Research on Optimal Strategy of Residential Buildings Energy Based on Standardized Euclidean Distance Measure Similarity Search Method

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Abstract. Aiming at the integrated energy optimization problem of residential buildings including production energy, energy storage and energy use objects, such as photovoltaic power generation, solar heat, electric heating, heat storage, battery, household power load and so on, this paper formulate the energy scheduling policy under the current running state referring to the scheduling policy of similar running state in history from the point of view of data mining. Firstly, a random matrix of basic status of residential buildings energy is constructed. Based on this, a similarity search method based on standardized Euclidean distance measure is proposed. This method forms four standardized Euclidean distances that are the solar irradiance vector, outdoor temperature vector, residential buildings' electric load vector and heat load vector by the similarity measure calculation based on the standardized Euclidean distance model. The weight analysis method is used to uniformly process a standardized European distance comprehensive index as a measure of similarity. Then, the paper analyses the threshold setting principle of similarity measure. Finally, the optimization process of scheduling strategy of residential buildings energy based on similarity search method is given. A simulation example of an actual residential buildings under a typical scenario of sunny day in winter shows that the proposed similarity search method based on the standardized Euclidean distance measure can make full use of a large amount of historical operating data and speed up the optimization efficiency of optimal scheduling strategy for integrated buildings energy. The scheduling strategy can guide energy storage to play the role of energy transfer, and guide the electric heating equipment and the time-shifting electric load to work in the valley period through the peak and valley electricity prices, thereby the user's bill is effectively reduced.

Key words: residential buildings; Euclidean distance; similarity search; energy optimization strategy.

1. Introduction
In recent years, under the new situation of solving the energy crisis and preventing haze from the end consumption area, the "coal-to-electricity" project carried out in residential buildings in northern China...
has achieved great results [1]. Various types of electric heating equipment represented by air-source heat pump have been installed. At the same time, with the support of the government's "photovoltaic poverty alleviation" policy, the majority of residents users have installed solar energy resource utilization equipment such as photovoltaic power generation and solar heat plate collector on their buildings [2], forming an integrated energy system of residential buildings that includes production energy, energy storage and energy use objects [3], therefore, the potential of comprehensive regulation and control of residential buildings is greatly enhanced. This kind of integrated building energy system can combine the thermal load, electrical load and solar energy utilization in residential buildings, and achieve the purpose of reducing the energy cost of residential buildings and improving the energy utilization rate through comprehensive optimization and regulation technology [4].

Aiming at the energy scheduling problem of integrated energy system, traditional scheduling strategies mainly include day-ahead planning, rolling planning, and real-time scheduling. These three scheduling strategies mainly aim at three different time scales to carry out energy prediction and scheduling [5]. The literature [6] considered the influence of source load uncertainty and energy storage equipment configuration on integrated energy system. It proposed a coordinated optimal scheduling strategy of integrated energy system based on multi-time scale and hybrid energy storage system and established optimization scheduling model aiming at three time-scales which are day-ahead planning, day rolling and real-time feedback; the literature [7] considering the factors such as electric loads, heat loads and wind power prediction accuracy, proposed multi-time scale rolling scheduling strategies for heat and power systems and built a multi-time scale optimal scheduling model; in literature [8], a general energy transfer model of the district heating network was established based on the heat transfer theory. The heat power loss equation for the heating network was derived and linearized to form the energy flow model. To solve the flow and temperature of the media in the heating network, the flow-temperature function was derived. This paper developed an optimal scheduling strategy based on the minimum operating cost of regional integrated energy utilization system. The energy-optimized scheduling strategy in the above literatures are only to formulate energy-optimized scheduling strategies with different time scales from the perspective of energy prediction. From the point of view of the optimization algorithm, the optimal scheduling strategies are often based on the characteristics of the system physical model. The optimization algorithm often cannot reliably converge, and the optimization efficiency is not high.

