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Constructing the Comprehensive Benefit Evaluation Model of Micro-Energy Network in Residential Building

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Abstract: *Micro-energy network is a kind of regional network for intelligent energy synthesis. At present, there is a lack of rich theoretical studies for an in-depth evaluation of its comprehensive benefits. Based on the existing evaluation methods, this paper explores the comprehensive benefits of micro-energy networks in residential buildings, and constructs a comprehensive benefit evaluation model for micro-energy networks in residential buildings based on the load characteristics of residential buildings in terms of economic benefits, energy saving benefits and emission reduction benefits, so as to provide a reference for decision-making in the investment and construction of smart residential buildings.*

Keywords: *Micro-energy Network, Residential Building, Comprehensive Benefit*

1. Introduction

With the development of human society, fuel resources are getting depleted, the structure of power system is aging, and it is difficult to break through the bottleneck of energy utilization efficiency, so the existing energy system is difficult to adapt to the requirements of reliability and security of users. While the energy problem is facing serious challenges, many scholars have focused on distributed energy. Microgrids are developed along with distributed energy sources, which not only take full advantage of distributed power sources, but also reduce the impact of distributed power generation on the grid. The concept of "microgrid" is extended in the process of planning and field application to form a micro-energy network. The micro-energy network integrates electricity, heat, cooling and gas resources to achieve distributed multi-energy supply in a synergistic and complementary way. Compared with micro-grid, it has greater promotion value and higher economic benefits.

Micro-energy network provides convenience for regional power supply and helps to promote clean energy consumption, further realizing the goal of "clean, low-carbon, safe and efficient" energy system construction. As an effective means of clean energy consumption, combined with the necessary needs for improving people's livelihood, the comprehensive evaluation of the benefits of micro-energy networks in residential buildings is of great significance for the planning, construction and operation of micro-energy networks that are closely integrated with people's livelihood.

For the comprehensive evaluation of the benefits of micro-energy networks in residential buildings, three processes are generally required, namely, index system construction, index weight calculation and comprehensive evaluation. For the construction of the index system, scholars have carried out multidimensional in-depth evaluation of the comprehensive benefits of distributed energy generation [1], integrated energy systems [2], and microgrids [3], which provide references for the study of micro-energy networks in residential buildings. For the calculation of indicator weights, most scholars currently use subjective weights, objective weights and comprehensive weights, etc. Subjective weights are based on expert knowledge and experience to judge indicators, reflecting the subjective importance of indicators, and specific methods include hierarchical analysis [4], eigenvalue method [5], program preference assignment method [6], etc.; objective weights are based on the assessment of objective data with the help of mathematical model theory and computer means, and specific methods include entropy weights. The specific methods include entropy weighting method [7] and rough set method [8], etc.; comprehensive weighting is the combination of subjective and objective weighting methods for comprehensive calculation. For comprehensive evaluation objects, traditional evaluation methods and

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intelligent evaluation methods are mainly used, i.e., comprehensive evaluation through mathematical models or computer technology; traditional evaluation methods include TOPSIS method [9], etc., and intelligent evaluation methods include machine learning [10], etc.

Based on the above-mentioned literature research, this chapter adopts the 3E benefit evaluation method from three aspects: economic benefit, energy saving benefit and emission reduction benefit, and sets the traditional energy consumption mode of residential buildings as the reference system to evaluate the comprehensive benefits of micro-energy networks in residential buildings, so as to provide a decision basis for the construction of intelligent residential buildings and the investment and operation of micro-energy networks.

2. Micro-Energy Network Operation Mode Analysis

For the micro-energy network system, the operation mode is generally set according to the priority of both power supply and heat supply in the system. The following is a specific analysis of the two modes of operation: "electricity to heat" and "heat to power".

The "heat by electricity" mode includes three possible scenarios. Scenario 1 is when the electricity demand of the customers in the system is lower than the start-up condition of the generating units in the system, then the system electricity is supplied by the public grid and the cooling and heating demand is supplied by the cooling and heating systems in the system. Scenario 2 is that the electricity demand reaches the start-up condition, the user's electricity demand is satisfied in priority, the heat generated is used for heating (cooling) through the heating (cooling) system, the waste heat is exhausted, and the shortage is supplied by the heating system. Scenario 3 is that the electricity demand exceeds the system generation capacity, the generator sets in the system operate according to the rated power, the electricity cannot be satisfied by the public grid, the heat generated is used for heating (cooling) through the heating (cooling) system, the surplus is emptied, and the insufficient part is supplied by the heating system.

