The Energy Saving Renovation of Regional Buildings Based on Bayesian Estimation

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Abstract. With China's new urbanization vision and existing urban renewal and building energy efficiency improvement project, large-scale energy conservation renovation of regional buildings has become an important content of ecological environmental protection and low-carbon and an important means to improve the regional energy efficiency level. Of energy-saving reform foundation database is presented in this paper, including construction, power consumption, equipment, operation, technology and willingness to word stock, statistics obtained the regional energy complex parameter (envelope thermal performance, elevator equipment, power and efficiency of cooling and heat sources, etc.) statistical rule and can use the benchmark, build the regional buildings energy consumption prediction model based on bayesian estimation, The probability matrix of large-scale reconstruction of regional buildings is obtained. At the same time, the global sensitive parameter analysis method and the single parameter regression model of energy saving transformation factor are established, and it is found that the internal load factor has the most significant effect on energy consumption. By adjusting energy parameters, the probability distribution curve of energy saving and the distribution of normalized value under the constraint conditions of different reconstruction scenarios were simulated, and the discrete MC simulation method was used to predict the regional overall energy saving reconstruction based on renovation intention, which could realize the trade-off judgment and gradual optimization of the strategy package of energy saving measures combination.

Keywords: Regional architectural complex; Bayesian estimation; Energy consumption prediction model; Monte Carlo simulation; Energy parameters; Probability distribution curve.

1. Introduction

At present, China is in a period of rapid urbanization. In some megalopolises that have achieved urbanization first, the investment in large-scale new expansion has been gradually slowed down, and the focus has begun to shift to urban upgrading and renewal. There are three characteristics: Adaptive integration of environment, energy and resources and transformation of urban renewal model; Second, ecological energy saving and low-carbon will become a key yardstick to measure the success or failure of future urbanization goals, and regional large-scale building upgrading will be an important direction of future urban renewal and transformation. Some cities began to study the overall transformation plan of central urban areas, especially for the stock public buildings in central urban areas with the characteristics of "three high and one low" (high energy consumption, high intensity, high potential and low energy efficiency). According to the international energy agency's report, the building energy consumption has reached a third of the total energy consumption, so building energy conservation has become the key to the world energy saving and low carbon development, in order to achieve global carbon dioxide emissions targets, the implementation of the total energy consumption and intensity of dual index control strategies, building energy conservation management in our country pay attention to the promotion of building energy efficiency from the application of technical measures, Gradually change to building energy consumption and unit consumption index control. The Chinese government requires large-scale energy conservation renovation of existing buildings and projects to improve the energy efficiency of regional public buildings. In order to achieve the goal of energy conservation and emission reduction in the 14th Five-Year Plan, energy conservation renovation of existing public buildings will remain the focus of building energy conservation work[1].

2. The analysis method of large-scale energy conservation renovation of regional building complexes

2.1. The definition of energy conservation renovation for regional buildings

China has both construction energy conservation transformation has been more than 20 years, from scientific research to the engineering practice, the single section from building to building new can system integration optimization of technological transformation to the building, from improving the efficiency of the use of non renewable energy development and utilization of energy, in both the construction energy conservation transformation in our country has accumulated rich experience. The research object of this article area buildings, positioning between blocks and the urban area of regional city within the scope of both piece of buildings, it is by the large stock of buildings, a variety of forms, a variety of architectural styles of complex mixture of building groups, building number could reach hundreds or thousands of scale. Area buildings with different cold and heat source, a variety of energy system, diversification of terminal energy-using equipment, among these different groups of buildings energy demand characteristics and heterogeneous architecture with the multivariate function properties, under different operating conditions, the use of different can use for model, to achieve the balance between energy demand and energy.

2.2. Typical building energy balance principle

The building thermal balance generally includes exterior thermal balance of envelope, interior thermal balance and air thermal balance. The heat balance of the exterior surface establishes the energy exchange mechanism between the building and the outdoor environment through the heat conduction of the temperature difference between inside and outside of the non-transparent envelope, and the heat conduction and radiation mode of the temperature difference between the transparent envelope. External heat exchange forms include solar radiation, outdoor air convection and so on. Internal surface heat balance through indoor air convection, radiation form, complete outdoor and indoor environment heat exchange. Indoor including indoor heat source radiation, envelope heat conduction. Air thermal balance refers to the cold and hot air generated by air conditioning or heating equipment sent into the building through the air system. After sufficient heat exchange with the indoor return air, fresh air and permeable air, it reaches a stable heat balance. The establishment of typical building energy model generally includes heat balance equation of exterior wall, heat conduction equation of exterior wall, heat balance equation of interior wall and heat balance equation of indoor air. Dedicated building energy consumption simulation software has established the complex thermal transient simulation software energy consumption model of single building, considering the unsteady heat transfer of the wall and the dynamic thermal characteristics of the wall, the description of the main building physical model is accurate enough to approximate the dynamic heat balance process of the actual building. The building is regarded as a boundary, and heat exchange is carried out through heat conduction, convective heat transfer, radiation and indoor environment of the building. The steady-state equation of heat balance of a typical building is established, and the energy flow of a typical building is shown in Figure 1. Matter indoor heat load on the human body heat, lighting, electrical equipment, such as heat dissipation, external heat load with solar radiation, palisade structure heat load and fresh air load, while maintaining stability under the condition of indoor environment, the cold cold heat source supply shall be equal to the total heat load of the building, thus can get building heat and heat dissipation of heat balance equation[2].

