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Research Article

Coordination and Coupling of Active and Passive Energy Optimization in Public Institutions: A Case Study of Hunnan District, Shenyang in China

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Taking Hunnan District of Shenyang City as an example, this paper investigates 32 government agencies, 17 tertiary first-class hospitals, and 15 colleges and universities in Hunnan region and analyzes the energy consumption characteristics of three types of public institutions. Through the use of DeST energy consumption software to simulate the energy consumption of three types of public institutions, combined with the load density method to predict the total energy demand of hospitals, universities, and government agencies in Hunnan area and the MARKAL model coupling mechanism, the coupling model of active and passive energy suitable for public institutions is presented. According to the forecast results of energy demand, combined with the energy consumption structure and energy conversion efficiency, the energy supply of each subitem of the public institution was solved and the energy supply of the public institutions in Hunnan District was optimized in accordance with the relevant constraints. Through calculation, it is found that by 2020, the passive energy supply of public institutions in Hunnan District will account for 19.79% and active energy sources such as coal and petroleum will still be the main type of energy used by public institutions. Based on the research on the active and passive energy coupling supply of public institutions in Hunnan District, the active and passive energy coupling model and algorithm of public institutions constructed can provide a reference basis for the active and passive energy coupling utilization of public institutions in China.

1. Introduction

At this stage, the energy consumption per unit area of public institutions in China is high and energy consumption is growing rapidly. During the "Twelfth Five-Year Plan for Public Institutions" in China, there were 670,600 public institutions in education, 446,200 public institutions in central and state institutions, and 281,400 public institutions in health [1]. China's "Thirteenth Five-Year Plan for Public Institutions" aims to use energy resource consumption in 2015 as a base. By 2020, per capita comprehensive energy consumption will decrease by 11% and energy consumption per unit of building area will decrease by 10%. The total energy consumption of public institutions is controlled within 2.25 million tons of standard coal [2]. With the development of the economy, the number of public institutions in China will continue to increase, the energy consumption demand of public institutions will continue to increase, and insufficient supply of energy resources will restrict the development of our economy.

Because this paper mainly uses Hunnan District of Shenyang City as an example to coordinate and optimize the supply of active and passive energy in public institutions, this paper first studies relevant optimization methods at home and abroad and then investigates the current status of public institution research. The main purpose of energy optimization is to obtain the best energy supply structure at a lower cost, while reducing constraints such as carbon emissions [3]. Lee et al. proposed a multiobjective genetic algorithm that can find the optimal solution under multiple targets, and the NSGA-II algorithm used has been authorized in multiple fields [4,5]. The algorithm has good performance and can quickly find a highly suitable solution [6]. Meyarivan et al. also developed a series of algorithms for

NSGA-II, which can solve the problems of cost, carbon emissions, and soil erosion in land management [7]. Song and Chen proposed an improved knowledge-informed nondominated sorting genetic algorithm II (NSGA-II) algorithm when rationally optimizing land allocation under multiobjective and multiconstraint conditions. When compared with the traditional NSGA-II algorithm, it is found that the improved algorithm can give a more effective and reasonable solution in land planning [8]. Among many optimization methods, Omidvar et al., inspired by nature, imitated the instinctual behavior of birds, designed a new optimization algorithm, and used the optimization algorithm to analyze the behavior of birds [9]. Yasrebi et al. designed a droplet optimization algorithm based on the phenomenon of rainfall. The algorithm is simple and convenient. Through the comparison and analysis with some of the latest optimization algorithms, it is found that the droplet optimization algorithm is better than some of the latest optimization algorithms [10]. Omidvar et al., based on the random behavior of natural phenomena and the behavior of chicks, constructed a See-See Partridge Chicks Optimization (SSPCO) algorithm and compared it with the latest optimization algorithm. It was found that the scheme given by this algorithm was better than the existing algorithms [11].

Aiming at the research status of public institutions, Seoul conducted research on 105 office buildings and found that the optimal energy consumption per unit area of office buildings is 31.41 square meters per person [12]. After researching the basic data of 4336 public building cases, a benchmark database was established to lay the foundation for energy conservation of public institutions [13]. The UK has also simulated the energy needs of higher education institutions in public institutions to study changing energy usage patterns in higher education institutions [14]. The energy consumption of public institutions in China is huge. Based on a survey of the energy consumption of 20 typical large public buildings, Zhu et al. put forward measures to control the energy consumption of large public buildings from both technical and management aspects [15].