3. Residential Building Load Characteristics

This section analyzes the seasonal and temporal load characteristics of residential buildings mainly from the time dimension and takes the northern region as the research center.

From the annual load: the heat load of residential buildings mainly includes heating load and hot water load, and the heat demand is distributed throughout the year; due to the low temperature in winter, the heating load is concentrated in November, December, January and February, while the hot water load is dominant in other months. The cooling load mainly covers June to September, especially July and August are generally the hottest period of the year, and the cooling load in these two months is the highest. Electricity load demand is more average and smaller in quantity.

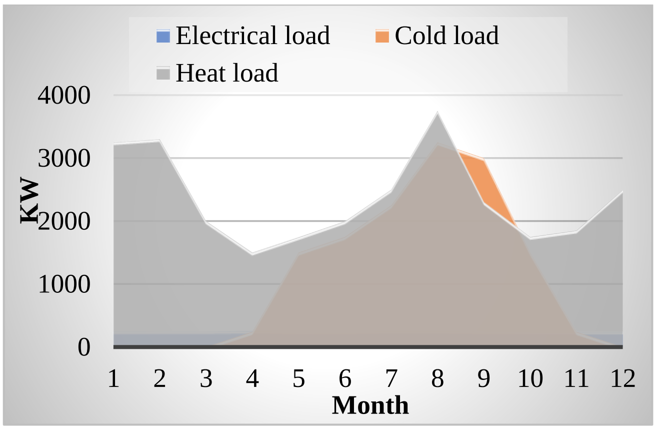

Figure 1: (a): Annual load of residential building

From the daily load point of view: winter daily cold load is almost zero; heat load is mainly at night, from the beginning of working hours gradually declining to reach the trough, as the end of the workday is approaching and gradually rise; electric load includes essential electricity and non-essential electricity, because non-essential electricity demand is small, while essential electricity demand time is

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more fixed, generally distributed in the midday 11-13 and 17-20 points, electric load level is low;. In summer, the cold load exists all the time, and the peak period is at noon (11-15pm) and evening (18-24pm), while the heat load is low and mainly hot water load, and the electric load has the same trend as winter day. The typical annual and daily load variations of residential buildings are shown in Figure 1 (a), (b) and (c).

