Research on Load Modeling Method for Typical Low Carbon Energy Consumption Scenarios in Border and Cross border Regions Considering Seasonal Migration Characteristics

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Abstract. With the process of urbanization and the 'the Belt and Road' initiative, the cross-border energy demand in southwest China has grown rapidly, driving the development of the energy system. The accuracy of load forecasting directly affects the application of energy systems, so it is crucial to conduct research on load forecasting for energy terminals in border and cross-border areas. However, there is a seasonal shift in the diverse energy consumption loads in border and cross-border regions, and currently, research on load forecasting and simulation of typical low-carbon energy consumption scenarios under this feature is basically in a blank state. Based on existing problems, this article conducts research on load modeling methods under the significant 'seasonal migration' characteristics of border and cross-border loads, conducts research on characteristic industries in border and cross-border areas, establishes typical low-carbon energy consumption scenarios and simulation models in border and cross-border areas, and uses sensitivity analysis method of dynamic simulation to analyze the impact of different influencing factors on the load of various building types, The Monte Carlo simulation prediction method is used to obtain the sensitivity probability distribution of various influencing characteristic factors, and the typical energy consumption building load model is modified. Finally, by comparing the energy consumption simulation results with statistical results, the accuracy of simulation energy consumption prediction is verified to be higher than 90%.

1 Introduction

China is in the process of rapid industrialization and urbanization, and the contradiction between energy supply and demand is becoming increasingly prominent. At present, China is facing two major problems: energy shortage and environmental pollution, and energy conservation and clean utilization have become a major strategic demand for the country. In recent years, comprehensive and intelligent energy technologies have received increasing attention, and the research and application of related energy technologies have gradually shifted from centralized heating in northern regions and comprehensive energy system utilization in more developed regions to personalized energy utilization in small and medium-sized cities. Under the 'the Belt and Road' initiative, the demand for energy in the areas bordering Myanmar, Laos and Vietnam in southwest China is growing rapidly, and the demand for various energy technologies is also increasing.

The growth of energy demand in border and cross-border regions has directly driven the development and application of related energy system technologies. Due to the rapid development of urbanization in China, the total carbon emissions in the construction industry are high, accounting for a high proportion. In 2019, the energy consumption of buildings in the operational stage in China was 1.03 billion tce, accounting for 46.1% of the total energy consumption of buildings, with HVAC systems accounting for more than half of the energy consumption in the operational stage[1]. In order to optimize energy scheduling and develop relevant strategies to reduce energy consumption in heating and cooling systems, accurately predicting the cold, heat, electricity, and gas consumption of regional energy terminals is crucial for the application of energy system related technologies, optimization of energy planning and design schemes, and improvement of energy operation efficiency in the region. Therefore, based on the characteristics of border and cross-border regions, it is particularly important to conduct more in-depth research on the different types of hourly cooling, heating, electricity, and gas loads of energy terminals. This article aims to provide a method for modeling the energy load of cross-border regions by studying the hourly load characteristics of typical buildings' cold, hot, and electrical systems in typical low-carbon energy consumption scenarios. This can solve the key problems of unclear demand for characteristic energy

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use, insufficient research on the characteristics of cold and hot electrical multiple load data, and the lack of modeling methods for typical energy load simulation in border and cross-border regions, providing basic theories and technologies for the healthy development of energy technology in border and cross-border regions.

2 Overseas and Domestic Research Status

The existing load forecasting modeling methods can be divided into three types: physical based white box models, data-driven black box models, and gray box models in between. The white box model is based on heat transfer mechanisms and typically predicts cold and hot loads through simulation. The establishment of a white box model can be based on some commercial software, such as EnergyPlus and TRNSYS. The grey box model simplifies building heat treatment, and due to the dynamic, random, and time-varying cooling and heating loads, the prediction accuracy of the grey box model may be negatively affected[2]. The black box model is widely used in many systems with available input and output measurement data.

Azar[3] et al. conducted a systematic analysis of the factors affecting building energy performance in Kuwait using mixed statistics and energy modeling methods. By collecting local building characteristics and energy information, they analyzed data and driving factors affecting energy use. He used EnergyPlus to establish a building performance simulation model for typical commercial buildings in Kuwait City, which set basic information such as building geometric parameters, design parameters, and operating schedules. Finally, the model was calibrated by verifying the range of different input parameters, in order to apply the model to actual commercial buildings. Ruiqing Du[4] et al. coupled the parameterized model of building effects with the building energy model to establish a weather research forecast model for studying the air conditioning loads of different building categories under local climate conditions in Hong Kong. The establishment of the model takes into account the parameters and characteristics of urban microclimate, natural environment, and different building types. This model is also widely used to simulate high/low rise residential and commercial buildings in cities such as Beijing, Tokyo, Daidai, and Borzano.

At present, research on building load modeling mostly focuses on a single building type, while research on load models for multiple building types mainly focuses on economically developed regions or large cities. Research on the seasonal migration analysis of characteristic multiple loads in border and cross-border regions and the establishment of dynamic simulation models for typical low-carbon energy consumption scenarios is basically in a blank stage. However, due to the special geographical location, there are some energy issues in border and cross-border areas: residents in the southwest border area have frequent trade exchanges, but due to factors such as labor methods and resource conditions, the activity area is unstable and there is a possibility of migration. Moreover, the border tourism industry has the characteristics of spatiotemporal evolution, with significant seasonal differences in passenger flow distribution. The seasonal migration characteristics of industrial and commercial activities directly exacerbate the instability of load in border and cross-border areas. The instability of energy supply restricts the research on flexible and efficient collaborative technologies for new energy systems in border and cross-border regions. Therefore, this study aims to establish a model of typical low-carbon energy consumption scenarios in border and cross-border regions, simulate the multiple loads of cold and hot electricity, clarify the impact of seasonal migration characteristics of border and cross-border regional loads on characteristic energy demand, obtain a method for simulating typical energy consumption loads, and provide basic theories and technologies for the healthy development of energy technology in border and cross-border regions.

