results, the parameters of the three typical models of the five climate zones are assumed to be consistent.

Table 4. Building design parameters.

Function	**Temperature (Summer/Winter)**	**Humidity (Summer/Winter)**	**Occupant Density (Persons/m^2)**	**Power Density of Equipment (W/m^2)**
Outpatient department	26 °C/20 °C	60%/40%	0.17	20
Medical technology department	26 °C/22 °C	65%/30%	0.10	64
Circulation space	27 °C/18 °C	60%/35%	0.25	13

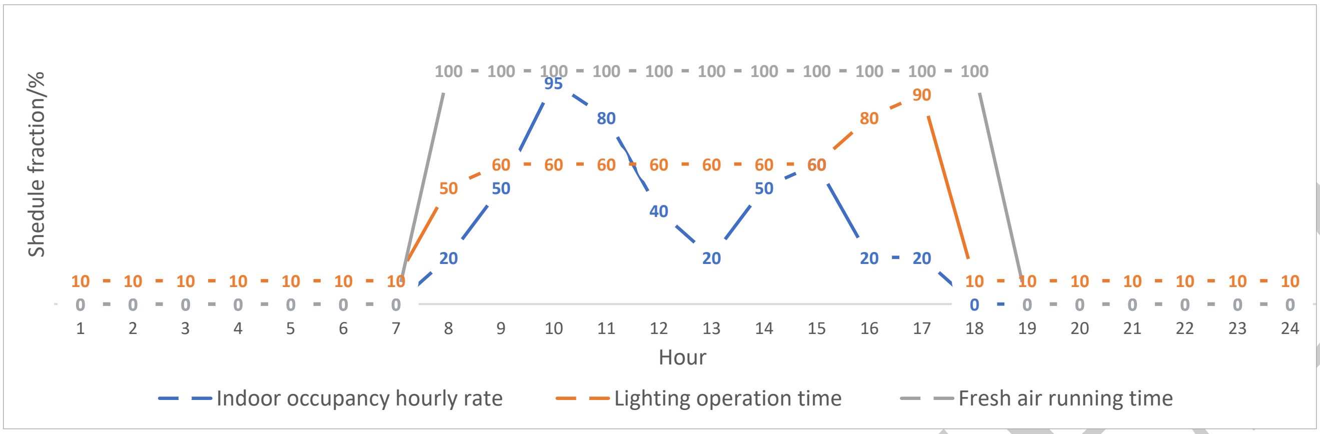


Figure 7. Operation time of the outpatient building system.

3.3. Parameter Setting of Envelope Structure

There is a strong correlation between building energy consumption and the heat transfer coefficient, thermal resistance value, building material characteristics, material thickness, and other parameters of building envelope. Therefore, in order to ensure the accuracy of the simulation results, this study sets the envelope parameters according to the requirements of the "Thermal design of civil buildings in the different climatic zones" (GB 50176-2016) in different climate zones. The specific parameters are provided in the tables below (Tables 5–7).

Table 5. The glass parameter setting in the five climate zones.

	Harbin	Xi'an	Shanghai	Shenzhen	Kunming
U value (W/m^2·K)	1.93	2.32	2.58	2.61	2.85
Solar heat gain coefficient (SHGC)	0.63	0.63	0.35	0.30	0.36

Table 6. The wall parameter setting in the five climate zones.

	Construction of the Exterior Wall	
Location	Layers (from inside to outside)	U value (W/m^2·K)
Harbin	20 mm gypsum plaster + 120 mm concrete blocks (medium-weight (MW)) + 70 mm foam-polyurethane, freon-filled + 120 mm concrete blocks (lightweight)	0.29
Xi'an	20 mm gypsum plaster + 200 mm concrete blocks (lightweight) + 50 mm foam-polyurethane + 20 mm lime plaster	0.32
Shanghai	20 mm gypsum plaster + 200 mm concrete blocks (MW) + 35 mm foam-polyisocyanate + 20 mm lime plaster	0.55
Shenzhen	20 mm gypsum plaster + 200 mm concrete blocks (lightweight) + 20 mm lime plaster	0.77
Kunming	25 mm cement plaster + 200 mm hollow concrete blocks (lightweight) + 20 mm gypsum plaster	1.48
	Construction of the interior wall	
	20 mm gypsum plaster + 180 mm concrete blocks (MW) + 20 mm gypsum plaster	1.4

Table 7. The floor and roof parameter setting in the five climate zones.

	Construction of the Roof	
Location	Layers (from inside to outside)	U value ($W/m^2 \cdot K$)
Harbin	20 mm gypsum plaster + 120 mm cast concrete (lightweight) + 60 mm air gap (downwards) + 90 mm foam-polyurethane, freon-filled + 10 mm asphalt	0.26
Xi'an	20 mm gypsum plaster + 100 mm cast concrete (lightweight) + 50 mm air gap (downwards) + 60 mm foam-polyurethane + 10 mm asphalt	0.35
Shanghai	20 mm gypsum plaster + 100 mm cast concrete (lightweight) + 50 mm air gap (downwards) + 40 mm foam-polyurethane + 10 mm asphalt	0.47
Shenzhen	20 mm gypsum plaster + 100 mm cast concrete (lightweight) + 50 mm air gap (downwards) + 25 mm MW glass wool (rolls) + 10 mm asphalt	0.76
Kunming	25 mm gypsum plaster + 100 mm cast concrete (lightweight) + 50 mm air gap (downwards) + 25 mm MW glass wool (rolls) + 10 mm asphalt	0.76
	Construction of the floor	
	9 mm ceramic floor tiles + 20 mm cement screed + 100 mm cast concrete (lightweight) + 20 mm plaster ceiling tiles	1.63

3.4. Parameter Setting of Air Conditioning System

The calculation time of heating energy consumption is consistent with the heating period in typical cities in each climate zone. The heating period in Harbin lasts from October to April of the following year, the heating period in Xi'an ranges from November to March of the following year, and the heating period in Shanghai lasts from December to February of the following next year.