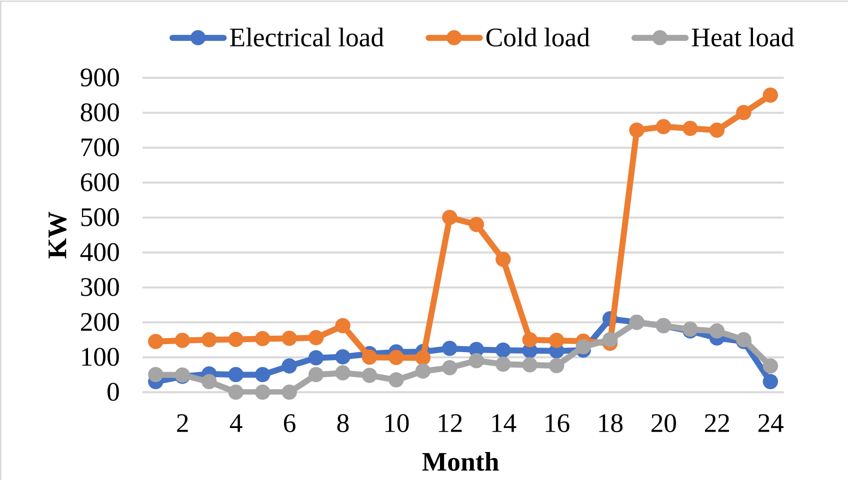

Figure 1: (b): Daily load of residential building in summer

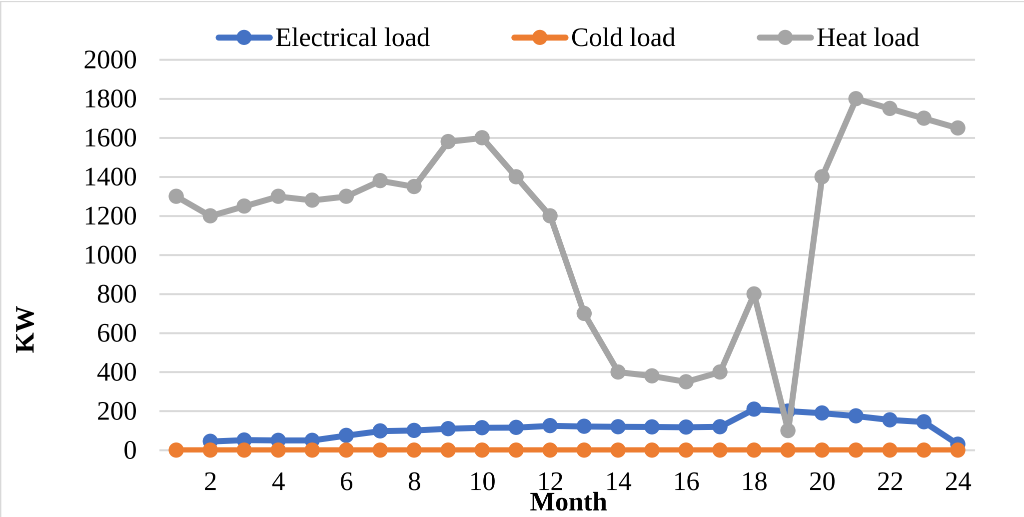

Figure 1: (c): Daily load of residential building in winter

4. Micro-Energy Network Structure Analysis

Under the independent operation structure, the micro-energy network system of residential buildings stores or discharges excess energy to the outside when supply is greater than demand, and is replenished by the public network or gas boiler (GB) when supply is less than demand. Inside the system, distributed photovoltaic (DPV) and gas-fired internal combustion engine (GICE), generate electricity to supply electricity in the building or compressed production z cooler (CRM); the waste heat generated by the internal combustion engine is recovered through the waste heat recovery device (HR) for heating or cooling, providing heat through heat exchanger (HE) in winter and cooling through absorption chiller (AR) in summer, and the excess energy is stored through electricity storage (ES) and Excess energy is stored through devices such as electrical storage (ES) and thermal storage (HS) or converted to energy through electrical to thermal equipment (P2H).

5. 3E Benefit evaluation model

In order to evaluate the benefits of the micro-energy network, this paper selects the cost saving rate,

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primary energy saving rate, and CO_2 reduction rate as the benefit evaluation indexes from the economic benefits and energy saving and emission reduction benefits.

5.1 Cost Saving Rate

The total cost includes equipment investment cost, system operation and maintenance cost, gas purchase cost, and electricity purchase cost. The specific formula is as follows.

$$C_j = C_j^{inv} \quad C_j^{op} \quad C_j^{gp} \quad C_j^{ep}$$

Where: $C_j$represents the total cost of independent operation of the microgrid j, represents $C_j^{inv}$the investment cost of the microgrid j, represents $C_j^{op}$the operation and maintenance cost of the microgrid j, represents $C_j^{gp}$the cost of gas purchase of the microgrid j, represents $C_j^{ep}$the cost of the microgrid j from the public grid to purchase electricity. The cost breakdown is as follows:

The investment operation and maintenance cost include the initial investment of the equipment converted to the daily investment amount and the daily operation and maintenance cost of the equipment.

$$C_j^{inv} = A_j \cdot C_j^{unit} \cdot W_j/365$$

$$s.t. A_j = r/(1-(1+r)^{-y})$$

Where:A_jRepresents the capital recovery coefficient of equipment j,C_j^{unit}Represents a devicejunit cost,W_jRepresents the capacity of the device j, r represents the interest rate, and y represent the service life. The operation and maintenance fee includes fixed O&M costs and variable O&M costs, as follows:

$$C_j^{op} = C_j^f \cdot W_j + \sum_{t=1}^{N} C_j^v \cdot E_{j,t}^{output}$$

Where: C_j^fit represents the unit fixed cost, represents the unit variable C_j^vcost, and represents the output $E_{j,t}^{output}$energy.

