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Grounding Electrode Double-line Fault Location Based on Characters of Amplitude and Phase Angle of High-frequency Measured Impedance

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ABSTRACT

With the rapid development of the global economy, the world energy consumption is increasing day by day. Mankind is facing the problem of energy shortage. Energy conservation and emission reduction has become the focus of countries all over the world. In order to study the influence of building envelope on building energy efficiency in severe cold area, the sensitivity analysis is used to analyze the influence relationship between building envelope and building energy efficiency. Combined with DeST simulation software, the building model is established, and the arc mean elasticity method is used to analyze the sensitivity of building energy load to different building envelope parameters. The results show that the external windows of the building envelope have the greatest impact on the building energy efficiency, followed by the external walls, and the roof has the least impact on the energy efficiency. The sensitivity coefficients of the annual cumulative load to the external windows, exterior walls and roofs of buildings are 7.93%, 5.76% and 5.75% respectively. Studying the influence of enclosure structure on building energy efficiency in severe cold areas has important practical value for reducing building energy consumption in severe cold areas and provides data reference for scientifically improving building energy efficiency and building skill transformation in severe cold areas.

1. INTRODUCTION

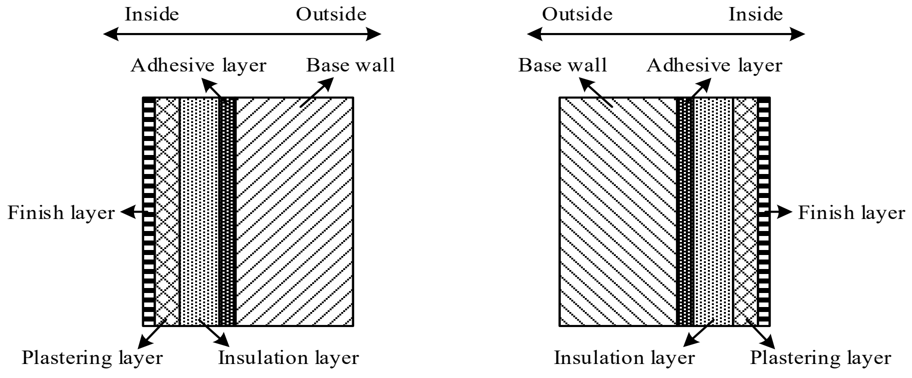
With the increasing material demand of people and the rapid development of social economy, the problem of energy consumption gradually appears. Oil, coal and other non-renewable energy sources are drying up, and the energy crisis has become an important problem to be solved [1]. In recent years, countries have taken various measures to transform the energy structure, increase the utilization rate of clean energy, and strive to reduce the total world energy consumption and improve the world energy efficiency [2]. Building is one of the three major areas of energy consumption. Building energy consumption accounts for more than 60% of the total social energy consumption. Therefore, building energy conservation is a key area in the process of energy conservation and emission reduction in the world [3, 4]. Affected by the environmental conditions, buildings in severe cold areas have high requirements for building thermal insulation performance.

Especially in the severe cold environment in winter, buildings have large energy consumption in regulating indoor temperature, which does not meet the overall requirements of green and low-carbon development in China [5, 6]. Therefore, aiming at the problems of large building energy consumption and poor thermal performance of building envelope in severe cold areas, this study explores the impact of envelope on building energy efficiency in severe cold areas, so as to provide data reference for building energy-saving transformation in severe cold areas.

2. BUILDING ENVELOPE MODEL AND IMPACT SENSITIVITY ANALYSIS

2.1. Energy Saving Technology Analysis and DeST Model Simulation of Enclosure Structure

The building envelope mainly includes the external door, external wall, external window, roof and other structures of the building. The building envelope is in direct contact with the natural external environment of the building. Scientific building envelope is of great significance to the control of building energy consumption. The building envelope can reflect the energy-saving effect of the building to a great extent [7, 8]. The energy-saving technology of building roof mainly enhances the thermal insulation performance of building roof by four ways: positive roof, inverted roof, flat to sloping roof and roof greening, adjusts the structural sequence of building roof or uses plant greening to adjust the thermal insulation of Roof [9, 10]. Starting from the doors and windows of the building, the thermal insulation transformation is mainly to adjust the heat transfer coefficient and air tightness of the external windows of the building, reduce the loss of indoor heat, or carry out thermal insulation by taking shading measures [11, 12]. The external wall of a building is the largest part of the building envelope and has the greatest impact on the building energy consumption. The external wall energy conservation is mainly to strengthen the thermal insulation performance of the external wall of the building. Four means of external thermal insulation, internal thermal insulation, self-thermal insulation and sandwich thermal insulation are used to place the thermal insulation layer on the internal and external surfaces of the external wall or between the internal and external walls or use exterior wall materials with good thermal insulation performance to enhance the thermal insulation of the exterior wall [13, 14]. The structural design of external wall internal and external insulation system is shown in Figure 1.