2. Methods

China's energy conservation work is divided into six major categories: industrial energy conservation, building energy conservation, primary and tertiary industry energy conservation, transportation energy conservation, public institution energy conservation, and social energy conservation [16]. Regarding energy conservation in public institutions, the "Regulations on Energy Conservation in Public Institutions" divides public institutions into eight categories: education, central and state organs, health, social organizations, science and technology, other, cultural, and sports [17]. In order to facilitate the research of public institutions, this paper divides them into education, health, and government agencies according to the characteristics and quantity of energy consumption of public institutions. Aiming at the three types of public institutions, research was conducted on institutions of higher education, tertiary hospitals, and government agencies. Secondly, the basic data of passive energy in Hunnan District of Shenyang City and the energy application of typical public institutions were investigated. The BIGEMAP software was used to statistically analyze the number and area and location of the main top three hospitals, universities, and government agencies in Hunnan District. By comparing the advantages and disadvantages and applicability of various types of energy demand forecasting methods, the load density method and DeST energy consumption simulation were selected to predict the total energy demand of public institutions in Hunnan District [18]. Combined with the energy consumption structure of Hunnan District, various energy sources with comprehensive energy conversion efficiency, you can solve the subitem energy supply of public institutions in reverse and then calculate the proportion of passive energy supply in the total energy supply of public institutions, and based on the coupling mechanism of the MARKAL model, the active and passive energy coupling of the public institution model can be established. In the model structure, the demand side is government building, education building, and sanitation building, the supply side is coal, oil, natural gas, geothermal energy, solar energy, and other active and passive energy sources, and the energy flow direction is from demand side to supply side. According to the simulation results, the scenario assumption method is used to provide the optimal technical solution for the coupling of active and passive energy sources in public institutions in Hunnan District.

2.1. Selection of Energy Demand Forecasting Method. Energy demand forecasting methods mainly include load density method, per capita index method, elastic coefficient method, unit consumption method, mathematical model prediction, and other methods [19]. Since this topic is mainly aimed at public institutions in the planning area, the per capita indicator method cannot accurately describe the energy consumption characteristics of public institutions. The elastic coefficient method mainly reflects the statistical laws of energy consumption and national economic development. The unit consumption method is mainly for the industrial sector. Energy demand is preside [20].

The load density method can be used for public institutions, according to the historical energy consumption statistics of various types of land in the planning area, combined with the future development degree of various types of land use, predicting the corresponding energy consumption of various types of land during the planning period. This paper uses DeST to simulate the energy consumption of typical public institutions in the planning area, calculate its energy consumption requirements, and combine the load density method to predict the energy consumption requirements of public institutions in the planning area.

3. Hunnan District Public Institution Research

This paper firstly conducted a network survey on the topography, climatic characteristics, hydrological characteristics,

resources, and environment of Hunnan District in Shenyang and then used BIGEMAP software to calculate the number, size, and location of major hospitals, universities, and government agencies in Hunnan District, as shown in Figure 1.

In the survey, the hospitals do not include private hospitals, dental hospitals, community service stations, and medical and beauty hospitals, mainly only for hospitals above the third grade; government agencies mainly include government buildings, meteorological bureaus, customs, people's courts, and other government buildings, excluding township government agencies at all levels and police stations of various jurisdictions; the school classes are mainly colleges and universities and do not include junior high school and high school schools. Table 1 is a summary table of various public institutions in Shenyang, Hunnan District, mainly through network research to obtain relevant data.

4. Forecast of Total Energy Consumption Demand of Public Institutions in Hunnan District

Firstly, this paper selects the typical building types (hospitals, universities, and government agencies) in Hunnan District and sets the hourly meteorological parameters of Hunnan District, as shown in Figure 2.

Defining building performance by setting the usage schedule for the building according to different building types, set the boundary conditions such as enclosure structure and climate parameters to simulate the energy consumption of the building. If the actual characteristics of the building are met, the results will be aggregated and calculated and the corresponding energy consumption characteristics of the public institutions in the planning area will be obtained. The data in Table 2 is the enclosure structure parameters of the public institutions in Shenyang, Hunnan District, selected according to the Liaoning Provincial Local Standard "Public Building Energy Conservation (65%) Design Standard" [21].

