

Research on Energy-Saving Optimization of Civil Hotel Envelope in Hot Summer and Cold Winter Zone Based on DeST

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Abstract

Aiming at the energy consumption issues of civil hotels, this study takes a hotel in Shanghai as an example and uses DeST simulation and orthogonal tests to analyze the effects of exterior wall insulation thickness (60-100 mm) and window materials (common insulating glass, Low-E coated low-emissivity insulating glass, Low-E coated vacuum glass) on building energy use. Results show that window materials have a more significant impact (range: 36,088 kW·h). The optimal scheme (100 mm insulation + Low-E coated low-emissivity insulating glass) achieves the lowest total load of 289,114 kW·h, saving 23.9% energy compared with the baseline. Prioritizing window upgrades to balance efficiency and cost is recommended for low-carbon building development.

Keywords

Civil hotel; DeST; building envelope; orthogonal test.

1. Building Overview and Parameter Selection

According to the China Building Energy Consumption Research Report (2020), the total energy consumption of the whole building process in China in 2020 was 2.27 billion tce, accounting for 45.5% of the national total energy consumption. For a long time, civil hotel buildings have lacked systematic planning and unified construction standards, and their envelope thermal insulation performance is poor, leading to excessive dependence on energy to improve indoor comfort [1]. Therefore, promoting the energy-saving and low-carbon development of civil buildings is one of the important tasks to achieve the "dual carbon" goals of the construction industry [2,3,4]. Based on the reality of civil hotels, reasonably improving the hotel envelope performance to reduce energy consumption is particularly important for enhancing hotel indoor comfort and exploring low-carbon pathways for hotels.

This paper selects a civil hotel building in Shanghai for field investigation. Aiming at the energy-saving status and problems of the hotel, DeST (DeST-c) building energy simulation software is used to establish a model [5,6,7], and the orthogonal test method is adopted to combine various energy-saving retrofit schemes, calculate the annual cumulative load index, and obtain the optimal envelope energy-saving retrofit scheme.

1.1. Hotel overview and modeling

The building is located in Shanghai and was built in 2010. The building has a flat roof and faces south, a total of one floor, the height of the floor is 3m, the height of the building is 3.6 m, and the total construction area is 2740.83 m². Functional rooms mainly include : lobby, guest rooms, restaurants, toilets, stairwells, etc.

The house is modeled by DeST software for simulation calculation. The specific model is shown in Figure.1.

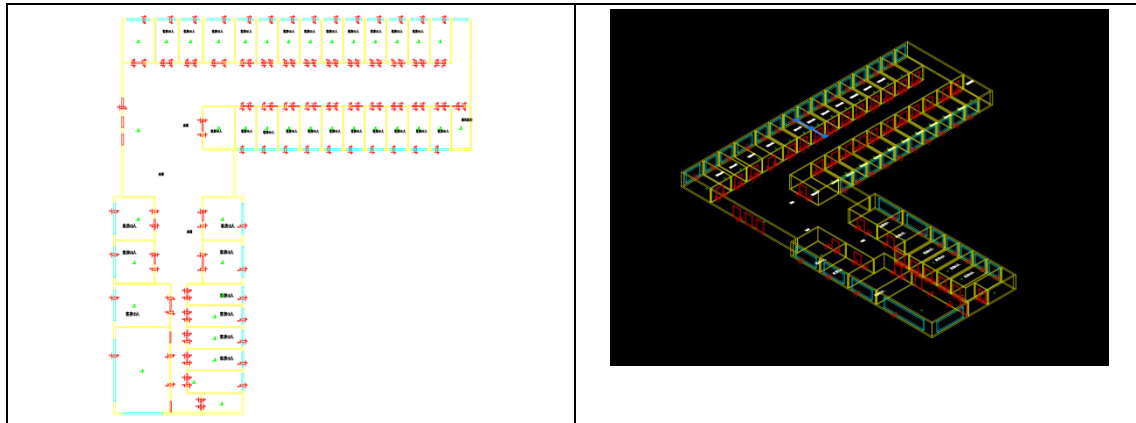


Figure 1. Hotel plan (left) and hotel axonometric drawing (right)

1.2. DeST software parameter setting

1.2.1. General situation parameter setting

Shanghai is located in the hot summer and cold winter zone (Zone IIIA), characterized by hot summers, cold winters, and four distinct seasons. The annual average temperature is about 16 °C, the annual sunshine duration is 1,900-2,100 hours, and the annual precipitation is 1,000-1,200 mm. The temperature parameters of the typical meteorological year in Shanghai selected from DeST are shown in Figure.2.