(a) External wall internal insulation structure (b) External insulation structure of exterior wall

Figure 1: Module structure of DeST simulation software

DeST (Designers Simulation Tookit) carries out building model simulation with phased simulation as the core, provides auxiliary reference for actual building design, and has significant advantages in the coupling of building energy consumption simulation and building air conditioning system design [15, 16]. DeST simulation software combines the simulated building with the environmental control system by using the natural room temperature, which can accurately describe the thermal characteristics of the building, accurately analyze the natural room temperature of each room in the building and analyze the building energy consumption in combination with the research of air conditioning system [17, 18]. Moreover, DeST simulation software develops a graphical interface based on AutoCAD drawing software, combines various parameter information of simulated building with user graphical interface by using database, selects or sets building and system parameters through database, and realizes accurate description of simulated building information [19, 20]. Finally, the results of building simulation parameters are classified and output in the form of Excel, which is convenient for users to query and use data at any time and has the advantage of simple and convenient use. DeST simulation software realizes the overall design of the building through the design and analysis of several modules. The subsequent modules take the results of the previous modules as input conditions and known parameters for analysis and research. The overall design process has strong logic, and the interaction and influence between various modules [21, 22]. The module structure of DeST simulation software is shown in Figure 2.

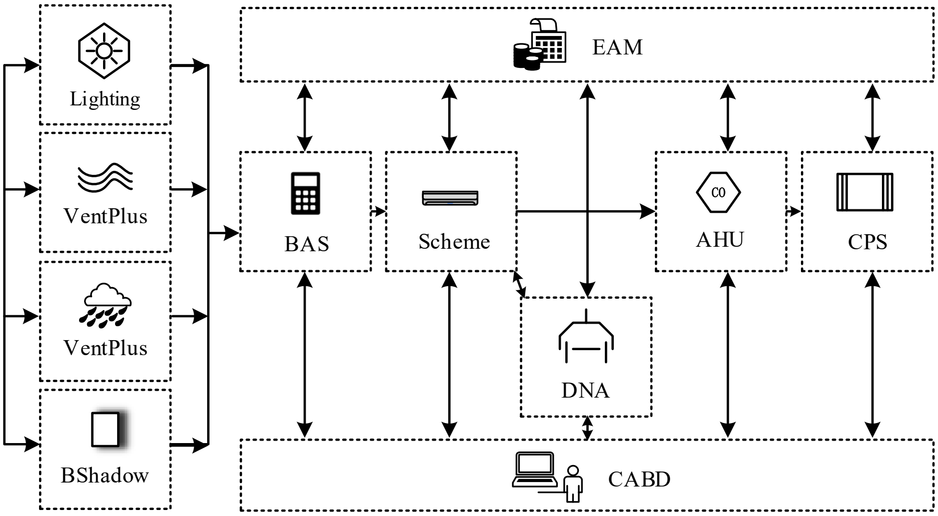


Figure 2: Module structure of DeST simulation software

The lighting module mainly calculates the indoor lighting of the simulated building and simulates the indoor lighting of the building based on the service time of lighting lamps that can be determined inside the building. Ventplus module simulates the natural ventilation of the building and uses the ventilation to simulate and calculate the indoor thermal environment of the building. Medpha module is a meteorological module, which uses the typical meteorological annual data of the area where the building is located to simulate the basic data of the outdoor environment of the building throughout the year. Bshadow module analyzes the shadow of the building and calculates the occlusion data of the building. Bas (building automation system) module is the core of building thermal characteristic calculation. It dynamically simulates building load based on building thermal balance.