Under the background of the rapid development of intelligent equipment such as intelligent monitoring system, sensor and so on, the distributed photovoltaic power generation and residential buildings load have accumulated a large amount of historical operating data. If we can analyze the historical operation data from the perspective of data mining, we can make full use of the similarity between the historical operating status and the current operating status, so as to draw on the scheduling strategy formulated in the historical operating status to formulate the scheduling strategy of the current operating status. This will be able to deviate from the physical model specified by the system at a certain extent [9], and solve the energy optimization strategy problem in the current running state of residential buildings more efficiently and reliably [10-11]. Therefore, the core problems to be solved are the similarity judgment and historical operating status search that is highly similar to the current operating status of the residential buildings. Researching from the similarity search data mining perspective has been carried out in the field of load forecasting. Literature [12] used data mining method to search load sequences of similar climate conditions with predicted days. It not only simplifies the amount of data, but also effectively improves the efficiency and accuracy of the prediction results; in literature [13], Analytic Hierarchy Process (AHP) was applied to establish a decision tree. The search was carried out in the decision tree based on the attributes of the forecast day, and the search result was taken as the input of support vector machine. This method improved the prediction accuracy of traditional support vector machines; literature [14] clustered climate information of historical load data based on k-means method. Then the sample data was selected as the input data of support vector machine prediction model according to the clustering results. The algorithm speed and prediction accuracy were improved.
This paper will propose a similarity search method based on standardized Euclidean distance measure to solve the historical operating status similarity search problem. The energy optimization scheduling strategy method of residential buildings based on historical operating status similarity search is developed. According to the basic forms of production energy, energy storage and energy use of the residential buildings energy system, firstly, constructing a random matrix of the basic status of the residential buildings energy system. Based on this, a daily search method for historical similarity of energy status of residential buildings based on standardized Euclidean distance measure is proposed. This method forms four standardized Euclidean distance that are the solar irradiance vector, outdoor temperature vector, user's electric load vector and heat load vector by the similarity measure calculation based on the standardized Euclidean distance model. The weight analysis method is used to uniformly process a standardized European distance comprehensive index as a measure of similarity. Then the paper analyzes the threshold setting principle of similarity measure. Finally, the optimization process of scheduling strategy based on similarity search method is given. The effectiveness of the proposed method is verified by formulating optimal scheduling strategies of an actual residential buildings energy.

2. Construction of basic operating status random matrix of residential buildings energy

The goal of optimization scheduling of residential buildings energy is usually that the total daily electricity cost of residential buildings is minimum. It optimizes and makes the heat output of the controllable heat source at each time of the next day, the input and output energy of energy storage, and the user's conventional time-shifting load work plan, so as to form optimal strategy of residential buildings energy. The output power data of the residential buildings photovoltaic power generation equipment in each period, the heat output data of the solar heat plate collector, and the electric load and heat load data of the residential buildings in each period determine the basic operating status of residential buildings energy. Mathematically, the difference in operating status is the direct cause of different optimal scheduling strategies. The scheduling strategies of two similar operating status days must be similar or identical. Therefore, this paper will use the big data effect that the increase of data volume will make the system analysis simplify and efficient to study the optimization technology of residential buildings energy optimization scheduling strategy based on similarity analysis theory. The basic idea is that in the historical operation data of the residential buildings energy, search for the historical scheduling day that is highly similar to the current scheduling day operating status. The purpose of efficiently optimizing the energy scheduling strategy for the current scheduling day is achieved by directly referring to the scheduling strategy of the similar day or improving the scheduling strategy based on the scheduling strategy of the similar day. Therefore, we must first construct a random matrix of the basic operating status of the residential buildings energy. They are the output power data of the residential buildings photovoltaic power generation equipment in each period, the heat output data of the solar heat plate collector, and the residential buildings' electric load data and heat load data in each period. The constituent elements of the basic operating status random matrix will be the objects of the similarity search.