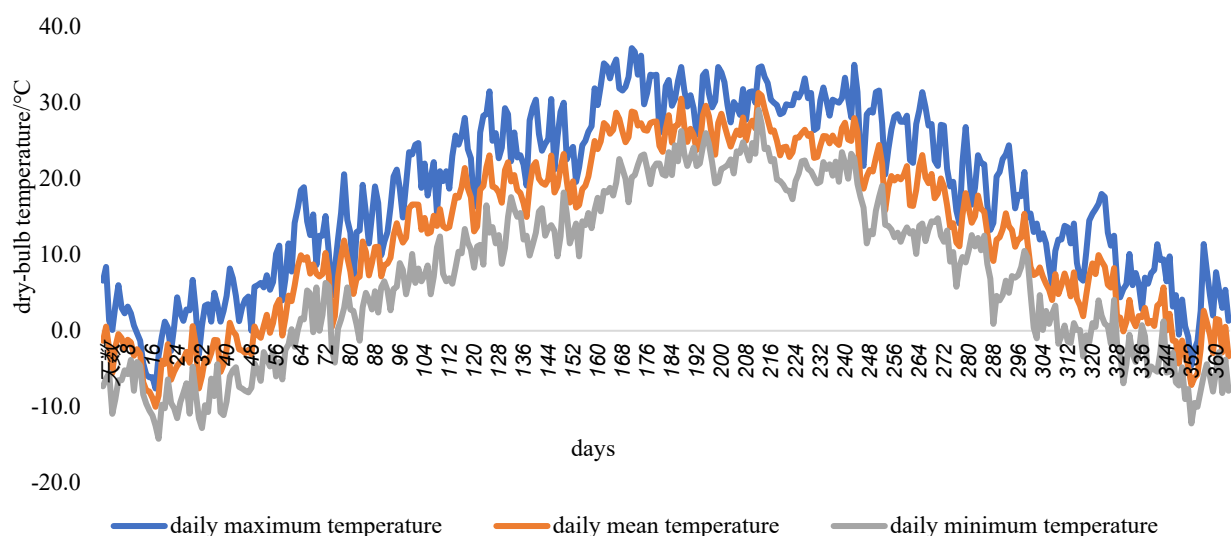


Figure 2. Temperature parameters of typical meteorological years in Shanghai

1.2.2. Building parameter setting

The functional rooms of the building include lobby, guest rooms, restaurants, toilets, stairwells and so on. Among them, there are 1 lobby, 37 rooms, 1 restaurant and 2 stairwells. The indoor thermal disturbance factors, indoor personnel, equipment, lighting and other working hours studied in this paper all use the default values in DeST software, and the parameters of each room are shown in Table 1.

Table 1. The main functional rooms and their parameters of the building

Function room	Room quantity	Maximum number of persons	Maximum power of the equipment/W	Per capita calorific value/W	Per capita moisture production / kg / (person · h)	Furniture coefficient
Hall	1	200	1430	58	0.184	10
Hotel room	37	3	20	61	0.109	30
Dining hall	1	470	250	66	0.102	10

1.2.3. Parameter setting of enclosure structure

The building envelope structure and its thermal parameters are shown in Table 2.