2.2. Impact Analysis of Retaining Structure Based on Sensitivity Coefficient

Based on the building DeST modeling, the envelope scheme design is carried out. Combined with the building cooling and heating load information obtained from the DeST modeling analysis, the influence relationship between the building energy load and the envelope parameters is understood through the parameter sensitivity analysis. The sensitivity relationship between building energy load and energy-saving transformation technology is analyzed by using the building arc mean elasticity, and the influence of different parameters of energy-saving transformation technology on building energy load is compared longitudinally, so as to obtain the influence law of different energy-saving transformation technical parameters on building energy load. Then compare the impact of different energy-saving transformation technologies on building energy load horizontally, so as to obtain the impact degree of different energy-saving transformation technologies on building energy load and provide parameter suggestions and guidance for reducing building energy load in severe cold areas. Using the parameter sensitivity ranking obtained from sensitivity analysis, we can understand the priority parameters in building energy load control and design the envelope transformation scheme in severe cold area. Sensitivity analysis starts from the observation and Research on the response changes under the excitation in economics and automatic control, studies the influence degree of a factor or different factors on the target through quantitative analysis, and uses sensitivity to evaluate the influence degree of the target results [23, 24]. The schematic diagram of sensitivity analysis is shown in Figure 3. The simulation system is used to simulate the influence process of parameter changes, and the influence degree of parameters on the target structure is observed through the changes of input parameters and output parameters.

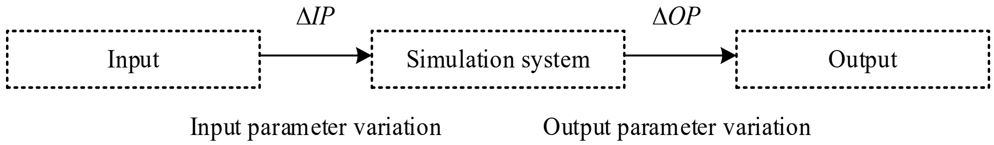


Figure 3: Schematic diagram of sensitivity analysis

The sensitivity coefficient of parameters is calculated as follows:

$$IC = \frac{Output\ Change}{Input\ Change} = \frac{\partial OP}{\partial IP} = \frac{\Delta OP}{\Delta IP} \tag{1}$$

In equation (1), ΔIP represents the change of input parameters and ΔOP represents the change of output parameters.

Sensitivity analysis can be divided into local sensitivity analysis and global sensitivity analysis according to the number of independent variables. The sensitivity analysis between building energy load and energy-saving transformation technology is mostly local sensitivity analysis, which mainly investigates the influence degree of single parameter on building energy load and analyzes the leading factors in energy-saving transformation technology [25, 26]. Based on the basic formula of sensitivity analysis, five sensitivity coefficient calculation formulas can be extended, namely influence coefficient, point elasticity, interval elasticity, arc mean elasticity and arc mean elasticity. The arc mean elasticity (MAE) method is used to analyze the influence relationship between building energy load and envelope parameters. The mean value within the variation range of input parameters is $\overline{IP}$, and the mean value within the variation range of output parameters is $\overline{OP}$. The arc mean value elasticity is the ratio between the percentage of output parameters and $\overline{OP}$ and the percentage of input parameters and $\overline{IP}$. Arc mean elasticity is a dimensionless index, which can directly analyze the sensitivity of different factors to the target results. Compared with other sensitivity analysis formulas, it has the advantages of simplicity and rapidity. Moreover, the arc mean elasticity can make full use of all data, the objectivity of the sensitivity analysis calculation results is high, and the reliability of the result data is good. The use of arc mean elasticity can also sort the sensitivity degree between different parameter factors and analyze the sensitivity trend of parameters. Compared with other calculation methods, the analysis function of arc mean elasticity method is more complete. The calculation formula of arc mean elasticity is as follows:

$$MAE = \left(\frac{\Delta OP}{\Delta IP}\right) \div \left(\frac{\overline{OP}}{\overline{IP}}\right) \tag{2}$$