Energy consumption costs include the cost of natural gas purchase and the cost of public grid electricity purchase, as follows:

$$C_j^{gp} = \sum_{t=1}^{N} (P_t^g \cdot E_{j,t}^{gp} + P_t^e \cdot E_{j,t}^{ep} + P_t^h \cdot E_{j,t}^{hp} + P_t^c \cdot E_{j,t}^{cp})$$

Wherein:P_t^g, ,P_t^e $P_t^h$and represent the price of natural gas, the price of electricity in the public P_t^cgrid, the external heat price and the external cooling price, and the$E_{j,t}^{gp}$,$E_{j,t}^{ep}$ $E_{j,t}^{hp}$, and represent the purchase of $E_{j,t}^{cp}$gas, the external purchase of electricity, the external purchase of heat and the external cooling, respectively.

In order to evaluate the economic benefits of micro-energy networks, cost saving rate indicators are introduced as follows:

$$R_{sc} = \frac{\Delta C_{j,ref}^{tt}}{C_{ref}^{tt}} \times 100\%$$

Where: R_{sc}represents the cost saving rate, represents the ΔC_{ref}^{tt}cost difference between the micro-energy grid j and the reference system, and represents $C_{ref}^{tt}$the reference system.

5.2 Primary Energy Saving Rate

The primary energy saving rate reflects the degree of saving of primary energy resources after the operation of the residential building micro-energy network. If the primary energy utilization rate reaches a high level, it means that the energy-saving optimization effect of the microgrid needs to be further improved. Through the primary energy saving rate evaluation, the energy saving effect of the microgrid is understood, so as to analyze the energy saving potential of the promotion and application of the microenvironment grid. The specific formula is as follows:

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$$R_{se} = \frac{S_{ref}^{se} - S_j^{se}}{S_{ref}^{se}}$$

$$S_j^{se} = \sum_t (g_{h,t}^{se} + g_{e,t}^{se} + \frac{E_{j,t}^{ep}}{\xi_{th}\xi_{grid}})$$

$$S_{ref}^{se} = \sum_t (g_{h,t,ref}^{se} + g_{e,t,ref}^{se} + \frac{E_{j,t,ref}^{ep}}{\xi_{th}\xi_{grid}})$$

Where: R_{se} represents the primary energy saving rate, represents S_j^{se} the micro-energy grid j primary energy consumption, represents $g_{e,t}^{se}$ the micro-energy grid j

The air consumption of the medium motor $g_{h,t}^{se}$ represents the boiler gas consumption in the micro-energy grid, and ξ_{th} the thermal power generation efficiency of the public power grid ξ_{grid}.It represents the transmission and distribution efficiency of the power grid, S_{ref}^{se} represents the primary energy consumption of the reference system, $g_{h,t,ref}^{se}$ and $g_{e,t,ref}^{se}$ represents the reference system respectively Motor and boiler air consumption.

5.3 CO_2 Emission Reduction Rate

The difference between CO_2 produced in micro-energy grid applications and CO_2 from energy consumption in the traditional way is defined as CO_2 emission reductions, divided by the reference system CO_2 Emissions are CO_2 emission reduction rates. The CO_2 emissions of the micro -energy network should be calculated from the CO_2 emissions during the combustion of natural gas and the CO_2 emissions of purchased electricity. The calculation formula for CO_2 emissions from the natural gas combustion process is as follows:

$$O_{g,grid} = \sum_t L_{g,t} \cdot \varphi_{co_2} \quad (1)$$

$$L_{g,t} = \sum_t S_j^{se} \cdot HV \cdot 10^{-6} \quad (2)$$

$$\varphi_{co_2} = \varphi_c \cdot {}^{44}/_{12} \quad (3)$$

Wherein: represents the $O_{g,grid}$ CO_2 emission within the micro-energy network, represents the natural gas $L_{g,t}$ activity level, φ_{co_2} represents the CO_2 emission factor; represents the gas consumption, represents S_j^{se} the calorific value of natural gas; HV φ_c Represents carbon emission factor.

