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Simulation of rural residential energy consumption in different climate zones based on Dest-H

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Keywords: Dest-H, Building Energy Consumption, Absorption Rate, Air Conditioning Load, Envelope Structure

Abstract: The number of rural housing construction in our country is increasing daily. With the appeal of energy-saving renovations in rural housing, improving the rural living environment has become a problem that can not be ignored. In this paper, the Dest-H energy simulation software was used to simulate the cooling and heating loads of a rural residential building in different climatic regions of our country under different absorption rates of the external surface. The results show that the total air conditioning load can be reduced by increasing the absorption rate of the enclosure appropriately in the cold and cold areas. For the areas with hot summer and cold winter, hot summer and warm winter, and mild areas, reducing the sunlight absorption rate of the external protective structure can reduce the total air conditioning load of the year. With the absorption rate of the outer sheath, the natural room temperature also gradually increased.

1. Introduction

With the acceleration of the reform and opening up of the process, and the "16th Five-Year Plan" proposed to promote the construction of a "new socialist countryside solidly," the rural housing construction of our country has rapidly developed. However, in the pursuit of a comfortable living environment, the problem of building energy consumption has become increasingly prominent. According to statistics, building energy consumption accounts for 40% of the total energy consumption of society [1]. Among them, the building energy consumption of rural residential buildings accounts for about 23.76% of the total building energy consumption. It can be seen that the energy consumption of rural buildings is also one of the essential problems to be solved [2]. At present, the energy-saving methods of rural residential buildings mainly include a series of technologies such as the change of peripheral protection structure, the change of shading ventilation, the change of the ratio of window to wall, and the addition of a south-facing sunlight room. Due to the non-transparent envelope structure's large surface area and heat capacity, the thermal insulation is more prominent than other structures in the building. It is the central part of the entire building heat exchange. Therefore, transforming the opaque outer envelope structure is an essential measure of energy saving. The primary way to transform the external envelope structure is to change its material, such as adding an insulation layer. However, increasing the insulation layer of the external envelope structure to reduce the total load of the building throughout the year is also limited by the internal conditions of the building, such as when the internal heat source in the building is significant, the use of insulation will backfire. Insulation removal can reduce the total load throughout the year [3]. Compared with the internal materials, improving the thermal radiation properties of the opaque building envelope is another idea that can effectively reduce building energy consumption and improve the indoor thermal environment. The coating can change the thermal radiation properties of the outer protective structure. From the mechanism level, the analysis is mainly to enhance the thermal insulation performance by reducing the thermal conductivity of the coating or to improve the thermal radiation properties of the outer surface by changing the ratio of the solar absorption rate and the emissivity of the coating surface. This measure can be effectively applied to the energy-saving transformation of existing buildings, so it has been rapidly developed in recent years [4]. Starting from changing the thermal radiation properties of the opaque outer envelope of the building, this paper mainly achieves the purpose of energy saving by changing the solar absorption rate of the outer envelope of rural residential buildings. The better solar absorption rate of the outer envelope of rural residential buildings in different climate regions is obtained through software simulation. Let the residents' housing conditions be improved to better meet the modern quality of life requirements in the new countryside.

2. Rural house model

2.1 Building model establishment

This paper establishes a benchmark building housing model using Dest-H simulation software applied to Harbin, a typical city in a cold region. Beijing is a typical city with a hot summer and cold winter region. Chongqing is a typical city with a hot summer and warm winter, and Kunming is a mild region. The benchmark building model is north-south facing, with a north-south depth of 8 m and an east-west span of 10 m. The floor height is 3.1 m, and the shape coefficient is 0.773. There are Windows on the north and south walls with area ratios of 0.12 and 0.23, respectively. The house has six rooms and a hallway. Bedrooms and living rooms are air-conditioned. The Elevation of a building is shown in Figure 1, and the Architectural plan is shown in Figure 2.