3 Research on the Industrial Characteristics of Border and Cross border Regions

Based on the above issues, this study conducts research on the modeling method of multi industry and multi energy loads under the significant "seasonal migration" characteristics of border and cross-border loads. Conduct research on the characteristic industries (tourism, interconnected railway economy, agriculture, industry, etc.) in border and cross-border areas. Based on the research and data collection, the current situation of border areas is mainly focused on tourism and production. The development and evolution of regional tourism usually rely on certain basic support and condition guarantees. Taking Yunnan Province as an example, as the forefront of Southwest China's opening up, the border areas of Yunnan Province are located in the hub area of the four countries and two regions, making them important nodes in the internal and external transportation routes. Good transportation development conditions provide key support for border tourism activities. The number of tourists in border and cross-border areas has periodicity and seasonality. The peak season of tourism in Yunnan is mainly concentrated in May October each year, and the number of tourists is relatively small at other times. The trend of the annual cycle is basically consistent. At the same time, the development of the tourism industry also has transferability. Taking Pu'er, Yunnan as an example, from 2007 to 2017, the development focus of the tourism industry in the border areas of Yunnan was roughly distributed between 100.623 ° E to 100.773 ° E, and 23.611 ° N to 23.728 ° N. It has always been located within the territory of Pu'er City, showing a migration trend from northwest (2007-2008) to southeast (2008-2013) to northwest (2013-2017), overall showing a migration towards the northwest direction. The development of the tourism industry is closely related to the level of openness in border areas, investment in tourism factors, and economic development level. Influenced by various factors, the migration characteristics of the tourism industry are obvious in the development process. For the analysis of industrial and agricultural research results in border and cross-border areas, take the sucrose industry as an example. The sucrose industry is a combination of industry and agriculture, and is a traditional pillar industry in the border areas of Yunnan. As a production factor for sugarcane cultivation, land supply directly affects the planting area of sugarcane. According to the statistics of sugarcane cultivation in Yunnan border areas from 2011 to 2017, the supply and demand gap between land supply area and sugarcane demand area decreased from the 2011/2012 crushing season to the 2013/2014 crushing season, and has since increased year by year. The inability of land production factors to meet market demand has constrained the development of the sugar industry, resulting in sugar making enterprises not being able to achieve saturation production, high equipment idle rate, and thus affecting the energy demand of the industry, increasing the instability and seasonal changes in the load in border areas.

Based on the research situation, the cyclical, seasonal, and migratory characteristics of industrial load demand in border and cross-border regions were analyzed, and combined with data information such as building types, climate conditions, industrial characteristics, resource characteristics, and population information, a typical low-carbon energy consumption scenario with border and cross-border regional characteristics was constructed.

4 Building models for low-carbon energy consumption scenarios in typical border and cross-border regions

Establish building models covering different regions, industries, and building forms based on typical low-carbon energy consumption scenarios in cross-border regions. Establish a building load simulation model for multiple typical cities in Yunnan and Guangxi provinces in the southwestern cross-border region, which is basically the same as the local office, hotel, residential, and hospital buildings. The simulation model includes the basic form of the building, enclosure structure, energy supply equipment, and other related structures and parameters of the target building. Use local historical climate data to conduct dynamic cold and hot electrical load simulation of typical buildings in typical cities.

In order to improve building energy efficiency and sustainability, building energy consumption simulation tools are used to design, debug, analyze parameters, and optimize simulations of one or more building energy systems. This study mainly uses TRNSYS software to simulate and calculate building energy consumption.

4.1 Basic information of typical building terminal simulation models

There are many types and scopes of typical building models, which involve a lot of information. This article presents and explains the architectural forms, energy consumption characteristics, main setting information, and building model simulation of five types of public and residential buildings, including office buildings, shopping malls, hotels, hospitals, and schools. Basic information of typical energy consulting builds can be found in Table 1.

Table 1. Basic information of typical energy consuming buildings.

Typical energy-efficient office buildings	Floor space	36，640m^2
	Functional zoning	Office, interior area
	Energy consumption characteristics	Continuous use on weekdays from 8:00 to 18:00, with concentrated personnel and high peak cooling load
	HVAC system forms under different climate zone conditions	Severe cold areas: air conditioning systems - fan coil units with fresh air Heating System - Radiator Cold regions: air conditioning systems - fan coil units with fresh air Heating System - Radiator Hot summer and cold winter areas: air conditioning systems - fan coil units with fresh air Heating system - fan coil unit with fresh air Hot summer and warm winter areas: air conditioning systems - fan coil units with fresh air Heating system - None
	notes	Zoned dual duct fan coil system
Typical energy consuming hotel buildings	Floor space	38，200m^2
	Functional zoning	Guestrooms, restaurants, conferences, banquets
	Energy consumption characteristics	Operating 24 hours a day, open year-round, with high personnel fluctuations and varying peaks of internal and external disturbances
	HVAC system forms under different climate zone conditions	Severe cold areas: air conditioning systems - fan coil units with fresh air/full air Heating System - Radiator Cold regions: air conditioning systems - fan coil units with fresh air/full air Heating System - Radiator Hot summer and cold winter areas: air conditioning systems - fan coil units with fresh air/full air Heating system - fan coil unit with fresh air/full air Hot summer and warm winter areas: air conditioning system - fan coil unit with fresh air/full air Heating system - fan coil unit with fresh air/full air
	notes	A five-star hotel with 1-3 floors of podium for large-scale conference and catering functions
	Floor space	30，286m^2