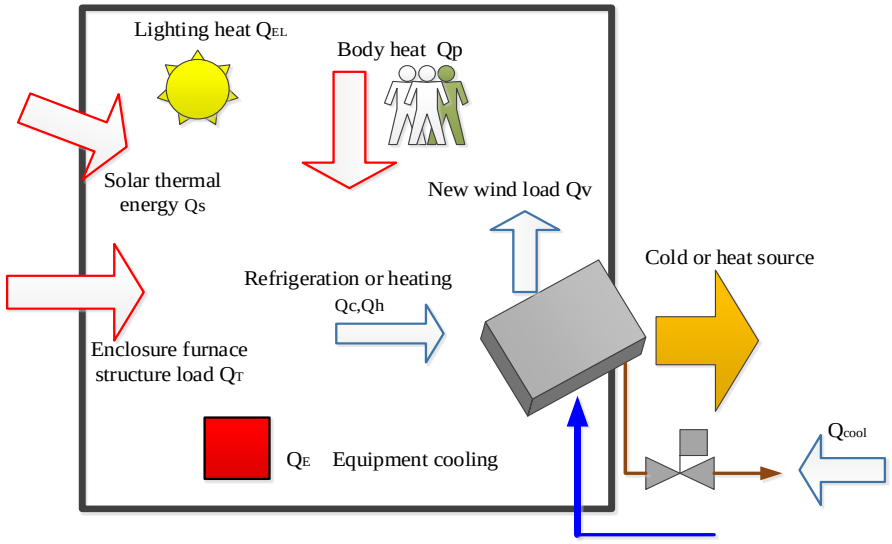


Fig. 1 Typical building energy flow diagram

The steady-state calculation of heat gain or heat dissipation of a typical building at a certain time is shown in Equations (1), (2), (3) and (4). Heat transfer by the envelope (QT):

$$Q_{T,t} = U \times (\theta_{out} - \theta_{in,set}) \times t \tag{1}$$

Where, U is heat transfer coefficient of envelope($W/m^2 \cdot K$), $\theta_{out}, \theta_{in,set}$ is building outdoor and indoor design temperature (℃)

Heat transfer from fresh air system(Q_V):

$$Q_{V,t} = L_{fr} \times (h_{out} - h_{in,j}) \times t \tag{2}$$

In type, L_{fr} represents fresh air flow rate(kg/s), $h_{out}, h_{in,j}$Denotes outdoor air enthalpy and indoor air enthalpy of buildings(kj/kg),So the sun radiates heat(Q_s):

$$Q_{S,t} = G_{so} \times S_{win} \times \alpha_{sol} \times \alpha_{sh} \times t \tag{3}$$

Among them, $G_{so}$is solar radiation intensity(W/m^2), S_{win} is Outer and outer window area of enclosure furnace structure(m^2), α_{sh} is Exterior window shielding coefficient; α_{sol} is Sunshine heat gain factor.Therefore, the heat gained inside the building is expressed as Q(Q_I):

$$Q_{I,t} = (\alpha_{oc} q_{oc} IFA_{oc} + \alpha_{ap} q_{ap} IFA_{ap} + \alpha_{li} q_{li} IFA_{li}) \times t \tag{4}$$

Q_I represents the sum of heat dissipated from the building's internal heat sources(W),Including lighting, electrical appliances and personnel cooling; $\alpha_{li}$is lighting heat dissipation coefficient, q_{li} is power density of lighting installation(W/m^2); α_{oc} is indoor personnel heat dissipation coefficient, q_{oc} is Outdoor personnel density(people$/m^2$); α_{ap} is heat dissipation coefficient of electrical equipment.

