Study on the influence of key parameters of exterior window structure on building energy saving effect

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Abstract. On account of the problem which was related to the negative effect of exterior windows energy saving in current residence building, we constructed a single energy-saving building with same structure and different exterior windows. Meanwhile, taking indoor temperature field and building energy consumption as entry points, the key parameters of the energy saving effect of the exterior window were compared and analyzed to study the indoor temperature field and the building thermal load and cooling load in the heating, cooling and transition season of energy-saving buildings which had exterior window structures (standard external windows, blue heat-absorbing glass windows, thermal reflection glass with high light transmission, ordinary hollow glass windows, low-E insulating glazing units, low-E high through glass windows, ordinary 3mm glass windows) with different window frames under the same climate environment. In addition, the grey theory and regression analysis were used to get the correlation degree and matrix equation between the energy-saving effect (the indoor temperature in heating season, the indoor temperature in refrigeration season, the indoor temperature in transition season, the annual cumulative heat load index, the annual cumulative cooling load index, the heating season heat load index, the air-conditioning season cooling load index) and key parameters (the glass thickness, the air layer thickness, the glass layer number, the heat transfer coefficient, the solar heat gain coefficient, the shading coefficient, the solar transmittance, the solar reflectance, the visible light transmittance, the visible light reflectance) in energy-saving buildings.

1. Introduction
The energy consumption of existing buildings in China occupied about 33% of the total social energy consumption. In addition, 90 percent of the nearly 40 billion m² of existing construction area were high energy consumption building. Also, more than 95% were high energy-consuming buildings as usual among the nearly 2 billion m² area of newly-built buildings each year. Therefore, building energy conservation was imminent. Besides, in various projects of building energy consumption, heat transfer loss through the envelope accounted for 70%-80% of the total heat loss of the building. However, the exterior window was important part of the building envelope and the weakest link in the building thermal insulation. To sum up, the performance of exterior windows was closely related to the energy-saving effect of buildings [1].

In recent years, scholars at home and abroad have done a lot of research on external window energy saving. W. Guo [2] et al. discussed the energy saving effects of heat-reflective insulation coating on exterior envelope walls in the hot summer and cold winter zone. V.V. Tyutikov [3] et al. installed thermal reflection screens on windows to determine the minimum indoor air temperature under...
standby heating. Both of the above studies can reduce indoor ambient temperature and improve building energy efficiency; Kimmo Hilliaho [4] et al. studied simplified evaluation methods for the energy saving and interior air temperature evaluation of glazed spaces, and the presented method can be used for optimizing and showing the energy saving impact as well as the mean, maximum and minimum temperatures of different type of glazed spaces in the preliminary design stage; Elad Negev [5] et al. emphatically analyzed that adding microalgae culture in building windows can provide energy saving for buildings, and solved the main design factors affecting energy saving and other energy aspects; By simulating the full-size model, Marina Aburas [6] et al. concluded that the difference in energy performance of thermochromic windows was 73.4% when the same film type was used in different cities. However, when different types of films were used in the same city, the energy performance of thermochromic windows was only 21.6% differences; ZHU hui [7] and ZHANG Jun [8] and Rickard T [9] et al. have both studied smart windows, but the first study of smart windows can dynamically adjust solar radiation and automatically adapt to ambient temperature. The second study of smart window integrates dye-sensitized solar cells with electrochromic supercapacitors to provide excellent heat dissipation function and stable circulation system. The final study of intelligent window study concluded that electrochromatic windows have the greatest potential for reducing energy requirements under all conditions and locations. All of these provide new strategies for intelligent reduction of building energy consumption; WANG Jian-hua [10] and Ingy El-Darwish [11] and Fan Y [12] et al. studied energy-saving benefit of building envelope reconstruction from different angles and different approaches. Their results all have been shown to be very helpful in building energy efficiency; CHANG Chen-chen [13] et al. used EnergyPlus to generate and simulate UBEM automatically. CHANG Chen-chen [14] et al. built the two models by the use of MATLAB Neural Network Toolbox, one was post evaluation model based on the spot test data and a parameter called as Refrigeration Operation Energy saving Effect Ratio (ROEER), and the other was the prediction evaluation model based on Back-Propagation Artificial Neural Network. They both studied the energy-saving effects of air-conditioning (HVAC) system renovation, but the former also studied the modification of heating and ventilation systems; SUN Yan-yi [15] et al. investigated the annual energy performance of a typical office served by window integrated STPV glazing through EnergyPlus simulation for various window designs. The simulation showed that PV window can result in considerable energy saving; W.J.Hee [16] et al. intended to reveal the impacts of window glazing on the energy and daylighting performances of building through the previous researches; SHEN Chong [17] presented cooling pipes embedded in the venetian blinds of a double-skin envelope as a system for reducing the heat transfer of the glass envelope in summer; WU Hang [18] investigated the effect of the building envelope on cooling load in low latitude and hot-humid area. In addition, the energy-saving system was established and determined the energy-saving effect of external walls, windows, roof, shading on the building cooling load; K.Hassouné [19] et al. calculated heating and cooling loads, and compared results with the values for the same building after amendments to the windows and walls. It has been found that choosing a larger window area facing south, east and west and using a certain types of double glazing can save more energy in winter and decreasing the heating costs; LIU Yu [20] et al. developed a prototype of the integrated cooling unit with rotary booster and compressor and established a data center model reflecting the characteristics of energy consumption and environmental requirements. The results showed that compared with the traditional computer room air conditioner, the energy-saving ratio of the integrated system can be as high as 39.55% for the whole year, and the energy-saving effect is remarkable. In the above study, no matter it was numerical simulation, experimental test or theoretical research, the researches on the energy-saving effect of building exterior windows were relatively single without systematic analysis, and the applicability of exterior windows of buildings with different energy saving effects has not been studied comprehensively as well.

Based on the above questions, In this article, we constructed a single energy-saving building with same structure and different exterior windows. Meanwhile, taking indoor temperature field and building energy consumption as entry points, the key parameters of the energy saving effect of the exterior window were compared and analyzed to study the indoor temperature field and the building
thermal load and cooling load in the heating, cooling and transition season of energy-saving buildings which had exterior window structures (standard external windows, blue heat-absorbing glass windows, thermal reflection glass with high light transmission, ordinary hollow glass windows, low-E insulating glazing units, low-E high through glass windows, ordinary 3mm glass windows) with different window frames under the same climate environment. In addition, the grey theory and regression analysis were used to get the correlation degree and matrix equation between the energy-saving effect (the indoor temperature in heating season, the indoor temperature in refrigeration season, the indoor temperature in transition season, the annual cumulative heat load index, the annual cumulative cooling load index, the heating season heat load index, the air-conditioning season cooling load index) and key parameters (the glass thickness, the air layer thickness, the glass layer number, the heat transfer coefficient, the solar heat gain coefficient, the shading coefficient, the solar transmittance, the solar reflectance, the visible light transmittance, the visible light reflectance) in energy-saving buildings.

2. Design principle of building energy-saving windows

In this article, we constructed a single energy-saving building with same structure and different exterior windows (standard external windows, blue heat-absorbing glass windows, thermal reflection glass with high light transmission, ordinary hollow glass windows, low-E insulating glazing units, low-E high through glass windows, ordinary 3mm glass windows).

2.1. Establishment of basic model

We chose a single residential building in Wenzhou as the research object and its orientation was 62° north by west. The building size was 9000mm×7800mm×3700mm, the window size was 3800mm×1460mm, the window height was 1000mm, the door size was 1240mm×2960mm, the distance from the west wall was 500mm, and the indoor area was 70.20m². The specific size and section diagram of the single residential building were shown in Figure 1 and Figure 2.

2.2. Specific method and thermal parameters of Model envelope structure

In order to compare the energy-saving effect of different glass windows (standard exterior window, blue heat-absorbing window, high light transmission heat-reflecting window, ordinary hollow glass window, low-E through glass window, low-E through glass window and ordinary 3mm glass window) with different window frames, and in the single energy-saving residential buildings studied, the materials and structures of roof, exterior wall, door and floor were unified. In addition, the thermal parameters of the enclosure structure of the energy saving building met the requirements of Design Standards for Energy Saving of Residential Buildings in Hot Summer and Cold Winter [21]. The practices of energy saving building envelopes were shown below. The practice of inverted roof was as follows: From top to bottom: 70mm thick cement cinder slope layer, 20mm thick cement mortar
leveling layer, 10mm thick modified asphalt flexible linoleum waterproof layer, 130mm thick extraction-type polystyrene board, 20mm thick cement mortar protective layer, 100mm thick reinforced concrete, 20mm thick cement mortar plastering; The practice of wall was as follows: From outside to inside: 20mm thick cement mortar plastering, 200mm thick reinforced concrete, 20mm thick cement mortar plastering; The practice of floor was as follows: From top to bottom: 12mm thick marble floor tile, 100mm thick reinforced concrete; The practice of single-layer solid wood exterior door was as follows: 25mm thick pine and spruce wood door. The thermal parameters of the envelope are as follows: The thermal resistance of thermal conductivity of the wall was 0.16 (m·K)/W, the heat transfer coefficient of the wall was 3.16 W/(m²·K) and the thermal inertness index of the wall was 2.64; The thermal resistance of thermal conductivity of the floor was 0.06 (m·K)/W, the heat transfer coefficient of the floor was 4.55 W/(m²·K) and the thermal inertness index of the floor was 2.86; The thermal resistance of thermal conductivity of the inverted roof was 4.39 (m·K)/W, the heat transfer coefficient of the inverted roof was 0.22 W/(m²·K) and the thermal inertness index of the inverted roof was 2.84; and the thermal resistance of thermal conductivity of the single-layer solid wood exterior door was 0.18 (m·K)/W, the heat transfer coefficient of the single-layer solid wood exterior door was 2.95 W/(m²·K).