Typical Energy Emporium Buildings	Functional zoning	Shopping malls, restaurants, cinemas
	Energy consumption characteristics	Long operation time, high personnel density, high heat dissipation, large fresh air volume, and high cooling and heating load
	HVAC system forms under different climate zone conditions	Severe cold and cold regions: air conditioning systems - all air Heating System - Radiator Hot summer and cold winter areas: air conditioning system - all air Heating System - All Air Hot summer and warm winter areas: air conditioning system - all air Heating system - None
	notes	Including first floor dining and first floor cinema
Typical energy-efficient hospital buildings	Floor space	52，162m^2
	Functional zoning	Outpatient, surgical, testing, ICU
	Energy consumption characteristics	Long usage time, high personnel density, and no holidays. High requirements for indoor air purification and high load of fresh air for air conditioning. Large medical equipment.
	HVAC system forms under different climate zone conditions	Severe cold and cold regions: air conditioning systems - fan coil units with fresh air/full air Heating System - Radiator Hot summer and cold winter areas: air conditioning systems - fan coil units with fresh air/full air Heating system - fan coil unit with fresh air/full air Hot summer and warm winter areas: air conditioning system - fan coil unit with fresh air/full air Heating system - fan coil unit with fresh air/full air
	notes	Comprehensive Medical Technology Building of Third Class Hospital
Typical Energy School Buildings	Floor space	52，162m^2
	Functional zoning	Classrooms, multimedia classrooms, teacher offices
	Energy consumption characteristics	Not used on weekends, during winter and summer vacations, with a long daily usage period
	HVAC system forms under different climate zone conditions	Severe cold and cold regions: Air conditioning system - None Heating System - Radiator Cold regions: air conditioning systems - unit air conditioning units Heating System - Radiator Hot summer and cold winter areas: air conditioning systems - unit air conditioning units Heating System - Unit Air Conditioner (Heat Pump) Hot summer and warm winter areas: air conditioning systems - unit air conditioning units Heating system - None
	notes	High school and secondary university teaching buildings
Typical energy consuming residential buildings	Floor space	12，145m^2
	Functional zoning	residence
	Energy consumption characteristics	The heating energy consumption in the northern region is relatively high, while the air conditioning energy consumption in the southern region is relatively high. Other energy consumption is less affected by the climate, mainly influenced by the living habits of users.
	HVAC system forms under different climate zone conditions	Severe cold areas: Air conditioning system - None Heating System - Radiator Cold regions: air conditioning systems - unit air conditioning units Heating System - Radiator Hot summer and cold winter areas: air conditioning systems - unit air conditioning units Heating System - Unit Air Conditioner Hot summer and warm winter areas: air conditioning systems - unit air conditioning units Heating system - None

4.2 Simulation modeling parameter settings

The establishment of a typical energy consuming building terminal simulation model involves various model parameters such as enclosure structure, internal settings, electromechanical systems, etc. The building shape, size, orientation, internal space division, and usage functions must comply with the actual building situation and be representative. On the basis of a large amount of data collection and organization work, this article compares the forms and characteristics of various types of typical energy consuming building terminals, references relevant literature and standard specifications, and determines the various parameters required for modeling.

1) Enclosure structure

The project has determined the typical urban building model enclosure structure information required for the project according to relevant domestic standards and regulations. The basic information of typical building models is shown in Table 2, and some reference standards are shown in Table 3.

Table 2. Information contained in typical building models.

General Information	Building Information	Enclosure structure	Equipment
Position	Number of floors	Exterior wall	Lighting
Total building area	Aspect ratio	Roof	HVAC system form
Socket load	Window to wall ratio	Ground	Cooling equipment
Ventilation requirements	Window position	External window	Equipment efficiency
Personnel density	Sunshade	Inner wall	Control strategy
Indoor temperature and humidity conditions	Floor height	Permeation	
Run Policy	Orientation		

Table 3. Reference standards.

Parameter	Setting basis
Indoor design parameters	Code for design of heating, ventilation, and air conditioning in civil buildings [5]
Indoor lighting, personnel, equipment parameters	Energy efficiency design standard for public buildings [6] Specification for technical requirements for architectural design of subway stations in rail transit Unified standard for industrial building design Energy efficiency standards for buildings in various regions

Due to the vast territory of our country, the climate varies greatly among different regions. The northern region mainly considers the winter cold insulation of buildings, usually using an external wall insulation system[7]. By referring to the relevant design standards for energy efficiency in residential and public buildings in various regions and comparing them in simulation software, the enclosure structure practices of different types of buildings in different cities are obtained. The heat transfer coefficient of the exterior window of the building model is obtained by using the WINDOW6 software component DOE-2 format window parameter database and using Trnsys calculation software for energy consumption simulation calculation.

2) Indoor and outdoor calculation parameters of buildings.

The hourly meteorological data for each city in the simulation of building energy consumption in this study are EPW and TMY data, mainly sourced from data provided by the US Department of Energy[8]. The design temperature for building heating is usually set at 16 ℃~22 ℃, and the relative humidity is controlled within the range of 15%~55%. The design temperature range for air conditioning cooling is 22 ℃~28 ℃, and the relative humidity is between 40%~70%. The maximum allowable indoor wind speed is generally about 0.3m/s. Refer to the ‘Code for Design of Heating, Ventilation, and Air Conditioning in Civil Buildings’ (GB50736-2012). The energy consumption simulation model of the fresh air system is established in accordance with the provisions of the national standards ‘Energy Efficiency Design Standards for Public Buildings’ (GB50189-2015) and ‘Design Code for Heating, Ventilation, and Air Conditioning in Civil Buildings’ (GB50736-2012) for the minimum designed fresh air volume. The indoor personnel density and operating schedule of buildings vary greatly among different types of buildings. According to relevant standards, the per capita occupied area and usage time characteristics of different types and levels of buildings are determined.