Table 2. Envelope construction and thermal parameters

Category	Structure	Thickness / mm	Thermal conductivity λ / (W / m · K)	Heat transfer coefficient K / (W / m · K)
External wall	Heavy mortar clay	240	1.616	0.564
	Pure gypsum board	10		
	Polystyrene foam	60		
	Pure gypsum board	8		
Interior wall	Cement mortar	20	0.430	1.515
	Haydite concrete	180		
	Cement mortar	20		
External door	Single-layer solid wooden door	25.3	0.072	2.000
Inner door	Single-layer solid wooden door	25.3	0.072	2.000
External window	Ordinary hollow glass	24		2.900

1.2.4. Air conditioning system settings

According to the investigation of the real state of the hotel, the air conditioning time and temperature are set as follows : the air conditioning calculation period in summer is from June 15 to September 15, and the air conditioning refrigeration temperature is set to 26 °C ; the heating time in winter is from December 1 to February 1 of the following year, and the heating temperature is set at 18 °C.

2. Building Energy Consumption Simulation Calculation

According to the above parameters, DeST software is used to calculate the energy consumption. The annual cumulative heat load of the building is 235387 kW · h, the air conditioning cooling load is 144366 kW · h, and the annual cumulative total load index is 379753 kW · h.

3. Orthogonal Test Method

3.1. Determination of Factors and Levels

According to the Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone (JGJ134-2010), the hotel belongs to the hot summer and cold winter zone (Zone IIIA). The limit values of the heat transfer coefficient are 1.0 W/(m²·K) for exterior walls,

0.4 W/(m²·K) for roofs, 2.0 W/(m²·K) for exterior doors, and 2.0 W/(m²·K) for exterior windows [8,9]. Factors such as exterior walls, roofs, windows, floor height, window-to-wall ratio, and external shading all affect building energy consumption [10]. To simplify the test, this study selects the two most influential factors: the thickness of exterior wall insulation and the window material.

Civil buildings often achieve insulation by increasing the thickness of brick walls and mortar, but the effect is poor and the wall thermal performance is not significantly improved. In this study, expanded polystyrene (EPS) is selected as the exterior wall insulation material [11], and the original ordinary single-glazed windows are replaced with energy-efficient glass windows. A thicker wall and roof insulation layer and better window energy performance lead to a higher energy-saving rate. However, considering the relationship between energy-saving benefits and initial retrofit investment, existing building retrofit cannot blindly pursue energy-saving efficiency [12]. Therefore, this study uses the orthogonal test method to combine multiple schemes and compare them, comprehensively evaluating the annual cumulative total load and economic benefits of each scheme to obtain the optimal energy-saving retrofit scheme. The factor-level settings for the orthogonal test are shown in Table 3.

Table 3. Orthogonal test factor-level settings

Level	Insulation thickness /mm	Window material
1	60	Ordinary insulating glass
2	80	Low-E coated low-emissivity insulating glass
3	100	Low-E coated vacuum glass

3.2. Orthogonal Test Table

For the above two factors (exterior wall and window) with three levels, a full factorial design would require 3*3=9 tests. The orthogonal array for the two factors at three levels is shown in Table 4.

Table 4. Orthogonal test design table (2 factors, 3 levels)