2.3. Outdoor meteorological data
The YG-QXZ-350 automatic weather station was used to all-weather real-time monitor the test environment. The monitoring content included wind direction, wind speed, temperature, relative humidity, solar radiation, sunshine duration and other meteorological factors. Then, researchers selected representative hourly weather data which was collected through the data acquisition instrument throughout the year and establish a typical meteorological year, to provide a reliable basis for the analysis of energy saving characteristics of single residential buildings with different exterior windows [22].

2.4. Indoor energy consumption mode
The building was a single residential building, which used air conditioning for cooling and heating, The indoor energy consumption mode was set as follows: on weekdays, go out at 8:00 a.m. and go home at 17:00 on time, the lighting equipment in the room was an incandescent lamp with a minimum illumination of 300lx. The specific behavior habit parameters were shown below: During the natural ventilation season from November to February, the window opening time was from 12:00 to 14:00 everyday. During the natural ventilation season from March to June, the time for both opening doors and opening windows was from 8:00 to 19:00 everyday; during the air conditioning heating season from December to February and air conditioning refrigeration season from June to October, the working hours of the air conditioner were as follows: 18:00 to 7:00 on weekdays and 18:00 to 7:00 on weekends; for indoor lighting, the lights are turned on from 17:00 to 24:00 and from 6:00 to 7:00, and turned off from 1:00 to 5:00 and from 8:00 to 16:00.

According to the indoor air quality standard [23], the working conditions of air conditioning were set as follows: the upper limit of air conditioning starting temperature was 26 °C. The lower limit of air conditioning starting temperature was 18 °C. The upper limit of humidity from November to march was 40%. The upper limit of humidity from April to October was 60%. The lower limit of humidity from May to September was 50%. The lower limit of humidity from October to April was 35%. The upper limit of indoor temperature was 29 °C, and the lower limit of indoor temperature was 16 °C.

2.5. Different exterior window structures
Different exterior window structures are composed of different glass windows (standard external windows, blue heat-absorbing glass windows, thermal reflection glass with high light transmission, ordinary hollow glass windows, low-E insulating glazing units, low-E high through glass windows, ordinary 3mm glass windows) with different window frames (non insulated metal window frame,
insulated metal window frame and plastic window frame [24]) The optical parameters and thermal parameters of typical glass were shown in Table 1.

### Table 1. Detail of the typical glass.

| Standard external windows | Blue heat-absorbing glass windows | Thermal reflection glass with high light transmission | Ordinary hollow glass windows | Low-E insulating glazing units | Low-E through glass windows | Ordinary 3mm glass windows |
|---------------------------|----------------------------------|-----------------------------------------------------|-------------------------------|--------------------------------|-----------------------------|-----------------------------|
| Thickness                 | 6                                | 6                                                   | 6+12+6                       | 6(Low-e)+9+6                  | 6(Low-e)+9+6                | 3                           |
| Glass layer               | 1                                | 1                                                   | 1                            | 2                             | 2                           | 2                           |
| Heat transfer coefficient | 5.7                              | 5.7                                                 | 5.7                          | 3.4                           | 4                           | 4                           |
| Solar heat gain coefficient | 0.8                            | 0.7                                                 | 0.6                          | 0.8                           | 0.4                         | 0.5                         |
| Shading coefficient       | 0.9                              | 0.7                                                 | 0.6                          | 0.9                           | 0.5                         | 0.6                         |
| Solar transmittance       | 82                               | 62                                                  | 56                           | 75                            | 44                          | 51                          |
| Solar reflectivity        | 0                                | 0                                                   | 0                            | 11                            | 26                          | 21                          |
| Visible light transmittance | 77                             | 54                                                  | 56                           | 71                            | 55                          | 61                          |
| Visible light reflectivity | 0                               | 0                                                   | 30                           | 13                            | 23                          | 19                          |

3. Different energy-saving effects of exterior windows

3.1. Indoor temperatures of different exterior Windows

Using DeST software to simulate, we chosen the insulation metal window frame with different glasses to form different exterior windows and compare the insulation effect of different glass windows (standard external windows, blue heat-absorbing glass windows, thermal reflection glass with high light transmission, ordinary hollow glass windows, low-E insulating glazing units, low-E high through glass windows, ordinary 3mm glass windows). Then we selected January as the lowest ambient temperature month, July as the highest ambient temperature month and the transition season (April and October) as the test cycle and the indoor temperatures of single energy-saving buildings with different exterior windows in different seasons were compared with the outdoor environmental temperature. The results were shown in Figure 3.

Figure 3 showed that indoor daily average temperature of a single energy-saving building with different exterior windows, and it is shown in the Table 2.

a) Daily average temperature in January

b) Daily average temperature in April

c) Daily average temperature in July

d) Daily average temperature in October

Figure 3. Daily average temperature graph of different structure windows in different seasons.
Table 2. Indoor daily average temperature of a single energy-saving building with different exterior windows.

| Month | The window type | standard external windows | Blue heat-absorbing glass windows | thermal reflection glass with high light transmission | ordinary hollow glass windows | low-E insulating glazing units | Low-E high through glass windows | ordinary 3mm glass window |
|-------|----------------|---------------------------|----------------------------------|-----------------------------------------------------|-------------------------------|--------------------------------|--------------------------------|---------------------------|
| January |                | 5.04 °C-14.10 °C         | 4.99 °C-14.02 °C                 | 4.98 °C-13.99 °C                                    | 5.11 °C-14.07 °C             | 5.02 °C-13.96 °C             | 4.99 °C-13.90 °C             | 5.02 °C-14.07 °C          |
| April  |                | 13.28 °C-20.51 °C        | 13.20 °C-20.38 °C                | 13.17 °C-20.33 °C                                  | 13.28 °C-20.45 °C            | 13.18 °C-20.29 °C            | 13.10 °C-20.14 °C            | 13.24 °C-20.46 °C         |
| July   |                | 26.12 °C-29.98 °C        | 26.05 °C-29.89 °C                | 26.03 °C-29.86 °C                                  | 26.04 °C-29.88 °C            | 25.99 °C-29.82 °C            | 25.88 °C-29.67 °C            | 26.09 °C-29.94 °C         |
| October|                | 16.94 °C-24.70 °C        | 16.88 °C-24.60 °C                | 16.86 °C-24.56 °C                                  | 16.96 °C-24.63 °C            | 16.86 °C-24.51 °C            | 16.81 °C-24.42 °C            | 19.62 °C-24.66 °C         |

3.2. Thermal insulation performance of different exterior windows

Under the same outdoor environment and when the window frame was insulation mental window frame, the indoor daily average temperature of the single energy-saving buildings with different external windows from high to low was sorted into standard external window, ordinary 3mm glass window, ordinary hollow glass window, blue heat-absorbing glass window, thermal reflection glass with high light transmission, low-E insulating glazing unit, Low-E high through glass window in different months (January, April, July and October). And on condition that the indoor temperature of single energy-saving buildings with standard exterior windows higher than others, the performance accounted for 95.20%-100% of the total data. On condition that the indoor temperature of single energy-saving buildings with ordinary 3mm glass window higher than others, the performance accounted for 69.9%-83.3% of the total data. On condition that the indoor temperature of single energy-saving buildings with ordinary hollow glass window higher than others, the performance accounted for 59.7%-83.9% of the total data. On condition that the indoor temperature of single energy-saving buildings with blue heat-absorbing glass window higher than others, the performance accounted for 48.4%-57.0% of the total data. On condition that the indoor temperature of single energy-saving buildings with thermal reflection glass with high light transmission higher than others, the performance accounted for 29.6%-33.3% of the total data. On condition that the indoor temperature of single energy-saving buildings with low-E insulating glazing unit higher than others, the performance accounted for 16.7%-22.0% of the total data. On condition that the indoor temperature of single energy-saving buildings with Low-E high through glass window higher than others, the performance accounted for 0%-1.1% of the total data.