In order to maintain a constant temperature and humidity in the hospital, the indoor equipment needs to be opened 24 hours a day. According to the student's work schedule, the indoor equipment should be closed with the departure of the indoor staff. The working schedule of the government equipment building indoor equipment should also be consistent with the routine of the indoor staff. Due to the different operating rules of the equipment of the three types of public institutions and the different characteristics of the indoor personnel, the energy consumption characteristics are different. DeST software can set the energy consumption characteristics of different public institutions and the operation law of indoor equipment and set the ratio of the energy consumption equipment of public institutions in the indoor. Table 3 shows the setting table of the stopping ratio of the energy-consuming equipment of public institutions in Hunnan District.

Table 4 shows the statistical results of the energy consumption per unit area of the DeST simulation units of the public institutions in Hunnan District, Shenyang City.

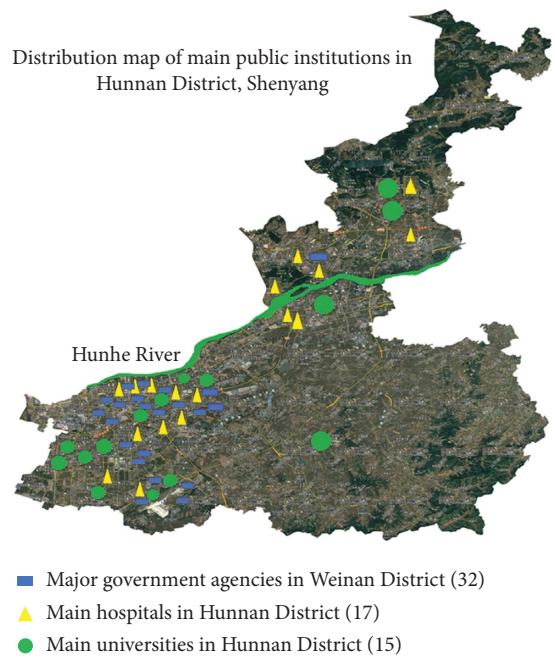

Figure 1: Location map of major public institutions in Hunnan District, Shenyang, in China.

Table 1: Summary of the construction area of public institutions in Hunnan District, Shenyang (unit: $\times 10^6$ m^2).

School class	Hospital class	Government agency	The total area
About 3.4	About 1.5	About 6.3	About 5.7

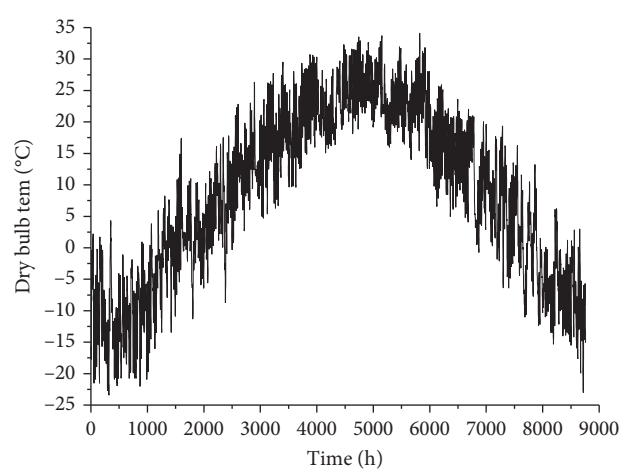

Figure 2: Temporary dry bulb temperature map of Hunnan District, Shenyang.

Table 2: Building envelope parameters for public institutions in Hunnan District (unit: W/m^2·K).

Building component	Exterior wall	Interior wall	Outside window	Door
Heat transfer coefficient	0.54	1.51	2.3	0.17

Table 3: Setting of work schedules for energy-consuming equipment in public institutions in Hunnan District.

Organization type	Time	Interior wall (%)	Outside window (%)	Door (thermal conductivity) (%)	Floor (thermal conductivity) (%)	Roof (%)
Hospital	Ratio	100	100	100	100	100
University		0	0	0	0	50
Government agency		0	100	30	100	50

Table 4: The energy consumption of Hunnan District public institution.

Mechanism	Hospital	University	Government agency
Energy consumption per unit area	53.7 kWh/m^2	108 kWh/m^2	42.8 kWh/m^2

During the simulation, the energy demand of various public institutions is mainly based on the hot and cold load demand in winter and summer, including the load change caused by indoor personnel heat dissipation, lighting heat dissipation, and heat dissipation of energy-consuming equipment, excluding the use of hot and cold water in public institutions. It can be seen from the simulation results that among the three types of public institutions, colleges, and universities have the largest energy consumption per unit area.