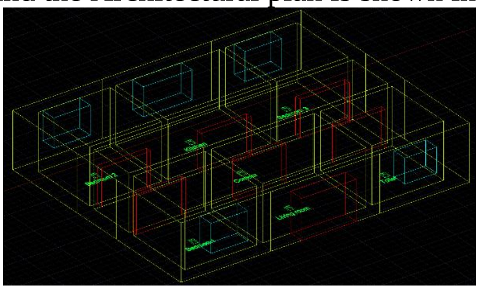


Figure 1: Elevation of a building

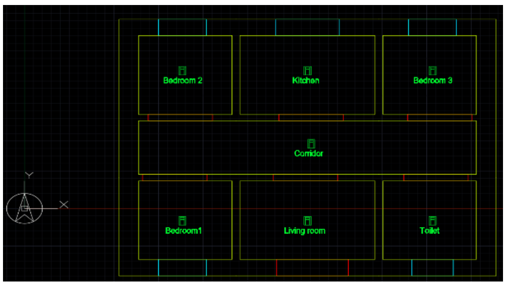


Figure 2: Architectural plan

2.2 Selection of building model parameters

2.2.1 Parameters of Envelope Structure

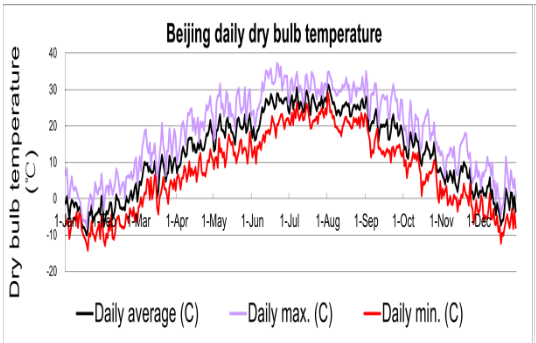
For the cold area, the thermal performance parameter limits of the external envelope structure have higher requirements. For the roof, the heat transfer coefficient K value is required to be less than 0.15 W/m^2 K, the heat transfer coefficient K value of the external wall is less than 0.25 W/m^2 K, and the heat transfer coefficient K value is required to be less than 1.4 W/m^2 K for the external window with an area ratio of less than 0.3. To meet the energy-saving factors, the thermal performance parameters of the outer envelope structure in other climate regions can be selected according to the cold area. The detailed thermal parameters of the enclosure structure are shown in Table 1 below [5] [6].

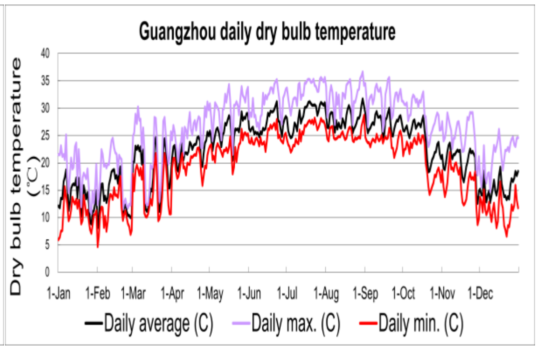
Table 1: Thermal parameters of envelope structure

Type of enclosure structure	Area m^2	Material categories	Name of the material	Thermal-conduction resistance m^2 K/W	Heat transfer coefficient W/m^2 K	Heat inertia index
	m^2					
Outer wall	96.5	37 Brick wall	Cement mortar + Heavy mortar clay + Expanded perlite	4.016	0.24	8.008
Interior wall	77.6	Plain brick interior walls	Ceramsite concrete	0.430	1.515	2.69
Door	26.0	Wooden interior door	Pine and spruce	2.857	0.350	/
Window	10.7	Ordinary insulating glass	Aluminium alloy 6+9A+6	0.833	1.2	/
Floor	80.0	Aluminium alloy Concrete floor	Aluminium alloy Cement mortar + porous concrete	0.978	1.022	2.861
Roof	80.0	Roof	Aluminium alloy Cement mortar + Expanded perlite + Reinforced concrete	6.656	0.147	10.55