Based on the basic formula of arc mean value elasticity, building load related parameters are introduced to analyze the sensitivity relationship between building energy load and envelope parameters. Let (MAE_{AC}) represent the arc mean value elasticity coefficient of building cooling load, (MAE_{AH}) represent the arc mean value elasticity coefficient of building heat load, $(\overline{MAE_{AC}})$ represent the arc mean value elasticity average of building cooling load, and $(\overline{MAE_{AH}})$ represent the arc mean value elasticity average of building heat load, Through the sensitivity of building cooling and heating load to different parameters, the influence of enclosure structure on building efficiency in severe cold area is analyzed. Assuming that the influencing factors of building load are a_x and $x = 1,2,\cdots,n$, the annual cooling load of buildings corresponding to a_x is Q_{xc}, the annual heat load of buildings is Q_{xh}, and the annual cumulative total load of buildings is Q_x. The calculation formula of the arc mean elasticity MAE_{AC} of the annual cooling load of buildings corresponding to a_x is shown as follows:

$$\begin{cases} MAE_{AC} = \left(\frac{\Delta Q_{xc,(x+1)c}}{\Delta a_{x,x+1}}\right) \div \left(\frac{\overline{Q_{xc}}}{\bar{a}}\right) \\ \frac{\Delta Q_{xc,(x+1)c}}{\Delta a_{x,x+1}} = \left|\frac{Q_{(x+1)c}-Q_{xc}}{a_{x+1}-a_x}\right| \\ \overline{Q_{xc}} = \frac{\sum_{x=1}^{x=n} Q_{xc}}{n} \\ \bar{a} = \frac{\sum_{x=1}^{x=n} a_x}{n} \end{cases} \tag{3}$$

In equation (3), $\bar{a}$ represents the average value of all values of influencing factors, $\Delta a_{x,x+1}$ represents the parameter change amount of different values of influencing factors, $\overline{Q_{xc}}$ represents the average value of building cooling load corresponding to all values of influencing factors, $\Delta Q_{xc,(x+1)c}$ represents the change amount of building cooling load corresponding to different values of influencing factors, and n represents the number of values of influencing factors. The elastic MAE_{AH} calculation formula of the arc mean value of building annual heat load corresponding to a_x is shown as follows:

$$\begin{cases} MAE_{AH} = \left(\frac{\Delta Q_{xh,(x+1)h}}{\Delta a_{x,x+1}}\right) \div \left(\frac{\overline{Q_{xh}}}{\bar{a}}\right) \\ \frac{\Delta Q_{xh,(x+1)h}}{\Delta a_{x,x+1}} = \left|\frac{Q_{(x+1)h} - Q_{xh}}{a_{x+1} - a_x}\right| \\ \overline{Q_{xh}} = \frac{\sum_{x=1}^{x=n} Q_{xh}}{n} \end{cases} \tag{4}$$

In equation (4), $\overline{Q_{xh}}$ represents the average value of building heat load corresponding to all values of influencing factors and represents the change of building heat load corresponding to different values of influencing factors. The influence of different factors on the annual cooling load and heat load of buildings is analyzed by using the elasticity of the average arc mean of buildings.[27] The calculation formula of the elastic average of the average arc mean of the annual cooling load of buildings is shown as follows:

$$\overline{MAE_{AC}} = \frac{\sum_{x=1}^{x=n-1}(MAE_{AC})}{n-1} \tag{5}$$

The calculation formula of the average elastic value of the arc mean value of the building's annual heat load is as follows:

$$\overline{MAE_{AH}} = \frac{\sum_{x=1}^{x=n-1}(MAE_{AH})}{n-1} \tag{6}$$

Combined with the longitudinal comparison between the arc mean elasticity of building cooling load and the arc mean elasticity of building heat load, the influence of different parameters of building envelope on the annual cumulative cooling load and heat load is analyzed [28,29]. Combined with the horizontal comparison between the average elastic value of the arc mean of building cooling load and the average elastic value of the arc mean of building heating load, the influence degree of building energy load and parameters is sorted, and the factors that need to be given priority in the reconstruction of building envelope in severe cold areas are obtained [30-32].

3. ANALYSIS OF PARAMETER SENSITIVITY RESULTS

A public building in northern China is selected for envelope impact analysis. The building integrates office, commercial and other functions, with a total building area of 32421 m^2. The building is modeled by DeST simulation software to form an enclosure structure consistent with the original characteristics of the building. The outer wall of the enclosure structure is a concrete insulation wall with a thickness of 200mm, the inner wall of the building is a concrete wall with a thickness of 140mm, and the heat transfer coefficient of the outer wall of the building is 0.96 $W/(m^2 \cdot K)$. The building roof is a 120 mm thick waterproof and thermal insulation roof, and the heat transfer coefficient of the building roof is 0.98 $W/(m^2 \cdot K)$. The building floor is 150mm thick reinforced concrete floor, and the heat transfer coefficient of the building floor is 2.71 $W/(m^2 \cdot K)$. The building floor is 200mm thick concrete, and the heat transfer coefficient of the building floor is 1.12 $W/(m^2 \cdot K)$. The external windows of the building are hollow glass, and the heat transfer coefficient of the external windows is 2.8 $W/(m^2 \cdot K)$.