Table 5 shows the energy demand forecast results of various public institutions in Hunnan District, Shenyang City. The total energy consumption of hospital buildings is 3×10^7 kWh/year. The total energy consumption of college buildings is 6.2×107 kWh/year, and the total energy consumption of government office buildings is 1.8×10^6 kWh/year. From the simulation results, the total energy consumption of college buildings in Hunnan District is relatively large and the hospital is in the middle level. The government's energy demand is the least. The main reason is that college buildings are with high-density people, and the personnel distribution is relatively concentrated. Therefore, a large amount of energy is required to maintain indoor temperature and humidity, so energy consumption is the highest. The indoor staff of office buildings is mainly sitting quietly, and there is regular movement of staff, so energy consumption is the least.

The total energy demand forecast of public institutions in Hunnan District of Shenyang City is 9.4×10^7 kWh/year. Because the total energy consumption of public institutions is currently not counted and cannot be compared, this paper uses DeST to simulate the energy consumption per unit area multiplied by the total building area of a single public institution and compares it with the actual energy consumption of the public institution. The result is within a reasonable range. Therefore, this paper is credible for predicting the total energy demand of public institutions in Hunnan District.

5. Establishment of the Coupled Active and Passive Energy in Public Institutions

5.1. Objective. Based on 2010 as the base year and 5 years as the time span, simulate the optimal supply of passive energy in public institutions in the planning area from 2010 to 2030.

Table 5: Energy consumption demand forecast results of various public institutions in Hunnan District.

Building types	Total energy consumption	Various types of institutions	Total regional energy consumption
Hospital	8.5×10^6 kWh/a	1.4×10^6 m^2	30×10^6 kWh/a
University	8.6×10^6 kWh/a	3.4×10^6 m^2	62.1×10^6 kWh/a
Government agencies	7.3×10^6 kWh/a	356×10^6 m^2	1.8×10^6 kWh/a

5.2. Model. Through the comparison and learning of various energy coupling models, this paper uses the MARKAL model as the basis model to optimize the coupling of the main and passive energy supply of public institutions. The MARKAL model is a dynamic linear programming model that determines the energy supply structure that minimizes energy system costs while meeting a given energy demand and pollutant emission limits [22], which is essentially provided by exogenous The useful energy needs to determine the optimal energy supply to meet this demand [23]. The MARKAL model is mainly composed of five modules: energy carrier, energy conversion technology, terminal energy carrier, terminal utilization technology, and demand equipment [22]. This paper only considers the active and passive energy supply of public institutions, and the construction model is shown in Figure 3.

5.3. Objective Function. The establishment of the active and passive energy coupling model of public institutions in this paper mainly refers to the research of Chen and Wu [24], Yin and Chen [25], and He [26]; that is, the minimization of energy system cost in the planning area is used as the optimization objective function [24–26]:

$$Z = \min \sum_i C_i X_i, \quad i = 2, 3. \tag{1}$$

C_i in formula (1) is a known energy flow cost coefficient matrix from the energy supply side to the terminal demand side. X_i represents the energy flow vector from the primary energy supply to the terminal energy demand, which is the explanatory variable we need to optimize. In order to simplify the calculation, this paper simplifies the energy flow from the supply side to the demand side of the energy source, considering only the beginning and the end of the energy supply to the terminal demand, and the intermediate conversion link is replaced by the estimated comprehensive efficiency coefficient. In the formula, $i = 2$, 3 indicates the flow direction of energy; 2 is the demand side of the energy

