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Article

Study on the Influencing Factors of Energy Consumption of Nearly Zero Energy Residential Buildings in Cold and Arid Regions of Northwest China

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Abstract: There are many factors influencing the energy consumption of buildings in complex working conditions. In order to study the factors influencing the energy consumption of residential buildings with nearly zero energy in cold and arid regions of northwest China, factors such as the roof heat transfer coefficient (K_R), exterior wall heat transfer coefficient (K_E), ground heat transfer coefficient (K_G), exterior window heat transfer coefficient (K_{EW}), north window wall ratio (WWR_N), south window wall ratio (WWR_S), east west window wall ratio (WWR_{WE}), building orientation (BO), and ventilation times (VT) are taken as the influencing factors in this paper. Using the orthogonal test, 135 building energy consumption calculation models were built in DeST, and the influence of 9 factors on building energy consumption in 5 types of regions (severe cold region A (1A), severe cold region B (1B), severe cold region C (1C), cold region A (2A), and cold region B (2B)) were analyzed. The conclusions are as follows: in the process of realizing nearly zero energy of residential buildings in the cold and arid regions of northwest China, the K_R, K_E, K_G, K_{EW}, WWR_N, WWE_{WE} should be reduced as much as possible in the five regions. The 1A,1B,1C regions should increase WWE_{WE} and VT, with BO of about 15° east of due north and VT of about 5, 8, and 10 times per hour, respectively. The WWE_S, BO and VT for the 2A region should be set at round 0.45, north-south, and about 10 times per hour, respectively. For the 2B region, WWE_S should be set at around 0.45, BO around 15° east of due north, and VT as low as possible within the scope of the 'technical standard for nearly zero energy buildings'.

Keywords: nearly zero energy building; building energy consumption; orthogonal test; multifactorial influence

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1. Introduction

The energy consumed by the construction industry accounts for about 36% of the global total energy consumption, and building energy consumption will continue to increase in the future [1–3]. However, a large amount of energy consumption of buildings is bound to bring about a large amount of carbon emissions, resulting in serious environmental problems. Reducing building energy consumption is a problem that must be considered. From the point of view of the factors affecting the building energy consumption, the method to reduce the building energy consumption appears to be feasible.

There are many factors influencing building energy consumption. Scholars mainly study the influence of building envelope, meteorological factors, window wall ratio, natural and social environment factors, the building itself, and other factors [4–11]. Fatima Harkouss et al. took energy consumption demand as the starting point and studied the optimal envelope structure and the optimal window wall ratio in 25 climate zones through optimization algorithm [12]. De Masi Rosa Francesca et al. studied energy and environment in Naples, Munich, Paris, and analyzed the sensitivity of building materials in these three areas [13]. Rabani Mehrdad et al. studied windowing, envelope structure, shading device, and other factors through a new optimization method [14]. Gianluca Pappaccog Li et al. analyzed the sensitivity of urban climate conditions and building energy consumption to the parameters of urban materials and building environment, and obtained the biggest influencing factors of indoor predetermined temperature [15]. Bingwen Zhao et al. took a public building in China as the research object and established a benchmark model by using EnergyPlus to analyze the influence of main thermal performance of building envelope on energy consumption in different climate regions, and obtained the order of factors affecting building energy consumption in different regions [16]. Junsheng Hu et al. took Beijing as an example to study the influence of different thermal physical envelope structures on building energy consumption, and obtained the order of influencing factors of public building energy consumption [17].

In 1976 Danish scientists came up with the concept of "zero energy building" while studying solar energy for winter heating. In recent years, domestic and foreign scholars' research on nearly zero energy buildings has developed rapidly, and the relevant research mainly focuses on the following aspects: (1) Feasibility research: a feasibility study is mainly based on the local legislation, geography and climate, technology and economic factors, using the net present value (NPC), payback period and operating costs and other economic parameters to test the cost effectiveness of the project, analyze the feasibility of zero energy building in the local [18–21]. (2) Envelope structure: The research on the envelope structure mainly focuses on two aspects: 1) to transform the envelope structure of the existing building; 2) to put forward suggestions on the selection of the envelope structure of the new building through the research on the thermal parameters of the building envelope [12–14]. (3) Research on multi-objective optimization: multi objective optimization studies of near-zero energy buildings mainly focus on the thermal parameters of the envelope, the windowing/wall ratio, the capacity of the photovoltaic power generation system, wind power generation system and other energy supply systems as optimization parameters, and the system cost, energy production, carbon dioxide emissions, indoor thermal comfort as objective functions. In general, the thermal parameters, heating/cooling temperature and energy consumption indexes of the envelope structure stipulated in the existing standards are taken as the constraints for multi-objective optimization [22–25].

Although the influencing factors of building energy consumption have been studied, they ignore the premise of nearly zero energy consumption in terms of factors affecting building energy consumption in the cold and arid regions of northwest China. As a result, the research on the influencing factors of nearly zero energy residential building energy consumption in the cold and arid areas of northwest China is still limited. The relationship between the influencing factors and the building energy consumption cannot be accurately predicted in the design stage of the nearly zero energy building, which leads to the excessive use of technology and energy input in the design process of the nearly zero energy building, resulting in a large amount of energy waste. In addition, as the Ministry of Housing and Urban-Rural Development of the People's Republic of China issued the Technical Standard for Nearly Zero Energy Buildings (GB/T 51350-2019) in 2019, the development of nearly zero energy buildings has unique advantages in the cold and arid northwest of China, which is rich in renewable energy. Therefore, it is urgent to study the influencing factors of energy consumption of residential buildings with nearly zero energy consumption in such regions.

This paper identifies the specific effects of nine factors on heating energy consumption, cooling energy consumption and annual total energy consumption of five types of nearly zero energy consumption buildings in the cold and arid regions of northwest China are studied, and the measures that should be taken to reduce heating energy consumption, cooling energy consumption and annual total energy consumption are clarified. This paper aims to study how nine factors affect the energy consumption of five types of buildings in the cold and dry regions of northwest China. This paper also obtained the specific ways of nine influencing factors on the building energy consumption through orthogonal test and DeST. North-west China has abundant renewable energy sources and has begun the development of nearly zero energy consumption buildings. Based on research into the nine factors, we can better understand the status of renewable energy development in northwest China. We aimed to improve near zero energy consumption in the course of the architectural design process. Finally, we found that abuse of products and overuse of technology and energy input is a common phenomenon, which has important theoretical significance and application value for the promotion and application of near-zero energy consumption buildings in cold and dry land, and put forward suggestions for the realization of nearly zero energy buildings in northwest China.