3) Building energy system parameters

In this study, office buildings and hotel buildings used fan coil units with fresh air systems, shopping mall buildings used all air systems, hospital buildings used fan coil units with fresh air systems and all air systems, and schools and residential buildings used unit air conditioning.

The lighting system is mainly affected by outdoor illumination and user usage. This study sets up the lighting system in the model building according to the ‘Building Lighting Design Standards’[9].

The power equipment in buildings mainly includes elevators, domestic water supply pumps, and other equipment. The configuration of the number of elevators is based on the ‘Residential Design Code’[10], ‘Office Building Design Code’, and relevant literature on elevator electrical equipment, to determine the number of elevators and elevator power.

5 Research on Multidimensional Characteristics of Seasonal Migration Simulation Model Based on Uncertainty Analysis

This study first uses dynamic simulation calculations and a logistic regression machine learning method based on single factor sensitivity analysis to investigate the impact of single factor changes on the multivariate load changes of various types of energy terminal buildings, including the number of tourists received throughout the year, the total number of urban passenger transport, the annual output of the sugar industry, and the total output of grain. Secondly, the Monte Carlo simulation method is used to predict the characteristics of uncertain factors, and the sensitivity probability distribution of each influencing characteristic factor to the influence of multiple loads is obtained. Subsequently, in order to avoid the limitations of the single factor sensitivity analysis method and comprehensively consider the coupling effect of various influencing characteristic factors on the target relationship, the Monte Carlo simulation method is used to obtain the sensitivity weight ratio of the uncertain characteristics prediction results of each influencing characteristic factor to the building load. This completes the quantitative analysis of seasonal migration influencing characteristic factors and is used to correct the multiple loads of various energy consuming building terminals in typical cross-border low-carbon energy consumption scenarios. It has played a good guiding role in the formulation of regional system planning and achieved significant results[11].

5.1 Sensitivity analysis of seasonal migration influencing feature factors based on dynamic simulation and logistic regression learning algorithm

This article takes the hotel building as an example to study the multi-dimensional characteristics of seasonal migration simulation models. The seasonal migration characteristics of other types of energy use terminal buildings are obtained similarly. Conduct dynamic simulation calculations of building multiple loads when the number of tourists received throughout the year, the total number of urban passenger transport, the annual output of the sugar industry, and the total output of grain are subject to single factor changes. Introduce a machine learning algorithm called logistic regression to analyze the sensitivity of feature factor classification based on the single factor impact results.

This paragraph discusses the impact of the number of tourists received throughout the year on hotel buildings in typical cross-border low-carbon energy consumption scenarios. Assuming that other application conditions remain unchanged and the number of tourists received throughout the year varies within the range of 0% -200% of the initial value of 20 million, complete the simulation calculation of building cold, hot, and electrical multiple load under 100 sets of random independent variables. This article uses logistic regression method to conduct data mining on the relevant characteristics of feature influencing factors and complete feature classification analysis of single factor influence.

After analyzing the impact of the number of tourists received throughout the year on the load of hotel buildings in typical cross-border low-carbon energy consumption scenarios, the main impact distribution is shown in the following figure.

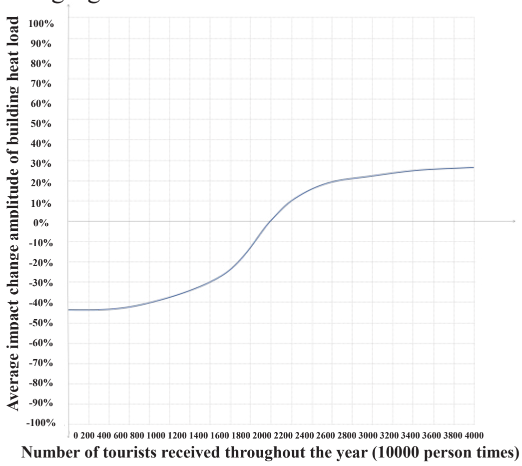

Fig. 1. Sensitivity Analysis of the Average Variation of Building Heat Load under Different Annual Visitor Reception Conditions.

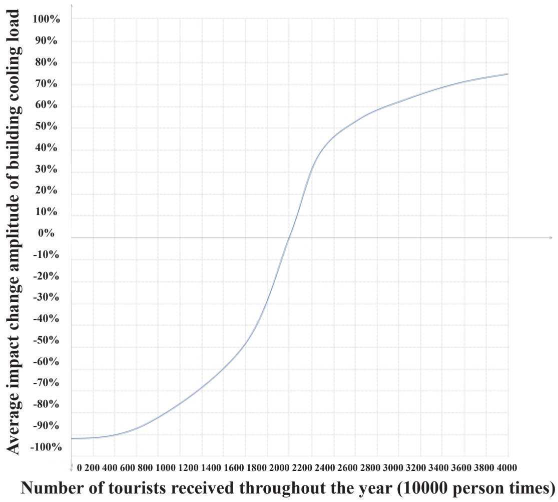

Fig. 2. Sensitivity Analysis of the Average Variation of Building Cooling Load under Different Annual Visitor Reception Conditions.