The cooling period is automatically initiated at a temperature higher than 30 °C. The air conditioning system is a multiline + fresh air system. The fresh air system is set according to the fresh air requirements of the different functional areas. The running time is determined by the simulation tool based on the calculated indoor temperatures and the set timetable. According to actual hospital conditions, the coefficient of performance (COP) of the multiline cooling system is set to 3.0, and that of the heating system is set to 2.5.

4. Analysis of the Effect of Building Shape on Energy Consumption

This paper uses Design Builder to simulate the annual energy consumption of three typical models. The cooling energy consumption, the heating energy consumption, and the comprehensive (heating + cooling) energy consumption were compared, respectively, and the simulation results were converted into an energy saving rate as the judgment basis for the shape selection. Energy saving rate is a comprehensive index reflecting the degree of energy saving, and Formula (1) is its calculation formula. In order to judge the merits of the three typical models, the average energy consumption of the three models is used as the reference building energy consumption value.

$$R = 1 - Q_1 \times (1 - r)/Q_3. \quad (1)$$

R—Energy saving rate.

Q_1—Actual building energy consumption value.

r—Energy saving standard percentage, $r = 75\%$. <General code for energy efficiency and renewable energy application in buildings> (GB 55015-2021).

Q_3—Reference building energy consumption value.

4.1. Comprehensive Energy Consumption Analysis

The comprehensive energy consumption mentioned in this section refers to the heating and cooling energy consumption together, and not considering each type of energy consumption separately. The simulation results are divided into five groups according to the climate zone. Figure 8 shows the following: (1) The order of the comprehensive energy consumption in each group is consistent: Shape-3 > Shape-2 > Shape-1. (2) Compared to the results of the five simulation groups, the comprehensive energy consumption of the warm climate zone is the lowest, while the comprehensive energy consumption of the severe climate zone and the hot summer and warm winter climate zone is relatively high, with the latter being about 4–8 times higher than that of the former. This result implies that the cooling and heating energy consumption accounts for a large percentage of total building energy consumption (include lighting, equipment, etc.). (3) Shape-1 and Shape-2 have little difference in the cold climate zone, and both are reasonable choices, while Shape-1 is the best choice in other climate zones. However, the above analysis did not consider the factors of regional energy cost, energy type, and building orientation, which can cause energy consumption difference.

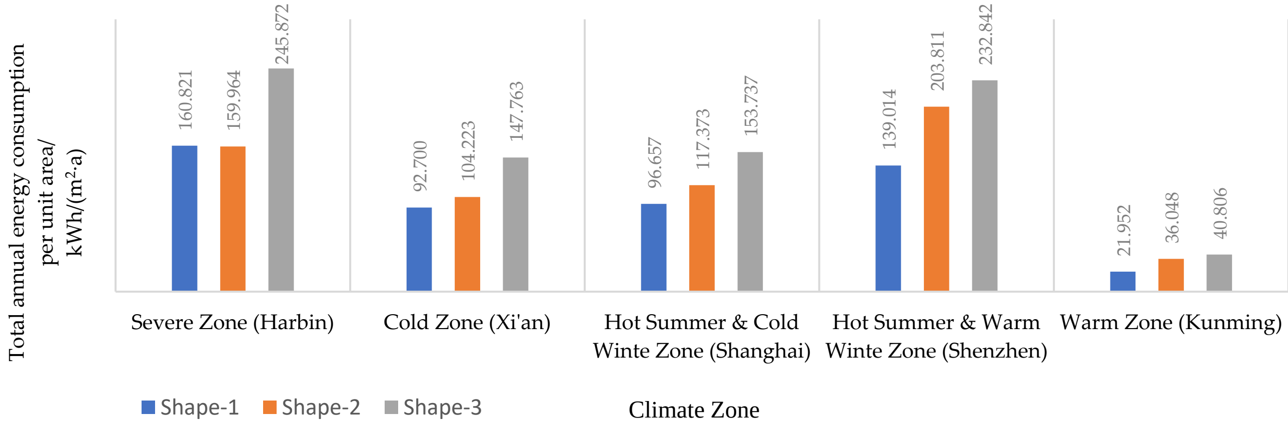


Figure 8. Comparison of simulation results of three typical models in five climate zones.

Therefore, the following is a comparative analysis of the three typical models from the perspectives of cooling and heating energy consumption, so as to make the selection of building shape more consistent with regional climate characteristics and usage habits.

4.2. Heating and Cooling Energy Consumption Analysis

In different climate zones, the energy consumption performance of cooling and heating of the three typical models is quite different. The simulation results (Figure 9) show the following: In the severe cold zone, the heating demand is much higher than the cooling demand, and the energy saving effect of Shape-2 is better. In the cold zone, there is little difference between heating demand and cooling demand, and Shape-1 has a good energy-saving effect. In the hot summer and cold winter zone, the heating demand is slightly lower than the cooling demand, and Shape-1 has a good energy saving effect. In the hot summer and warm winter zone, the heating demand is much lower than the cooling demand, and Shape-1 has a good energy-saving effect. In the warm zone, the heating and cooling requirements are both low, and there is little difference between the three typical models, and Shape-1 has the best energy saving effect.