2. Materials and Methods

In order to study the factors influencing the energy consumption of residential buildings with nearly zero energy consumption in cold and arid areas of northwest China, the roof heat transfer coefficient (K_R), exterior wall heat transfer coefficient (K_E), ground heat transfer coefficient (K_G), exterior window heat transfer coefficient (K_{EW}), north window wall ratio (WWR_N), south window wall ratio (WWR_S), east west window wall ratio (WWR_{WE}), building orientation (*BO*) and ventilation times (*VT*) are taken as the influencing factors. An orthogonal test is designed and building energy consumption simulation software DeST was used to obtain the energy consumption of five typical residential buildings in cold and arid regions of northwest China under the influence of nine factors.

2.1. Typical Buildings

Located in the inland of northwest China, the cold and arid regions of Northwest China cover a vast area, accounting for 31.7% of China's land area. Winter is cold and dry; according to the geographical location, the average temperature of the coldest month is about −5 °C to −15 °C, most areas belong to the central heating area. According to the Chinese standard GB 50176-2016 Code for Thermal Design of Civil Buildings, the main thermal design areas in Northwest China belong to severe cold region A (1A), severe cold region B (1B), severe cold region C (1C), cold region A (2A) and cold region B (2B). For these five climate regions, Gangca (belongs to 1A), Altay (belongs to 1B), Jiuquan (belongs to 1C), Yinchuan (belongs to 2A) and Xi'an (belongs to 2B) are taken as the typical regions in this paper. The general situation of typical buildings in these five typical regions is shown in Table 1. Table 2 shows the structure of exterior wall, roof, and floor.

Table 1. Typical architectural overview of five typical regions [26,27].

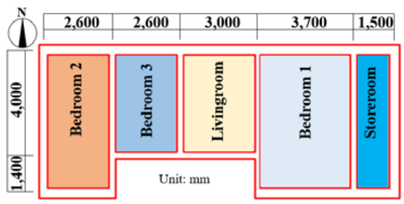
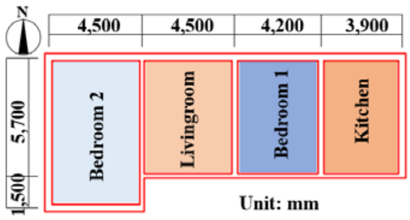
Climatic Region	Building Height(m)	Energy Supply area(m^2)	Area of Air Conditioning	Building Layout
1A	4	56.42	bedroom1 bedroom2 bedroom3 living room	
1B	3.5	79.80	bedroom1 bedroom2 living room	

Table 1. *Cont.*

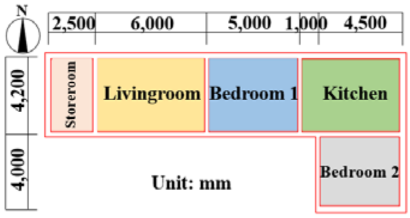
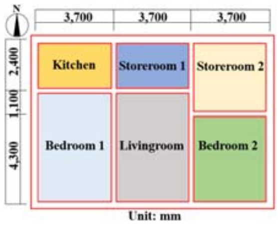
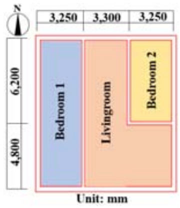
<table>
<tr><th>Climatic Region</th><th>Building Height(m)</th><th>Energy Supply area(m^2)</th><th>Area of Air Conditioning</th><th>Building Layout</th></tr>
<tr><td>1C</td><td>3</td><td>64.20</td><td>bedroom1
bedroom2
living room</td><td>
</td></tr>
<tr><td>2A</td><td>3.6</td><td>55.87</td><td>bedroom1
bedroom2
living room</td><td>
</td></tr>
<tr><td>2B</td><td>3.4</td><td>107.8</td><td>bedroom1
bedroom2
living room</td><td>
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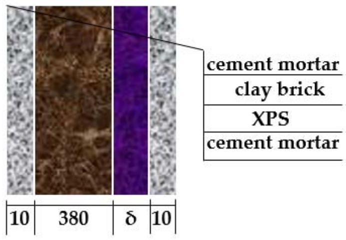
Table 2. Structure of exterior wall, roof, and floor.

<table>
<tr><th>Construction Site</th><th>Structure</th></tr>
<tr><td>wall</td><td>
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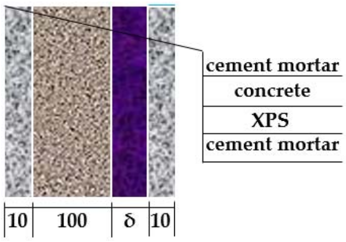
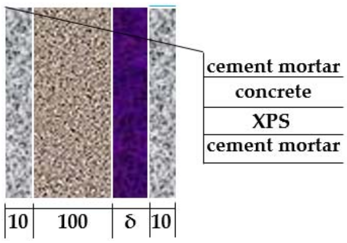
<tr><td>roof</td><td>
</td></tr>
<tr><td>floor</td><td>
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2.2. Orthogonal Test Design

In China's national standards, the comprehensive value of building energy consumption is less than or equal to 55 kWh/(m^2·a), the technical parameters of nearly zero energy residential buildings are specified as Tables 3 and 4.

Table 3. Heat transfer coefficient parameters of nearly zero energy consumption residential buildings in China.

Part of the Envelope Structure		K(W/(m^2·K)) Severe Cold Region	Cold Region
Roof		0.1–0.15	0.1–0.2
Exterior Wall		0.1–0.15	0.15–0.2
Ground and Exterior Slab		0.15–0.3	0.2–0.4
Exterior Window		≤1.0	≤1.2
SHGC	Winter	≥0.45	≥0.45
	Summer	≤0.3	≤0.3

Table 4. Window-wall ratio parameters of nearly zero energy consumption residential buildings in China.

The Window Towards	Severe Cold Region	Cold Region
North	≤0.25	≤0.30
West, East	≤0.30	≤0.35
South	≤0.45	≤0.50

In order to study the influence of multiple factors on building energy consumption, an orthogonal test method was adopted. The orthogonal test method is a design method to study multi-factors and multi-levels. Compared with a comprehensive test, the orthogonal test can reduce the number of tests, and it represents a high efficiency, rapid and economic experimental design method. In this study, K_R, K_E, K_G, K_{EW}, WWR_N, WWR_S, WWR_{WE}, BO, and VT are used as influencing factors, and orthogonal factor table and orthogonal factor level table are designed to study their influence on building energy consumption.