According to the principle of building energy balance, the equations of building cooling capacity and heat demand can be calculated respectively. Building cooling and heat demand is expressed in Formula (5) :

$$Q_T = Q_{T,t} + Q_{V,t} + Q_{S,t} + Q_{I,t} \tag{5}$$

2.3. Validation of stochastic model for regional large-scale energy prediction

The accuracy of the calibration standard model can be evaluated according to the historical energy consumption observation data of the modeled buildings. This criterion can evaluate the reliability of the benchmark model, but it cannot prove that the calibrated model can reliably predict the effect of regional energy saving transformation. Because the regional building energy stochastic model

approximates the mathematical representation of the regional building physical system, it may reduce the confidence of the prediction. The monthly data is enough to verify the accuracy of the model. The calibration is judged by the deviation (MBR) and the coefficient of variance of mean square deviation (CV) (RMSE). CV(RSME) reflects the degree of coincidence between the simulated value and the observed value. The more accurate the prediction, the better the model verification[3].

$$MBR_{month} = \frac{(EN_M - EN_s)_{month}}{EN_M} \times 100\%$$

$$RSME_{month} = \sqrt{\frac{\sum_{month}(EN_M - EN_s)^2_{month}}{N_{month}}}$$

$$CV_{(RSME_{month})} = \frac{RSME_{month}}{(\frac{\sum M_{month}}{N_{month}})}$$

In the formula, EN_M is Actual monthly power consumption(J); EN_s is Simulate monthly power consumption(J);N is number of months per year.

Matlab model input parameters of the sampling results, such as analog computation, 2000 times by predicting regional complex observations of actual energy consumption data to check the accuracy of the stochastic model, stochastic model for calibration, set up the region's benchmark model of energy consumption, checking of the observed and predicted, confidence interval evaluation model accuracy and output results. Through 2000 times of model simulation, the average predicted annual total energy consumption of regional buildings is 2.246×1015J, and the standard deviation is 9.455×1013J. The actual energy consumption investigated is 2.295×1015J. The error between actual annual total energy consumption and simulated energy consumption is 2.14%, and the CV($RSME_{month}$) index is 6%. The model can be used to simulate the total and sub-energy consumption of regional buildings and predict the regional energy saving potential.The prediction frequency distribution of annual total energy consumption of regional buildings is shown in fig. 2.

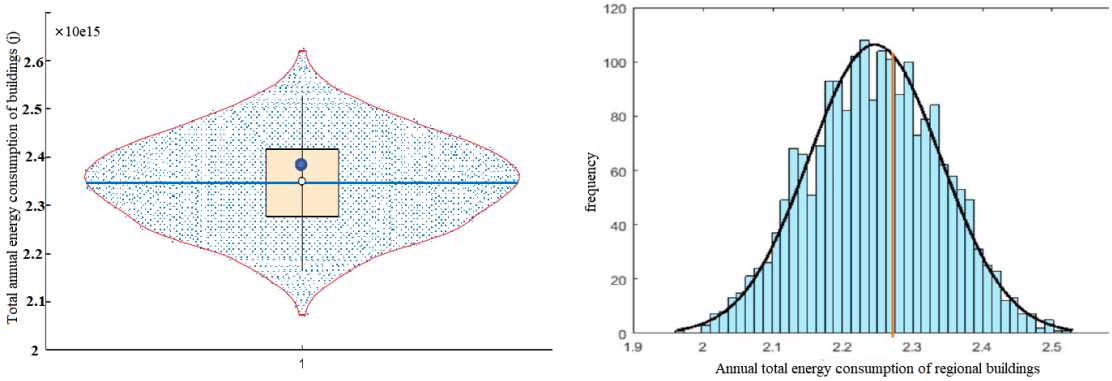


Fig. 2 Frequency distribution of total energy consumption forecast for regional buildings

3. Energy consumption prediction and reconstruction of regional buildings based on Bayesian estimation

3.1. Bayesian energy dissipation correction model under given conditions

There are some uncertain parameters in the stochastic model of energy consumption prediction of regional building complexes. Since it is difficult to obtain the real values, the conclusions obtained from statistical rules or analysis of these parameters are regarded as prior information, and the regional building energy consumption is established on the premise of these prior information. In such a scenario, the posterior probability distribution of energy parameters is obtained by adjusting the energy parameters in the stochastic model of regional energy consumption based on the observable regional building energy consumption value and bayesian theory. Bayesian estimation

solves the problems such as the uncertainty of energy parameters, the deviation between theoretical model and building prototype and the transmission of observation error, and estimates the model error[4].