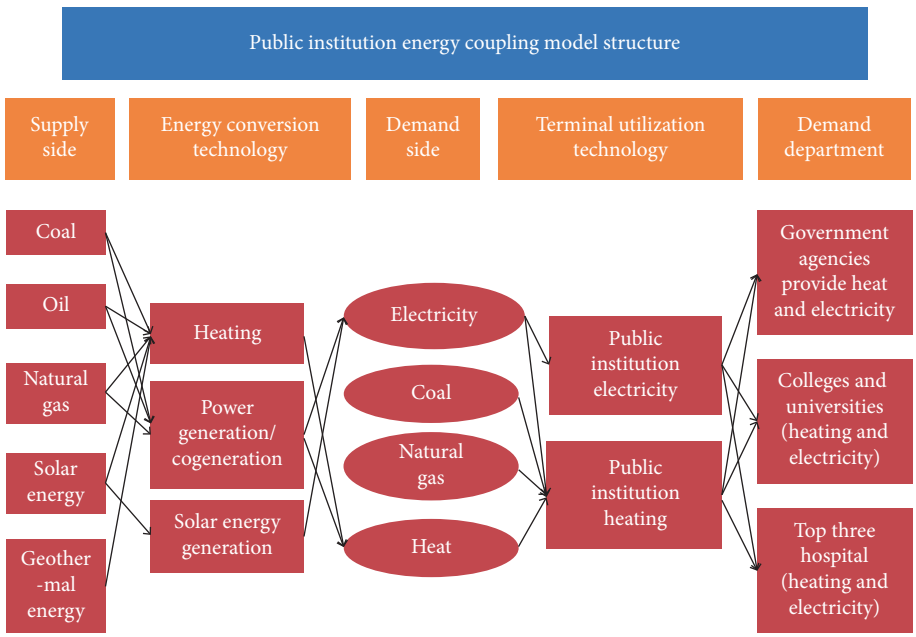

Figure 3: Structure diagram of the main and passive energy coupling model of public institutions.

consumption terminal of the public institution and 3 is the primary energy supply side.

5.4. Constraint Equation

(1) The supply of primary energy cannot exceed the stock of resources, that is, the equilibrium equation of total energy supply:

$$X_3 \leq \mathrm{SUP}. \tag{2}$$

(2) The energy carrier balance equation indicates that the energy consumption of each link cannot exceed the energy conversion of the previous link from the supply side to the demand side:

$$X_{i-1} \leq E_i X_i, \quad i = 2, 3. \tag{3}$$

(3) Energy supply and demand balance equation indicates that the supply of terminal energy should be greater than the energy demand:

$$E_2 X_2 \geq D. \tag{4}$$

(4) The balance equation of production operation conditions, that is, the production capacity of energy should be less than the maximum capacity limit of production operation under the given technical conditions at the present stage:

$$E_i X_i \leq \mathrm{CAP}_i, \quad i = 2, 3. \tag{5}$$

(5) Carbon emission constraint equation indicates that the sum of carbon emissions in each link is less than a certain limit:

$$\sum_i EM_i X_i \leq EM, \quad i = 2, 3. \tag{6}$$

In the above constraint equations, SUP represents the resource vector, expressed as the total energy output of the planning period reference year (standard coal), E_i is the integrated energy conversion efficiency matrix, D is the public institution terminal energy demand vector, and CAP is the production technology capability limit. The vector EM_i is the pollutant discharge of each link, and EM is the pollutant discharge limit during the entire optimization period.

5.5. Input Parameters of the Model Equation. The input parameters of the model equation include the unit comprehensive cost from the supply side to the demand side energy flow, the total energy output of the base year in the southern part of the country, the comprehensive energy conversion efficiency from the supply side to the demand side, and the public institutions in Hunnan District. The input parameters of the model equation also include the predicted terminal energy demand of public institutions in the Hunnan District, the maximum capacity limit of energy production and operation under a given technical condition, and the carbon emission limit of each link of energy flow.

Table 6 shows the unit's comprehensive cost from the supply side to the demand side energy flow. The data is obtained by the author in the form of network research.

Table 7 shows the total energy output of the base year. According to the literatures, including "Shenyang Statistical Yearbook 2010" and Liaoning Energy Consumption Structure [27], the total production value of Hunnan District is 154.917 million yuan (excluding the industrial output value). China has a calorific value of 7,000 kcal per kilogram of standard coal, and the price of provisional standard coal is

Table 6: Unit cost of each link from supply side to demand side energy flow.

Coal yuan/ton	Oil USD/barrel	Natural gas yuan/m^3	Geothermal energy yuan/m^2	Solar energy yuan/kWh
400	60	4	100	6.5

Table 7: Total energy output of base year (unit: ×106 yuan/ton of standard coal).

Coal	Oil	Natural gas	Geothermal energy	Solar energy	Total
26.3	7.4	1.7	1.9	1.4	38.7

set at 400 yuan/ton. The total production value of Hunnan District is 38,874,875 tons of standard coal. Combined with the energy output ratio of Liaoning Province in 2010, the subenergy composition of Hunnan District was estimated.