The solar irradiance and outdoor temperature of the current scheduling day can be obtained through weather forecast. The output power of the photovoltaic power generation device is closely related to the solar irradiance as shown in the formula (1) and the output heat of solar heat plate collector is closely related to outdoor temperature as shown in equation (2), so the basic operating status of the residential buildings energy can be determined by solar irradiance data, outdoor temperature data, residential buildings' electric load data, and heat load data.

$$L_{pv} = \frac{E_L \cdot Q \cdot \eta}{E_{\lambda,\text{max}}}$$

(1)

Where $L_{pv}$ is photovoltaic output; $E_L$ is solar irradiance; $Q$ is rated capacity; $\eta$ is power generation efficiency; $E_{\lambda,\text{max}}$ is the maximum solar irradiance.
Where $AF r_{tAF} \tau \Delta t$ is the solar radiant energy absorbed by the solar heat plate collector; $AF' u(T_r - T_{tAF}) \Delta t$ is the heat loss energy of the solar heat plate collector body; $T_r = \frac{1}{2}(T_{r,s} + T_{r,d})$, $T_{r,s}$ is the output temperature of hot water for the collector during t period, $T_{r,d}$ is the return water temperature of the heating system during t period.

Therefore, the constituent elements of the basic operating status random matrix of residential buildings energy are the solar irradiance vector, outdoor temperature vector, residential buildings’ electric load vector and heat load vector. Random matrix is represented by A, and the expression is shown in equation (3).

$$A = \begin{bmatrix} F \ W \ E \ H \end{bmatrix}^T$$  \hspace{1cm} (3)

Where F is the solar irradiance vector; W is the outdoor temperature vector; E is the residential buildings' electric load vector; H is the residential buildings' heat load vector.

In a certain scheduling day, the scheduling period is T, so equation (3) is a matrix with 4 rows and T columns. That is

$$A_{4 \times T} = \begin{bmatrix} F_1 & F_2 & \cdots & F_{T-1} & F_T \\ W_1 & W_2 & \cdots & W_{T-1} & W_T \\ E_1 & E_2 & \cdots & E_{T-1} & E_T \\ H_1 & H_2 & \cdots & H_{T-1} & H_T \end{bmatrix}$$  \hspace{1cm} (4)

3. Historical similarity day search method of operating status for the state of residential buildings energy based on standardized European distance measure

3.1. Similarity measure calculation based on standardized Euclidean distance model

In the basic operating status random matrix $A^X$ composed of historical operating data of residential buildings energy, searching for a historical scheduling day that is most similar to the basic operating status random matrix $A^Y$ of the current scheduling day requires a similarity measure method. In order to ensure the calculation speed of the algorithm and reduce the impact of the numerical difference of each data, the paper adopts a standardized Euclidean distance model with simple model, clear meaning, and eliminating the influence of numerical differences for similarity measure calculation. The calculation aims at basic operating status random matrix $A$ composed of solar irradiance vector, outdoor temperature vector, residential buildings’ electric load vector and heat load vector. The standardized Euclidean distance mathematical models of the solar irradiance vector are shown in equations(5).

$$S_{SED}^E(F^X, F^Y) = \sqrt{\sum_{i=1}^{T} \left( \frac{F^X_i - F^Y_i}{s'_i} \right)^2}, \text{ where } s'_i = a \left( \sum_{i=1}^{T} (F^X_i - F^Y_i)^2 \right)^{0.5} \text{ and where } F^X_i = \frac{\sum_{d=1}^{D} F^X_{i,d}}{D}$$  \hspace{1cm} (5)

Where $S_{SED}^E(F^X, F^Y)$ is the standardized Euclidean distance between the solar irradiance vector of a historical scheduling day and the solar irradiance vector of the current scheduling day; $F^X$ is the solar irradiance vector of a historical scheduling day; $F^Y$ is the solar irradiance vector of the current scheduling day; $T$ is the number of scheduling periods on the scheduling day; $F^X_i$ and $F^Y_i$ are the $i$-th element respectively of the vector $F^X$ and vector $F^Y$ taking the solar irradiance of the historical scheduling day and the solar irradiance of the current scheduling day at i-th period respectively; D is the total number of historical scheduling days participating in the similarity search; $s'_i$ is the sample data
standard deviation of solar irradiance for the D historical scheduling days at i-th period; $\overline{F_i^X}$ is the sample data average value of solar irradiance for the D historical scheduling days at i-th period.