3.3. Energy saving effect of exterior windows of different structures

In order to study the effect of single energy-saving buildings with different external window detailed structures, we combined different glass windows (standard external windows, blue heat-absorbing glass windows, thermal reflection glass with high light transmission, ordinary hollow glass windows, low-E insulating glazing units, low-E high through glass windows, ordinary 3mm glass windows) and different window frames (insulation metal window frame, non-insulation metal window frame and plastic window frame) to form 21 single structures. In the lowest ambient temperature month of different single energy-saving buildings (January), the highest ambient temperature month of different single energy-saving buildings (July) and the transition season (April and October), the results were shown in Figure 4 by comparing several indicators (average indoor temperature, annual cumulative cooling and heating load index, heating load index in heating season and cooling load index during air conditioning season).

Figure 4 can be shown in Table 3:
Figure 4. Comparison of key parameters of energy efficiency of different single energy-saving buildings.

Table 3. Comparison of key parameters of energy efficiency of different single energy-saving Buildings.

| Window types                                      | Average indoor temperature from November to January (°C) | Average indoor temperature from May to August (°C) | Average indoor temperature in other natural ventilation months (°C) | Annual cumulative heat load index (kW·h/m²) | Annual cumulative cooling load index (kW·h/m²) | Heat load index in heating season (W/m²) | Cooling load index in air conditioning season (W/m²) |
|---------------------------------------------------|---------------------------------------------------------|-----------------------------------------------|-----------------------------------------------------------------|----------------------------------------|-------------------------------------------|--------------------------------------|------------------------------------------|
| Standard external windows with non insulation metal window frame | 13.53                                                   | 25.93                                        | 18.08                                                          | 59.55                                  | 7.00                                      | 18.90                                | 2.35                                    |
| Blue heat-absorbing glass windows with non insulation metal window frame | 13.41                                                   | 25.85                                        | 17.99                                                          | 60.86                                  | 6.45                                      | 19.30                                | 2.17                                    |
| Thermal reflection glass with high light transmission with non insulation metal window frame | 13.37                                                   | 25.83                                        | 17.95                                                          | 61.36                                  | 6.23                                      | 19.45                                | 2.09                                    |
Ordinary hollow glass windows with non insulation metal window frame  
13.51 25.87 18.04 58.82 6.46 18.67 2.17  

Low-E insulating glazing unit with non insulation metal window frame  
13.32 25.79 17.91 61.26 5.96 19.42 2.00  

Low-E high through glass windows with non insulation metal window frame  
13.27 25.70 17.83 61.84 5.35 19.58 1.79  

Ordinary 3mm glass windows with non insulation metal window frame  
13.49 25.90 18.05 60.06 6.78 18.06 2.28  

b) Insulation metal window frame  

| Window types                                 | Average indoor temperature from November to January(°C) | Average indoor temperature from May to August(°C) | Average indoor temperature in other natural ventilation months (°C) | Annual cumulative heat index (kW·h/m²) | Annual cumulative cooling load index (kW·h/m²) | Heat load index in heating season(W/m²) | Cooling load index in air conditioning season (W/m²) |
|---------------------------------------------|---------------------------------------------------------|--------------------------------------------------|---------------------------------------------------------------------|----------------------------------------|-----------------------------------------|---------------------------------------|-------------------------------------------------|
| Standard external windows with insulation metal window frame  
| 13.54 25.93 18.09 59.23 7.01 18.81 2.36  
| Blue heat-absorbing glass windows with insulation metal window frame  
| 13.43 25.86 17.99 60.54 6.47 19.20 2.17  
| Thermal reflection glass with high light transmission with insulation metal window frame  
| 13.38 25.83 17.96 61.04 6.25 19.35 2.10  
| Ordinary hollow glass windows with insulation metal window frame  
| 13.52 25.87 18.04 58.44 6.44 18.55 2.16  
| Low-E insulating glazing unit with insulation metal window frame  
| 13.35 25.79 17.92 60.53 5.98 19.19 2.01  
| Low-E high through glass windows with insulation metal window frame  
| 13.28 25.69 17.83 61.46 5.31 19.46 1.78  
| Ordinary 3mm glass windows with insulation metal window frame  
| 13.50 25.90 18.05 59.79 6.79 18.98 2.28  

c) Plastic window frame  

| Window types                                | Average indoor temperature from November to | Average indoor temperature from May to | Average indoor temperature in other natural ventilation months | Annual cumulative heat load index | Annual cumulative cooling load | Heat load index in heating season(W/m²) | Cooling load index in air conditioning season (W/m²) |
|---------------------------------------------|--------------------------------------------|----------------------------------------|---------------------------------------------------------------|---------------------------------|-------------------------------|---------------------------------|-------------------------------------------------|
| Standard external windows with plastic window frame | January(°C) | August(°C) | ventilation month(°C) | (kW·h/m²) | index (kW·h/m²) |
|--------------------------------------------------|------------|------------|----------------------|----------|----------------|
| Blue heat-absorbing glass windows with plastic window frame | 13.56      | 25.93      | 18.10                | 58.79    | 7.03           | 18.67 | 2.36 |
| Thermal reflection glass with high light transmission with plastic window frame | 13.44      | 25.86      | 18.00                | 60.09    | 6.47           | 19.06 | 2.17 |
| Ordinary hollow glass windows with plastic window frame | 13.39      | 25.83      | 17.97                | 60.60    | 6.26           | 19.22 | 2.10 |
| Low-E insulating glazing unit with plastic window frame | 13.55      | 25.80      | 17.93                | 60.38    | 5.98           | 19.15 | 2.01 |
| Low-E high through glass windows with plastic window frame | 13.28      | 25.69      | 17.83                | 61.14    | 5.27           | 19.36 | 1.76 |
| Ordinary 3mm glass windows with plastic window frame | 13.51      | 25.91      | 18.06                | 59.36    | 6.80           | 18.84 | 2.28 |

From Figure 4 can be concluded that:

1. Under the same outdoor environment, the trend of energy-saving effect (the average indoor temperature in the month with the lowest ambient temperature (January), the average indoor temperature in the month with the highest ambient temperature (July), the average indoor temperature in the transition season (April and October), annual cumulative heat load index, annual cumulative cooling load index, heating load index in heating season, cooling load index of air conditioning season) under different window frames (insulation metal window frame, non-insulation metal window frame and plastic window frame) is the same for different glass windows (standard external windows, blue heat-absorbing glass windows, thermal reflection glass with high light transmission, ordinary hollow glass windows, low-E insulating glazing units, low-E high through glass windows, ordinary 3mm glass windows): Annual cumulative heat load of the standard external window is higher. But heat load in winter is less and cooling load in summer is more. Annual cumulative heat load of Low-e high through glass windows is less. But heat load in winter is more and cooling load in summer is less. Blue heat absorbing glass windows heat is more balanced throughout the year building. The heat load required for heating in winter and the cooling load required for air conditioning in summer are also more balanced and more suitable for hot summer and cold winter regions and mild regions.

2. Under the same outdoor environment, the glass window with plastic window frame has the best thermal insulation performance, and its annual cumulative heat load index is significantly higher than that with non-thermal metal window frame and thermal metal window frame. The heat load index during heating season of non-insulated metal window frame is significantly higher than that of plastic window frame and insulated metal window frame. Among them, the annual cumulative cooling load index and cooling load index during air conditioning season of standard window with plastic window frame are the highest. The annual cumulative heat load index and heat load index during heating season of low-E high through glass window and non-insulated metal window frame are the highest.

4. Data analysis
Grey theory analysis was a quantitative description and the method of comparison of the development and change of a system. Its basic idea was to determine whether the reference data column was closely
related to several comparison data columns by determining their geometric shape similarity, and it reflected the degree of correlation between curves. Building energy efficiency was a complex system problem, and there are still many unclear conditions and uncertain factors, so it was suitable for the study of grey system theory. Under the combined action of glass thickness, air layer thickness, glass layer, heat transfer coefficient, solar heat gain coefficient, shading coefficient, solar energy transmittance rate, solar reflective rate, visible transmittance and visible reflectance, grey theory was used to analyze which factors have greater and lesser influence on heating season temperature, cooling season temperature, transition season temperature, annual cumulative heat load index, annual cumulative cooling load index, heat load index during heating season and cooling load index during air conditioning season; Identifying the factors with high impact and ignoring those with low impact to simplify the complexity of building energy efficiency.

4.1. Grey theory analysis and calculation method

(1) Initialization of the original sequence

There are two requirements for the data which was used for grey correlation degree calculation. In addition to having the same dimensions, there must be common points of intersection and the initialization of original data was the basic method [25-26] to solve this problem.

There was a sequence of numbers:

\[ X_i = (x_i(1), x_i(2), \ldots, x_i(n)) \]  

(1)

D was the sequence operator, and

\[ X'_i = X_i D = (x_i(1)d, x_i(2)d, \ldots, x_i(n)d) \]  

(2)

if \( x_i(k)d = \frac{x_i(k)}{x_i(1)} \), X.D was the image of Xi under initial valued operator D and abbreviated as initial valued image.