The energy demand forecast of public institutions in Table 10 is based on the prediction of DeST and load density method, combined with the population forecast during the planning period of Hunnan District, the assumption of the urbanization rate, and the assumption of the GDP growth rate in Hunnan District, and the comprehensive factors such as the proportion of industrial structure are derived. According to the national standard "General Rules for the Calculation of Energy Consumption" (GBT2589-2008), the conversion factor: 10000 kWh = 1.229 tons of standard coal.

The maximum capacity limit for energy production operations is based on the total installed capacity of Liaoning Province and the proportion of installed energy capacity announced by the Liaoning Provincial People's Government Network. The author estimates the maximum capacity limit of energy production in Hunnan District by weighting and averaging the population and GDP of Hunnan District in the total population and total GDP of Liaoning Province. The carbon emission data of all aspects of energy flow are derived from the "People's Republic of China Petrochemical Industry Standards" (SH/T5000-2011). The total pollutant discharge limit data during the optimization period is derived from the "2016 Hunnan District Key Pollution Source Sewage Discharge Information List" from the Hunnan District Government Network. The total pollutant discharge limit data during the optimization period is derived from the "2016 Hunnan District Key Pollution Source Sewage Discharge Information List" from the Hunan District Government Network.

6. Results and Analysis

Through model optimization simulation, we can visually see the ratio of active and passive energy in public institutions, and by changing the limits of constraints, we can get different optimization results. Table 11 shows the simulation optimization results obtained in the case of the carbon emission constraints in Hunnan District.

According to the simulation results, under the optimal total cost of public institutions in Hunnan District, by 2020, the total supply of passive energy such as solar energy and geothermal energy will be 1.85 × 105 tons of standard coal, accounting for 19.79% of the total energy supply of public institutions .By 2030, the active and passive energy supply of public institutions in Hunnan District will be 12.61 × 105 tons of standard coal, of which the total supply of passive energy will be 2.88 × 105 tons of standard coal, accounting for 22.81% of the total energy supply of public institutions. Nonrenewable energy sources such as coal, oil, and natural gas are still the main energy sources for public institutions. Their annual growth rates are 12.1%, 19.1%, and 27.6%, respectively. The fastest annual growth rate is mainly due to increased carbon emission constraints. At the optimum total cost, natural gas has the lowest carbon emissions. The development of geothermal energy and solar energy in passive energy sources is relatively fast, with the average annual growth rate of 29.05% and 43.69%, respectively. However, since this optimization simulation does not consider renewable energy such as wind energy and biomass energy, which results in a small base in total energy supply, the impact on the total energy supply of public institutions in Hunnan District is small.

Table 8: Integrated energy conversion efficiency from supply side to demand side.

Coal	Oil	Natural gas	Geothermal energy	Solar energy
30%~40%	23%~34%	50%~55%	5%~20%	11%~19%

Note: The data in Table 8 is partly taken from "Analysis of the Ways to Promote China's Energy Production Revolution" [28] (International Gas Network), "Development and Utilization of Clean Energy Geothermal Energy" [29], and the rest is obtained through network research.

Table 9: Hypothesis of population and urbanization rate in Hunnan District, Shenyang.

Year	The total population of the district	Urbanization rate (%)
2010	304700	50
2015	512600	73
2020	573400	85
2025	652200	90
2030	741300	98

Note: Table 9 data is taken from Shenyang Statistical Yearbook. Through the assumption of population growth in Hunnan District, the assumption of urbanization rate and the future trends of the first, second, and third industrial structures in Hunnan and the terminal energy demand of public institutions during the optimization period can be predicted.

Table 10: Public institution terminal energy demand forecast (unit: ×10^4 tons of standard coal).

Years	2020	2025	2030
Total amount	10.7	12.6	14.1

7. Discussions

This study has a role in guiding and demonstrating the active and passive energy coupling of public institutions in various regions of the country. The active and passive energy

Table 11: Energy supply optimization results of public institutions in Hunnan District, Shenyang (unit: $\times 10^5$ tons of standard coal).