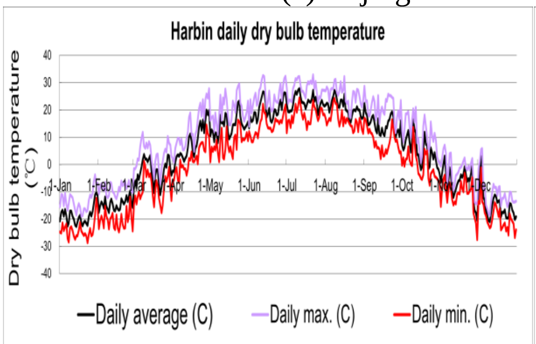
2.2.2 Outdoor meteorological parameters

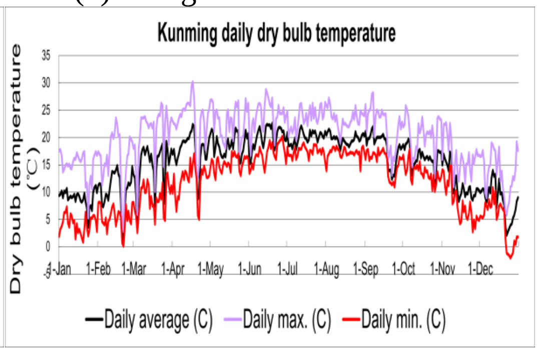
The outdoor climate parameters, sky background radiation, and sun-shielding can be set directly using the DeST-H software default parameters for the design area. The annual daily average outdoor dry bulb temperature and monthly average outdoor dry bulb temperature in different regions are shown in Figure 3 and Figure 4.