(2) Differencing sequence

After initialization, the sequence was:

\[ X'_i = (x'_i(1), x'_i(2), \ldots, x'_i(n)) \]  

(3)

find

\[ \Delta(k) = |x'_i(k) - x'_i(k')| \]  

(4)

i = 0, 1, 2, \ldots, m

(3) Find the maximum and minimum difference of two levels

\[ M = \max_{i} \max_{k} \Delta(k) \]  

(5)

\[ m = \min_{i} \min_{k} \Delta(k) \]  

(6)

Find the correlation coefficient

\[ \xi(k) = \frac{m + \zeta M}{\Delta(k) + \zeta M} \]  

(7)

In the formula: \( \zeta \) —— Resolution, whose function was to improve the significance of the difference between grey correlation coefficients, was generally set at 0.5.

(4) Find the degree of correlation

\[ \gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_{ik}(k) \]  

(8)

i = 0, 1, 2, \ldots, m,

(5) Exhaust Association sequence

When there were m comparison sequences, there were also m relative correlation degree values (\( \gamma \)), which were arranged in order of their numerical size and was called the relational order. The correlation degree directly reflected the advantages and disadvantages of each comparison sequence to the reference sequence.
4.2. Grey theory analysis and calculation results

According to Table 4, optical and thermal parameters of windows were set, including glass thickness $X_1$, air layer thickness $X_2$, glass layer $X_3$, heat transfer coefficient $X_4$, solar heat gain coefficient $X_5$, shading coefficient of SC value $X_6$, solar transmittance $X_7$, solar reflectance $X_8$, visible transmittance $X_9$, visible light reflectance $X_{10}$. Each of the above factors was computed with the sequence operator $D$ (the result simulated by DeST) to obtain the initial image $X_iD$. After initialization, the glass thickness, air layer thickness, glass layer, heat transfer coefficient, solar heat gain coefficient and shading coefficient of SC value, solar energy transmittance rate, solar reflective rate, visible transmittance, visible reflectance were obtained respectively, then find the maximum difference $M$ and minimum difference $m$ between the two stages, get the correlation coefficient 

$$
\xi(k) = \frac{m + \zeta M}{A(k) + \zeta M}
$$

, and finally get the correlation degree 

$$
\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_{ik}(k)
$$

. When there were $m$ comparison sequences, there were $m$ relative correlation values ($\gamma$), which was expressed as $\gamma_m$. Then it was concluded that grey correlation between the above factors and heating season temperature $\gamma_{i1}$, cooling season temperature $\gamma_{i2}$, transition season temperature $\gamma_{i3}$, annual cumulative heat load index $\gamma_{i4}$, annual cumulative cooling load index $\gamma_{i5}$, heat load index during heating season $\gamma_{i6}$ and cooling load index during air conditioning season $\gamma_{i7}$. The results was shown in Table 4.

**Table 4. Grey correlation analysis with various factors.**

| Influencing factors of energy saving effect | Temperature in heating season $\gamma_{i1}$ | Cooling season temperature $\gamma_{i2}$ | Transition season temperature $\gamma_{i3}$ | Annual cumulative heat load index $\gamma_{i4}$ | Annual cumulative cooling load index $\gamma_{i5}$ | Heating load index in heating season $\gamma_{i6}$ | Cooling load index of air conditioning season $\gamma_{i7}$ |
|--------------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| The thickness of the glass                | 0.93                            | 0.95                            | 0.93                            | 0.94                            | 0.87                            | 0.94                            | 0.87                            |
| Air thickness                             | 0.94                            | 0.93                            | 0.94                            | 0.94                            | 0.91                            | 0.94                            | 0.91                            |
| Glass layer                               | 0.91                            | 0.89                            | 0.91                            | 0.92                            | 0.84                            | 0.92                            | 0.84                            |
| Heat transfer coefficient                 | 0.61                            | 0.57                            | 0.61                            | 0.59                            | 0.63                            | 0.59                            | 0.63                            |
| Solar heat gain coefficient               | 0.53                            | 0.50                            | 0.53                            | 0.50                            | 0.61                            | 0.50                            | 0.61                            |
| Shading coefficient                       | 0.53                            | 0.49                            | 0.52                            | 0.50                            | 0.61                            | 0.50                            | 0.61                            |
| Solar transmittance                      | 0.62                            | 0.59                            | 0.61                            | 0.58                            | 0.71                            | 0.58                            | 0.71                            |
| solar reflectance                         | 0.72                            | 0.72                            | 0.72                            | 0.73                            | 0.70                            | 0.73                            | 0.70                            |
| Visible Light Transmitted                | 0.68                            | 0.66                            | 0.67                            | 0.73                            | 0.62                            | 0.73                            | 0.62                            |
| Visible light reflectance                 | 0.69                            | 0.68                            | 0.69                            | 0.70                            | 0.69                            | 0.70                            | 0.69                            |

From the results in Table 4, we can see that:

The influence factors of the temperature in heating season were air layer thickness, glass thickness, number of glass layers, solar reflective rate, visible reflectance, visible transmittance, solar energy transmittance rate, heat transfer coefficient, solar heat gain coefficient, shading coefficient of SC value.

(1) $\gamma_{i1} = 0.93$, $\gamma_{i2} = 0.94$, $\gamma_{i3} = 0.91$, $\gamma_{i4} = 0.61$, $\gamma_{i5} = 0.53$, $\gamma_{i6} = 0.53$, $\gamma_{i7} = 0.62$, $\gamma_{i8} = 0.72$, $\gamma_{i9} = 0.68$, $\gamma_{i10} = 0.69$. namely $\gamma_{i2} > \gamma_{i1} > \gamma_{i3} > \gamma_{i4} > \gamma_{i10} > \gamma_{i8} > \gamma_{i9} > \gamma_{i7} > \gamma_{i6} > \gamma_{i5} = \gamma_{i10}$. That was to say, in the order of large to
small, the grey correlation of the temperature in heating season was air layer thickness, glass thickness, number of glass layers, solar reflective rate, visible reflectance, visible transmittance, solar energy transmittance rate, heat transfer coefficient, solar heat gain coefficient, shading coefficient of SC value.

(2) \( \gamma_{12}=0.95, \gamma_{22}=0.93, \gamma_{32}=0.89, \gamma_{42}=0.57, \gamma_{52}=0.50, \gamma_{62}=0.49, \gamma_{72}=0.59, \gamma_{82}=0.72, \gamma_{92}=0.66, \gamma_{102}=0.68 \), namely \( \gamma_{12} \succ \gamma_{22} \succ \gamma_{32} \succ \gamma_{82} \succ \gamma_{102} \succ \gamma_{92} \succ \gamma_{72} \succ \gamma_{42} \succ \gamma_{52} \succ \gamma_{62} \). That was to say, in the order of large to small, the grey correlation degree of the temperature in cooling season was thickness of glass, thickness of air layer, number of glass layers, solar reflective rate, visible reflectance, visible transmittance, solar energy transmittance rate, heat transfer coefficient, solar heat gain coefficient, shading coefficient of SC value.

(3) \( \gamma_{13}=0.93, \gamma_{23}=0.94, \gamma_{33}=0.91, \gamma_{43}=0.61, \gamma_{53}=0.53, \gamma_{63}=0.52, \gamma_{73}=0.61, \gamma_{83}=0.72, \gamma_{93}=0.67, \gamma_{103}=0.69 \), namely \( \gamma_{13} \succ \gamma_{23} \succ \gamma_{33} \succ \gamma_{83} \succ \gamma_{103} \succ \gamma_{93} \succ \gamma_{73} \succ \gamma_{53} \succ \gamma_{63} \). That was to say, in the order of large to small, the grey correlation degree of the temperature in transitional season was air layer thickness, glass thickness, number of glass layers, solar reflective rate, visible reflectance, visible transmittance, heat transfer coefficient, solar energy transmittance rate, solar heat gain coefficient, shading coefficient of SC value.

(4) \( \gamma_{14}=0.94, \gamma_{24}=0.94, \gamma_{34}=0.92, \gamma_{44}=0.59, \gamma_{54}=0.50, \gamma_{64}=0.50, \gamma_{74}=0.58, \gamma_{84}=0.73, \gamma_{94}=0.62, \gamma_{104}=0.69 \), namely \( \gamma_{14} \succ \gamma_{24} \succ \gamma_{34} \succ \gamma_{84} \succ \gamma_{104} \succ \gamma_{94} \succ \gamma_{74} \succ \gamma_{44} \succ \gamma_{54} \). That was to say, in the order of large to small, the grey correlation degree of the temperature of annual cumulative heat load index was thickness of glass, thickness of air layer, number of glass layers, solar reflectance, visible reflectance, visible transmittance, heat transfer coefficient, solar energy transmittance rate, solar heat gain coefficient, shading coefficient of SC value.