Formula (6) expresses the relationship between the energy model output value of a single building and the actual energy consumption of the building:

$$y(x) = \eta(x, \theta) + \delta(x) + \epsilon(x) \tag{6}$$

The bayesian energy correction model can be established by referring to formula (7) for energy saving reconstruction of regional architectural complexes. There are three types of uncertainty :(1) uncertainty of parameters in building energy consumption model; (2) the difference between the physical model and the building prototype and the real behavior of the building; (3) For the error of observation itself, the posterior distribution of uncertain parameters is obtained by multiplying the likelihood function and all prior density functions according to Bayes' theorem.

$$P\ y/\theta = \frac{1}{(2\pi\delta_E^2)^{Nd/2}} exp\left\{-\frac{\sum_{j=1}^{N_D}[y(x_j)-\eta(x_j,\theta)]^2}{2\delta_E^2}\right\} \tag{7}$$

A gaussian process model with mean function and covariance function is established to obtain the posterior distribution. Gaussian process is a random process in probability theory, which is a series of exponential combinations of random variables subject to normal distribution. In the posterior simulation, the prediction ability of high energy model is improved by updating the prior distribution of hyperparameters and parameters at the same time.

3.2. Energy saving reconstruction prediction and verification of building group sample information

In order to verify the accuracy of energy saving transformation prediction of random model and the consistency of potential data of energy saving transformation in database. In the research area, the energy consumption data of qiao dong buildings which have completed energy conservation renovation are evaluated. These 15 buildings are hotel buildings and business buildings, and the building area accounts for 24% of the whole area. By observing these building samples, the distribution of building energy conservation rate obtained after taking comprehensive energy conservation measures package. To demonstrate the accuracy of the prediction output of the model on a large regional scale. Since the overall operating conditions and environment of these reconstructed building samples did not change much in the study area, monthly energy bill method was used to compare the output results with the prediction model,and the fixed information input parameters of the 15 reconstructed buildings are shown in table 1.

Table. 1 Fixed information input parameters table of 15 retrofit building

Building Inf	energy consumption(Ori)	Energy consumption (After Mod)	Construction area	The height	h0	Ka	a	(k+1)/k	h0/a	h0/h
Hotel.1	8.55E+13	6.94E+13	113980	59	3	97	20	1.21	0.15	0.02
Hotel.2	6.30E+13	5.23E+13	68200	29	3	118	20	1.17	0.15	0.03
Hotel.3	4.88E+13	4.29E+13	56300	27	3	301	60	1.20	0.15	0.04
Hotel.4	3.82E+13	2.96E+13	44897	14	3	158	20	1.13	0.15	0.07
Hotel.5	1.30E+13	1.03E+13	20100	25	3	40	20	1.50	0.15	0.04
Hotel.6	1.02E+13	7.96E+12	23600	20	3	52	20	1.39	0.15	0.05
Business floor. 1	3.85E+13	3.13E+13	103544	32	3	81	40	1.50	0.08	0.03
Business floor.2	2.91E+13	2.66E+13	55410	42	3	66	20	1.30	0.15	0.02
Business floor.3	2.03E+13	1.46E+13	31806	24	3	66	20	1.30	0.15	0.04
Business floor.4	1.92E+13	1.54E+13	53990	34	3	79	20	1.25	0.15	0.03
Business floor.5	1.35E+13	1.10E+13	29860	25	3	54	20	1.37	0.15	0.04
Business floor.6	9.93E+12	6.94E+12	23680	27	3	44	20	1.46	0.15	0.04
Business floor.7	9.24E+12	7.49E+12	30840	30	3	51	20	1.39	0.15	0.03
Business floor.8	9.22E+12	5.12E+12	17600	21	3	42	20	1.48	0.15	0.05
Business floor.9	9.58E+13	8.09E+13	284650	32	3	400	300	1.75	0.01	0.03

Based on bayesian theory, a regional building complex energy correction model was established, and the posterior distribution of parameters to be estimated was obtained by using Hamilton Markov chain Monte Carlo algorithm based on observable energy consumption data of building complex. Taking commercial buildings of the same type in a regional building group as the research object, the energy saving effect of qiao building which has been implemented in the regional building

group was compared. The total energy consumption of the observed 15 building samples before the transformation was 505 TJ, accounting for 22% of the total energy consumption of the regional building. A total of 93 energy-saving measures were taken to reduce energy consumption by 90TJ, and the overall energy-saving rate of the observed sample buildings was 18%.