Year	Coal	Oil	Natural gas	Geothermal energy	Solar energy	Total	Passive energy ratio (%)
2010	2.67	1.59	0.88	0.67	0.24	6.06	15.12
2015	2.98	1.90	1.17	0.93	0.37	7.34	17.71
2020	3.50	2.44	1.57	1.29	0.56	9.37	19.79
2025	3.83	2.77	1.91	1.52	0.79	10.82	21.34
2030	4.21	3.20	2.32	1.85	1.03	12.61	22.81

coupling model of public institutions constructed and various data results calculated and analyzed can provide the active and passive energy coupling of public institutions in other regions of China Reference. The coupling of active and passive energy supply in public institutions is mainly based on the building energy demand side and energy resource supply side, and no specific research is carried out on the energy conversion links from the resource supply side to the energy demand side. For example, this paper only considers the comprehensive energy conversion efficiency from the energy supply side to the end energy demand, does not make specific research on the energy conversion efficiency of specific links, and only considers the impact of carbon emissions in the constraints. The related parameters of the coupling model are obtained based on DeST energy simulation and related statistical yearbooks, and some data are obtained through online surveys.

Through the simulation of active and passive energy coupling of public institutions in Hunnan District, the passive energy utilization of public institutions in Hunnan District from 2020 to 2030 was predicted. This method can also be used to calculate the active and passive energy utilization of public institutions in various climatic subregions across the country, to forecast and analyze the future in combination with constraints such as population and GDP to give the optimal macroallocation scheme of active and passive energy coupling for public institutions and to provide technical ideas for energy conservation in public institutions in China.

8. Conclusions

Taking the Hunnan District of Shenyang City as an example, this paper studies the active and passive energy coupling of public institutions and builds a model of active and passive energy coupling of public institutions. Using the load density method and DeST energy consumption software, a method suitable for the energy demand forecast of public institutions is given. Combined with the energy consumption structure and energy conversion efficiency, the total energy supply of public institutions was obtained from the demand side. The total energy supply of Hunnan District public institutions in 2020 is predicted to be 9.37×10^5 tons of standard coal, and the total energy supply of 2030 will be 12.61×10^5 tons of standard coal. Passive energy accounted for 19.79% and 22.81% of the total energy supply of public institutions, respectively. Compared with 2015, passive energy supply increased by 0.55×10^5 and 1.58×10^5 tons of standard coal, respectively. Active energy sources such as coal and petroleum are still the main types of energy used by public institutions, mainly due to the energy consumption structure of public institutions.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] State Organs Affairs Administration, *National Development and Reform Commission (2011) "Twelfth Five-Year Plan" for Energy Conservation in Public Institutions*, State Organs Affairs Administration, Beijing, China, 2011.

[2] State Organs Affairs Administration, *National Development and Reform Commission (2016) "13th Five-Year Plan" for Energy Conservation of Public Institutions*, State Organs Affairs Administration, Beijing, China, 2016.

[3] Y. Chen, H. Tan, J. Wu, and X. Song, "Resilient regional energy benchmarking of classified public buildings," *Energy Procedia*, vol. 142, pp. 2365–2370, 2017.

[4] Y. Lee, T. J. Choi, and C. W. Ahn, "Multi-objective evolutionary approach to select security solutions," *CAAI Transactions on Intelligence Technology*, vol. 2, no. 2, pp. 64–67, 2017.

[5] Y. Lee, J. Jung, and C. W. Ahn, "Design of selecting security solution using multi-objective genetic algorithm," *Bio-inspired Computing—Theories and Applications*, vol. 48, pp. 512–517, 2016.

[6] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," *IEEE Transactions on Evolutionary Computation*, vol. 6, no. 2, pp. 182–197, 2002.

[7] D. K. Meyarivan, C. M. Deb, F. G. Fonseca, F. G. Lobo, P. A. Condado, and J. Seixas, "Multi-objective evolutionary algorithm for land-use management problem," *International Journal of Computational Intelligence Research*, vol. 3, no. 4, pp. 371–384, 2007.

[8] M. Song and D. Chen, "An improved knowledge-informed NSGA-II for multi-objective land allocation (MOLA)," *Geospatial Information Science*, vol. 21, no. 4, pp. 273–287, 2018.

[9] M. N. Omidvar, S. Nejatian, H. Parvin, V. Rezaie, and M. Yasrebi, "A nature-inspired algorithm based on classical-conditioning theory," *Tabriz Journal of Electrical Engineering*, vol. 49, no. 2, pp. 487–501, 2019.