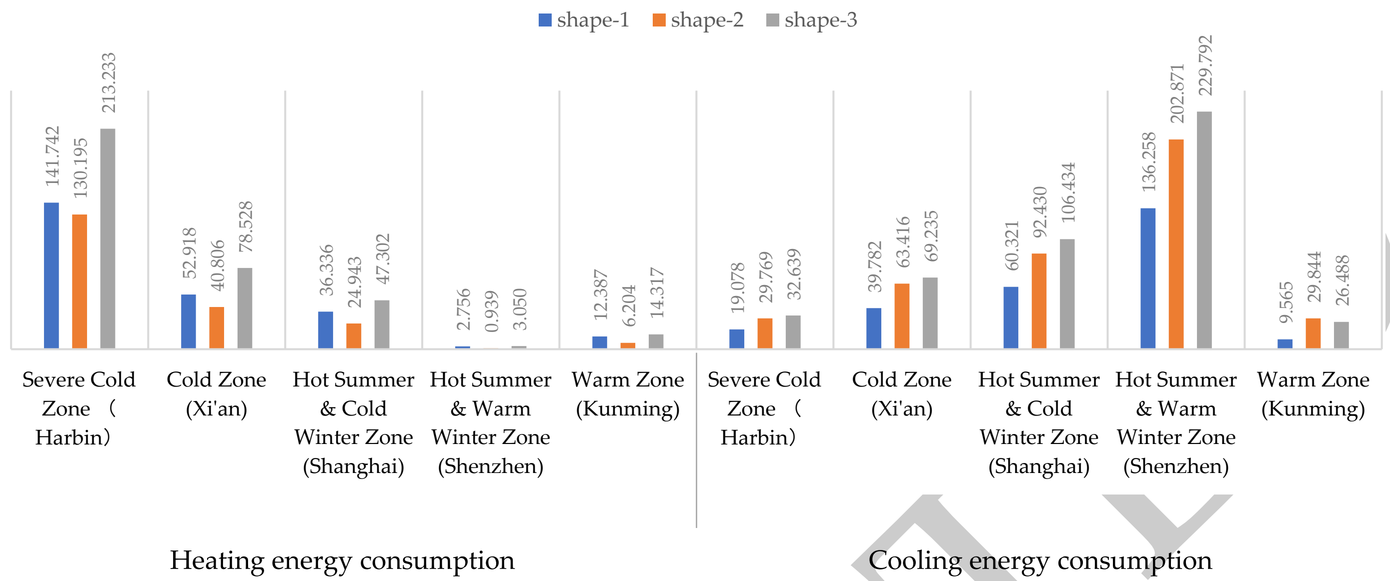


Figure 9. Comparison of simulation results of three typical models in five climate zones.

4.3. Analysis of Energy Saving Rate between Three Typical Models

In order to further determine the energy saving effects of the three typical models in different climate zones, we quantified the energy saving rates of heating energy consumption and cooling energy consumption, as shown in Figure 10. The results are as follows: (1) The energy saving rate of Shape-1 for heating and cooling is 19.36–56.45% and −22.90–12.00%, respectively. The energy saving effect of cooling is better than that of heating, and the energy saving rate of cooling in mild climate zone is the highest. (2) The energy saving rate of heating and cooling of Shape-2 is between 19–58.22% and −35.86–1.71%, respectively, and the energy saving effect of heating is better than that of cooling. (3) Both the cooling and heating energy saving rates of Shape-3 are negative, lower than the average level of the three models. A reasonable optimization design should be carried out in the construction scheme stage.