Similarly, the standardized Euclidean distance of the outdoor temperature vector $S_{ED}^W(W_i^X, W_i^Y)$, the standardized Euclidean distance of the residential buildings' electric load vector $S_{ED}^E(E_i^X, E_i^Y)$ and the standardized Euclidean distance of the residential buildings' heat load vector $S_{ED}^H(H_i^X, H_i^Y)$ can be obtained.

### 3.2. Comprehensive index of standardized Euclidean distance based on weight analysis

The standardized European distance calculation is performed between the current scheduling day and a historical scheduling day aiming at the solar irradiance vector, outdoor temperature vector, residential buildings' electric load vector, and heat load vector of residential buildings. It will produce four standardized Euclidean distance values. In order to form a unified measure of similarity, it is necessary to fit these four standardized Euclidean distance according to their weights into a unified comprehensive index that can be judged, and it is expressed by $S_{S,ED}$. This paper uses the method of determining the index weight in the AHP to determine the unified standardized Euclidean distance comprehensive index. The expression of $S_{S,ED}$ is as follows.

$$S_{S,ED} = \alpha S_{ED}^W + \beta S_{ED}^E + \lambda S_{ED}^E + \mu S_{ED}^H$$  \hspace{1cm} (6)

Where $\alpha$, $\beta$, $\lambda$, and $\mu$ are the weight coefficients of the solar irradiance vector, outdoor temperature vector, residential buildings' electric load vector, and residential buildings' heat load vector when fitting the standardized Euclidean distance, $\alpha + \beta + \lambda + \mu = 1$. For residential buildings, the electric load and heat load required by users on different typical days in different seasons have formed a certain law, but the photovoltaic output and the solar heat output have a large uncertainty. Therefore, the weights of $\alpha$ and $\beta$ are relatively large, and the value ranges from 0.3 to 0.4. The weights of $\lambda$ and $\mu$ are relatively small, and the value ranges from 0.1 to 0.2.

### 4. Optimization flow of scheduling strategy based on similarity search method

The specific solution steps to formulate the optimal scheduling strategy of residential buildings energy are as follows.

1. Input the original data such as solar irradiance, outdoor temperature, electric load power, heat load power and necessary parameters in the calculation model;
2. Construct a random matrix A of the basic operating status for residential buildings energy. The matrix elements include the solar irradiance vector, outdoor temperature vector, residential buildings' electric load vector, and residential buildings' heat load vector;
3. Use equation (5) to calculate the standardized Euclidean distance of the solar irradiance vector between the current scheduling day and the historical scheduling day, the standardized Euclidean distance of the outdoor temperature vector, the standardized European distance of the residential buildings' electric load vector, and the standardized European distance of the residential buildings' heat load vector. Then the four types of standardized Euclidean distance are unified according to formula (6). If the unified standardized Euclidean distance is within the threshold range, use its scheduling strategy to analyze the scheduling strategy of the current scheduling day. If not, fine-tune the strategy based on expert experience to obtain the scheduling strategy of the household integrated energy system;
4. Use the scheduling strategy of the historical scheduling day or use the scheduling strategy of the historical scheduling day that is fine-tuned by expert experience, then analyze the scheduling strategy of the current scheduling day, calculate the total daily cost, and obtain the optimal results.
5. Examples

5.1. System data and scene description
The simulation experiment is carried out with an actual residential buildings energy. The system has a photovoltaic power source of 5kW, a solar heat plate collector of 11kw, and an air source heat pump of 3kW, with an energy efficiency ratio of 4. The storage tank has a capacity of 1m³. The upper limit of heat storage is the heat stored when the tank is full, and the lower limit is 0. The heating area of residential buildings is 200 m². Since the residential buildings' area performs peak-valley electricity price for heating in winter, and the government subsidizes 0.2 yuan /kWh for power consumption in the valley period, this paper adopts the valley electricity price of 0.1 yuan /kWh from 21:00 to 6:00 in the next day. The purchase price of other peak hours is 0.48 yuan /kWh. The electricity selling price is set at 0.99 yuan /kWh, taking into account the subsidy for photovoltaic power generation of residential buildings.