The level of influencing factors is based on the technical standard for nearly zero energy buildings (GB/T 51350-2019) and general code for energy efficiency and renewable energy application in buildings (GB 55015-2021) issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China. The designed orthogonal factor level table and orthogonal table are shown in Appendix A.

2.3. Simulation Tools and Conditions

DeST is an effective building energy simulation tool developed by Tsinghua University in 1989. From the development of the software to the present, it has been widely used in building thermal process calculation through many cases verifications [28].

In the process of using DeST simulation, with nine influencing factors as independent variables, with the building heating energy consumption and cooling energy consumption as dependent variables, through the orthogonal Appendix A design and orthogonal test. In the process of building simulation, other variables (such as heating temperature, cooling temperature, equipment power and lighting density of each room, etc.) are based on the technical standard for nearly zero energy buildings (GB/T 51350-2019), the design standard for energy efficiency of residential buildings in severe cold and cold regions (JGJ 26-2018) and the general code for energy efficiency and renewable energy application in buildings (GB 55015-2021).

3. Results and Discussion

According to the tests arranged by orthogonal tables, 135 tests are required for typical buildings in 5 categories. Building energy consumption simulation software DeST was used for the test.

3.1. Analysis of Orthogonal Test Results

In order to analyze the order of influence of various factors on building energy consumption under the premise of building parameters stipulated in the technical standard for nearly zero energy buildings, the extreme value (EV) analysis of test results are carried out. Extreme value represents the maximum difference between the mean values of each factor, which can reflect the influence of all factors affecting energy consumption on building energy consumption [29]. As the horizontal values of each parameter in the design of the orthogonal table are all taken within the scope of the technical standard for nearly zero energy buildings (GB/T 51350-2019), the following analysis was carried out under the premise of the range of building parameters stipulated in the technical standard for nearly zero energy buildings (GB/T 51350-2019).

3.1.1. Severe Cold Region A

As can be seen from Figures 1 and 2, for region 1A, the factors influencing the cumulative annual heat load of buildings are BO, WWR_S, K_{EW}, K_E, K_R, K_G, WWR_N, VT, and WWE_{WE} in descending order. Among them, BO has the strongest influence on the cumulative heat load, and the cumulative heat load decreases rapidly from 15° west of due north to 15° east of due north, VT has a weak influence on the cumulative indoor heat load throughout the year, and WWR_S is negatively correlated with the heat load. The influence of other factors on the cumulative heat load increases with the increase of each parameter.

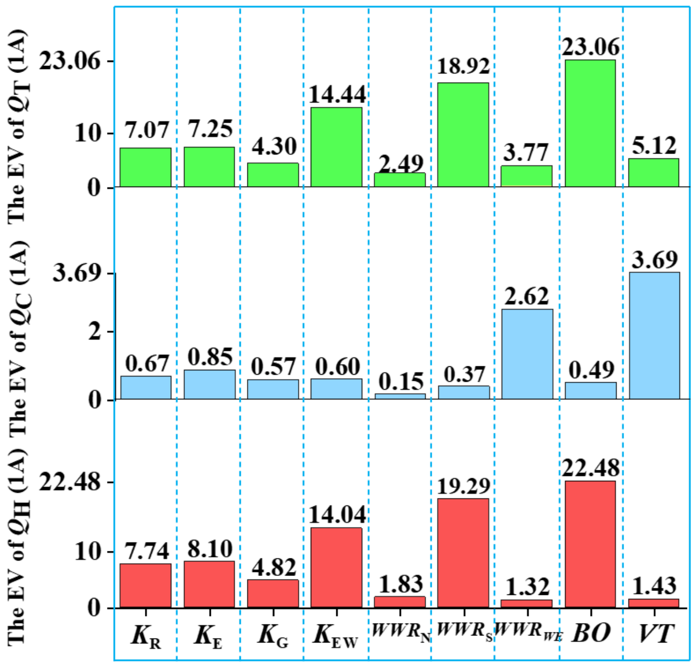

Figure 1. Extreme value of each factor(1A).

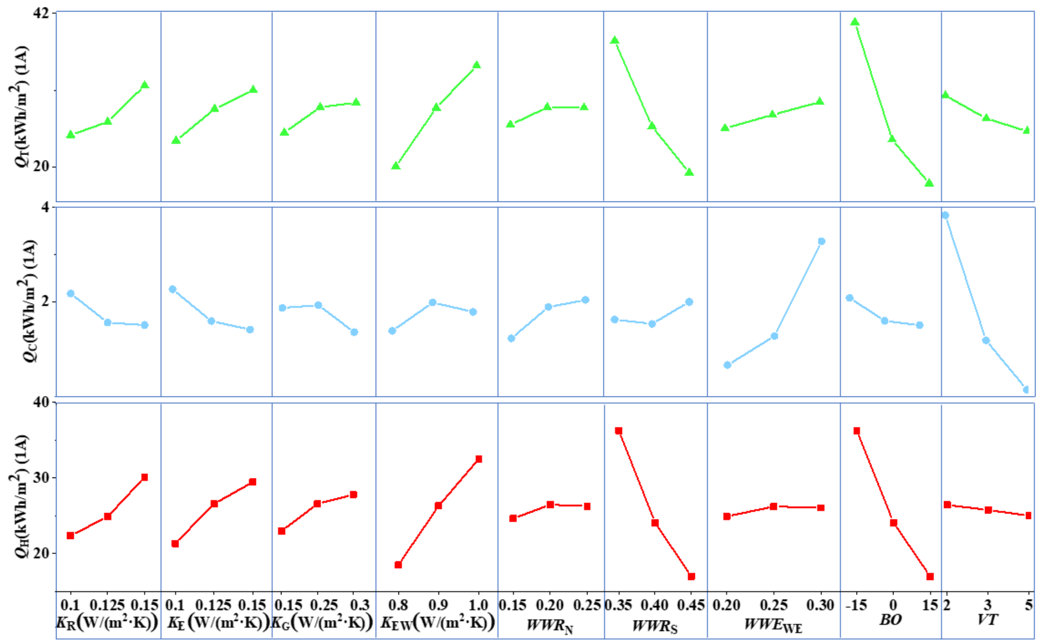

Figure 2. Influence trend of various factors on building energy consumption (1A).