CO_2 emissions from purchased electricity are calculated as follows:

$$O_{g,exter} = \sum_t E_{j,t}^{ep} \cdot \varphi_{co_2,exter} \quad (4)$$

Wherein: represents the $O_{g,exter}$ CO_2 emissions generated by the purchase of electricity from the public grid, and represents the $\varphi_{co_2,exter}$ CO_2 emission factor of the public grid. The CO_2 emission reduction rate is calculated as follows:

$$R_{er} = \frac{(O_{g,grid}^{ref} + O_{g,exter}^{ref}) - (O_{g,grid} + O_{g,exter})}{O_{g,grid}^{ref} + O_{g,exter}^{ref}} \times 100\% \quad (5)$$

Wherein: R_{er} represents the CO_2 emission reduction rate; represents the CO2 $O_{g,grid}^{ref} + O_{g,exter}^{ref}$ emissions of the reference system, represents the $O_{g,grid} + O_{g,exter}$ CO2 of the residential building after the application of the micro-energy grid Emissions.

5.4 Comprehensive Benefits

The cost saving rate, primary energy saving rate and CO_2 emission reduction rate are empowered, and different weight values are given to the three types of indicators according to the evaluation center of gravity, and the comprehensive benefit score is finally obtained.

$$I = \eta_1 R_{sc} + \eta_2 R_{se} + \eta_3 R_{er} \quad (6)$$

In the formula: represents the I comprehensive benefit score, η_1 and the, η_2, η_3 represents the weight of various indicators.

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6. Study Analysis

6.1 Basic Data

In order to evaluate the3E benefits of the micro-energy grid of residential buildings, the traditional energy consumption method of residential buildings is used as a reference system. Residential buildings operate in summer with FPL and winter with FHL. The user load in the building is shown in Section IV. The electricity price standards implemented by residential buildings are shown in Table 1. The calorific value of natural gas takes 39MJ/m3, and the gas price is 0.349 yuan /kWh after conversion.

Table 1: Price data

The user type		Time period (electricity)		Electricity prices in the microgrid	Electricity prices for public grids
		summer	winter	(Yuan/kWh)	(Yuan/kWh)
Residential buildings	peak	11:00-24:00	6:00-9:00 17:00-24:00	0.87	1.34
	flat	6:00-11:00	9:00-17:00	0.45	0.85
	valley	0:00-6:00	0:00-6:00	0.23	0.43

Equipment parameters mainly include capacity configuration (capacity parameters), rated efficiency and energy efficiency ratio (technical parameters), unit fixed cost and unit operation and maintenance cost (economic parameters), the specific data is shown in Table 2. Each equipment has a service life of20 years, an interest rate of 8%, a grid transmission efficiencyof90%, a thermal power plant power generation efficiency of85%, and an internal combustion engine starting condition of5% of the rated capacity. Set 3E indicator weights are 1/3.

Table 2: Equipment parameters

Parameter / Equipment	Capacity (kW)	Rated power (%)	EER	Thermo electric ratio	Unit fixed cost (yuan/kW)	Unit operation and maintenance cost (yuan/kWh)
GICE	900	85.4	-	1.49	5494.2	0.056
	1500	80.8			5221.7	
	1800	78.2			5124.5	
DPV	20	-	-	-	3640	0.12
HR	1000	80	-	-	806	0.017
HE	1000	80	-	-	200	0.017
AR	1000	-	0.7	-	1200	0.006
CRM	1000	-	4.0	-	970	0.009
GB	2000	85	-	-	620	0.017
ES	200	96	-	-	-	0.49
HS	100	98	-	-	-	0.49
P2H	1500	-	4.0	-	970	0.009

Internal combustion engines, gas boilers and utility grid power supplies all emit CO_2, and their CO_2 emission factors are shown in Table3.

Table 3: CO_2 Emission factors

	CO2Emission factors
Public power grids	1200
Natural gas combustion within the microgrid	202

Refer to the system operation results

Based on the basic data, the operation data of the residential buildings under the traditional energy consumption in the reference system is calculated, and the specific cost results are shown in Figure 2:

As can be seen from the Figure 2, the distribution of residential building costs in the summer is relatively stable, and the winter costs are in the trough area in the afternoon hours. Overall, the cost of winter is higher than the cost of summer.

The distribution trend of primary energy consumption is similar to the cost situation, residential

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buildings consume the least energy in summer and are evenly distributed, and the energy consumption of residential buildings in winter shows a reverse trend, that is, there is a trough area in the afternoon.