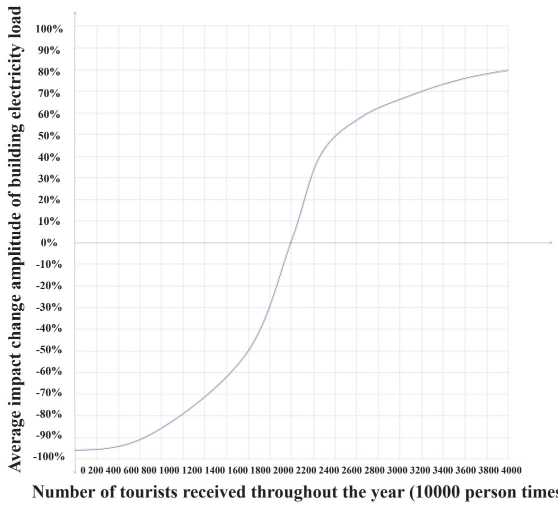

Fig. 3. Sensitivity Analysis of the Average Variation of Building Electricity Load under Different Annual Visitor Reception Conditions.

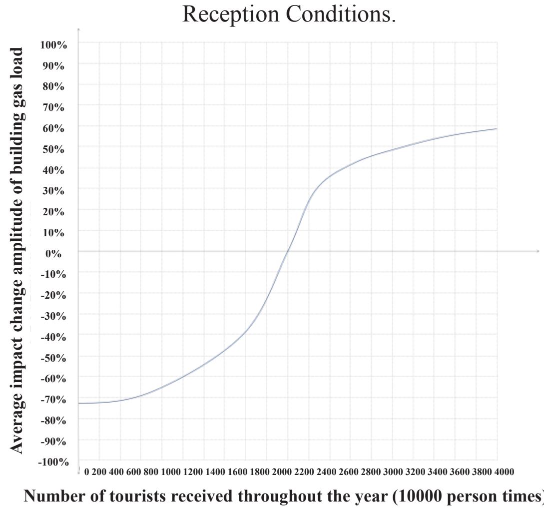

Fig. 4. Sensitivity Analysis of the Average Variation of Building Gas Load under Different Annual Visitor Reception Conditions.

The calculation results of the average range of changes in the cold, hot, and electrical loads of hotel buildings under different conditions of receiving tourists throughout the year are shown in Figures 1-4. The number of tourists has a significant impact on the cooling load, electrical load, and gas load of the hotel, while the impact on the hotel's heating load is not significant.

Simulate sugar production, total grain production, and urban passenger traffic using the same method to obtain sensitivity analysis of various influencing factors on the load changes of hotel buildings in typical cross-border low-carbon energy consumption scenarios. The impact of total passenger volume conditions in different cities on the cold and hot electrical load of hotels is similar to the impact on the number of tourists received throughout the year. The changes in annual production and total grain production of different sugar industries have no significant impact on the cooling load, electrical load, and gas load of hotels, and do not directly affect the heating load and gas load of hotels.

5.2 Comprehensive impact analysis of cross-border load characteristics based on Monte Carlo uncertainty prediction

This article takes hotel buildings in typical cross-border low-carbon energy consumption scenarios as an example, and uses Monte Carlo simulation as an uncertainty prediction method to obtain the sensitivity probability distribution of various influencing factors on the impact of multiple loads, focusing on the characteristics of the number of tourists received throughout the year, the total number of urban passenger transport, the annual output of the sugar industry, and the total output of grain. Using Monte Carlo simulation method to obtain the sensitivity weights of various influencing characteristic factors on building load, quantitative analysis of seasonal migration influencing characteristic factors is completed, and used to correct the multiple loads of various energy consuming building terminals in typical cross-border low-carbon energy consumption scenarios.

Monte Carlo sensitivity probability distribution prediction of the influence of characteristic factors on multivariate loads. Monte Carlo simulation is an uncertainty prediction method that simultaneously processes multiple variables. The simulation steps are shown in the flowchart. For this project problem, the algorithm process is divided into two layers: the inner layer solves the optimization capacity allocation problem of a multi energy system, obtains the comprehensive evaluation objective of the system's capacity allocation, and brings the results into the evaluation index model to calculate the values of each evaluation index of the system; Perform Monte Carlo simulation on the outer layer to obtain the probability distribution of the target variable values.

1) Sensitivity probability distribution of characteristic factors affecting thermal load

Based on the simulation results of the influence of various characteristic factors on building load in the previous text, using Monte Carlo method, the impact of the number of tourists received throughout the year on the magnitude of heat load variation is shown in Table 4.

Table 4. Characteristics of the impact of the number of tourists received throughout the year on the changes in building heat load.

	Minimum impact amplitude	Average impact amplitude	Maximum impact amplitude
Number of tourists received throughout the year	2.17%	22.33%	42.51%

Based on the sensitivity analysis of the impact of building heat load changes on the number of tourists received throughout the year, the Monte Carlo method was introduced to obtain the probability distribution of the impact sensitivity. The results showed a normal distribution, with an average sensitivity of 22.33%. Probability distribution of the impact of the number of tours received through the year on building heat load changes is shown in Fig. 5.

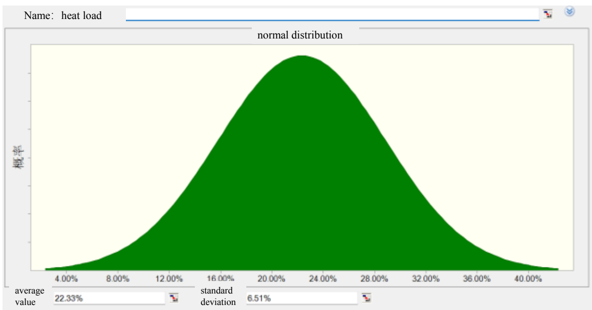

Fig. 5. Probability distribution of the impact of the number of tourists received throughout the year on building heat load changes.