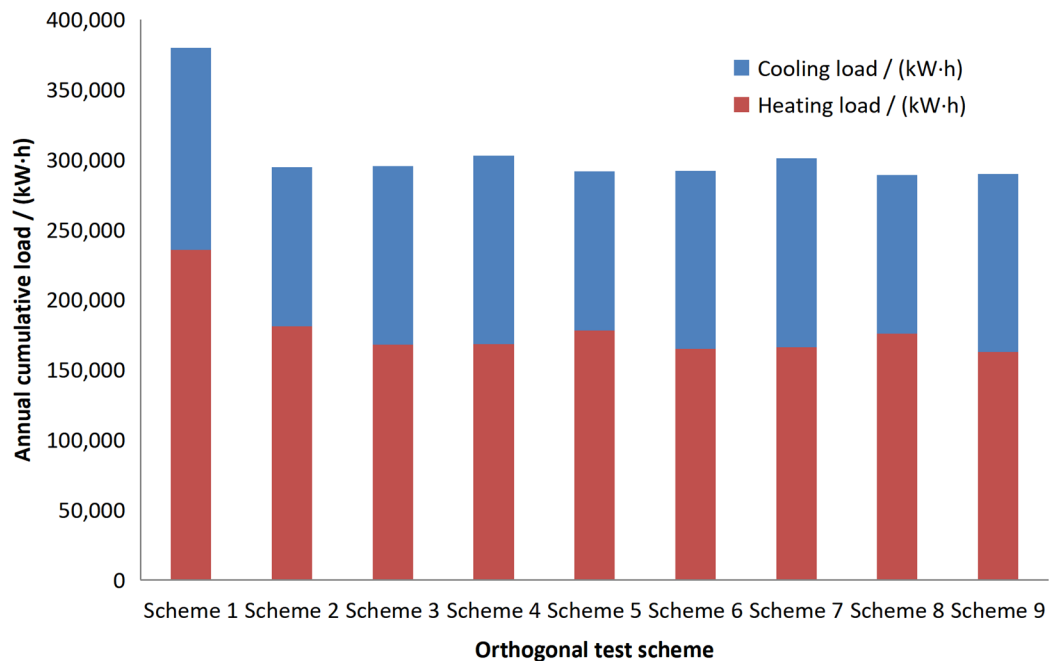
No.	Factor A	Factor B
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

3.3. Simulation and Calculation

Through DeST simulation, the combination of each scheme and its annual cumulative total load index are shown in Table 5, Figure 3.

Table 5. Cooling/heating load and total load of each scheme

No.	Insulation thickness A	Window material B	Heating load /($\text{kW}\cdot\text{h}$)	Cooling load /($\text{kW}\cdot\text{h}$)	Total load /($\text{kW}\cdot\text{h}$)
1	1	1	235387	144366	379753
2	1	2	180966	113819	294785
3	1	3	167940	127256	295196
4	2	1	168215	134767	302982
5	2	2	177854	113576	291430
6	2	3	164875	127083	291958
7	3	1	166156	134703	300859
8	3	2	175743	113371	289114
9	3	3	162796	126958	289754

**Figure 3.** Comparison of annual cooling/heating load of each orthogonal test scheme

4. Simulation Results and Analysis

Range analysis is used to judge the influence degree of each factor on the total load index. The primary and secondary factors are determined by calculating the range of the mean total load at each factor level. The specific results are shown in Tables 6 and 7.

Table 6. Range analysis of factor A

Factor A	Mean heating load /($\text{kW}\cdot\text{h}$)	Mean cooling load /($\text{kW}\cdot\text{h}$)	Mean total load /($\text{kW}\cdot\text{h}$)
Level 1	194764	128480	323245
Level 2	170315	125142	295457
Level 3	168232	125011	293242
Range	26533	3470	30002

Table 7. Range analysis of factor B

Factor B	Mean heating load /(kW·h)	Mean cooling load /(kW·h)	Mean total load /(kW·h)
Level 1	189919	137945	327865
Level 2	178188	113589	291776
Level 3	165204	127099	292303
Range	24716	24357	36088

As shown in Table 6, as the exterior wall insulation thickness increases from 60 mm to 100 mm, the mean heating load decreases by 26,533 kW·h, while the mean cooling load only decreases by 3,470 kW·h, indicating that thickening the insulation layer has a more significant effect on reducing heating load (winter heating demand).

The range of the mean total load is 30,002 kW·h, indicating that the exterior wall insulation thickness has a certain influence on the overall building energy consumption, but the variation in cooling load is small.

As shown in Table 7, after replacing with energy-efficient windows, the mean heating load decreases by 24,716 kW·h and the mean cooling load decreases by 24,357 kW·h, indicating that the window material has a significant influence on both heating and cooling loads.

The range of the mean total load is 36,088 kW·h. The influence of window material on the total load is greater than that of exterior wall insulation thickness, especially the largest gap between level 1 (ordinary glass) and level 2 (Low-E insulating glass), indicating that upgrading window energy performance is the key measure to reduce energy consumption.