The sensitivity of building exterior wall to building energy load is analyzed by changing the thickness of external insulation material of building, simultaneous interpreting the influence degree of external wall with different heat transfer coefficient on building energy load. According to the external wall parameters of the original building, the external wall enclosure structure is simulated, and the heat transfer coefficient of the external wall under different insulation materials is set to 0.36 $W/(m^2 \cdot K)$ to 0.96 $W/(m^2 \cdot K)$. Simultaneous interpreting the external walls with different heat transfer coefficients by 0.1 $W/(m^2 \cdot K)$ as the analysis step. Under the condition of keeping other parameters unchanged, calculate the arc mean elastic values of annual cooling load (MAE_{AC}), annual heating load (MAE_{AH}) and annual cumulative load (MAE_{AT}) of buildings under different external wall heat transfer coefficients. The change of sensitivity coefficient of building energy load to external wall heat transfer coefficient is shown in Figure 4.

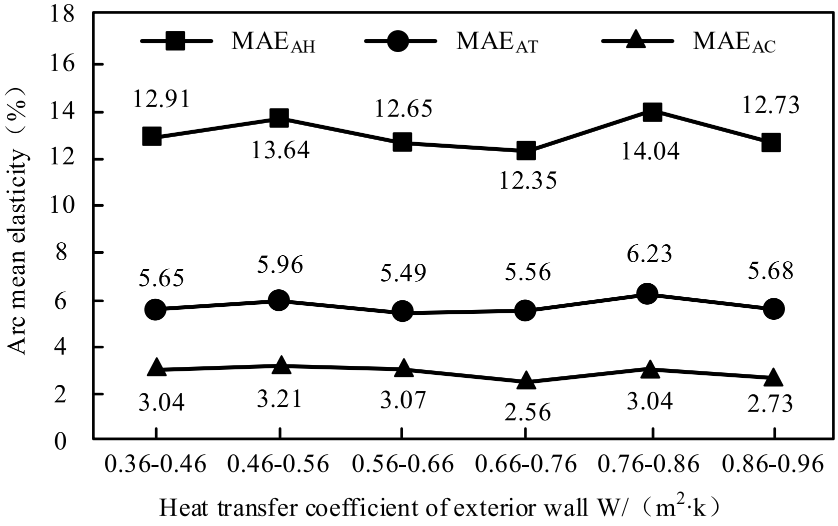


Figure 4: Variation of sensitivity coefficient of building energy load to external wall heat transfer coefficient

As can be seen from Figure 4, with the change of the heat transfer coefficient of the building exterior wall, the change range of the average elastic value of the building annual cooling load arc is 2.56% to 3.21%, and the change range of the average elastic value of the building annual heat load arc is 12.35% to 14.04%, indicating that the sensitivity of the building heat load to the heat transfer coefficient of the exterior wall is higher than that of the building cooling load. When the external wall heat transfer coefficient is in the range of 0.76 W/($m^2 \cdot K$) - 0.86 W/($m^2 \cdot K$), the annual cumulative load sensitivity and annual heat load sensitivity of the building are the highest, which are 6.23% and 14.04% respectively. When the heat transfer coefficient of exterior wall is in the range of 0.46 W/($m^2 \cdot K$) - 0.56 W/($m^2 \cdot K$), the sensitivity of building annual cooling load is the highest, and its arc mean elasticity value is 3.21%. The change of arc mean elasticity of building load is small, which proves that the sensitivity of building to the change of external wall heat transfer coefficient remains in a stable state.

Insulating glass is adopted for the external windows of the building for thermal insulation. The heat transfer coefficient of the external windows of the simulated building is set to change uniformly in the range of 2.2 W/($m^2 \cdot K$) to 2.8 W/($m^2 \cdot K$) with 0.1 W/($m^2 \cdot K$) as the analysis step. The changes of the arc mean elastic values of the annual cooling load, annual heat load and annual cumulative load of the building under different external window heat transfer coefficients are shown in Figure 5.