[10] M. Yasrebi, A. E. Baghban, H. Parvin, and M. Mohammadpour, "Optimisation inspiring from behaviour of raining in nature: droplet optimisation algorithm," *International Journal of Bio-Inspired Computation*, vol. 12, no. 3, p. 152, 2018.

[11] M. N. Omidvar, S. Nejatian, H. Parvin, and V. Rezaie, "A new natural-inspired continuous optimization approach," *Journal of Intelligent & Fuzzy Systems*, vol. 35, no. 3, pp. 3267–3283, 2018.

[12] H. Kang, M. Lee, T. Hong, and J.-K. Choi, "Determining the optimal occupancy density for reducing the energy consumption of public office buildings: a statistical approach," *Building and Environment*, vol. 127, pp. 173–186, 2018.

[13] D. W. Choi, Y. M. Kim, and S. E. Lee, "Development of an energy benchmarking database based on cost-effective energy performance indicators: case study on public buildings in South Korea," *Energy and Buildings*, vol. 191, pp. 104–116, 2019.

[14] W. Zia, R. Sarah, and S. Jan, "Modelling energy demand from higher education institutions: a case study of the UK," *Applied Energy*, vol. 233-234, pp. 816–826, 2019.

[15] J. Zhu and D. Li, "Current situation of energy consumption and energy saving analysis of large public building," *Procedia Engineering*, vol. 121, pp. 1208–1214, 2015.

[16] P. Xiao, "The basic characteristics of energy saving in public institutions in China," *Ningbo Energy Conservation*, vol. 4, pp. 35-36, 2012.

[17] State Council Office of State Affairs, *Regulations on Energy Conservation in Public Institutions*, State Council Office of State Affairs, Beijing, China, 2008.

[18] C. Tian and G. H. Feng, "Study on regional energy planning mode in severe cold and cold regions-taking liaobin coastal economic zone as an example," Thesis, Shenyang Jianzhu University, Shenyang, China, 2014.

[19] Q. Zhao, Q. Bai, B. Liu et al., "Application of MARKAL model in Beijing middle and long term energy development research," *China Energy*, vol. 6, pp. 37–41, 2004.

[20] X. Zhao, Q. Lin, and H. Yu, "An improved mathematical model for green lock scheduling problem of the three gorges dam," *Sustainability*, vol. 11, no. 9, p. 2640, 2019.

[21] DB21/T1477-2006, *Design Standards for Energy Efficiency of Public Buildings*, Liaoning Provincial Construction Department, Liaoning Provincial Quality and Technical Supervision Bureau, Shenyang, China, 2006.

[22] X. R. Ji, Y. F. Jiang, and Y. S. Zheng, *Introduction to MARKAL Energy Supply Model and User Guide*, Tsinghua University Press, Beijing, China, 1988.

[23] W. Y. Chen and Z. X. Wu, "Using MARKAL model to study China's future sustainable energy development strategy," *Journal of Tsinghua University. Science and Technology*, vol. 12, pp. 103–106, 2001.

[24] W. Y. Chen and Z. X. Wu, "Countermeasures for SO_2 and CO_2 emission control in China in the future," *Journal of Tsinghua University. Science and Technology*, vol. 10, pp. 1320–1323, 2002.

[25] X. Yin and W. Y. Chen, "Comparison of carbon emission scenarios based on China TIMES model," *Journal of Tsinghua University. Science and Technology*, vol. 53, no. 9, pp. 1315–1321, 2013.

[26] X. B. He, "Prediction of shanxi renewable energy development under Subsidy Policy and emission limit-scenario analysis based on MARKAL model," *Journal of Jinan University. Philosophy and Social Sciences*, vol. 35, no. 12, pp. 1–8, 2013.

[27] H. Tian, W. X. Kang, and J. N. He, "Analysis of energy consumption structure in liaoning Province," *Journal of Central South University of Forestry and Technology*, vol. 31, no. 5, pp. 105–110, 2011.

[28] Z. Y. Li and G. S. Huang, "Analysis of the Ways to Promote China's energy production revolution," *Chemical Industry and Engineering Progress*, vol. 34, no. 10, pp. 3521–3529, 2015.

[29] X. X. Wang, "Development and utilization of low temperature geothermal energy," *Low Temperature Building Technology*, vol. 5, pp. 130-131, 2006.