The factors influencing the annual cumulative cooling load of buildings in descending order are *VT*, WWE_{WE}, K_E, K_R, K_{EW}, K_G, *BO*, WWR_S, and WWR_N, among which the *VT* has the greatest influence on the cumulative cooling load, and the cumulative cooling load decreases rapidly from two to five times per hour. The influence of K_R, K_E, K_G, and *BO* on the cumulative cooling load decreases with the increase of each parameter. However, the influence of K_{EW}, WWR_N, WWR_S, and WWE_{WE} on the cumulative cooling load show an overall upward trend with the increase of each parameter. The factors influencing the annual cumulative load of buildings are *BO*, WWR_S, K_{EW}, K_E, K_R, *VT*, K_G, WWE_{WE}, and WWR_N in descending order. The influence of each factor on the cumulative load is basically the same as that of each factor on the cumulative heat load. This is due to the fact that for region 1A, the cumulative heat load of buildings accounts for a large proportion of the cumulative load. In general, 1A region for severe cold region A, in the process of implementation nearly zero energy buildings, in addition to meet the requirements of almost the technical standard for nearly zero energy buildings' envelope structure, the effective method to reduce building energy consumption for building toward the 15° east of due north, low heat transfer coefficient of the transparent enclosure structure, a small south window wall ratio, and cooling during the summer to keep around 5 times per hour of ventilation.

3.1.2. Severe Cold Region B

As can be seen from Figures 3 and 4, for region 1B, the factors influencing the cumulative annual heat load of buildings are *BO*, K_{EW}, WWR_S, K_E, K_R, K_G, WWR_N, WWE_{WE}, and *VT* in descending order. Among them, as with region 1A, *BO* has the most obvious influence on cumulative heat load, and the cumulative heat load decreases rapidly in the range from 15° west of due north to 15° east of due north, *VT* has a weak influence on cumulative indoor heat load throughout the year, and WWR_S is negatively correlated with heat load. The influence of other factors on the cumulative heat load increases with the increase of each parameter. The factors influencing the cumulative cooling load of buildings are *VT*, WWE_{WE}, WWR_S, WWR_N, K_G, *BO*, K_E, K_{EW}, and K_R in descending order. *VT* has the greatest influence on the cumulative cooling load, and the cumulative cooling load decreases rapidly in the range from two times to eight times per hour. The influence of WWR_N, WWR_S and WWE_{WE} on the cumulative cooling load shows an upward trend with the increase of each parameter.

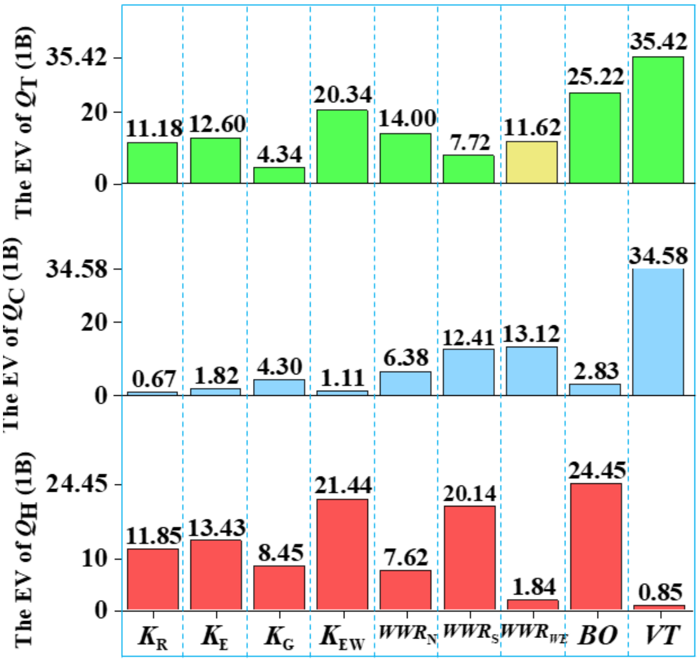

Figure 3. Extreme value of each factor (1B).

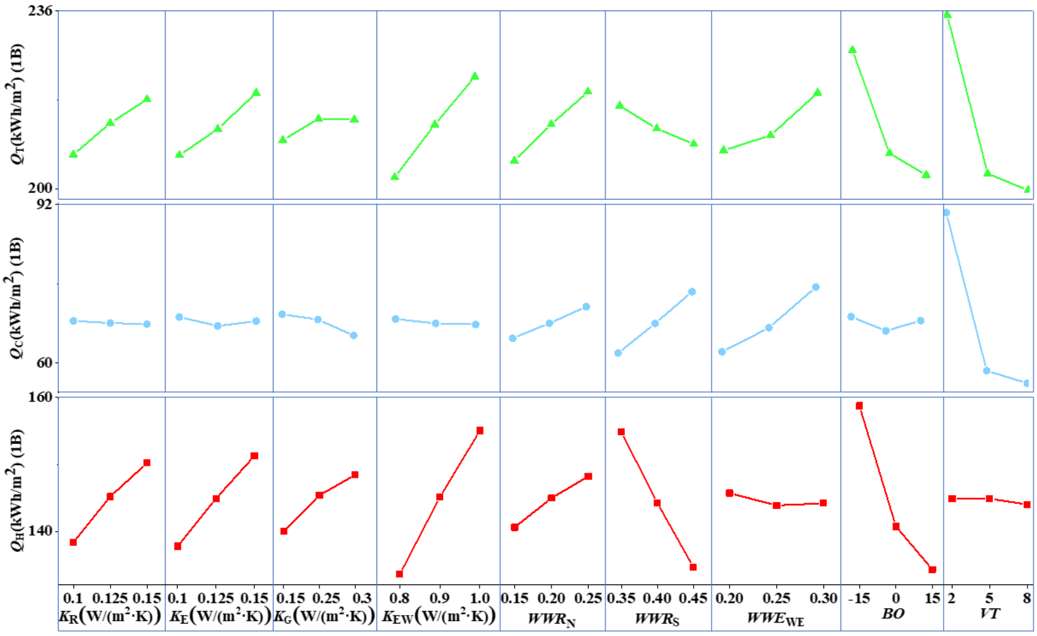

Figure 4. Influence trend of various factors on building energy consumption (1B).