Comparing the total load ranges of the two factors, the window material (factor B) range (36,088 kW·h) is greater than the exterior wall insulation thickness (factor A) range (30,002 kW·h). Therefore, in the hot summer and cold winter zone, the energy performance of window materials has a more significant influence on building energy consumption. Priority should be given to windows with a low heat transfer coefficient (such as Low-E coated insulating glass), which can substantially reduce the annual load. The range analysis clarifies that the window material is the dominant factor and the exterior wall insulation thickness is the secondary factor, providing data support for subsequent economic evaluation.

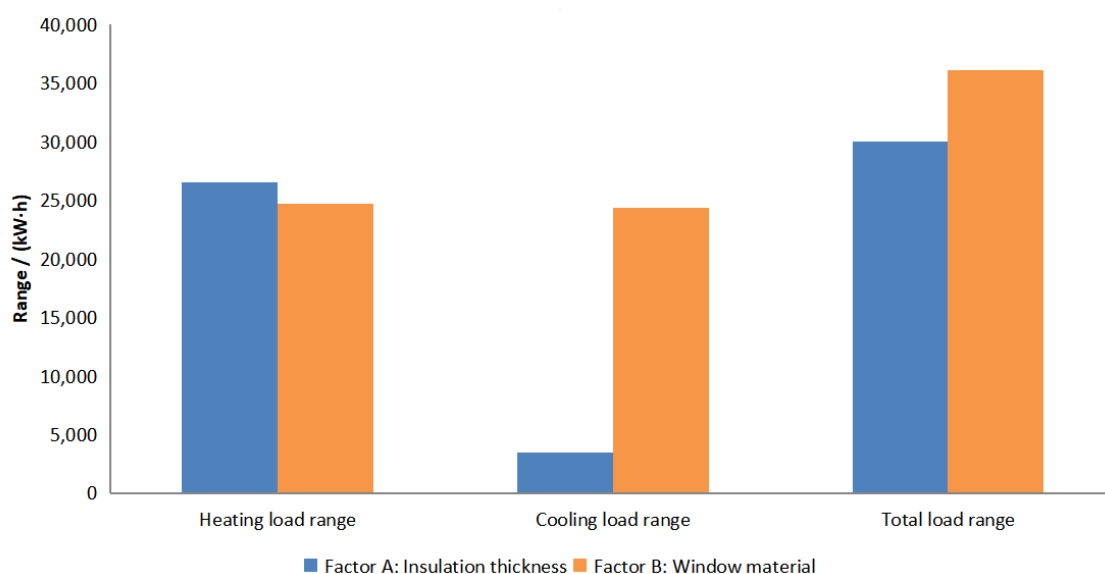


Figure 4. Range comparison of load between exterior wall insulation thickness and window material

According to the mean total load of each level combination, the combination of 100 mm exterior wall insulation (factor A3) and Low-E coated low-emissivity insulating glass (factor B2), i.e., Scheme 8, has the lowest total load (289,114 kW·h), which is the theoretical optimal scheme.

5. Conclusions

This study takes a civil hotel in Shanghai as the object and uses DeST-c modeling combined with the orthogonal test method to analyze the effects of exterior wall insulation thickness (60 mm, 80 mm, 100 mm) and window materials (ordinary insulating glass, Low-E coated low-emissivity insulating glass, Low-E coated vacuum glass) on building energy consumption. Range analysis shows that the window material has a more significant influence on the total load (range 36,088 kW·h), followed by the exterior wall insulation thickness (range 30,002 kW·h). Scheme 8 (100 mm insulation + Low-E coated low-emissivity insulating glass) has the lowest total load (289,114 kW·h), saving about 23.9% energy compared with the baseline. In combination with engineering practice, upgrading windows to low-heat-transfer materials (such as Low-E coated insulating glass) is the key measure to reduce energy consumption. The study shows that when optimizing the envelope, the energy-saving benefits and retrofit cost should be comprehensively considered. Priority should be given to improving window energy performance and reasonably selecting the insulation thickness, which can effectively promote the low-carbon development of civil buildings.

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