Using the same method, the impact of various factors such as the annual production of the sugar industry, the total number of urban passenger trips, and the total grain production on the magnitude of heat load changes can be obtained. Similarly, the impact characteristics of these four types of seasonal characteristics on the amplitude of changes in cooling load, electrical load, and gas load can be obtained through Monte Carlo method, as shown in the table 5.

Table 5. Characteristics of the impact of changes in building heating, cooling, electricity, and gas loads on the results.

		Minimum impact amplitude	Average impact amplitude	Maximum impact amplitude
Sensitivity probability distribution of characteristic factors affecting heat load	Number of tourists received throughout the year	2.17%	22.33%	42.51%
	Annual production of sugar industry	2.11%	5.26%	13.24%
	Total number of urban passenger trips	2.48%	13.74%	29.82%

	total grain output	0.18%	3.69%	7.26%
Sensitivity probability distribution of characteristic factors affecting cooling load	Number of tourists received throughout the year	9.88%	41.25%	91.97%
	Annual production of sugar industry	0.28%	13.57%	27.59%
	Total number of urban passenger trips	3.45%	32.82%	63.77%
	total grain output	0.31%	8.07%	16.83%
Sensitivity probability distribution of characteristic factors affecting electrical load	Number of tourists received throughout the year	9.92%	43.97%	97.31%
	Annual production of sugar industry	1.13%	16.72%	35.08%
	Total number of urban passenger trips	0.08%	36.11%	72.99%
	total grain output	0.29%	9.43%	18.74%
Sensitivity probability distribution of characteristic factors affecting gas load	Number of tourists received throughout the year	4.39%	33.09%	71.63%
	Annual production of sugar industry	1.17%	2.61%	6.41%
	Total number of urban passenger trips	0.27%	21.35%	43.24%
	total grain output	0.16%	4.27%	8.75%

In this study, four types of seasonal migration characteristics influencing factors, including the number of tourists received throughout the year, the annual output of the sugar industry, the total number of urban passenger transport, and the total output of grain, were studied. Based on sensitivity analysis results, historical data inference method was used to determine the probability distribution of various uncertain parameters in the multi energy system, and an objective function relationship composed of the amplitude of changes in influencing characteristic factors and sensitivity constants was constructed. By utilizing the sensitivity of various influencing factors to load changes, the impact changes of these factors are corrected to reflect the seasonal migration characteristics of typical cross-border low-carbon energy consumption scenarios in the multi factor load simulation model.

Y (Correction relationship for seasonal migration characteristics of load)=Magnitude of load impact on the number of tourists received throughout the year × Sensitivity of the impact of the number of tourists received throughout the year+magnitude of the impact of the annual output change load on the sugar industry × Sensitivity of the annual production impact of the sugar industry+magnitude of the load impact of changes in the total number of urban passenger trips × Sensitivity of the total number of urban passenger trips and the magnitude of the impact of changes in total grain production load × Sensitivity to the impact of total grain production

This study conducted 2000 simple random sampling of random variables to generate random numbers for the objective function of seasonal heat load migration characteristics. From the sampling results of the normal distribution parameters in the figure below, it can be seen that the histogram of the random parameter sampling results is close to the probability density function curve of the parameters, so the sampling frequency is sufficient and the sampling results conform to the distribution characteristics of the parameters is shown in Fig. 6.

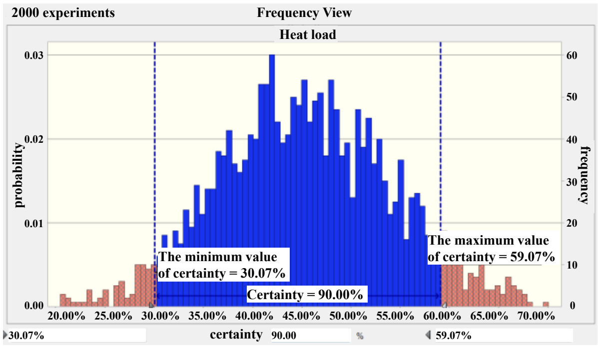

Fig. 6. The overall situation of the normal distribution of the correction relationship function for the seasonal migration characteristics of heat load.

Calculate the probability distribution of the target variable value. The relationship between the distribution of the objective function and the number of simulations is studied, and the results are shown in the figure. From the graph, it can be seen that when the number of simulations reaches 2000, the target variable values converge reliably, indicating good convergence of the algorithm.

Therefore, the sensitivity of the load impact on the number of tourists received throughout the year, the total number of urban passenger transport, the annual production of the sugar industry, and the total grain production is 56.50%, 33.60%, 7.60%, and 2.30%, respectively.