The factors influencing the annual cumulative load of buildings in descending order are VT, BO, K_{EW}, WWR_N, K_E, WWE_{WE}, K_R, WWR_S, and K_G. The influence of each factor on the cumulative load is basically the same as that of each factor on the cumulative heat load. This is due to the fact that for region 1B, the cumulative heat load of buildings accounts for a large proportion of the cumulative load. In general, region 1B is a severe cold region B. In the process of realizing the nearly zero energy building, in addition to meeting the requirements of almost the technical standard for nearly zero energy buildings' envelope structure, the effective methods to reduce the building energy consumption are a building orientation of about 15° east of due north, a low heat transfer coefficient of the transparent enclosure structure, and ventilation of about eight times per hour in summer when cooling.

3.1.3. Severe Cold Region C

As can be seen from Figures 5 and 6, for region 1C, the factors influencing the cumulative annual heat load of buildings are WWR_S, K_{EW}, K_G, K_R, WWR_N, BO, K_E, V_T, and WWE_{WE} in descending order. K_{EW} and WWR_S have a strong influence on the cumulative heat load. The influence of K_R, K_E, K_G, K_{EW}, and WWR_N on the cumulative heat load show a general upward trend with the increase of each parameter, while the influence of WWR_S, WWE_{WE}, BO, and VT on the cumulative heat load shows a general downward trend with the increase of each parameter.

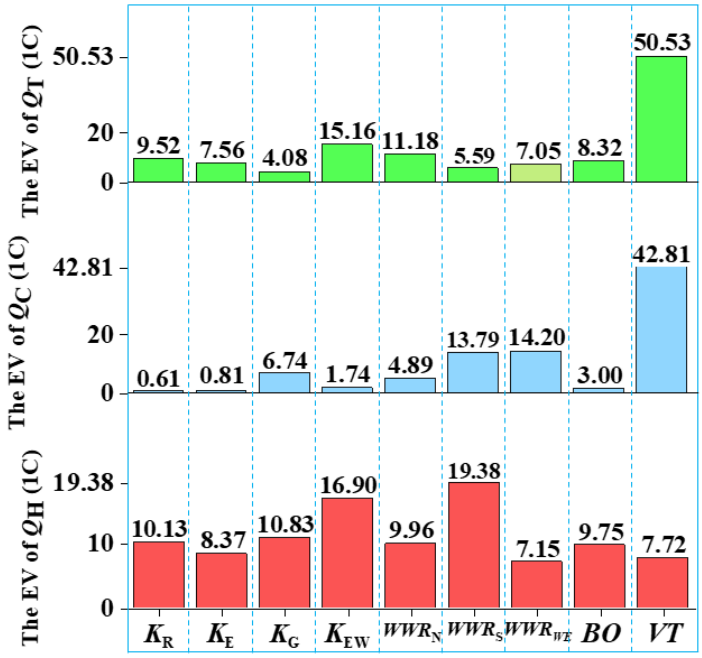

Figure 5. Extreme value of each factor (1C).

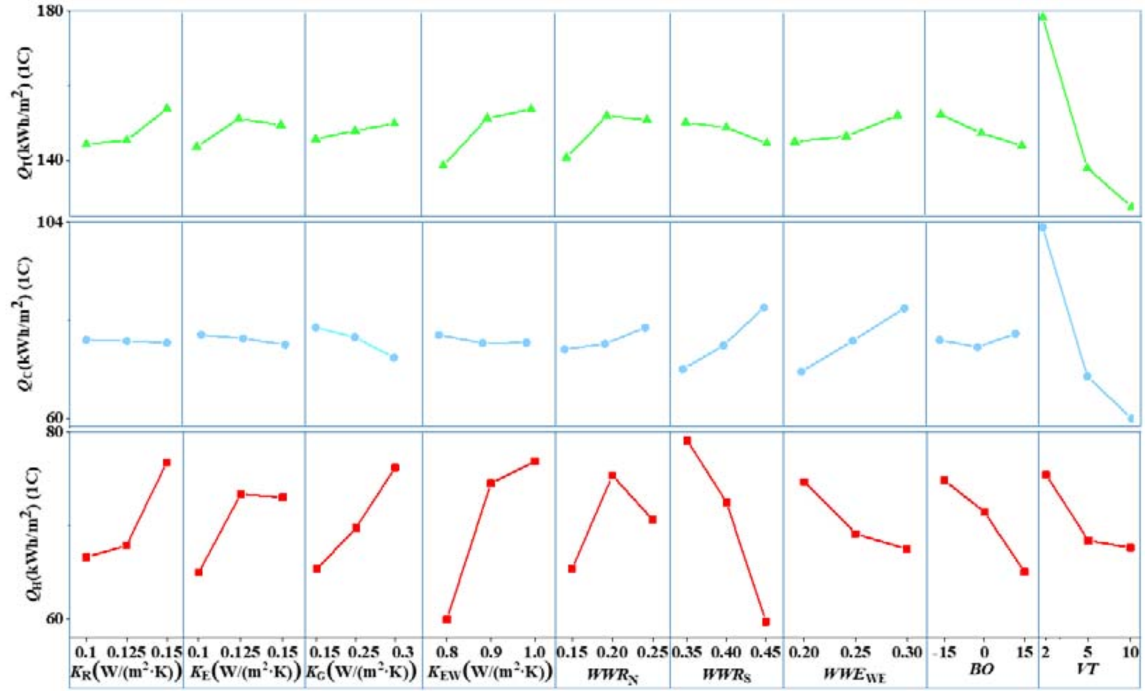

Figure 6. Influence trend of various factors on building energy consumption (1C).

The factors influencing the cumulative cooling load of buildings are VT, WWE_{WE}, WWR_S, K_G, WWR_N, BO, K_{EW}, K_E, and K_R in descending order. Among them, VT has the strongest influence on the cumulative cooling load, and the cumulative cooling load decreases rapidly in the range from 2 times to 10 times per hour. The influence of WWR_N, WWR_S and WWE_{WE} on the cumulative cooling load show an upward trend with the increase of each parameter. The factors influencing the annual cumulative load of buildings from large to small are VT, K_{EW}, WWR_N, K_R, BO, K_E, WWE_{WE}, WWR_S, and K_G among which, the influence on VT cumulative load is the strongest. In general, region 1C is a severe cold region C. In the process of realizing a near-zero energy building, in addition to meet the requirements of almost the technical standard for nearly zero energy buildings' envelope structure, maintaining ventilation at about 10 times per hour during cooling in summer is the most effective method.