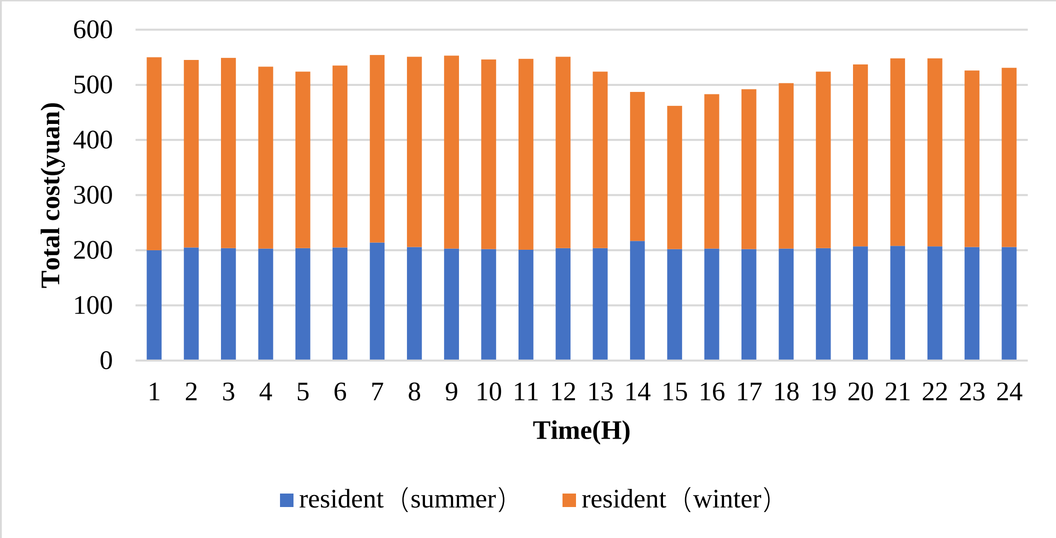

Figure 2: Total cost

CO2 emissions show a similar trend to primary energy consumption, that is between 8 and 21 points, CO2 emissions are at peak levels; residential building load demand is relatively low, so CO2 emission levels are relatively low.

6.2 3E results of the Evaluation

Based on the operation results of the reference system, it is calculated that the residential building micro-energy network is calculated in the case of 1/3of the weight of each index

Operational efficiency evaluation results. The results of the evaluation of the summer and winter operation efficiency of residential buildings are shown in Table 4.

Table 4: Benefit evaluation results of residential building in summer and winter

	Cost savings (yuan)	Cost saving rate	Primary energy saving(kWh)	Primary energy saving rate	CO_2 emission reduction(kg)	CO_2 emission reduction rate	Evaluation results (10-2)
summer	156.67	3.26%	0	0	0	0	1.09
winter	668.80	5.47%	347.81	18.21%	293.83	21.98%	15.22

Overall, the application of residential building micro-energy networks saves residents' living costs and is more conducive to the green and healthy development of society. From a seasonal point of view, the comprehensive score of micro-energy grid applications in winter is higher than that in summer, mainly because the demand for heat load in winter is large, resulting in an increase in surplus electricity; while the summer is dominated by electric loads, and the waste heat generated is larger. Compared to thermal energy, it shows greater flexibility and efficiency in energy conversion and inter-network processing, resulting in greater3E benefits.

7. Conclusion

Starting with the operation mode of micro energy network, this paper analyzes the two operation modes of FPL and PHL, takes residential buildings as the research object, constructs the current situation of residential building energy consumption under the traditional mode and the independent operation structure after the application of micro-energy network, and takes the residential building energy consumption under the traditional mode as the reference system, starting from the three dimensions of economic benefit, energy saving benefit and emission reduction benefit, The comprehensive benefit evaluation model of residential building micro-energy network operation is constructed, and finally an example is analyzed. The evaluation results show that: (1) the application of

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micro-energy network can realize the mutual transmission of surplus energy in the network, and finally achieve network interconnection and energy mutual aid; (2) The characteristics of electricity, heat and cooling loads in the network are different in different seasons. Compared with summer, winter shows stronger energy conversion flexibility.

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