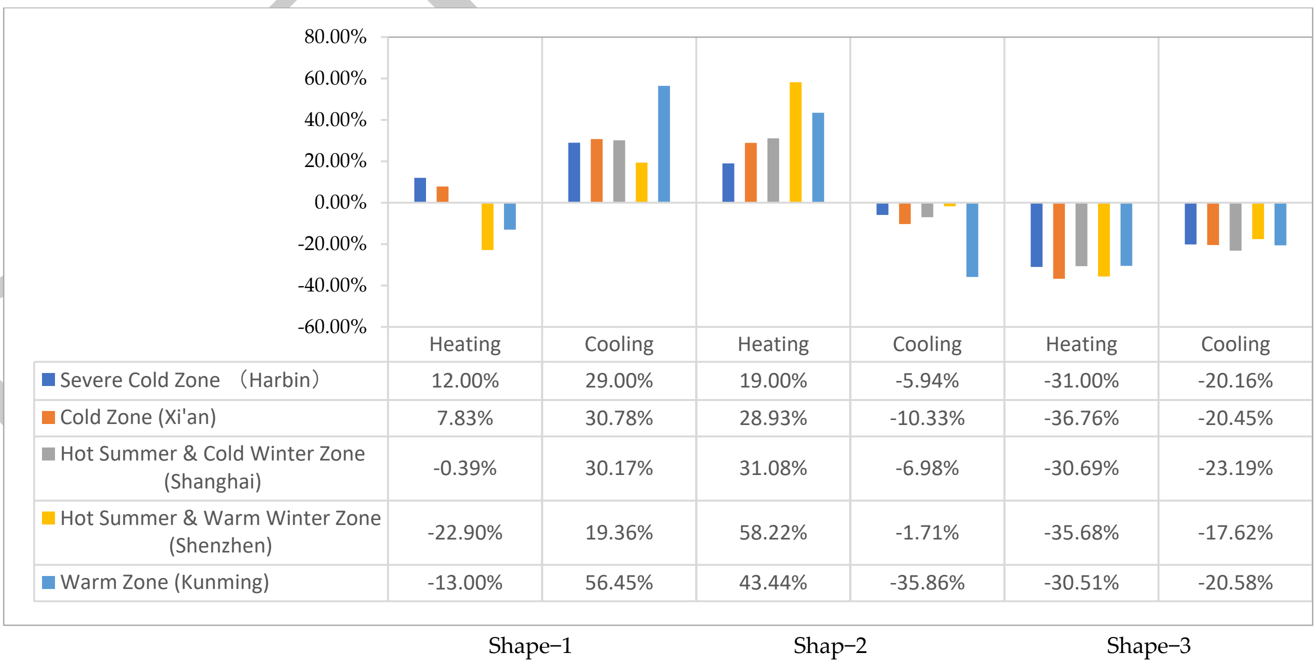


Figure 10. Energy saving rate of three models in five climate zones.

5. Analysis of the Building Orientation Effect on Energy Consumption

In the stage of architectural scheme design, building orientation is also an important factor affecting building energy consumption, which is directly related to lighting, ventilation, solar radiant heat, and so on [40]. Considering the shape symmetry of the three typical models, when the building orientation changes, only the angle changes within a certain range need to be considered. Therefore, the three typical models are simulated in different orientations (0°, 30°, 60°, and 90°) (Figure 11), including comprehensive energy consumption (Table 8) and individual energy consumption (heating and cooling) (Table 9). Based on the simulation results of energy consumption, the differences in energy consumption caused by different building orientations are compared and analyzed. It is used to determine the orientation of the building shape suitable for different climate zones, so as to meet the needs of energy conservation and provide a reference for architects. The results of the simulation tests are listed in the table below.

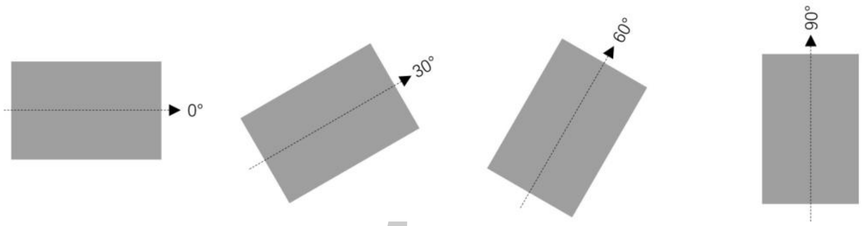


Figure 11. Setting of building angle in energy consumption simulation.

Table 8. Comprehensive energy consumption in different orientations.

Layout	Orientation	Harbin kWh/(m²·a)	Xi'an kWh/(m²·a)	Shanghai kWh/m²·a)	Shenzhen kWh/(m²·a)	Kunming kWh/(m²·a)
Shape-1	0°	***160.124***	**92.367**	96.005	**138.265**	***21.254***
	30°	161.354	93.125	**95.369**	138.917	21.976
	60°	163.014	94.368	96.475	139.324	22.248
	90°	*165.256*	*96.389*	*97.321*	*140.018*	*23.147*
Shape-2	0°	**159.964**	*106.254*	*118.325*	**202.358**	*37.035*
	30°	160.811	105.024	117.218	203.124	36.958
	60°	161.964	103.268	117.032	203.814	36.048
	90°	*162.500*	**102.354**	**116.695**	*204.040*	**35.247**
Shape-3	0°	**241.677**	**145.213**	**154.328**	231.985	**39.684**
	30°	243.513	147.763	155.013	**230.847**	40.806
	60°	244.875	148.165	155.951	233.547	41.367
	90°	*245.821*	*148.916*	*156.330*	*234.186*	*41.968*

Note: **Bold**: indicates the data have the lowest value. *Italics + underscores*: indicates the data have the highest value.

Table 9. The individual energy consumption of heating and cooling in different orientations.

Typical Model		Harbin kWh/(m²·a)		Xi'an kWh/(m²·a)		Shanghai kWh/(m²·a)		Shenzhen kWh/(m²·a)		Kunming kWh/(m²·a)	
		Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Shape-1	0°	**141.954**	**17.307**	**50.895**	**36.861**	**35.324**	**58.955**	**1.732**	137.203	**10.289**	**7.730**
	30°	*142.042*	19.295	53.083	43.399	36.330	60.947	2.724	137.227	12.270	8.712
	60°	142.742	19.078	52.918	39.782	36.336	60.321	2.756	**135.258**	12.387	9.565
	90°	*143.954*	*19.992*	*52.674*	*42.979*	*36.160*	*60.325*	*2.696*	*136.304*	*12.086*	*9.421*
Shape-2	0°	**129.946**	**27.100**	*42.350*	*63.513*	*25.941*	**92.403**	*0.881*	**200.076**	*6.956*	**27.878**
	30°	131.164	28.636	41.977	62.679	24.925	92.495	0.829	201.078	6.651	28.958
	60°	131.986	28.769	41.785	61.226	24.543	92.430	0.799	202.871	6.204	29.244
	90°	*133.497*	*29.003*	**40.648**	**60.988**	**24.177**	*93.260*	**0.736**	*203.104*	**6.120**	*29.892*
Shape-3	0°	**213.096**	**31.280**	**76.692**	**68.732**	**45.352**	**105.997**	*3.962*	**229.531**	*16.400*	**24.822**
	30°	213.658	32.145	77.229	69.173	46.324	106.147	3.544	230.432	15.998	25.723
	60°	214.233	32.639	78.528	69.235	47.302	106.434	3.150	230.792	15.317	26.488
	90°	*214.935*	*32.986*	*78.946*	*69.979*	*47.935*	*106.952*	**2.258**	*230.911*	**14.385**	26.556

Note: **Bold**: indicates the data have the lowest value. *Italics + underscores*: indicates the data have the highest value.