As can be seen from Figure 5, under the increasing change of the heat transfer coefficient of the external window of the building, the average elastic value of the arc of the annual cooling load of the building varies from 5.20% to 5.81%, and the average elastic value of the arc of the annual heat load of the building varies from 18.61% to 18.93%. The sensitivity of the heat transfer coefficient of the external window of the annual cooling load of the building is lower than that of the annual heat load of the building.

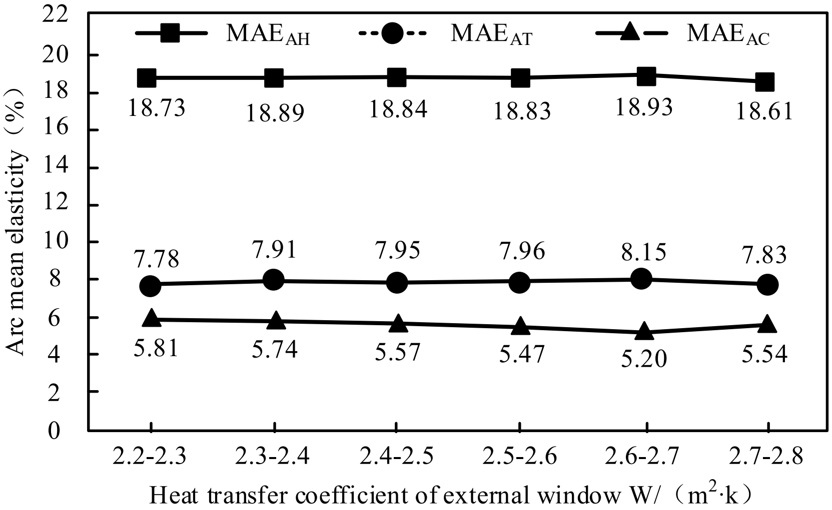


Figure 5: Variation of sensitivity coefficient of building energy load to external window heat transfer coefficient

When the heat transfer coefficient of the external window of the building changes in the range of 2.6 W/(m^2·K) - 2.7 W/(m^2·K), the annual cumulative load sensitivity and annual heat load sensitivity of the building are the highest, which are 8.15% and 18.93% respectively. When the heat transfer coefficient of the building's external window changes in the range of 2.2 W/(m^2·K) - 2.3 W/(m^2·K), the sensitivity of the building's annual cooling load reaches the highest, which is 5.81%. The arc mean elasticity of building load is generally stable, and the change of numerical value is small, which proves that the change sensitivity of building external window heat transfer coefficient is relatively stable.

The simulation model uses the external thermal insulation roof structure for waterproof and thermal insulation. By adjusting the thickness of building roof thermal insulation materials, the sensitivity relationship between building roof envelope and building energy load is analyzed. Set the range of heat transfer coefficient of building roof as 0.38 W/(m^2·K) to 0.98 W/(m^2·K). Take 0.1 W/(m^2·K) as the analysis step to simulate the building roof under different roof heat transfer coefficients. The arc mean elastic values of annual cooling and heating load and annual cumulative load under different roof heat transfer coefficients are shown in Table 1.

Table 1: Arc mean elasticity of building annual cooling and heating load and annual cumulative load

Roof heat transfer coefficient W/(m^2·K)	**MAE$_{AH}$ (%)**	**MAE$_{Ac}$ (%)**	**MAE$_{AT}$ (%)**
0.38-0.48	12.04	1.25	6.05
0.48-0.58	12.05	1.18	6.08
0.58-0.68	10.95	0.95	5.56
0.68-0.78	11.33	0.94	5.79
0.78-0.88	10.64	0.88	5.41
0.88-0.98	10.79	0.75	5.58

It can be seen from Table 1 that with the increase of building roof heat transfer coefficient, the variation range of building annual cooling load arc mean elastic value is 0.75% to 1.25%, and the variation range of building annual heat load arc mean elastic value is 10.64% to 12.05%, indicating that the sensitivity of building heat load to roof heat transfer coefficient is higher than that of building cooling load. When the roof heat transfer coefficient is in the range of 0.48 W/(m^2·K) - 0.58 W/(m^2·K), the annual cumulative load sensitivity and annual heat load sensitivity of buildings are the highest, which are 6.08% and 12.05% respectively. When the external wall heat transfer coefficient is in the range of 0.38 W/(m^2·K) - 0.48 W/(m^2·K), the sensitivity of building annual cooling load reaches the highest, and its arc mean elasticity value is 1.25%. The arc mean elasticity of building load gradually decreases with the increase of building roof heat transfer coefficient, indicating that the annual energy load sensitivity of building is inversely correlated with roof heat transfer coefficient.

