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Summary of Demand-side Response and Energy Transaction Strategy of Intelligent Building Clusters Driven by Data

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Abstract: At present, intelligent buildings have formed a relatively mature and complete industrial chain and industrial scale in China, but there are still some technical and application problems to be solved urgently, mainly including the lack of linkage between different demand-side energy demand scenarios, the inability to guarantee information security, and serious building energy consumption. In view of the above problems, scholars at home and abroad have launched relevant research, but they have not comprehensively considered the relevance of the above problems. Therefore, this article sorts out the research status of source-load joint forecast method of intelligent building clusters, and analyzes the related development trends, including three major directions: source-load joint forecast method of intelligent building clusters, key technologies of energy supply and demand data security of intelligent building clusters, and distributed energy transaction strategy of intelligent building clusters. Through combing and analysis, this article has formed a number of valuable research directions, which can provide directional reference and knowledge for the accurate response of electric-thermal load and energy transaction strategy of intelligent building clusters and P2P method theory in other scenarios.

Keywords: Data security technology; Distributed energy transaction; Source-load joint forecast; Demand-side response

1. Introduction

At present, the building industry is in urgent need of a change to break the downturn, and digital technology undoubtedly provides the best opportunity for the transformation and upgrading of the building industry. Intelligent building is the key factor and important basic unit for the future cities to become safe, intelligent and sustainable. Its intelligence, safety, green orientation and health have a far-reaching and lasting impact on the government, enterprises and individuals. Currently, intelligent buildings have formed a relatively mature and complete industrial chain and industrial scale in China. It is estimated that the proportion of intelligent buildings in new buildings in China is expected to reach 55.8% by 2024 [1]. At present, intelligent buildings have spread and popularized from traditional commercial buildings to other architectural forms such as communities, industrial parks, campuses, hospitals and other public buildings; technically, the technologies covered by intelligent buildings have developed from traditional electromechanical management to digitalization, informationization and networking, and are currently combined with artificial intelligence, 5G, big data, cloud platform and IoT technologies [2].

Although there are nearly 20 published product standards in the field of intelligent buildings, such as *Digital Technology Application in Buildings and Residential Areas*, *Building Automation and Control System and Smart Cities* [3], there are still the following technical and application problems in intelligent buildings that need to be solved urgently: (1) There is a lack of linkage between different demand-side energy demand scenarios. At present, due to the diversification of IoT hardware devices in different intelligent buildings, there are certain technical barriers, and the interconnection among devices, systems, platforms, data and scenarios cannot be formed. (2) Information security cannot be guaranteed. As a composite unit integrating "power generation and power consumption", intelligent buildings often adopt the energy strategy of "independent power generation for independent power consumption with margin sharing". With the integration and development of information technologies such as IoT, cloud computing and big data with intelligent buildings, the rapid and efficient connection and intercommunication of more and more equipment, systems and platforms in buildings also brings greater information security risks to intelligent buildings, which greatly limits the freedom of building owners of intelligent buildings to use their own energy and trade end-to-end (P2P) energy. (3) Building energy consumption is serious. Existing intelligent buildings lack correct and effective energy consumption evaluation methods and energy consumption optimization methods for building equipment, and lack of supervision ability for rational allocation of electric energy and heat energy leads to increased energy consumption.

In view of the above problems, in the aspect of lack of linkage between demand-side energy demand scenarios, scholars at home and abroad try to collect and centrally dispatch independent and different energy supply-side units (including distributed photovoltaic, thermal energy storage system, heat pump and related technologies) of intelligent buildings, in a bid to improve the interconnection among equipment, systems, platforms and scenarios of intelligent building clusters, give full play to the complementary advantages of various energy sources, and achieve the purpose of saving energy cost [4]. However, this strategy ignores the diversity of demand-side units (DC load, AC load and heat load), and cannot realize the real source-load joint forecast and accurate electric-heat load response. In the aspect of intelligent building network information security, soft encryption, chip encryption, gateway encryption and other methods are usually adopted to improve the security, autonomy, controllability and credibility of building information and data [5]. However, the above methods do not carefully consider the impact of energy-using equipment control strategy and demand-side response management on distributed energy transaction, and lack verification of the authenticity of information data on both sides of supply and demand. In terms of building energy consumption, in order to give full play to the energy-saving advantages of "power generation-power consumption" integration of intelligent buildings, scholars at home and abroad focus on exploring the economic and environmental protection energy storage methods and reasonable dispatching strategies, and constantly explore the methods to meet the real-time power demand response of the power side [6]. However, the related research lacks further exploration of the economic benefits generated by users' energy transactions, and does not comprehensively consider the selfish transaction strategy of different intelligent buildings by adjusting energy storage equipment to pursue the best operation energy consumption, so it is impossible to realize the cooperative operation of intelligent buildings with the best overall economy.

It can be found that there is a certain correlation between the above problems, and the main reason is that the unique "power generation-power consumption" integrated composite unit characteristics of intelligent buildings make its energy supply, energy consumption response and energy transaction interact with each other. Therefore, the research should not stay on the simple reasonable dispatching mode of electric energy or distributed energy transaction algorithm, but should analyze the energy supply and demand balance of the cluster where intelligent buildings are located from the perspective of "response-data security-transaction" in turn, so as to maximize the technical and economic benefits and minimize the energy consumption of the overall operation of the cluster. Relevant research results have not yet been found.