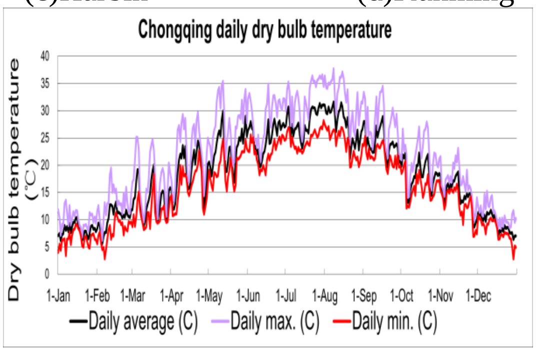


(a)Beijing (b)Guangzhou



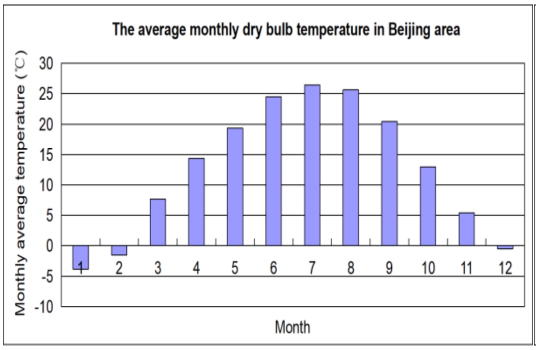


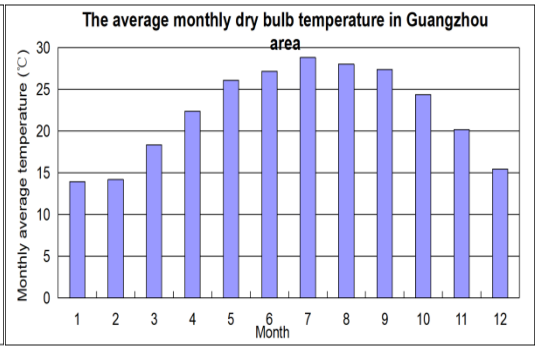
(c)Harbin (d)Kunming



(e)Chongqing

Figure 3: Annual dry bulb temperature statistics by region





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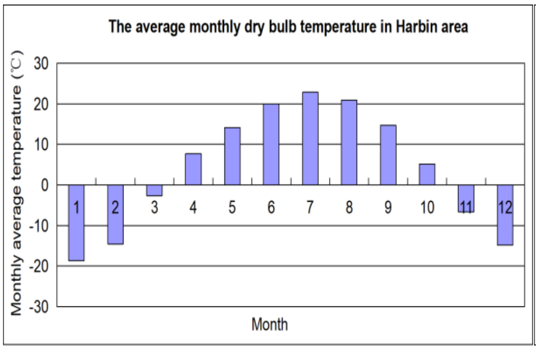
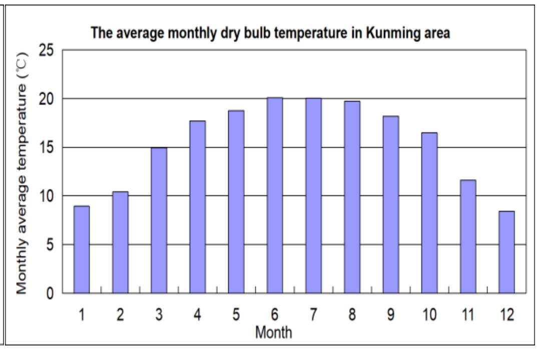
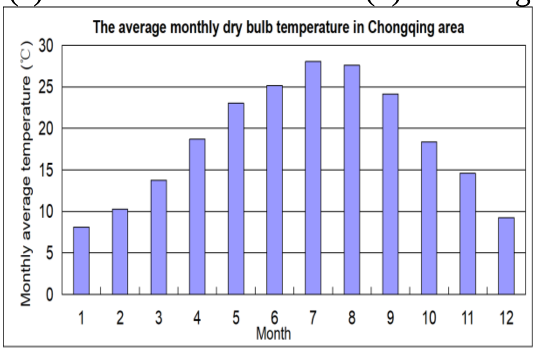




(c) Harbin (d) Kunming



(e)Chongqing

Figure 4: Monthly average outdoor dry bulb temperature statistics by region

According to the above figure and the meteorological parameter data in Dest, the coldest and hottest months for outdoor dry bulb temperatures in Chongqing are January and July, respectively. The average outdoor monthly temperature during heating is between 8.1 and 14.6 ℃, and the lowest average daily temperature is 2.8 ℃. The average outdoor monthly temperature during the cooling period is 25.2-28.1 ℃, and the highest average daily temperature is 37.7 ℃. Kunming's coldest and hottest months for outdoor dry bulb temperatures are December and June. The average outdoor monthly temperature during the heating period is 8.4-10.4 ℃, and the lowest average daily temperature is -2.1 ℃. The average outdoor monthly temperature during the cooling period is mainly between 20 ℃, and the highest average daily temperature is 30.2 ℃. For Harbin's annual outdoor dry bulb temperature, the coldest and hottest months are January and July, respectively. During the heating period, the average outdoor monthly temperature ranges from -18.7 ℃ to -6.6 ℃, and the lowest average daily temperature is -22.7 ℃. The average outdoor monthly temperature during the cooling period is mainly between 20.0-22.9 ℃, and the highest average daily temperature is 32.8 ℃. The coldest and hottest months for outdoor dry bulb temperatures in Beijing are January and July, respectively. The average outdoor monthly temperature during heating is between -3.8 and 5.4 ℃, and the lowest average daily temperature is -14.2 ℃. The average outdoor monthly temperature during the cooling period is between 24.5-26.4 ℃, and the highest average daily temperature is 37.2 ℃. The coldest and hottest months for outdoor dry bulb temperatures in Guangzhou are January and July, respectively. The average outdoor monthly temperature during the heating period is between 13.9-20.2 ℃, and the lowest average daily temperature is 4.7 ℃. The average outdoor monthly temperature during the cooling period is between 27.2-28.8 ℃, and the highest average daily temperature is 36.6 ℃.

2.2.3 Indoor Heat Disturbance Settings

The indoor thermal interference factors, such as personnel thermal interference, lighting thermal interference, and equipment thermal interference, the Settings are shown in Table 2.