3.1.4. Cold Region A

As can be seen from Figures 7 and 8, for region 2A, the factors influencing the cumulative annual heat load of buildings are BO, K_{EW}, K_R, WWR_S, K_E, K_G, WWR_N, VT, and WWE_{WE} in descending order. Among them, building orientation has a strong influence on cumulative heat load. The influence of K_R, K_E, K_G, K_{EW}, WWR_N, and VT on the cumulative heat load shows a general upward trend with the increase of each parameter, while the influence of WWR_S, WWE_{WE}, and BO on the cumulative heat load shows a general downward trend with the increase of each parameter.

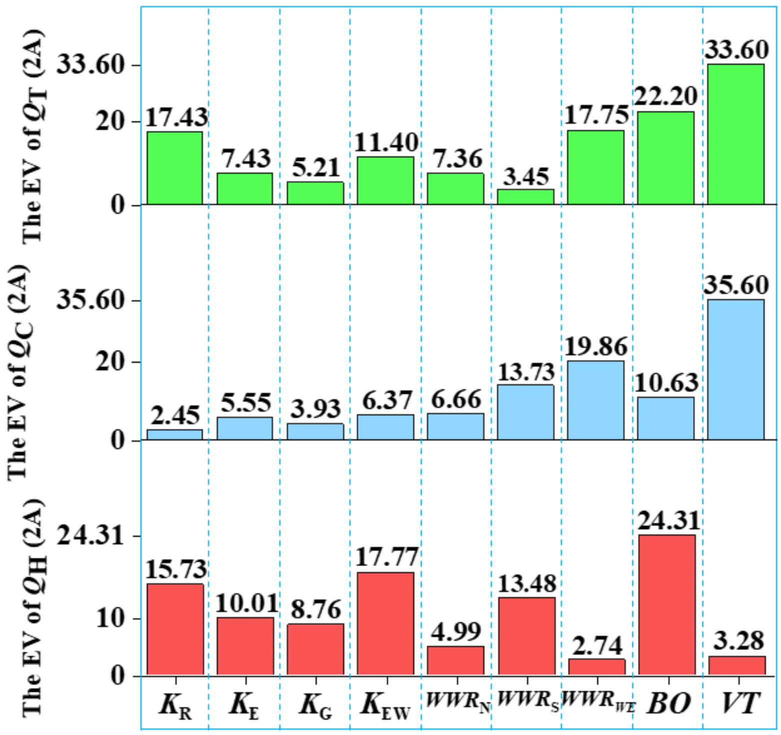

Figure 7. Extreme value of each factor (2A).

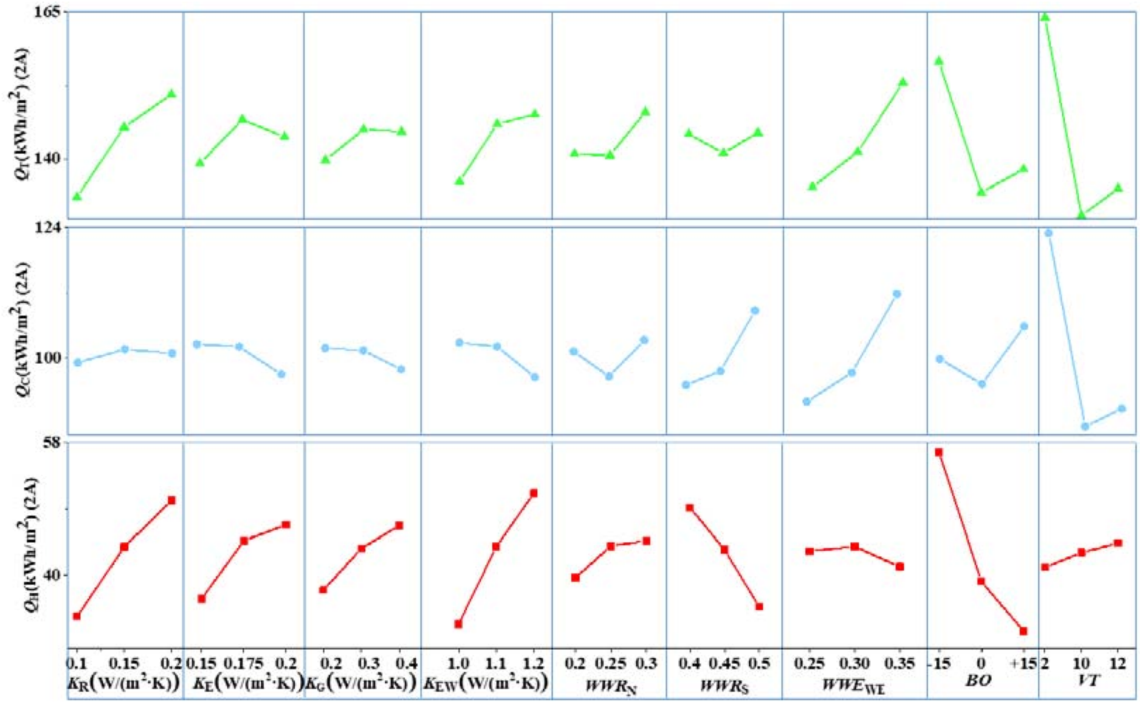

Figure 8. Influence trend of various factors on building energy consumption (2A).

The factors influencing the cumulative cooling load of buildings throughout the year are *VT*, WWE_{WE}, WWR_S, *BO*, WWR_N, K_{EW}, K_E, K_G, and K_R in descending order. *VT* has the strongest influence on the cumulative cooling load, and the cumulative cooling load decreases rapidly in the range from 2 times to 12 times per hour. The influence of WWR_S and WWE_{WE} on the cumulative cooling load shows an increasing trend with the increase of each parameter. The factors influencing the annual cumulative load of buildings are *VT*, *BO*, WWE_{WE}, K_R, K_{EW}, K_E, WWR_N, K_G, and WWR_S in descending order, among which, *VT* and *BO* have the strongest influence on the cumulative load. The influence of other factors on the load increases with the increase of each parameter.

In general, region 2A is a cold region A. In the process of realizing a near-zero energy building, in addition to meet the requirements of almost the technical standard for nearly zero energy buildings' envelope structure, it is necessary to maintain *VT* about 10 times per hour during cooling in summer and to have a small east-west window wall ratio (as well as a due south orientation).