Comprehensively analyze the sensitivity relationship between building envelope factors and building energy load and rank the influence degree of building energy load by building envelope parameters. The arc mean elastic mean value of building energy load is shown in Figure 6.

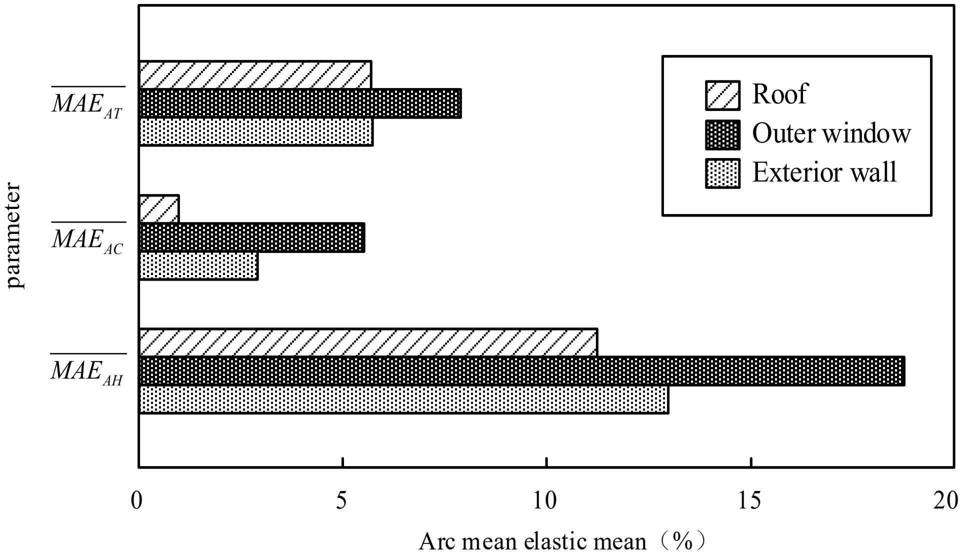


Figure 6: Arc mean elastic mean value of building energy load

As can be seen from Figure 6, the sensitivity between the annual cooling load of the building and the building envelope is ranked. The annual cooling load of the building is most affected by the external window, followed by the external wall, and the roof is the least sensitive. The sensitivity of building annual heat load to building envelope is analyzed. The influence degree of building annual heat load by building external window is greater than that of external wall, and the influence degree of external wall is greater than that of roof.

The sensitivity between the building annual cumulative load and the building envelope is sorted. The sensitivity of the building annual cumulative load is external window, external wall and roof from large to small. Therefore, in terms of the impact of building envelope on building energy efficiency, the external window of the building has the greatest impact, the external wall of the building takes the second place, and the roof of the building has the least impact. Its annual cumulative load sensitivity coefficients are 7.93%, 5.76% and 5.75% respectively.

4. CONCLUSION

Energy conservation and emission reduction is an important policy and means in China's sustainable development strategy. Building energy consumption accounts for a large proportion of the total social energy consumption. Building energy conservation is of great significance to control social energy consumption. In order to analyze the influence of building envelope on energy efficiency in severe cold areas, the sensitivity analysis is used to analyze the influence relationship between envelope parameters and building energy efficiency. Combined with DeST simulation software, the building model is established, and the arc mean elasticity method is used to study the sensitivity of building energy load to envelope parameters. The analysis results show that the external windows of the building envelope have the greatest impact on the building energy efficiency. The sensitivity coefficient of the annual cumulative load corresponding to the external windows is 7.93%, followed by the building exterior walls, with the corresponding annual cumulative load sensitivity coefficient of 5.76%. The building roof has the least impact on the energy efficiency, and the sensitivity coefficient of the overall cumulative load is 5.75%. The sensitivity coefficients of building annual heat load to external windows, exterior walls and roofs are 18.81%, 13.05% and 11.30% respectively, and the sensitivity coefficients of building annual cooling load to external windows, exterior walls and roofs are 5.56%, 2.94% and 0.99% respectively. The heat transfer coefficient of external windows should be given priority in the energy-saving transformation of buildings in severe cold areas.

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