Table 2: Indoor heat disturbance factor parameter setting

Functional area	Parameter determination
Personnel heat disturbance	Bedroom 2 people, living room 3 people. Bathroom, kitchen, dining room 1 person
Heat disturbance of light	Lighting power density 5 W/m^2
Equipment heat disturbance	Equipment power density 3.8 W/m^2
Calorific value per capita	Bedroom 62 W/person, living room 66 W/person, kitchen 61 W/ person
Humidity production per capita	Bedroom 0.068 kg/Hr, living room 0.102 kg/Hr, kitchen 0.260 kg/Hr

The Settings of other parameters in the heat disturbance cell are the default values of the software system. The parameter set by personnel thermal disturbance refers to the maximum number of people accommodated during indoor activities. By determining the maximum number of personnel, we can ensure that the air conditioning system meets the indoor environment's thermal comfort needs and that personnel will be well-mixed during indoor activities.

2.2.4 Setting Air Conditioner Parameters

Table 3: Indoor temperature and humidity parameter formulation table

Name of parameter	Parameter limit	Parameter definition
Upper room temperature limit	Heating 22 °C/ cooling 26 °C	The air conditioner reaches the upper limit of the preset temperature
The lower limit of room temperature	Heating 19 °C/ cooling 22 °C	The air conditioner reaches the lower limit of the set temperature
Maximum relative humidity	60%	If the humidity exceeds this value, the air conditioner starts to dehumidify.
Minimum relative humidity	35%	If the humidity is lower than this, the air conditioner starts humidifying.
The upper limit of the starting temperature of the air conditioner	Heating 24 °C/ cooling 28 °C	Higher than this value, the air conditioner starts cooling
Lower limit of starting temperature of air conditioner	Heating 17 °C/ cooling 20 °C	Lower than this value, the air conditioner starts heating

For this benchmark home, the heating period is from November 6 to February 12. The cooling period is from June 24 to August 26. According to the tolerance limit of the set temperature, the air conditioner starts to work. When the tolerance limit of the set temperature is lower than the tolerance limit of the set temperature, the air conditioner will operate autonomously. During this time, the indoor temperature is controlled within the range of the set temperature value. The temperature range set during air conditioning heating is 19-22 °C, and the upper and lower limits of tolerance temperature during this period are 24 °C and 17 °C, respectively. When the indoor temperature of the air-conditioned room is lower than 17 ℃ or higher than 24 ℃, the air conditioner starts to operate by itself to control the indoor temperature between 19-22 ℃. The temperature range set during the refrigeration period is between 22-26 ℃, and the upper and lower limits of the tolerable temperature during this period are 28 ℃ and 20 ℃, respectively.

The maximum humidity and minimum humidity set in the room are 60% and 35%, respectively. The proposed parameters are shown in Table 3 [7].

Independent air conditioning system is adopted. Figures 5 and 6, respectively, show the specific Settings of the start and stop work of the air conditioning in the bedroom and living room. Its operation schedule is determined by the room's function and personnel rate at different times of the day. For residential bedrooms, from 00:00 on Monday of the 45th week to 00:00 on Monday of the seventh week of the following year, the air conditioning starts heating from 20:00 every day to 7:00 the next day. From 00:00 on Monday of the 26th week to 00:00 on Monday of the 35th week, the air conditioning starts to cool from 20:00 every day to 7:00 the next day. The air conditioning for the residential living room starts heating from 6:00 to 20:00 on Monday of the 45th week to 00:00 on Monday of the seventh week of the following year. The air conditioning starts cooling from 6:00 to 20:00 on Monday of the 26th to 00:00 on Monday of the 35th week. The air conditioner's setting in the bedroom is shown in Figure 5, and the setting in the living room is shown in Figure 6.