5.1. Detailed Discussion of the Results for Severe Cold Zone (Harbin)

The comprehensive energy consumption results in Table 8 show the following: (1) In the same climate zone, the same typical model has a small difference, but there is a big difference between different typical models. This phenomenon shows that the building shape has a great influence on the simulation results. (2) Shape-2 (angle: 0°) has the lowest consumption, which is 159.964 kWh/(m^2·a), and Shape-3 (angle: 90°) has the highest, which is 245.821 kWh/(m^2·a). (3) The result shows that Shape-2 (angle: 0°) is more suitable for the severe cold climate zone.

The individual energy consumption results in Table 9 show the following: (1) The heating energy consumption is far higher than that of cooling. Therefore, a high energy saving rate shape should be considered first. (2) The heating energy consumption of shape-2 (angle: 0°) is the lowest, which is 129.946 kWh/(m^2·a). The heating energy consumption of Shape-3 (angle: 90°) is the highest, which is 214.935 kWh/(m^2·a). (3) The cooling energy consumption of the three typical models has little difference, and the order of cooling energy consumption is as follows: shape-3 (angle: 0°) > shape-2 (angle: 0°) > shape-1 (angle: 0°).

For the severe cold zone, taking Harbin as an example, the heating energy consumption is far higher than the cooling energy consumption (Figure 12). Therefore, we should make sure that the long side gets enough solar radiation, and the comprehensive energy consumption should be low. Considering the above factors, Shape-2 (angle: 0°) should be selected.

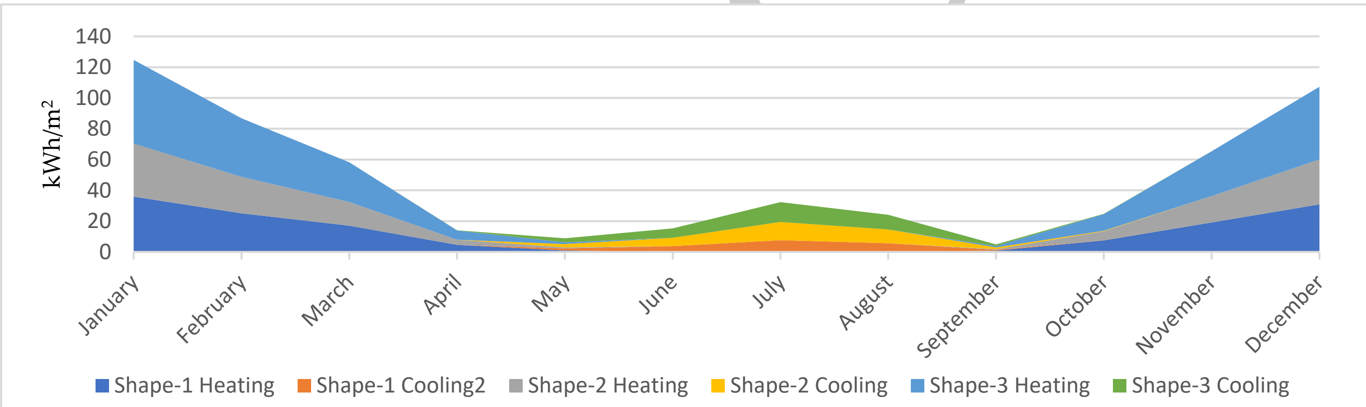


Figure 12. Monthly heating and cooling energy consumption in Harbin.

5.2. Detailed Discussion of the Results for Cold Zone (Xi'an)

The comprehensive energy consumption results in Table 8 show the following: (1) Shape-1 (angle: 0°) has the lowest consumption, which is 92.367 kWh/(m^2·a), and Shape-3 (angle: 90°) has the highest, which is 148.916 kWh/(m^2·a). (2) The result shows that Shape-1 (angle: 0°) is more suitable for the cold zone.

The individual energy consumption results in Table 9 show the following: (1) The distribution of the heating and cooling energy consumptions is relatively balanced. Therefore, they should be considered together. (2) For heating energy consumption, Shape-2 (angle: 90°) has the lowest consumption, which is 40.648 kWh/(m^2·a), and Shape-3 (angle: 90°) has the highest, which is 78.946 kWh/(m^2·a). (3) For cooling energy consumption, Shape-1 (angle: 0°) has the lowest, which is 36.861 kWh/(m^2·a), and Shape-3 (angle: 90°) has the highest, which is 69.979 kWh/(m^2·a).

For cold zone, taking Xi'an as an example, building shape selection should consider both winter and summer (Figure 13). Therefore, the shape with the lowest heating and cooling energy consumptions is preferred. Considering the above simulation results, Shape-1 (angle: 90°) should be selected. Its comprehensive energy consumption levels are the lowest, but its heating energy consumption is slightly higher in the winter, so it is necessary to consider strengthening insulation measures in the winter.