In summary, Y (correction relationship for seasonal migration characteristics of heat load)=magnitude of the impact of heat load on the number of tourists received throughout the year × 56.50%+Heat load impact amplitude of annual production changes in the sugar industry × 33.60%+The magnitude of heat load impact caused by changes in the total number of urban passenger trips × 7.60%+magnitude of heat load impact from changes in total grain production × 2.30%

Using the same method, the correction relationship for seasonal migration characteristics of cooling load can be obtained: Y (correction relationship for seasonal migration characteristics of cooling load)=the magnitude of the impact of cooling load on the number of tourists received throughout the year × 65.30%+The impact of cooling load on the annual production change of the sugar industry × 23.30%+The impact of changes in the total number of urban passenger trips on cooling load × 7.00%+magnitude of impact of changes in total grain production on cooling load × 4.40%

Y (Correction relationship for seasonal migration characteristics of electricity load)=Magnitude of impact of electricity load on the number of tourists received throughout the year × 62.50%+The impact of electricity load on the annual output change of the sugar industry × 28.70%+The magnitude of the impact of changes in the total number of urban passenger trips on electricity load × 6.60%+magnitude of electricity load impact from changes in total grain production × 2.20%

Y (Correction relationship for seasonal migration characteristics of gas load)=Magnitude of impact of gas load on the number of tourists received throughout the year × 72.70%+Annual production changes in the sugar industry, gas load impact amplitude × 25.00%+The impact of changes in the total number of urban passenger trips on gas load × 2.00%+Impact amplitude of gas load on total grain production changes × 0.30%

Based on the method proposed in this study, the sensitivity weights of multiple load seasonal migration characteristics for office, residential, school, hospital, shopping mall, transportation, and industrial building models were studied based on the correction relationship of seasonal migration characteristics for various types of energy consuming building terminal models. The sensitivity weights for the seasonal migration characteristics of multiple loads of various energy consuming building terminals under typical low-carbon energy consumption scenarios in cross-border regions are summarized as Table 6.

Table 6. Sensitivity Weights of Multivariate Load Seasonal Migration Characteristics for Various Typical Energy Use Building Terminal Simulation Models.

		Number of tourists received throughout the year	total number of urban passenger transport	total annual production of sugar industry	total grain production
Office building	Sensitivity weight of heat load impact	17.30%	15.20%	31.80%	35.70%
	Sensitivity weight of cooling load impact	26.40%	18.20%	37.50%	17.90%
	Sensitivity weight of electrical load impact	24.10%	17.50%	35.80%	22.60%
	Sensitivity weight of gas load impact	25.10%	26.30%	22.80%	25.80%
Residential buildings	Sensitivity weight of heat load impact	16.90%	37.20%	19.60%	26.30%
	Sensitivity weight of cooling load impact	17.30%	45.70%	17.50%	19.50%
	Sensitivity weight of electrical load impact	18.50%	44.90%	16.70%	19.90%
	Sensitivity weight of gas load impact	21.40%	41.20%	16.60%	20.80%
School buildings	Sensitivity weight of heat load impact	24.10%	28.60%	23.40%	23.90%
	Sensitivity weight of cooling load impact	34.30%	27.60%	18.30%	19.80%
	Sensitivity weight of electrical load impact	35.20%	26.20%	14.80%	23.80%
	Sensitivity weight of gas load impact	23.80%	25.70%	22.30%	28.20%
Hospital buildings	Sensitivity weight of heat load impact	37.30%	33.50%	21.50%	7.70%
	Sensitivity weight of cooling load impact	42.40%	35.70%	14.10%	7.80%
	Sensitivity weight of electrical load impact	41.80%	36.90%	12.10%	9.20%
	Sensitivity weight of gas load impact	21.70%	24.20%	25.60%	28.50%
Commercial building	Sensitivity weight of heat load impact	47.80%	31.40%	16.50%	4.30%
	Sensitivity weight of cooling load impact	54.10%	23.80%	9.70%	12.40%
	Sensitivity weight of electrical load impact	53.70%	21.50%	14.80%	10.00%
	Sensitivity weight of gas load impact	49.70%	31.50%	8.40%	10.40%
Transportation building	Sensitivity weight of heat load impact	41.60%	42.40%	3.70%	12.30%
	Sensitivity weight of cooling load impact	41.90%	55.70%	1.10%	1.30%
	Sensitivity weight of electrical load impact	42.70%	56.90%	0.08%	0.32%
	Sensitivity weight of gas load impact	31.90%	32.70%	19.40%	16.00%
Industry building	Sensitivity weight of heat load impact	5.10%	6.20%	54.80%	33.90%
	Sensitivity weight of cooling load impact	2.20%	3.70%	72.30%	21.80%

	Sensitivity weight of electrical load impact	1.80%	3.50%	71.50%	23.20%
	Sensitivity weight of gas load impact	3.60%	7.10%	69.80%	19.50%
Hotel building	Sensitivity weight of heat load impact	56.50%	33.60%	7.60%	2.30%
	Sensitivity weight of cooling load impact	65.30%	23.30%	7.00%	4.40%
	Sensitivity weight of electrical load impact	62.50%	28.70%	6.60%	2.20%
	Sensitivity weight of gas load impact	72.70%	25.00%	2.00%	0.30%

In summary, this section completed a single factor sensitivity analysis using dynamic simulation methods combined with logistic regression algorithms. The Monte Carlo simulation uncertainty prediction method was used to obtain the sensitivity weights of each influencing characteristic factor on the impact of multiple loads. The sensitivity weights of typical cross-border low-carbon energy consumption scenarios under the influence of seasonal migration characteristics were corrected for the energy terminal building load model.

5.3 Verification of accuracy of energy consumption calculation results

This article is based on the seasonal migration and multiple load characteristics of typical low-carbon energy consumption scenarios in the southwestern cross-border region. The simulation model of energy consumption building terminals is studied, and the energy consumption simulation results of typical energy consumption building terminal models are compared with statistical energy consumption data. Based on actual cases, a database is applied for load forecasting to verify the accuracy of the model.

Verify the overall accuracy of the building model based on the total energy consumption of the building, and use statistical data of actual operating energy consumption as a reference for comparison. Compare the actual energy consumption statistical information obtained through research with the average of simulated energy consumption calculation results for different types of buildings. The Statistical Table of Building Energy Consumption is shown in Table 7. The comparison results are shown in Fig 7.