(5) \( \gamma_{15}=0.87, \gamma_{25}=0.91, \gamma_{35}=0.84, \gamma_{45}=0.63, \gamma_{55}=0.61, \gamma_{65}=0.61, \gamma_{75}=0.71, \gamma_{85}=0.70, \gamma_{95}=0.73, \gamma_{105}=0.70 \), namely \( \gamma_{15} \succ \gamma_{25} \succ \gamma_{35} \succ \gamma_{85} \succ \gamma_{75} \succ \gamma_{95} \succ \gamma_{105} \succ \gamma_{45} \succ \gamma_{55} \). That was to say, in the order of large to small, the grey correlation degree of the temperature of annual cumulative cooling load index was air layer thickness, glass thickness, number of glass layers, visible transmittance, solar energy transmittance rate, solar reflectivity, visible reflectivity, heat transfer coefficient, solar heat gain coefficient, shading coefficient of SC value.

(6) \( \gamma_{16}=0.94, \gamma_{26}=0.94, \gamma_{36}=0.92, \gamma_{46}=0.59, \gamma_{56}=0.50, \gamma_{66}=0.50, \gamma_{76}=0.58, \gamma_{86}=0.73, \gamma_{96}=0.62, \gamma_{106}=0.69 \), namely \( \gamma_{16} \succ \gamma_{26} \succ \gamma_{36} \succ \gamma_{46} \succ \gamma_{106} \succ \gamma_{86} \succ \gamma_{96} \succ \gamma_{66} \). That was to say, in the order of large to small, the grey correlation degree of the temperature in heating load index in heating season was thickness of glass, thickness of air layer, number of glass layers, solar reflectance, visible reflectance, visible transmittance, heat transfer coefficient, solar energy transmittance rate, solar heat gain coefficient, shading coefficient of SC value.

(7) \( \gamma_{17}=0.87, \gamma_{27}=0.91, \gamma_{37}=0.84, \gamma_{47}=0.63, \gamma_{57}=0.61, \gamma_{67}=0.61, \gamma_{77}=0.71, \gamma_{87}=0.70, \gamma_{97}=0.73, \gamma_{107}=0.70 \), namely \( \gamma_{17} \succ \gamma_{27} \succ \gamma_{37} \succ \gamma_{97} \succ \gamma_{87} \succ \gamma_{107} \succ \gamma_{77} \succ \gamma_{47} \succ \gamma_{57} \). That was to say, in the order of large to small, the grey correlation degree of the temperature of cooling load index of air conditioning season was air layer thickness, glass thickness, number of glass layers, visible transmittance, solar energy transmittance rate, solar reflectivity, visible reflectivity, heat transfer coefficient, solar heat gain coefficient, shading coefficient of SC value.

4.3. The calculation method of multivariate regression analysis

The energy saving property of building exterior windows was mainly made of the indoor temperature, the annual cumulative heat load, the annual cumulative cooling load, the annual cumulative heat load index, the annual cumulative cooling load index, heat load index during the heating season and cooling load index during the air-conditioning season, and their influencing factors were diverse. The influencing factors included glass thickness, air layer thickness, glass layer, heat transfer coefficient, solar heat gain coefficient and shading coefficient of SC value, solar energy transmittance rate, solar reflective rate, visible transmittance, visible reflectance. Every above factor would have influence on glass thickness, air layer thickness, glass layer, heat transfer coefficient, solar heat gain coefficient and shading coefficient of SC value, solar energy transmittance rate, solar reflective rate, visible transmittance, solar reflective rate, visible transmittance, heat transfer coefficient, solar energy transmittance rate, solar heat gain coefficient, shading coefficient of SC value.
transmittance, visible reflectance. But scholars at home and abroad have not studied the specific
degree of influence. We built the corresponding model through the multivariate regression method
and changed influencing factors (glass thickness, air layer thickness, glass layer, heat transfer coefficient,
solar heat gain coefficient and shading coefficient of SC value, solar energy transmittance rate, solar
reflective rate, visible transmittance, visible reflectance). Finally we obtained different variations of
the energy-saving effect (indoor temperature, the annual cumulative heat load, the annual cumulative
cooling load, the annual cumulative heat load index, the annual cumulative cooling load index, the
heat load index during the heating season and the cooling load index during the air-conditioning
season).

(1) Multiple linear regression model with single dependent variable [27-29]
Assuming that there were m independent variables representing factors \(x_1, x_2, \ldots, x_m\), \(y\) was the
dependent variables representing the index. \(N\) tests were now conducted, and there were \(n\) sets of data
\(y_i, x_{i1}, x_{i2}, \ldots, x_{im}\) \((i=1, 2, \ldots, n)\). Assuming that the dependent variables \(y\) and \(m\) independent
variables \(x_1, x_2, \ldots, x_m\) had a linear relationship and the linear relationship could be represented by
the following model:

\[
y = \beta_0 + \beta_1 x_1 + \cdots + \beta_m x_m + \epsilon_i
\]  

Put \(n\) groups of data into, we can get

\[
y_1 = \beta_0 + \beta_1 x_{11} + \cdots + \beta_m x_{1m} + \epsilon_1 \\
y_2 = \beta_0 + \beta_1 x_{21} + \cdots + \beta_m x_{2m} + \epsilon_2 \\
\vdots \\
y_n = \beta_0 + \beta_1 x_{n1} + \cdots + \beta_m x_{nm} + \epsilon_n
\]

Among them, \(\beta_0, \beta_1, \ldots, \beta_m\) were the parameter to be estimated and we called them the regression
coefficient, \(\epsilon_1, \epsilon_2, \ldots, \epsilon_n\) were \(n\) independent random variables with the same normal distribution \(N(0, \sigma^2)\).

Then the matrix form of the regression model was:

\[
Y = C \beta + \epsilon
\]

The above model was a classical multiple regression model, where \(Y\) was an observable random
variable, \(\epsilon\) was an unobservable random variable, \(C\) was a known matrix and \(\beta, \sigma^2\) were unknown
parameters, and assuming that \(n > m\), \(\text{rank}(C) = m + 1\).

(2) Least squares estimation of parameter vectors
In the model, the least squares estimator \(\hat{\beta} = [\hat{\beta}_1, \hat{\beta}_2, \ldots, \hat{\beta}_m]\) of parameter \(\beta\) minimized the square sum of
error \(Q(\beta)\), which meant that for all of \(\beta\), \(Q(\hat{\beta}) = \min Q(\beta)\)

And among them

\[
Q(\beta) = \sum_{i=1}^{n} \epsilon_i^2 = \sum_{i=1}^{n} (y_i - (\beta_0 + \beta_1 x_{i1} + \cdots + \beta_m x_{im}))^2 = (Y - C \beta)'(Y - C \beta)
\]

If \(\hat{\beta}\) was the least squares estimation of \(\beta\), \(\hat{\beta}\) was the minimum variance linear unbiased estimation
of \(\beta\). If \(\epsilon \sim N_n(0, \sigma^2 I_n)\), \(\hat{\beta}\) was still the estimation of minimum variance in all unbiased estimators.
(3) The sum of squares decomposition
Array of observation data
\[
\begin{pmatrix}
  y_1 & x_{11} & \cdots & x_{1m} \\
  y_2 & x_{21} & \cdots & x_{2m} \\
  \vdots & \vdots & \ddots & \vdots \\
  y_n & x_{n1} & \cdots & x_{nm}
\end{pmatrix}
\]

There was a formula:
\[
\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 = \sum_{i=1}^{n}(y_i - \bar{y})^2 + \sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2
\]

Among them:
\[
y = \frac{1}{n}\sum_{i=1}^{n}y_i
\]
\[
\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i + \cdots + \hat{\beta}_m x_{im}
\]
\[
\hat{\beta} = \begin{pmatrix}
  \hat{\beta}_0 \\
  \vdots \\
  \hat{\beta}_m
\end{pmatrix} = (C' C)^{-1} C' Y
\]

It was the least squares estimation of \( \beta \). The above formula was called the sum of squares decomposition formula.

In the sum of squares decomposition formula, the left side of the equal \( \sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \) represented total variation size of the observed values of \( Y, y_1, y_2, \ldots, y_n \), which was called the square sum of total departure and was denoted as \( \text{Lyy or SST} \). The second term \( \sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2 \) on the right side of the equal, represented the variation size of n estimated values \( \hat{y}_1, \hat{y}_2, \ldots, \hat{y}_n \), it was due to the dependent variable \( Y \) does have a linear relationship with the independent variables \( x_1, x_2, \ldots, x_m \) and it was caused by changes in \( x_1, x_2, \ldots, x_m \). which we called the regression sum of squares, denoted as \( U \) or \( \text{SMM} \). And the first term \( \sum_{i=1}^{n}(y_i - \bar{y})^2 + \sum_{i=1}^{n}e_i^2 \) on the right side of the equal, was called the residual sum of squares , denoted as \( Q \) or \( \text{SEE} \). In the case of the model assumption, we have:
\[
E(Y) = \beta_0 + \beta_1 x_1 + \cdots + \beta_m x_m
\]

Q was caused by random error, so Q was also called residual sum of squares [30]. The sum of squares decomposition can also be abbreviated as:
\[
L_n = Q + U \quad \text{or SST} = SSE + SSM
\]

Meanwhile, the determination coefficient \( R^2 \) Square was used to represent the precision [31, 32] of linear regression equation, that was, the linear regression equation could explain the total variation degree of \( Y \) value.