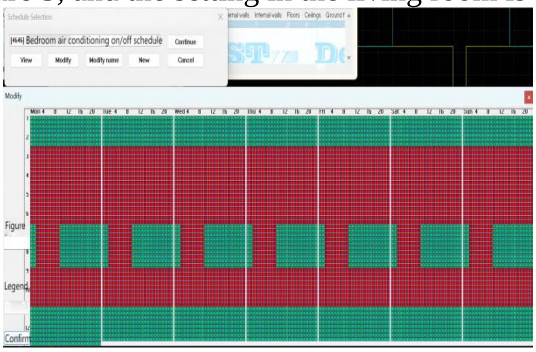


Figure 5: The air conditioner in the bedroom starts and stops working and rest Settings.

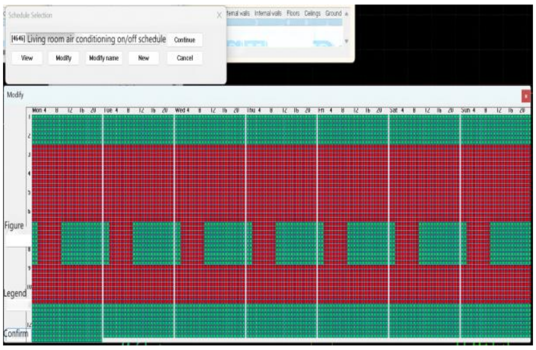


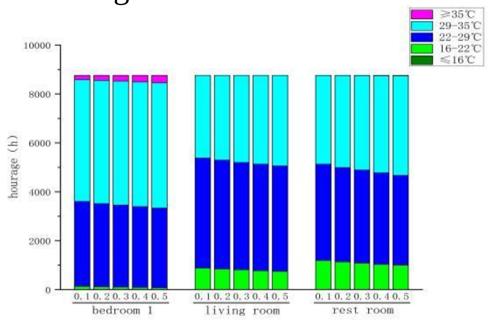
Figure 6: The air conditioning in the living room starts and stops working and rest Settings.

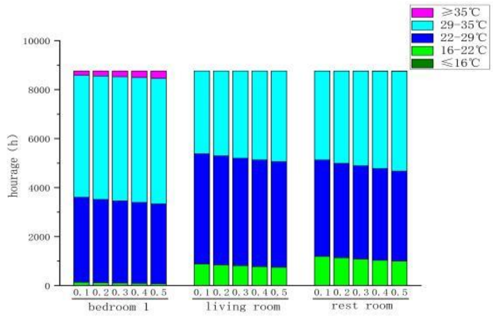
3. Simulation results

When the software residential load analysis calculation is performed, the calculation starts with one day and ends with 365 days. Since it is a rural area, it is assumed that no other tall buildings or trees are around the house, and the sun is not considered. However, the sky background radiation is taken into account in each simulation.

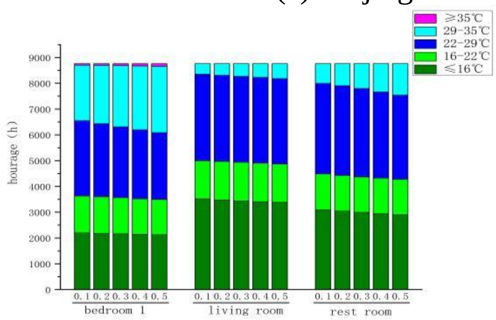
3.1 Calculation and analysis of natural room temperature

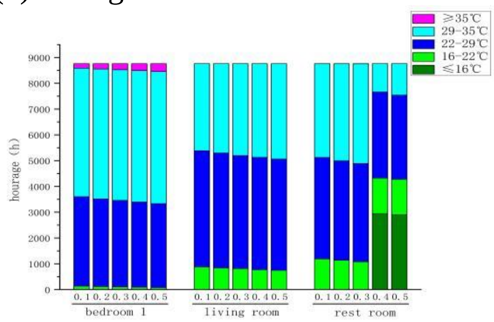
In the calculation and analysis of natural room temperature using software, the south-facing room of the residential building is mainly selected for analysis. Namely, bedroom 1, living room, and bathroom. The year-by-year natural room temperature chart and the year-natural room temperature distribution chart are obtained. It is divided into five intervals in the statistical graph. Below 16 ℃, 16-22 ℃, 22-29 ℃, 29-35 ℃ and five temperature ranges above 35 ℃. The natural room temperature statistics of the south-facing rooms under different absorption rates of residential buildings in each area are shown in Figure 7.