Table 7. Statistical Table of Building Energy Consumption [kWh/(m^2. a)].

	Office	hotel	shopping mall	school	hospital	residence
Average energy consumption statistics	89.15	98.73	149.5	60.19	217.51	42.54
Average energy consumption statistics	80	134	200	41	230	43

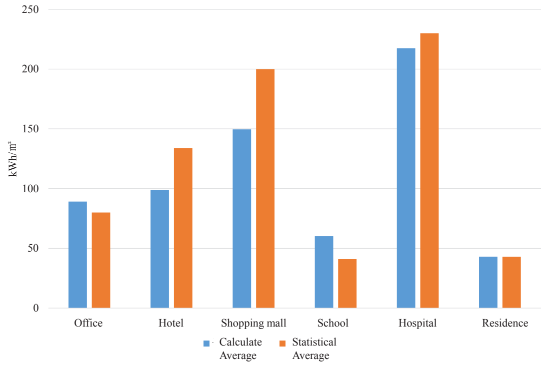

Fig. 7. Comparison between the calculated average energy consumption of buildings except for heating and the actual statistical average of buildings [kW. h/(m^2. a)].

The composition of building electricity consumption is relatively complex. Compare the average simulated energy consumption results of various types of buildings with the actual statistical average of building energy consumption. It can be seen that the average value of energy consumption simulation calculation results is basically at the same level as the actual average value of building energy consumption statistics, with an average difference of less than 10%. The accuracy of the calculation results is more reasonable than 90%. Therefore, it can be considered that the energy consumption simulation calculation model can better reflect the actual energy consumption characteristics of buildings.

The composition of total building energy consumption is relatively complex. The accuracy of the overall building energy consumption calculation results was verified earlier. The calculation results of each sub item building energy consumption were compared with the actual building energy consumption statistics by building type to obtain the accuracy verification of sub item energy consumption. Taking hotel construction as an example.

The proportion of sub item electricity consumption to total electricity consumption in hotel buildings is shown in the following Fig 8.

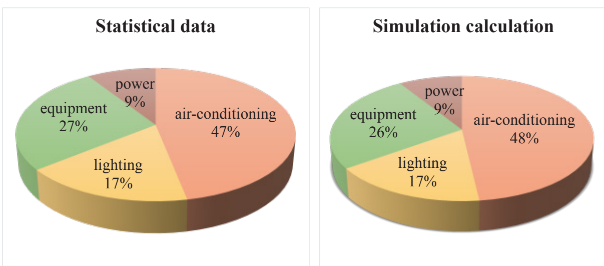

Fig. 8. Comparison of sub item energy consumption ratios in typical hotel buildings.

According to the energy consumption ratio chart, it can be seen that the HVAC energy consumption of hotel buildings accounts for about half of the overall building electricity consumption. The comparison between the sub item energy consumption ratio of hotel buildings and the statistical values of the sub item energy consumption ratio of hotel buildings is shown in the following figure. The simulation results are basically within the accuracy range of 91% compared to the actual values, and the simulation results are relatively reliable. The comparison results are shown in Fig 9.

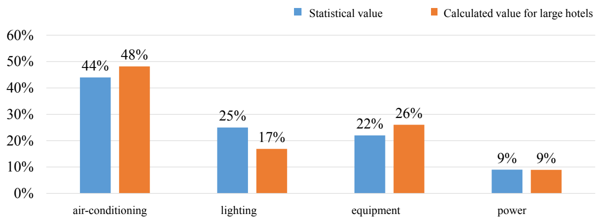

Fig. 9. Comparison between simulated and actual values of sub item energy consumption ratio in typical hotel buildings.

6 Conclusions

This article addresses issues such as unclear energy demand for border and cross-border regions, limited research on the characteristics of cold and hot electrical multiple load data, and missing simulation modeling of typical energy loads in border and cross-border regions. Based on the seasonal migration characteristics of border and cross-border regions, we conducted research on characteristic industries, constructed a key indicator system for typical low-carbon energy consumption scenarios in border and cross-border regions, and conducted research on modeling methods for multi industry and multi energy loads under significant seasonal migration characteristics of border and cross-border loads. At the same time, dynamic simulation, sensitivity analysis, and Monte Carlo methods are combined to analyze the influencing factors of seasonal migration characteristics in typical low-carbon energy consumption scenarios in border and cross-border areas using dynamic simulation and Rocky regression machine learning algorithms. Complete the weight determination of the influencing factors of seasonal and migratory load changes in border and cross-border regions, and use the dynamic characteristics of load migration to perform feature correction and fusion on typical dynamic load simulation data, ensuring the accuracy of typical dynamic load simulation data. Finally, based on the seasonal migration characteristics of border and cross-border energy consumption, the simulation data of typical low-carbon energy consumption scenarios using building terminals were compared with actual operating energy consumption data, and the accuracy of the modeling method was verified to be higher than 90%.

The main innovation points of this article are as follows:

1) This article innovatively introduces the Monte Carlo uncertainty prediction method into the study of seasonal migration load changes in border and cross-border regions, concretizing abstract problems and breaking through the limitations of existing research.

2) The method for modeling the load of typical energy consuming buildings in this study covers six representative types of buildings, including office buildings, hotel buildings, shopping malls, hospital buildings, residential buildings, and schools. It can be replicated and promoted in future research on cross-border regional energy systems.

3) The accuracy of the simulation data of typical low-carbon energy consumption scenarios using building terminals is higher than 90%, and this method is highly reliable.

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