(4) F test of regression effect
The rationality of regression model should be judged by significance test of regression effect. There were three methods for significance test of regression analysis effect: R test, F test and T test, which were essentially the same. In this project. In this project, F test method [33] was adopted to test the regression effect.
\[ F = \frac{r^2(n-2)}{1-r^2} F(1, n-2) \]  

For a given significance level \( \alpha \), if

\[ F \geq F_{1,\alpha}(1, n-2) \]  

It was considered that there was a significant linear relationship between \( x \) and \( y \), at this point, it was said that the linear regression effect was significant. Otherwise, the linear regression effect was not significant. The value of \( F_{1,\alpha}(1, n-2) \) could be obtained from the F distribution table.

### 4.4. Multivariate regression analysis and calculation results

**Table 5. Regression statistical results of each factor.**

| Statistical coefficient | Temperature in Heating season | Temperature in Cooling season | Temperature in transitional seasonal | Annual cumulative heat load index | Annual cumulative cooling load index | Heat load index in heating season | Heat load index in air conditioning season |
|-------------------------|--------------------------------|--------------------------------|-------------------------------------|----------------------------------|------------------------------------|----------------------------------------|-------------------------------------------|
| Multiple R              | 0.9995                         | 0.9994                         | 0.9995                              | 0.9972                           | 0.9996                             | 0.9971                                  | 0.9996                                    |
| R Square                | 0.9989                         | 0.9988                         | 0.9990                              | 0.9944                           | 0.9991                             | 0.9942                                  | 0.9991                                    |
| Standard error          | 0.0039                         | 0.0032                         | 0.0034                              | 0.0992                           | 0.0198                             | 0.0308                                  | 0.0067                                    |
| Probability of significance | 0                             | 0                              | 0                                   | 0                               | 0                                  | 0                                       | 0                                         |
| Intercept               | 6.1035                         | 17.6252                        | 9.8645                              | 139.3870                         | -48.9762                           | 42.0353                                 | -16.6031                                  |
| Partial regression coefficient \( \beta_1 \) | 0.7972                         | 0.9089                         | 0.8925                              | -8.7964                          | 6.0998                            | -2.5475                                 | 2.0655                                    |
| Partial regression coefficient \( \beta_2 \) | -0.4044                        | -0.4636                        | -0.4540                             | 4.4409                           | -3.1180                           | 1.2851                                  | -1.0558                                   |
| Partial regression coefficient \( \beta_3 \) | 0                              | 0                              | 0                                   | 0                               | 0                                  | 0                                       | 0                                         |
| Partial regression coefficient \( \beta_4 \) | -0.0154                        | -0.0026                        | -0.0091                             | 0.5132                           | -0.0040                           | 0.1589                                  | -0.0014                                   |
| Partial regression coefficient \( \beta_5 \) | 0                              | 0                              | 0                                   | 0                               | 0                                  | 0                                       | 0                                         |
| Partial regression coefficient \( \beta_6 \) | 0                              | 0                              | 0                                   | 0                               | 0                                  | 0                                       | 0                                         |
| Partial regression coefficient \( \beta_7 \) | 0.1561                         | 0.1744                         | 0.1727                              | -1.7264                          | 1.1683                            | -0.5010                                 | 0.3956                                    |
| Partial regression coefficient \( \beta_8 \) | 0.1719                         | 0.1965                         | 0.1927                              | -1.8954                          | 1.3199                            | -0.5488                                 | 0.4469                                    |
| Partial regression coefficient \( \beta_9 \) | -0.1305                        | -0.1485                        | -0.1460                             | 1.4444                           | -0.9920                           | 0.4184                                  | -0.3360                                   |
| Partial regression coefficient \( \beta_{10} \) | -0.1210                        | -0.1379                        | -0.1354                             | 1.3344                           | -0.9275                           | 0.3864                                  | -0.3141                                   |

Regression Analysis was a statistical and analytical method for determining quantitative relationships of interdependence between two or more variables. Using multiple regression analysis to describe the phenomenon and explain its causes so as to have better accuracy and reliability in the control process and had small variance and mean square error. The main method of regression analysis was to establish a regression model on the basis of known data. In this process, it was particularly important to select the appropriate and main variable among a variety of explanatory variables. In other words, on the premise that the number of independent variables was as small as possible, the independent variables closely related to dependent variables were saved as far as possible, and ignored the factors with small influence.

The building energy saving effect mainly consists of heating season temperature, cooling season temperature, transition season temperature, annual cumulative heat load index, annual cumulative...
cooling load index, heat load index during heating season and cooling load index during air conditioning season. The influencing factors of building energy saving effect were multiple, including glass thickness, air layer thickness, glass layer, heat transfer coefficient, solar heat gain coefficient, shading coefficient, solar energy transmittance rate, solar reflective rate, visible transmittance and visible reflectance. Each influencing factor will have an impact on the building energy saving effect. A corresponding model was established by multivariate regression method and the variation of building energy efficiency was analyzed when the above univariate impact factor changed in units.

(1) Multivariate regression analysis was used to study the variable relationships between glass thickness, air layer thickness, glass layer, heat transfer coefficient (W/m²·K), solar heat gain coefficient, shading coefficient of SC value, solar energy transmittance rate, solar reflective rate, visible transmittance and visible reflectance and the indoor temperature. The calculation results were shown in Table 5.

The fitting equation was obtained:

\[
\begin{align*}
\beta_1 &= 0.7972, -0.4044, 0.0154, 0.001561, 0.1719, -0.1305, -0.1210, 6.1035 \\
\beta_2 &= 0.9089, -0.4636, -0.0026, 0.001744, 0.1965, -0.1485, -0.1379, 17.6252 \\
\beta_3 &= 0.8925, -0.4540, -0.0091, 0.001727, 0.1927, -0.1460, -0.1354, 9.8465 \\
\beta_4 &= -8.7964, 4.4409, 0.05132, 0.017264, -1.8954, 1.4441, 1.3344, 139.3870 \\
\beta_5 &= 6.0998, -3.1180, 0.0040, 0.011683, 1.3199, -0.09920, -0.9275, -48.7962 \\
\beta_6 &= -2.5475, 1.2851, 0.01589, 0.005010, -0.5488, 0.4184, 0.3864, 42.0353 \\
\beta_7 &= 2.0655, -1.0558, -0.0014, 0.03956, 0.4469, -0.3360, -0.3141, -16.6031
\end{align*}
\]

(1) The partial regression coefficient \(\beta_1=0.7972\) said, when only a single factor changed, every increased 1mm thickness of the glass, the temperature in heating season increased by 0.7972 °C on average. The partial regression coefficient \(\beta_2=-0.4044\) indicated that every 1mm increased in air layer thickness, the temperature in heating season decreased by 0.4044 °C on average. The partial regression coefficient \(\beta_3=0\), said each additional layer of glass, the temperature in heating season increased by 0 °C on average. The partial regression coefficient \(\beta_4=0.0154\), every 1W/m²·K increased in heat transfer coefficient, the temperature in heating season decreased by 0.0154 °C on average. The partial regression coefficient \(\beta_5=0\) said, every 1 increased in solar heat gain coefficient, the temperature in heating season increased by 0 °C on average. The partial regression coefficient \(\beta_6=0\) said , every 1 increased in shading coefficient, the temperature in heating season increased by 0 °C on average. The partial regression coefficient \(\beta_7=0.1561\) said, every 1% increased in solar energy transmittance rate, the temperature in heating season increased by 0.1561 °C on average. The partial regression coefficient \(\beta_8=0.1719\), every 1% increased in solar reflectivity, the temperature in heating season increased by 0.1719 °C on average. The partial regression coefficient \(\beta_9=-0.1305\) said, every 1% increased in the visible transmittance, the temperature in heating season decreased by 0.1305 °C on average. The partial regression coefficient \(\beta_{10}=-0.1210\), every 1% increased in visible reflectance, the temperature in heating season decreased by 0.1210 °C on average. Goodness of fit was 0.9995, indicating that 99.95% of the total temperature variation in the heating season can be explained by the fitting relationship between the above factors. Meanwhile, R Square can represent the precision of the regression equation.R Square was 0.9989, which meant that this regression equation can explain 99.89% of the total variation in Y values. Therefore, the precision of the regression equation was higher and the effect was better. The standard error was 0.0039, indicating that when the above factors were used to predict the temperature in heating season, the average prediction error was 0.0039. It can be seen from the table of variance analysis, the significant probability was 0 less than 0.05, indicating that the fitting model between the temperature in heating season and the above factors was significant.