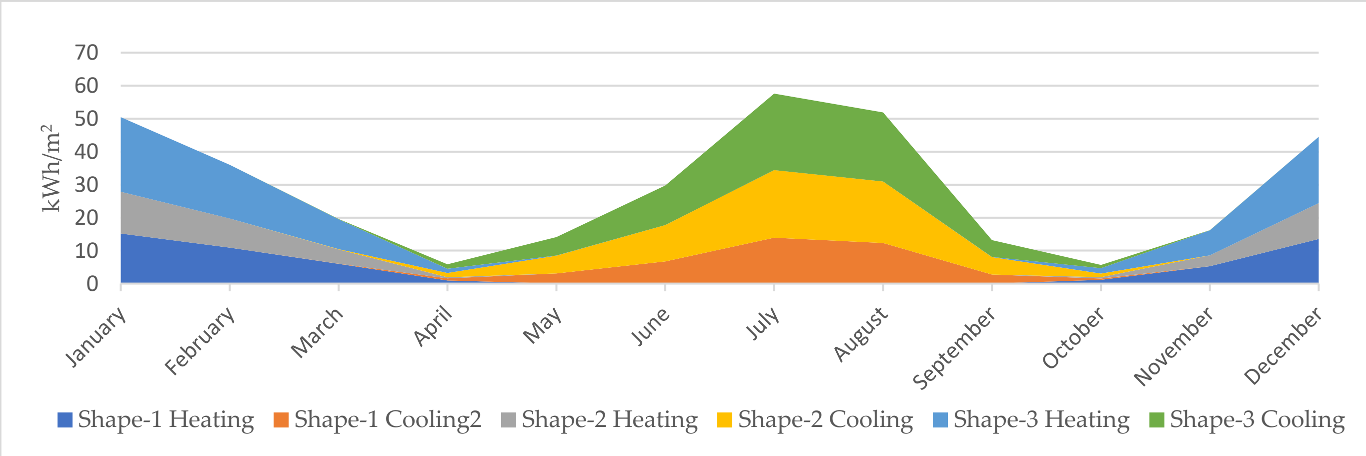


Figure 13. Monthly heating and cooling energy consumptions in Xi'an.

5.3. Detailed Discussion of the Results for Hot Summer and Cold Winter Zone (Shanghai)

Table 8 shows the following: (1) Shape-1 (angle: 30°) has the lowest consumption, which is 95.369 kWh/(m^2·a), and Shape-3 (angle: 90°has the highest, which is 156.330 kWh/(m^2·a). (2) In this climate zone, building energy consumption is not only affected by shape and orientation factors, but also by local monsoon factors. (3) The result shows that Shape-1 (angle: 30°) is more suitable for the hot summer and cold winter zone.

The individual energy consumption results in Table 9 show the following: (1) The cooling energy consumption is about 2–3 times that of heating, with the values being about 24–48 kWh/(m^2·a) and 60–110 kWh/(m^2·a), respectively, and the comprehensive energy consumption is not high. Therefore, in this climate zone, the main consideration should be cooling energy consumption. (2) For heating energy consumption, Shape-2 (angle: 90°) has the lowest consumption, which is 24.177 kWh/(m^2·a), and Shape-3 (angle: 90°) has the highest, which is 47.935 kWh/(m^2·a). (3) For cooling energy consumption, Shape-1 (angle: 0°) has the lowest consumption, which is 58.955 kWh/(m^2·a), and Shape-3 (angle: 90°) has the highest, which is 106.952 kWh/(m^2·a).

For the hot summer and cold winter zone, taking Shanghai as an example, according to its energy consumption distribution (Figure 14), building shape choice should mainly consider cooling energy consumption. Considering the simulation results above, Shape-1 (angle: 0°) should be selected.

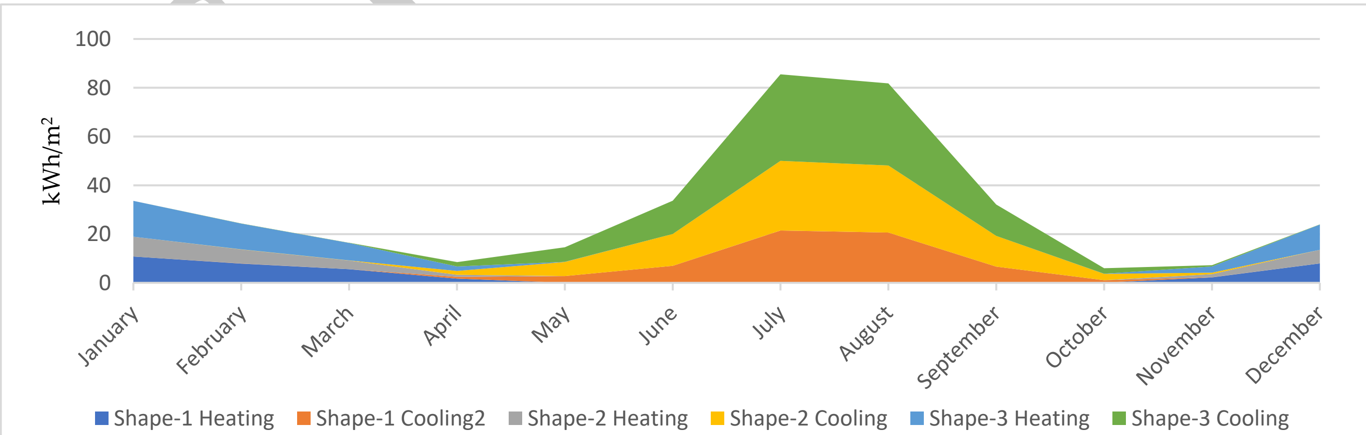


Figure 14. Monthly heating and cooling energy consumption in Shanghai.