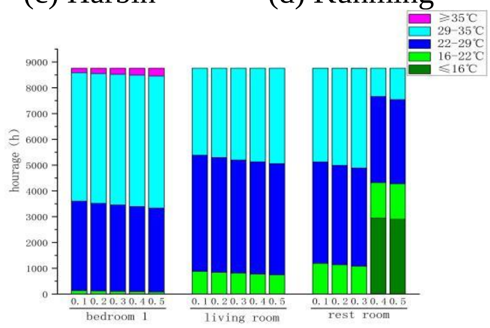


(a) Beijing (b) Guangzhou





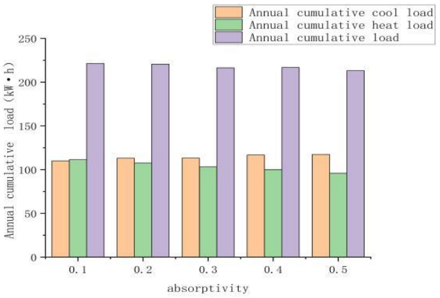
(c) Harbin (d) Kunming



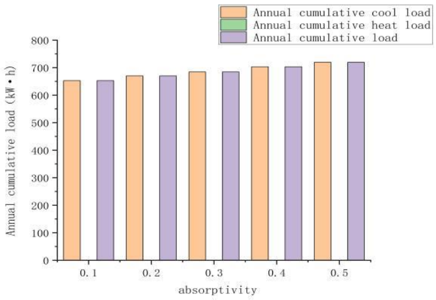
(e) Chongqing

Figure 7: Statistics of the natural room temperature of the southward room under different absorption rates of the residence in each region

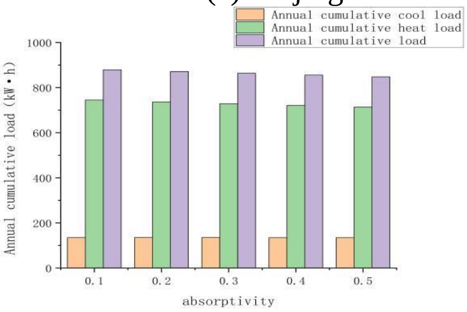
In the simulation, a single variable control method changes the solar absorption rate of the exterior wall and roof while keeping the thermal parameters of other enclosures unchanged. It varies from 0.1 to 0.5, and the step size is set to 0.1 for simulation calculation. The figure above shows that the natural room temperature in rural residential rooms in different climate zones gradually increases with the absorption rate of the opaque outer envelope increasing from 0.1 to 0.5. The temperature range with the most significant proportion of annual natural room temperature hours in different south-facing rooms of this rural house is 22-29 ℃, and the proportion of this temperature range gradually decreases with the increase of absorption rate, while the proportion of 29-35 temperature range gradually increases. For the natural room temperature greater than 35 ℃, the situation only appears in the bedroom of the south-facing room, and the proportion is the highest in Guangzhou. For Guangzhou and Kunming, the natural room temperature of the south-facing room of the house is lower than 16 ℃ throughout the year. Still, the temperature range in Harbin is relatively large, and the proportion of the living room is the largest, 40.17%. The temperature range of 22-29 ℃ accounts for the most significant proportion of hours in the Kunming area, and the proportion of this temperature range is mostly around 80% in the south-facing room. The cumulative annual residential load in each region is shown in Figure 8.