3.1.5. Cold Region B

As can be seen from Figures 9 and 10, for region 2B, the factors influencing the cumulative annual heat load of buildings are K_{EW}, K_R, *BO*, K_G, WWR_S, *VT*, K_E, WWR_N, and WWE_{WE} in descending order. Among them, *BO*, K_R, and K_{EW} have strong influence on cumulative heat load. Except for WWR_S, WWE_{WE}, and *BO*, the influence of other factors on building energy consumption generally presents an upward trend.

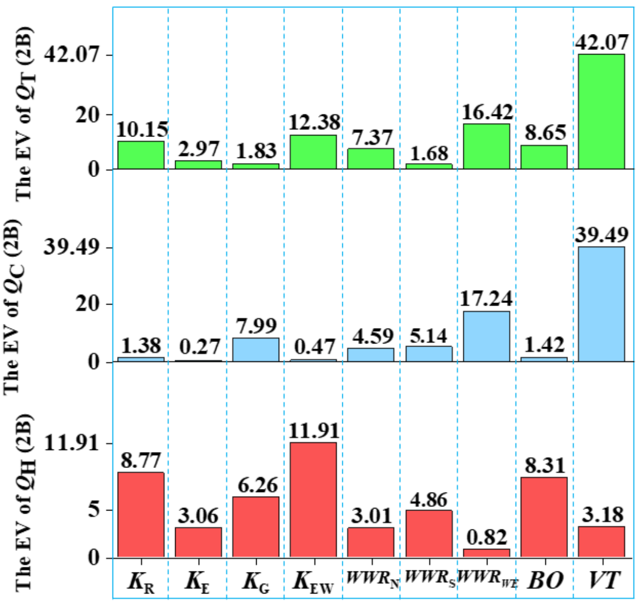

Figure 9. Extreme value of each factor (2B).

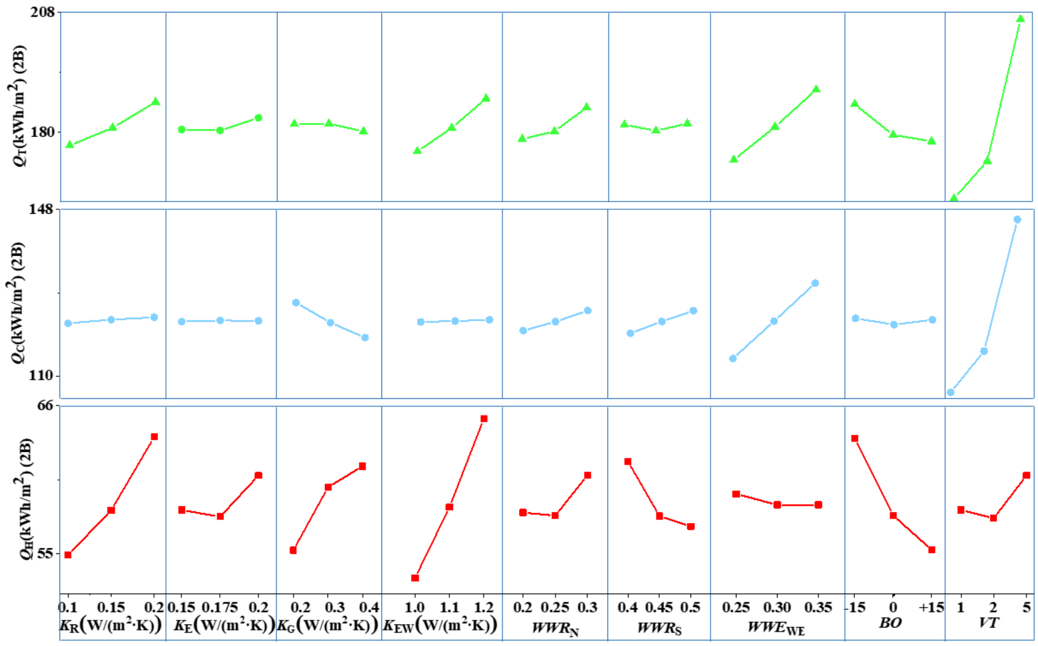

Figure 10. Influence trend of various factors on building energy consumption (2B).

The factors influencing the annual accumulative cooling load of buildings in descending order are *VT*, WWE_{WE}, K_G, WWR_S, WWR_N, *BO*, K_R, K_{EW} and K_E, among which *VT* has the strongest influence on the accumulative cooling load. Different from the other four types of areas, *VT* ranges from one to five times per hour. The accumulative cooling load rises rapidly, since the outdoor air temperature and indoor air temperature in class 2B region are different from the other four regions. The factors influencing the annual cumulative load of buildings from large to small are *VT*, WWE_{WE}, K_{EW}, K_R, *BO*, WWR_N, K_E, K_G, and WWR_S, among which *VT* has the strongest influence on the cumulative load. The influence of other factors on load shows a general upward trend with the increase of each parameter, while *BO* demonstrates the opposite trend. In general, region 2A is a cold region A. In the process of realizing the nearly zero energy building, in addition to meeting the requirements of almost the technical standard for nearly zero energy buildings' envelope structure, it is necessary to have a small east-west window-wall ratio, a building orientation about 15° west of due north, and a building ventilation kept as low as possible within the specified range.

3.2. Summary of Influencing Factors of Energy Consumption

For the annual cumulative heat load, K_R, K_E, K_G, K_{OW}, and WWR_N in the five types of regions are positively correlated with the annual cumulative heat load, while WWR_S and BO are negatively correlated with the annual cumulative heat load. In terms of WWE_{WE}, the heat loads of 1B,1C,2A and 2B decreased with the increase of WWE_{WE}, while the heat loads of 1A region decreased. In general, among many factors affect heat load; K_{EW}, WWR_S and BO are in the leading position, while WWE_{WE} and VT are in the weakest position.

For the annual cumulative cooling load, K_R, K_E, K_G, K_{EW}, WWR_N and BO have little influence on the annual cumulative cooling load of buildings, while WWR_S, WWE_{WE}, and VT have a great influence on the cooling load of buildings. Specifically, for the five types of regions, WWR_S, WWE_{WE} are positively correlated with the cooling load. For region 2B, VT is negatively correlated with cooling load, which is opposite to the other four areas.

For the annual accumulative load, K_R, K_E, K_G, K_{EW}, WWR_N, and WWE_{WE} are positively correlated with the annual accumulative load for the five types of regions. For the 1A,1B and 1C regions, WWE_{WE}, BO and VT are negatively correlated with the annual cumulative load. For the class 2A area, with the increase of WWE_S, BO and VT, the cumulative load curve showed an inflection point and showed a downward trend. But for area 2B, the WWE_S curve shows an inflection point at 0.45, BO is negatively correlated with the annual cumulative load, and VT is positively correlated with the annual cumulative load in region 2B.