5.4. Detailed Discussion of the Results for Hot Summer and Warm Winter Zone (Shenzhen)

Table 8 shows the following: (1) The comprehensive energy consumption of the three typical models in this climate zone is between 139.000–233.593 kWh/(m^2·a), which has a great energy saving potential. (2) The energy consumption of Shape-1 is lower than that of the other two models, and Shape-1 (angle: 0°) has the lowest energy consumption, which is 138.265 kWh/(m^2·a).

Table 9 shows the following: (1) The main energy consumption in this climate zone is cooling, while heating energy consumption can be ignored. Therefore, only the lower cooling energy consumption shape needs to be considered. (2) The cooling energy consumption of shape-1 in each direction has little difference, and Shape-1 (angle: 60°) has the lowest energy consumption, which is 135.258 kWh/(m^2·a). Shape-3 (angle: 90°) has the highest energy consumption, which is 230.911 kWh/(m^2·a).

For the hot summer and warm winter zone, taking Shenzhen as an example, according to its energy consumption distribution (Figure 15), the selection of building shape only needs to consider the cooling energy consumption. Considering the simulation results above, shape-1 (angle: 60°) should be selected.

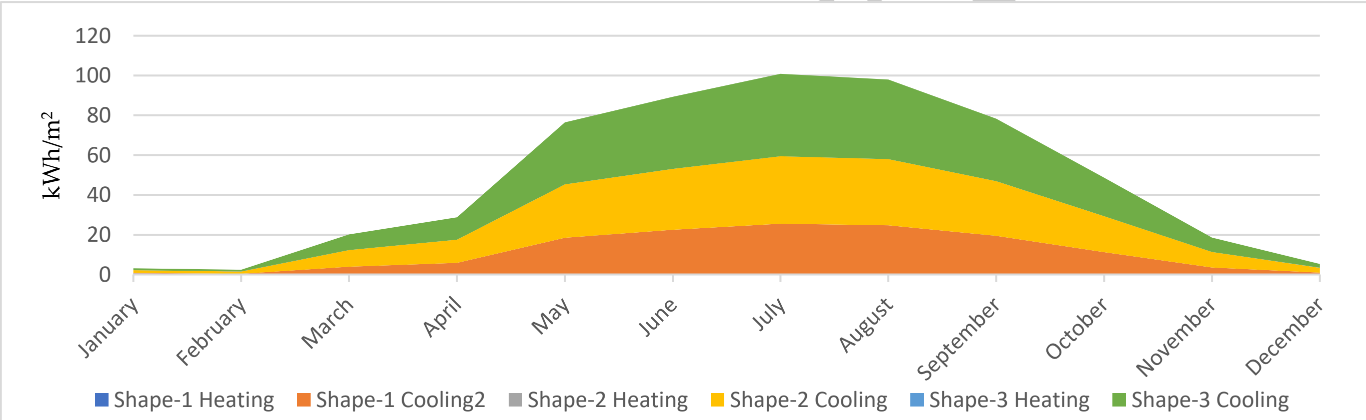


Figure 15. Monthly heating and cooling energy consumption in Shenzhen.

5.5. Detailed Discussion of the Results for Warm Zone (Kunming)

Table 8 shows the following: (1) The energy consumption of the three typical models is low, and the energy consumption value is between 21.507–41.222 kWh/(m^2·a), with a small difference. The change of building orientation has little influence on energy consumption. (2) Among all modes, Shape-1 (angle: 0°) has the lowest consumption, which is 21.254 kWh/(m^2·a). (3) The result shows that Shape-1 (angle: 0°) is more suitable for the warm zone.

Table 9 shows the following: (1) The cooling and heating energy consumption of the three typical models in this climate zone does not show an obvious difference, which has a low-level value. (2) For heating energy consumption, Shape-2 (angle: 60°) has the lowest consumption, which is 6.204 kWh/(m^2·a), and Shape-3 (angle: 0°) has the highest heating energy consumption, which is 16.400 kWh/(m^2·a). (3) For cooling energy consumption, Shape-1 (angle: 0°) has the lowest consumption, which is 7.730 kWh/(m^2·a), and Shape-2 (angle: 90°) has the highest cooling energy consumption, which is 29.892 kWh/(m^2·a).

For the warm zone, taking Kunming as an example, according to its energy consumption distribution (Figure 16), due to its climatic reasons, building shape and orientation have a little influence on energy consumption. Therefore, Shape-1 and Shape-2 can be the choice to meet the need of early design.