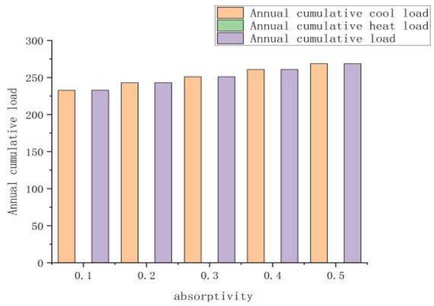
(a) Beijing



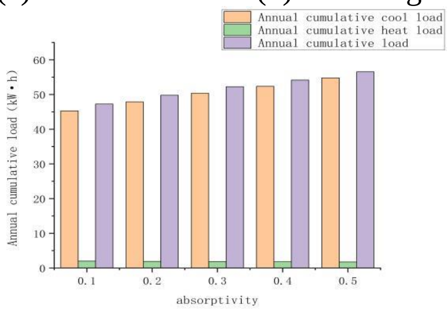
(b) Guangzhou



(c) Harbin



(d) Kunming



(e) Chongqing

Figure 8: Annual cumulative load statistics of the residence in each region

Software simulation was conducted to obtain the annual cooling and heating loads of residential buildings with different absorption rates, and numerical statistics were carried out to get the yearly total load of air conditioners, as shown in Figures 7 and 8. The simulation results show that when the absorption rate increases from 0.1 to 0.5 for the Harbin area, the cooling load first increases and then decreases, but the range of change is small. The heat load is gradually reduced to a minimum total load of 847.6 kW at an absorption rate of 0.5. For the Beijing area, the cooling load gradually increases, and the heat load gradually decreases when the absorption rate increases from 0.1 to 0.5. The minimum total load is 213.18 kW at an absorption rate of 0.5. For the Guangzhou area, the cooling load gradually increases when the absorption rate increases from 0.1 to 0.5. Since Guangzhou is in a hot summer and warm winter area, the indoor temperature in winter is within the set range of air conditioning parameter values, so there is no need for air conditioning heating; the heat load is always 0 throughout the year. The minimum total load is 652.75 kW at an absorption rate of 0.1. For the Chongqing area, the cooling load gradually increases, and the heat load gradually decreases when the absorption rate increases from 0.1 to 0.5. The minimum total load is 47.27 kW at an absorption rate of 0.1. For the Kunming area, the cooling load gradually increases when the absorption rate increases from 0.1 to 0.5. As the Kunming area is a mild area with relatively less heat load throughout the year, air conditioning is not used during the heating period when the absorption rate is enormous. The lowest total load was 232.87 kW when the absorption rate was 0.1.

4. Conclusion

The selection of thermal parameters of the building envelope will directly affect the thermal insulation performance of the building, resulting in the change of air conditioning load. In this paper, Dest-h, a building energy simulation software, is used to simulate and calculate the annual air conditioning load of a rural residential building by changing the solar energy absorption rate of the outer envelope. It can be used in cold, hot summers, cold winters, hot summers, warm winters, and mild areas, respectively. In addition, the software is used to calculate the natural room temperature of the south-facing room of the house. According to the above results, the following conclusions are drawn:

(1) For cold and cold areas, the total load of air conditioning throughout the year can be reduced by appropriately increasing the absorption rate of sunlight by the outer protective structure.

(2) For hot summer and cold winter, hot summer and warm winter and mild areas, the total load of air conditioning throughout the year can be reduced by appropriately reducing the absorption rate of sunlight by the outer protective structure.

(3) For the south-facing room, the natural room temperature also gradually increases with the absorption rate of the opaque outer envelope. The temperature range with the most significant proportion of natural room temperature hours throughout the year is 22-29 ℃.

For rural areas in different climate regions, the annual air-conditioning load should be changed by changing the outer envelope structure's solar absorption rate according to the house's architectural characteristics to achieve energy-saving transformation and reduce the energy consumption of the building. The research results are intended to provide a reference for the design of rural energy-saving housing, which is conducive to improving the energy-saving effect of residential buildings in rural areas, promoting energy conservation and emission reduction, and building a "resource-saving society."

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