3.3. The validation and comparison between the output of the prediction model and the data before and after the actual transformation

According to the fixed building information in the sample database of 15 building complexes and parameter adjustment before and after energy-saving transformation, the prediction model simulation can obtain the distribution comparison of energy consumption before and after the transformation. By comparing the simulated value with the actual result, the following results can be obtained(Fig.3): Before the modification of the prediction model, the average simulated energy consumption value was 518TJ, while the observed actual energy consumption value was 505TJ, with a deviation of 2.6%, and the actual energy consumption value fell within the range of the simulated value. After adjusting and modifying energy parameters, the average annual total energy consumption simulated by the prediction model is 408TJ, while the observed value of actual energy consumption is 411TJ, with a deviation of -0.73%, and the actual energy consumption value falls within the range of the simulated value.The average energy saving before and after the transformation is 110TJ and the energy saving rate is 21.2%, while the actual observed energy saving is 94TJ and the observed energy saving rate is 18.6%. The deviation between the two is 14.3%, and the deviation of the energy saving rate is greater than the deviation of the total energy consumption[5].

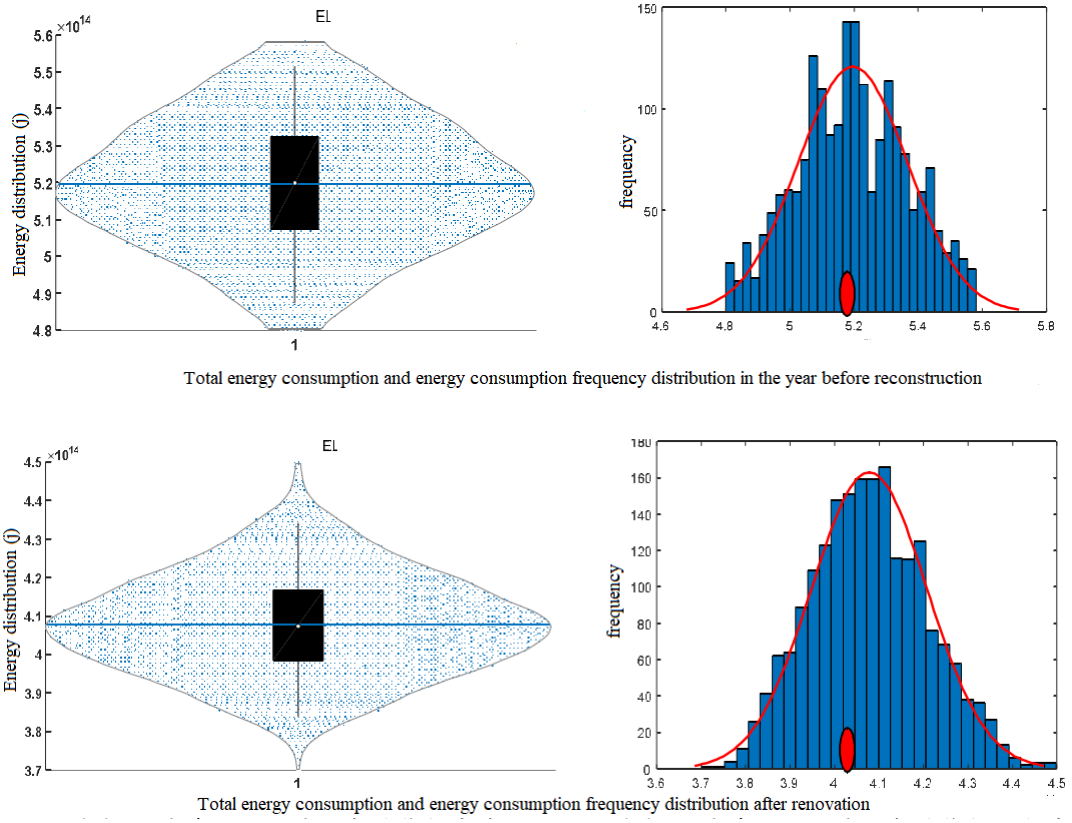


Fig. 3 Comparison of the simulated and observed energy consumption before and after building retrofit-The red dot represents the observed value

4. Conclusion

In this paper, the influence factors and the distribution rule of energy consumption parameters are analyzed by means of investigation, simulation and verification. At the same time, with the help of

the idea of reverse modeling, a stochastic model of energy conservation renovation prediction based on data mining is built, and a Bayesian prediction model of regional building complex energy conservation renovation is proposed. Monte Carlo technology is used to simulate random variables in the model, and the prediction model is verified by the actual observation of energy consumption data. The model solves the complex obstacles of regional building complex modeling and has high precision prediction, thus laying a theoretical foundation for the prediction of regional building complex energy consumption. The uncertainty of the model and the posterior distribution of energy parameters are obtained, so as to scientifically predict the energy consumption and renovation potential analysis, and put forward the optimal implementation strategy and incentive policy, so as to achieve the control target of the total energy consumption, energy intensity and energy efficiency level of regional buildings.

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