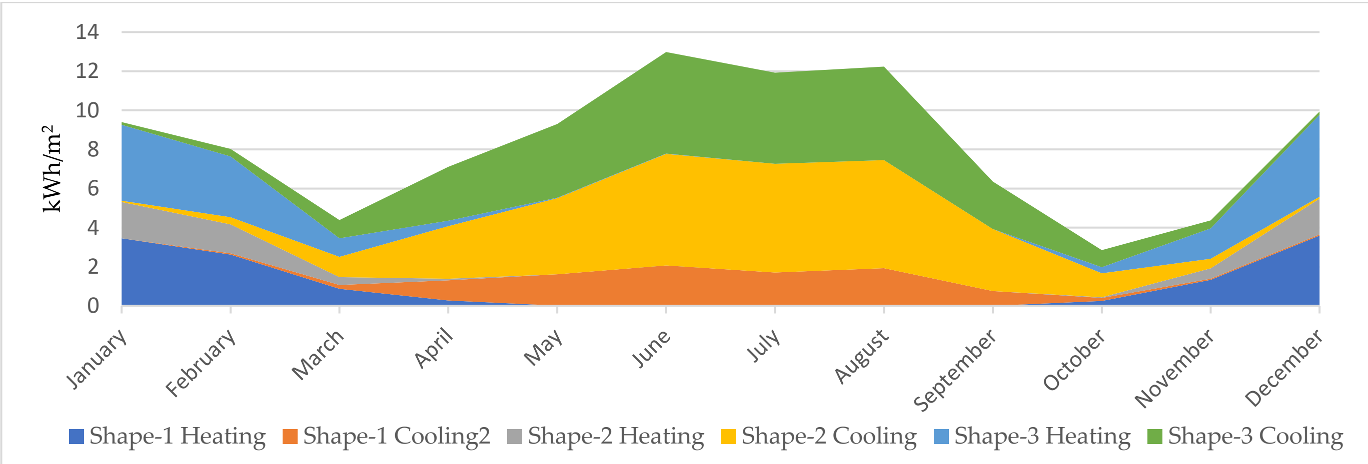


Figure 16. Monthly heating and cooling energy consumption in Kunming.

6. Discussion

In this paper, the energy consumption of different climate zones is simulated from the two aspects of building shape and building orientation. The energy consumption of different parameter combinations is quantified. According to the analysis, compared to the building shape, the change of building orientation has less impact on the building's operational energy consumption. However, as one of the unchangeable parameters in the later period, it has a great additional impact on the building's operational energy consumption. For example, the building's daytime energy consumption, heat loss of envelope structure, and the relationship between perennial monsoon and orientation. Therefore, the reasonable choice of the two parameters is also important to reduce the energy consumption of building operation.

The main research results of this paper are as follows: (1) The classification of outpatient buildings is clarified, which can be divided into three types: centralized-type (Shape-1), corridor-type (Shape-2), and courtyard-type (Shape-3). (2) The results show that different shapes can cause obvious energy consumption changes. Climatic conditions are an important factor in the selection of building shape. (3) The simulation results show that Shape-2 (angle: 0°) should be chosen in severe cold zone; Shape-1 (angle: 90°) should be chosen in cold zone; Shape-1 (angle: 0°) should be chosen in hot summer and cold winter zone; Shape-1 (angle: 60°) should be chosen in hot summer and warm winter zone; and Shape-1 or Shape-2 can be chosen in warm zone.

Compared to other similar research literature, this paper is supplemented in the following aspects: (1) This paper extends spatially to include five climate zones in China, and the suitable building shape for each climate zone is clearly identified. (2) The number of factors that affect building energy consumption is simplified, and the building shape and orientation are analyzed, which has a significant influence on the early design stage. (3) The application stage is clearly identified, which can effectively help architects provide guidance and suggestions for early design.

However, there are still many shortcomings in this study, including the following: (1) The simulate result shows that outdoor wind environment has a significant impact on building energy consumption, but it is not discussed in this paper. (2) There is no discussion on how to change the building shape to meet the multi-objective energy-saving requirements when other parameters, such as lighting and ventilation, are added. (3) Only three typical models of outpatient buildings in China were analyzed in this study. With the continuous optimization of spatial parameters, the energy consumption of other typical models can be studied in the future. Therefore, in future research, more detailed analysis can be strengthened to ensure the sustainable energy saving design of outpatient buildings.

7. Conclusions

This paper mainly studies the energy conservation design of outpatient buildings. Through the changes in building shape and orientation, the energy consumption performance of buildings in different scenes is compared and analyzed, and the selection principle of the building shape in different climate zones is clarified. The main conclusions are as follows:

(1) Without consider the building orientation factor, the energy consumption performance of the three typical models is consistent in the five climate zones. The energy consumption values in descending order are as follows: courtyard-type (shape-3) > corridor-type (Shape-2) > centralized-type.

(2) Considering the factor of building orientation, the suggestions for building shape choice in the five climate zones are as follows: Shape-2 (angle: 0°) should be chosen in the severe cold zone; Shape-1 (angle: 90°) should be chosen in the cold zone; Shape-1 (angle: 0°) should be chosen in the hot summer and cold winter zone; Shape-1 (angle: 60°) should be chosen in the hot summer and warm winter zone; and Shape-1 or Shape-2 can be chosen in the warm zone. However, in the three models, the courtyard-type (shape-3) has the highest energy consumption, which is not conducive to energy saving. If this shape is chosen, the insulation performance should be enhanced in other aspects.

(3) According the simulate results, the building orientation has little effect on the energy consumption, but it is related to building ventilation, lighting, and availability of or decrease in solar energy. Therefore, future work should combine the above factors to further analyze the effect of building orientation. A reasonable orientation selection can help architects make the decision of energy saving in the design stage.

In conclusion, the appropriate shape and orientation combination based on climatic conditions can effectively reduce the heating and cooling energy consumption of outpatient buildings. The research results provide suggestions for architects to select the correct building shape in different climate zones.

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