(2) The partial regression coefficient \(\beta_{12}=0.9089\) said, when only a single factor changed, every increase 1mm thickness of the glass, the temperature in cooling season increased by 0.9089 °C on average. The partial regression coefficient \(\beta_{22}=-0.4636\) indicated that every 1mm increased in air layer thickness, air layer thickness, glass layer, heat transfer coefficient, solar heat gain coefficient, shading coefficient, solar energy transmittance rate, solar reflective rate, visible transmittance and visible reflectance. Each influencing factor will have an impact on the building energy saving effect. A corresponding model was established by multivariate regression method and the variation of building energy efficiency was analyzed when the above univariate impact factor changed in units.
thickness, the temperature in cooling season decreased by 0.4636°C on average. The partial regression coefficient $\beta_{12}=0$, said each additional layer of glass, the temperature in cooling season increased by 0°C on average. The partial regression coefficient $\beta_{13}=-0.0026$, every 1W/m²·K increased in heat transfer coefficient, the temperature in cooling season increased by 0°C on average. The partial regression coefficient $\beta_{14}=0$ said, every 1% increased in shading coefficient, the temperature in cooling season increased by 0°C on average. The partial regression coefficient $\beta_{15}=0.1744$ said, every 1% increased in solar energy transmittance rate, the temperature in cooling season increased by 0.1744°C on average. The partial regression coefficient $\beta_{23}=0.1965$, every 1% increased in solar reflectivity, the temperature in cooling season increased by 0.1965°C on average. The partial regression coefficient $\beta_{24}=-0.1485$ said, every 1% increased in the visible transmittance, the temperature in cooling season decreased by 0.1485°C on average. The partial regression coefficient $\beta_{25}=0.1927$ said, every 1% increased in solar energy transmittance rate, the temperature in transition season increased by 0.1927°C on average. The partial regression coefficient $\beta_{33}=0.1727$, every 1% increased in solar energy transmittance rate, the temperature in transition season increased by 0.1727°C on average. The partial regression coefficient $\beta_{34}=-0.0091$, every 1% increased in the visible transmittance, the temperature in transition season decreased by 0.0091°C on average. The partial regression coefficient $\beta_{35}=0.1964$ said, every 1% increased in solar energy transmittance rate, the temperature in transition season decreased by 0.1964°C on average. The partial regression coefficient $\beta_{43}=0$ said, every 1% increased in solar energy transmittance rate, the temperature in transition season increased by 0.1% on average. The partial regression coefficient $\beta_{44}=-0.1485$, every 1% increased in solar energy transmittance rate, the temperature in transition season increased by 0.1485°C on average. The partial regression coefficient $\beta_{45}=0.1727$ said, every 1% increased in solar energy transmittance rate, the temperature in transition season increased by 0.1727°C on average. The partial regression coefficient $\beta_{53}=0.1965$, every 1% increased in solar energy transmittance rate, the temperature in transition season increased by 0.1965°C on average. The partial regression coefficient $\beta_{54}=-0.0091$, every 1% increased in the visible transmittance, the temperature in transition season decreased by 0.0091°C on average. The partial regression coefficient $\beta_{55}=0.1965$, every 1% increased in solar energy transmittance rate, the temperature in transition season increased by 0.1965°C on average. The partial regression coefficient $\beta_{102}=-0.1379$, every 1% increased in visible reflectance, the temperature in cooling season decreased by 0.1379°C on average. Goodness of fit was 0.9994, indicating that 99.94% of the total temperature variation in the cooling season can be explained by the fitting relationship between the above factors. Meanwhile, R Square can represent the precision of the regression equation. R Square was 0.9988, which meant that this regression equation can explain 99.89% of the total variation in Y values. Therefore, the precision of the regression equation was higher and the effect was better. The standard error was 0.0039, indicating that when the above factors were used to predict the temperature in cooling season, the average prediction error was 0.0032. It can be seen from the table of variance analysis, the significant probability was 0 less than 0.05, indicating that the fitting model between the temperature in cooling season and the above factors was significant.

(3) The partial regression coefficient $\beta_{13}=0.8925$ said, when only a single factor changed, every increase 1mm thickness of the glass, the temperature in transition season increased by 0.8925°C on average. The partial regression coefficient $\beta_{23}=-0.4540$ indicated that every 1mm increased in air layer thickness, the temperature in transition season decreased by 0.4540°C on average. The partial regression coefficient $\beta_{33}=0$, said each additional layer of glass, the temperature in transition season increased by 0.4540°C on average. The partial regression coefficient $\beta_{43}=-0.0091$, every 1% increased in the visible transmittance, the temperature in transition season decreased by 0.0091°C on average. The partial regression coefficient $\beta_{53}=0.1965$, every 1% increased in the visible transmittance, the temperature in transition season decreased by 0.1965°C on average. The partial regression coefficient $\beta_{102}=-0.1379$, every 1% increased in visible reflectance, the temperature in transition season increased by 0.1379°C on average. Goodness of fit was 0.9994, indicating that 99.94% of the total temperature variation in the cooling season can be explained by the fitting relationship between the above factors. Meanwhile, R Square can represent the precision of the regression equation. R Square was 0.9988, which meant that this regression equation can explain 99.89% of the total variation in Y values. Therefore, the precision of the regression equation was higher and the effect was better. The standard error was 0.0039, indicating that when the above factors were used to predict the temperature in cooling season, the average prediction error was 0.0032. It can be seen from the table of variance analysis, the significant probability was 0 less than 0.05, indicating that the fitting model between the temperature in cooling season and the above factors was significant.

(4) The partial regression coefficient $\beta_{13}=-8.7964$ said, when only a single factor changed, every increase 1mm thickness of the glass, the annual cumulative heating load index decreased by 8.7964 on
average. The partial regression coefficient $\beta_4=4.4409$ indicated that every 1mm increased in air layer thickness, the annual cumulative cooling load index increased by 4.4409 on average. The partial regression coefficient $\beta_6=0$, said each additional layer of glass, the annual cumulative heating load index increased by 0 on average. The partial regression coefficient $\beta_{13}=0.5132$, every 1W/m$^2$·K increased in heat transfer coefficient, the annual cumulative heating load index increased by 0.5132 on average. The partial regression coefficient $\beta_{17}=0$ said, every 1 increased in solar heat gain coefficient, the annual cumulative heating load index increased by 0 on average. The partial regression coefficient $\beta_{45}=0$ said, every 1 increased in shading coefficient, the annual cumulative heating load index increased by 0 on average. The partial regression coefficient $\beta_{54}=-1.7264$ said, every 1% increased in solar energy transmittance rate, the annual cumulative heating load index decreased by 1.7264 on average. The partial regression coefficient $\beta_{55}=-1.8654$, every 1% increased in solar reflectivity, the annual cumulative heating load index decreased by 1.8654 °C on average. The partial regression coefficient $\beta_{56}=1.4444$ said, every 1% increased in visible transmittance, the annual cumulative heating load index increased by 1.4444 on average. The partial regression coefficient $\beta_{16}=1.3344$, every 1% increased in visible reflectance, the annual cumulative heating load index increased by 1.3344 on average. Goodness of fit was 0.9972, indicating that 99.72% of the total variation of annual cumulative heating load index can be explained by the fitting relationship between the above factors.

Meanwhile, R Square can represent the precision of the regression equation. R Square was 0.9944, which meant that this regression equation can explain 99.44% of the total variation in Y values. Therefore, the precision of this regression equation was higher and the effect was better. The standard error was 0.0992, indicating that when the above factors were used to predict the annual cumulative heating load index, the average prediction error was 0.0992. It can be seen from the table of variance analysis, the significant probability was 0 less than 0.05, indicating that the fitting model between the annual cumulative heating load index and the above factors was significant.