According to the residential buildings' habits, half an hour is selected as the scheduling time. In order to verify the effectiveness of the scheduling strategy and optimization method, the optimal scheduling strategy of residential buildings energy is developed by taking typical weather scenario of sunny day in winter in the residential buildings' area as example. The curves of solar irradiance and outdoor temperature in the typical day are shown in figure 1.

![Figure 1. Comparison of solar irradiance and outdoor temperature curves for the typical weather day.](image)

5.2. Analysis of historical similar day search results based on standardized Euclidean distance measure
Aiming at a typical winter sunny day, the residential buildings energy is simulated and analyzed. The standardized Euclidean distance of the solar irradiance vector, the standardized Euclidean distance of the outdoor temperature vector, the standardized Euclidean distance of the electric load vector, the standardized Euclidean distance of the heat load vector, and the unified standardized Euclidean distance are shown in figure 2.
It can be seen from figure 2 that among the four standardized Euclidean distances, the standardized Euclidean distance of the solar irradiance vector and outdoor temperature vector have large uncertainties. Compared with the standardized Euclidean distance of the residential buildings’ electric load vector and heat load vector, the value is larger, and it basically maintains between 4 and 6. For the residential buildings’ electric load vector and heat load vector, the value basically maintains between 2 and 3. For the standardized Euclidean distance of the electric load vector, it was almost 0 on November 8, 2017, indicating that the electric load usage on this historical scheduling day is almost the same as the electric load usage on the current scheduling day. For the unified standardized European distance, we can see that the value on November 19, 2017 is the smallest, that is, the operation of the residential buildings energy on this scheduling day is the closest to the energy condition on the current scheduling day. So the paper selects November 19, 2017 as the optimal historical scheduling day for similarity search and cites its scheduling strategy.

5.3. Analysis of scheduling strategy under typical winter sunny day operation scenario

The similarity search method based on the standardized European distance measure is used to obtain the historical scheduling day that is most similar to the operating status of the current scheduling day. The scheduling strategy under the historical scheduling day is directly used. The comparison curves of the residential buildings' heat energy part before and after optimization are shown in figure 3(a) and figure 3(b), and the curve of heat energy storage before and after optimization is shown in figure 4.
Before optimization, combined with figure 3(a) and figure 4, it can be seen that the solar heat output is 0 from 0:00 to 10:00. The heat load curve coincides with the air source heat pump curve, indicating that all the heat required by the residential buildings' heat load is supplied by the air source heat pump, and the air source heat pump will always consume electricity; At 10:00-17:00, the solar heat output is greater than the heat load required by the residential buildings. In this case, in addition to meeting the heat load required by the residential buildings, the excess heat is stored in the hot water tank, and the air source heat pump does not work; At 17:00-24:00, the solar heat output is zero. The heat load is supplied by the heat stored in the hot water tank, and the air source heat pump does not work.

After optimization, combined with figure 3(b) and figure 4, it can be seen that at 10:00-17:00, it is same as before optimization. Besides this, the decision model directs the air source heat pump to run at full rated power at 0:00 to 2:00 in the valley period. In addition to meeting the heat load of the residential buildings in this period, the heat is stored to the hot water tank in advance at the cost of valley electricity price (In figure 5(a), the hot water tank has been increasing in this period after optimization) so that meet the heat required of the heat load during the period of insufficient light throughout the day. As a result, the electricity bill of residential buildings is reduced compared with that before optimization.