4. Conclusions

In this paper, based on the five types of reference buildings in the cold and arid regions of northwest China, through the method of orthogonal testing, in DeST energy consumption simulation software 5 types of regions, 3 levels, 9 factors, and a total of 135 kinds of building energy consumption calculation models were set up. Through the extreme value analysis of each type of building energy consumption simulation results, the following conclusions were obtained.

In the process of realizing nearly zero energy consumption for residential buildings in cold and arid areas of northwest China, the five types of residential buildings should reduce the roof heat transfer coefficient, the exterior wall heat transfer coefficient, the ground heat transfer coefficient, the exterior window heat transfer coefficient, the north window wall ratio, and the east west window wall ratio as much as possible within the scope prescribed by the technical standard for nearly zero energy buildings. Class 1A,1B,1C regions should increase the east west window wall ratio and ventilation times, with building orientations of about 15° east of due north and ventilation of about 5, 8, 10 times per hour, respectively. The south window wall ratio, building orientation and ventilation times for class 2A regions should be set at 0.45, north-south, and about 10 per hour, respectively. For class 2B regions, the south window wall ratio should be set around 0.45, building orientation around 15° east of due north, and the ventilation times should be kept as low as possible within the limits specified by the technical standard for nearly zero energy buildings.

By studying the influencing factors of energy consumption of nearly zero energy buildings in Northwest China, this paper obtains the specific influencing ways of each factor on energy consumption. In future studies, researchers can expand the building area and study the influencing factors of energy consumption of nearly zero energy buildings in different areas and larger areas.

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Appendix A

Table A1. Table of orthogonal factor levels of residential buildings in severe cold regions.

Level	Test Factor										
	K_R	K_E	K_G	K_{EW}	WWR_N	WWR_S	WWE_{WE}	*BO*	*VT* 1A	*VT* 1B	*VT* 1C
1	0.1	0.1	0.15	0.8	0.15	0.35	0.20	15° east of due north	2	2	2
2	0.125	0.125	0.25	0.9	0.20	0.40	0.25	due north	3	5	5
3	0.15	0.15	0.3	1.0	0.25	0.45	0.30	15° west of due north	5	8	10

Table A2. Orthogonal test table of residential buildings in severe cold regions L27.

Test	K_R	K_E	K_G	K_{EW}	WWR_N	WWR_S	WWE_{WE}	*BO*	*VT* 1A	*VT* 1B	*VT* 1C
1	3	3	1	1	3	3	1	1	2	2	2
2	2	2	2	2	3	1	2	1	3	3	3
3	1	1	3	3	3	2	3	1	1	1	1
4	1	2	1	2	1	3	3	3	2	2	2
5	3	1	2	3	1	1	1	3	3	3	3
6	1	1	2	2	2	3	2	1	1	1	1
7	1	2	3	1	3	1	2	3	2	2	2
8	3	1	3	1	2	3	2	3	3	3	3
9	1	3	1	3	1	2	2	2	3	3	3
10	2	1	2	1	3	2	3	2	2	2	2
11	2	1	3	2	1	1	1	2	2	2	2
12	3	2	1	3	3	1	2	2	1	1	1
13	2	3	2	3	3	3	1	3	1	1	1
14	2	3	1	2	2	1	3	3	1	1	1
15	1	2	2	3	2	2	1	3	2	2	2
16	3	2	3	2	2	2	1	2	1	1	1
17	2	3	3	1	1	2	2	3	1	1	1
18	2	2	3	3	1	3	3	1	3	3	3
19	3	2	2	1	1	3	3	2	1	1	1
20	2	1	1	3	2	3	2	2	2	2	2
21	1	3	2	1	2	1	3	2	3	3	3
22	2	2	1	1	2	2	1	1	3	3	3
23	1	1	1	1	1	1	1	1	1	1	1
24	1	3	3	2	3	3	1	2	3	3	3
25	3	3	2	2	1	2	2	1	2	2	2
26	3	3	3	3	2	1	3	1	2	2	2
27	3	1	1	2	3	2	3	3	3	3	3

Table A3. Table of orthogonal factor levels of residential buildings in cold regions.

Level	Test Factor									
	K_R	K_E	K_G	K_{EW}	WWR_N	WWR_S	WWE_{WE}	BO	VT 1A	VT 1B
1	0.1	0.15	0.2	1.0	0.2	0.4	0.25	15° east of due north	2	1
2	0.15	0.175	0.3	1.1	0.25	0.45	0.30	due north	10	2
3	0.2	0.2	0.4	1.2	0.3	0.5	0.35	15°west of due north	12	5

Table A4. Orthogonal test table of residential buildings in cold regions L27.

Test	K_R	K_E	K_G	K_{EW}	WWR_N	WWR_S	WWE_{WE}	BO	VT 2A	VT 2B
1	1	1	3	2	2	1	2	1	2	2
2	3	2	3	1	1	2	2	1	1	1
3	2	2	3	2	1	1	3	2	3	3
4	2	2	2	3	2	1	1	2	1	1
5	3	1	2	1	3	3	1	2	2	2
6	2	3	2	1	1	3	3	1	1	1
7	1	3	2	2	1	2	1	2	3	3
8	2	1	2	2	3	2	2	3	1	1
9	3	2	2	2	2	2	3	1	2	2
10	3	3	3	2	3	1	1	3	1	1
11	2	1	1	3	1	2	3	3	2	2
12	1	2	1	2	3	3	3	3	1	1
13	1	3	1	3	2	2	2	2	1	1
14	3	3	1	1	2	1	3	3	3	3
15	1	1	2	3	3	1	3	1	3	3
16	2	1	3	1	2	2	1	3	3	3
17	1	2	3	3	1	3	1	3	2	2
18	1	1	1	1	1	1	1	1	1	1
19	3	1	1	2	1	3	2	2	3	3
20	1	3	3	1	3	2	3	2	2	2
21	3	2	1	3	3	2	1	1	3	3
22	2	3	1	2	2	3	1	1	2	2
23	1	2	2	1	2	3	2	3	3	3
24	3	3	2	3	1	1	2	3	2	2
25	2	3	3	3	3	3	2	1	3	3
26	3	1	3	3	2	3	3	2	1	1
27	2	2	1	1	3	1	2	2	2	2

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