(5) The partial regression coefficient $\beta_{15}=6.0998$ said, when only a single factor changed, every increase 1mm thickness of the glass, the annual cumulative cooling load index increased by 6.0998 on average. The partial regression coefficient $\beta_{23}=-3.1180$ indicated that every 1mm increased in air layer thickness, the annual cumulative cooling load index decreased by 3.1180 on average. The partial regression coefficient $\beta_{15}=0$, said each additional layer of glass, the annual cumulative cooling load index increased by 0 on average. The partial regression coefficient $\beta_{45}=-0.0040$, every 1W/m$^2$·K increased in heat transfer coefficient, the annual cumulative cooling load index decreased by 0.0040 on average. The partial regression coefficient $\beta_{55}=0$ said, every 1 increased in solar heat gain coefficient, the annual cumulative cooling load index increased by 0 on average. The partial regression coefficient $\beta_{56}=1.3199$, every 1% increased in solar energy transmittance rate, the annual cumulative cooling load index decreased by 1.3199 on average. The partial regression coefficient $\beta_{57}=-0.9920$ said, every 1% increased in visible transmittance, the annual cumulative cooling load index decreased by 0.9920 on average. The partial regression coefficient $\beta_{165}=-0.9275$, every 1% increased in visible reflectance, the annual cumulative cooling load index decreased by 0.9275 on average. Goodness of fit was 0.9996, indicating that 99.96% of the total variation of annual cumulative cooling load index can be explained by the fitting relationship between the above factors. Meanwhile, R Square can represent the precision of the regression equation. R Square was 0.9991, which meant that this regression equation can explain 99.91% of the total variation in Y values. Therefore, the precision of the regression equation was higher and the effect was better. The standard error was 0.0198, indicating that when the above factors were used to predict the annual cumulative cooling load index, the average prediction error was 0.00198. It can be seen from the table of variance analysis, the significant probability was 0 less than 0.05, indicating that the fitting model between the annual cumulative cooling load index and the above factors was significant.
(6) The partial regression coefficient $\beta_{16} = -2.5475$ said, when only a single factor changed, every increase 1mm thickness of the glass, the heat load index in heating season decreased by 2.5475 on average. The partial regression coefficient $\beta_{28} = 1.2851$ indicated that every 1mm increased in air layer thickness, the heat load index in heating season increased by 1.2851 on average. The partial regression coefficient $\beta_{36} = 0$, said each additional layer of glass, the heat load index in heating season increased by 0 on average. The partial regression coefficient $\beta_{46} = 0.1589$, every 1W/m$^2$K increased in heat transfer coefficient, the heat load index in heating season increased by 0.1589 on average. The partial regression coefficient $\beta_{56} = 0$ said, every 1 increased in solar heat gain coefficient, the heat load index in heating season increased by 0 on average. The partial regression coefficient $\beta_{66} = 0$ said, every 1 increased in shading coefficient, the heat load index in heating season increased by 0 on average. The partial regression coefficient $\beta_{76} = -0.5010$ said, every 1% increased in solar energy transmittance rate, the heat load index in heating season decreased by 0.5010 on average. The partial regression coefficient $\beta_{86} = -0.5488$, every 1% increased in solar reflectivity, the heat load index in heating season decreased by 0.5488 on average. The partial regression coefficient $\beta_{96} = -0.4184$ said, every 1% increased in the visible transmittance, the heat load index in heating season increased by 0.4184 on average. The partial regression coefficient $\beta_{106} = 0.3864$, every 1% increased in visible reflectance, the heat load index in heating season increased by 0.3864 on average. Goodness of fit was 0.9971, indicating that 99.71% of the total variation of the heat load index in heating season be explained by the fitting relationship between the above factors. Meanwhile, R Square can represent the precision of the regression equation. R Square was 0.9942, which meant that this regression equation can explain 99.42% of the total variation in Y values. Therefore, the precision of the regression equation was higher and the effect was better. The standard error was 0.0308, indicating that when the above factors were used to predict the heat load index in heating season, the average prediction error was 0.0308. It can be seen from the table of variance analysis, the significant probability was 0 less than 0.05, indicating that the fitting model between the heat load index in heating season and the above factors was significant.

(7) The partial regression coefficient $\beta_{12} = 2.0655$ said, when only a single factor changed, every increase 1mm thickness of the glass, the cooling load index in air conditioning season increased by 2.0655 on average. The partial regression coefficient $\beta_{22} = -1.0558$ indicated that every 1mm increased in air layer thickness, the cooling load index in air conditioning season decreased by 1.0558 on average. The partial regression coefficient $\beta_{32} = 0$, said each additional layer of glass, the cooling load index in air conditioning season increased by 0 on average. The partial regression coefficient $\beta_{42} = -0.0014$, every 1W/m$^2$K increased in heat transfer coefficient, the temperature in heating season decreased by 0.0014 on average. The partial regression coefficient $\beta_{52} = 0$ said, every 1 increased in solar heat gain coefficient, the cooling load index in air conditioning season increased by 0 on average. The partial regression coefficient $\beta_{62} = 0$, every 1 increased in shading coefficient, the cooling load index in air conditioning season increased by 0 on average. The partial regression coefficient $\beta_{72} = 0.3956$ said, every 1% increased in solar energy transmittance rate, the cooling load index in air conditioning season increased by 0.3956on average. The partial regression coefficient $\beta_{82} = 0.4469$, every 1% increased in solar reflectivity, the cooling load index in air conditioning season increased by 0.4469 on average. The partial regression coefficient $\beta_{92} = -0.3360$ said, every 1% increased in the visible transmittance, the cooling load index in air conditioning season decreased by 0.3360 on average. The partial regression coefficient $\beta_{102} = -0.3141$, every 1% increased in visible reflectance, the cooling load index in air conditioning season decreased by 0.3141 on average. Goodness of fit was 0.9996, indicating that 99.96% of the total variation of the cooling load index in air conditioning season can be explained by the fitting relationship between the above factors. Meanwhile, R Square can represent the precision of the regression equation. R Square was 0.9991, which meant that this regression equation can explain 99.91% of the total variation in Y values. Therefore, the precision of the regression equation was higher and the effect was better. The standard error was 0.0067, indicating that when the above factors were used to predict the cooling load index in air conditioning season, the average prediction error was 0.0067. It can be seen from the table of
variance analysis, the significant probability was 0 less than 0.05, indicating that the fitting model between the cooling load index in air conditioning season and the above factors was significant.

5. Conclusions

As can be seen from the simulation results of DeST software, when the indoor temperature changes with the change of outdoor temperature, the turning point of change would be delayed by 0-2 hours. When the glass is ordinary glass, the incident rate of solar radiation is 100%. In the incident solar radiation, the reflectivity is 8%, transmittance is 80% and absorption rate is 12%. Among the absorbed solar radiation, 5% is re-radiated in and 7% is re-radiated out. In this case, 15% of the total solar radiant heat is isolated and 85% is transmitted indoors; When the glass is heat-absorbing glass, the incident rate of solar radiation is 100%. In the incident solar radiation, the reflectivity is 5%, transmittance is 31%, and absorption rate is 64%. Among the absorbed solar radiation, 25% is re-radiated in and 39% is re-radiated out. In this case, 44% of the total solar radiant heat is isolated and 55% is transmitted indoors; When the glass is reflected glass, the incident rate of solar radiation is 100%. In the incident solar radiation, the reflectivity is 57%, transmittance is 7%, and absorption rate is 36%. Among the absorbed solar radiation, 14% is re-radiated in and 22% is re-radiated out. In this case, 79% of the total solar radiant heat is isolated and 21% is transmitted indoors [34].

When studying the energy-saving performance of single energy-saving buildings with different exterior windows in different seasons, compared the indoor temperature with the outdoor temperature, the change value (indoor temperature of the single energy-saving buildings with the same structure and different exterior windows varies with the external temperature) from high to low is sorted into Low-e high through glass windows, low-E insulating glazing units, thermal reflection glass with high light transmission, blue heat absorbing glass windows, ordinary 3mm glass windows, ordinary hollow glass windows, and standard external window. So, the thermal insulation properties of glass windows from high to low is sorted into Low-e high through glass windows, low-E insulating glazing units, thermal reflection glass with high light transmission, blue heat absorbing glass windows, ordinary 3mm glass windows, ordinary hollow glass windows, and standard external window. When the frames (a non-insulated metal window frame, an insulated metal window frame and a plastic window frame) of outer window changed, annual cumulative heat load of the standard external window is higher. But heat load in winter is less and cooling load in summer is more. When the frames of outer window changed, Annual cumulative heat load of Low-e high through glass windows is less. But heat load in winter is more and cooling load in summer is less. Blue heat absorbing glass windows heat is more balanced throughout the year building. The heat load required for heating in winter and the cooling load required for air conditioning in summer are also more balanced and more suitable for hot summer and cold winter regions and mild regions. In addition, according to the grey correlation degree in Table 5 and the multivariate regression analysis statistics in Table 6, it is found that when the thickness of the air layer changed, the energy saving effect of the single energy-saving building with the same structure and different exterior windows changes most obviously, followed by the glass thickness. When the solar heat gain coefficient and the shading coefficient of SC value changed separately, the energy saving effect of the building can be ignored.

Therefore, in the optimization process of building exterior windows, we can firstly ignore the influence of solar heat gain coefficient and shading coefficient of SC value, and focus on the influence of glass thickness and air layer thickness changes on the energy-saving effect of glass windows. Secondly, different single factors need to be changed according to different requirements and performance indexes of exterior Wi0ndows. Such as, in the optimization research on the energy efficiency of building exterior windows, more research can be done on the thickness of glass, the thickness of the air layer, and the number of glass layers. Secondly, based on the problem (Annual cumulative heat load of Low-e high through glass windows is less but heat load in winter is more), we can solve it by appropriately increasing the thickness of the air layer and reducing the thickness of the glass. On the contrary, when based on the problem( annual cumulative heat load of the standard external window is higher but heat load in winter is more.), we can solve it by appropriately increasing
the thickness of the glass and reducing the thickness of the air layer. In the future, further optimization of the energy efficiency of building exterior windows will be carried out in three aspects: glass thickness, air layer thickness and glass layer number.

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