The comparison curves of the residential buildings' electric energy part before and after optimization are shown in figure 5(a) and figure 5(b), and the comparison of working periods before and after the optimization of time-shifting load is shown in table 1.

Before optimization, it can be seen from figure 5(a) that the output of photovoltaic power generation during 8:00-10:30 and 12:00-17:00 is larger than the electric load, so the residential buildings can obtain benefits through the photovoltaic subsidy electricity price through the way of excess electricity online. For the rest of the time, the load shortage caused by insufficient photovoltaic power generation needs to be purchased from the power grid.
After optimization, combined with figure 5(b) and table 1, it can be seen that, on the one hand, the decision model can guide electric vehicle charging and other time-shifting loads to work in the period of valley electricity price. On the other hand, the model guide the air source heat pump to run at full rated power from 0:00 to 2:00, so as to use the valley electricity price to store heat in advance. Therefore, the electric load after optimization and the electricity purchased from the grid are increased in the valley period compared with the before optimization period, thus reducing the residential buildings' electricity bill as a whole.

Table 1. Comparison table of time-shifting working hours before and after optimization.

| Load                  | Working time before optimization | Working time after optimization |
|-----------------------|---------------------------------|--------------------------------|
| dishwasher            | 7:00-8:00                       | 21:00-23:30                    |
| electric car charging | 12:00-13:00                     | 0:00-1:00                      |
|                       | 18:00-19:00                     | 0:00-4:00                      |
| electric bicycle charging | 3:30-7:30                     | 0:00-4:00                      |
| electric iron         | 20:00-21:00                     | 21:00-22:00                    |
| washing machine       | 20:00-21:00                     | 21:00-22:00                    |
| dryer                 | 20:00-21:00                     | 21:00-22:00                    |
| water heater          | 20:00-22:00                     | 21:00-23:00                    |
| electric kettle       | 20:00-21:00                     | 21:00-21:30                    |
| air source heat pump  | time-varying energy             | full rated power               |

Under the typical scenario of the sunny day in winter when the light intensity is relatively strong, the electricity cost before optimization is 6.76 yuan, and it is reduced to 5.05 yuan after optimization. It can be seen that the using the similarity search method based on the standardized Euclidean distance measurement proposed in this paper and the day-ahead optimization scheduling strategy based on the decision model that the total daily electricity cost is minimum can fully utilize the thermal energy transfer of thermal energy storage and the time-shifting characteristics of time-shifting electric loads, reducing the total electricity cost of residential buildings.

6. Conclusions

(1) Aiming at the scheduling strategy problems of residential buildings energy that includes photovoltaic power generation, solar heat, electric heating, energy storage and so on, firstly, a random matrix of basic operating status of residential buildings energy is constructed. Based on this, a similarity search method based on standardized Euclidean distance measure is proposed. This method forms four standardized Euclidean distance which aim at solar irradiance vector, outdoor temperature vector, user's electric load vector and heat load vector by the similarity measure calculation based on the standardized Euclidean distance model. The weight analysis method is used to uniformly process a standardized European distance comprehensive index as a measure of similarity. Then the paper analyzes the threshold setting principle of similarity measure. Finally, the optimization process of scheduling strategy based on similarity search method is given. Under the guidance of scheduling goal with the least daily total electricity cost, the controllable heat source output heat plan, energy storage input and output energy plans, and the residential buildings' conventional time-shifting electric load work plan for each period of the next day are made.

(2) The example of optimal strategy of residential buildings energy under typical winter sunny day shows that the proposed similarity search method based on standardized Euclidean distance measure can make full use of the energy optimization scheduling strategy of historical similar scheduling day. The decision model with the smallest total daily electricity cost can play the role for energy transfer of energy storage of all forms, so that the output energy of renewable energy equipment such as solar
collectors and photovoltaic power generation is maximum, and guide the air source heat pump electric heating equipment and the time-shifting electric load to work in the valley period through the peak and valley electricity prices, thereby the residential buildings' electricity bill is effectively reduced.

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