To sum up the above, this article thinks that it is very necessary to focus on the demand-side response of intelligent building clusters for multi-type demand-side units, and to further realize the privacy protection and attack location of distributed energy transactions considering the influence of demand-side response management. Starting from the goal of building the overall energy supply and demand balance of the cluster, the article innovates the decision-making method of energy transaction behavior that pursues the optimal overall economy of intelligent building clusters. The research content of this direction has the following important theoretical and practical significance:

(1) Expand the research on energy supply, energy response and energy transaction of intelligent buildings to the cluster field, and improve the standardization level of intelligent buildings. (2) Explore the interconnection, information sharing and business collaboration among building equipment, systems, platforms and scenarios for energy supply, energy response and energy transaction of intelligent building clusters, so as to avoid barriers between information systems, waste and duplication of construction. (3) Pursue the authenticity of information data on both sides of supply and demand, and promote the application of encryption algorithm and traceability algorithm in the field of intelligent building energy transaction. (4) Through relevant research, provide some new optimization models and analysis methods for the energy transaction theory of intelligent building clusters, and provide reference for the deep expansion of P2P methods in other scenarios.

2. Research Status and Development Trends of the Source-Load Joint Forecast Method for Intelligent Building Clusters

Intelligent building technology has helped thousands of buildings and homes consume energy more efficiently.

If photovoltaic, intelligent energy management and efficient co-generation of power and heat are combined, it will help to better manage and monitor the energy utilization and transaction of intelligent building clusters, and reduce energy costs and carbon emissions. At the same time, with the continuous development of emerging technologies, there are more and more opportunities for intelligent buildings to utilize new technological processes and data sources. Next, this article describes the research status and development trends in this field from three aspects: the electrical-thermal demand response of intelligent building clusters, the key technologies of data security and the distributed energy transaction strategy considering the characteristics of intelligent buildings.

Traditional building electric-thermal energy system managed and operated by different energy companies has the problem of loose energy coupling, so the demand forecast of various types of building energy can be relatively independent. Currently, many achievements have been made in load forecast for a single type. Common methods mainly include machine learning models represented by artificial neural network [7], support vector regression [8], long-term and short-term memory neural network [9], etc. On this basis, various modified comprehensive energy demand forecast models have also been proposed, such as MTL-GRU-Attention [10], ALIF-LSTM [11], ResNet-LSTM [12], MMoE-LSTM [13]. The above models are all based on the input of historical data of cold, heat and power energy supply and demand, meteorological data and calendar rules for multi-task learning to achieve the corresponding load forecast function.

As the core component of intelligent building energy demand, its power demand has the characteristics of promoting clean energy consumption, which means that the AC/DC hybrid power supply system scheduling strategy considering clean energy generation such as wind and light and flexible DC loads such as electric vehicles, complex LCT and LED lighting equipment can reduce building energy consumption more effectively. With AC/DC microgrid as the core, through various energy conversion equipment and energy storage equipment including DC, AC and heat, it can realize the coordinated planning, collaborative management, interactive response and mutual aid among traditional energy systems, which is more ideal for meeting the demand-side response of intelligent building clusters. Therefore, the existing forecast models ignoring clean energy generation and DC load are not suitable for the energy demand forecast scenarios of intelligent buildings.

Moreover, intelligent energy systems of different types of intelligent building clusters and large-scale access of distributed energy will accumulate massive historical information data on both sides of supply and demand, big data on both sides of cluster energy supply and demand will be gradually formed, with the characteristics of decentralization, diversity, complexity and real-time, which promotes the application of data-driven technology in the process of planning, operation control and scheduling on both sides of cluster energy supply and demand, and is the second reason why the existing forecast models are not suitable for the energy demand forecast scenarios of intelligent building clusters. In addition to traditional machine learning, data-driven technologies applied to energy and power systems of intelligent building clusters mainly include theoretical frameworks such as reinforcement learning, deep learning, transfer learning and integrated learning [14]. For big data on both sides of cluster energy supply and demand, large-scale data development and parallel processing can be realized by improving classical algorithms through big data processing framework, and cutting-edge machine learning represented by deep learning can also be promoted.

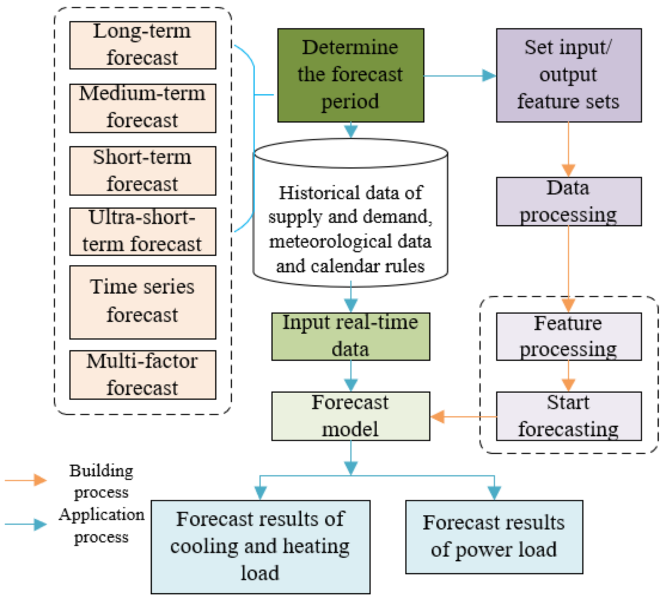

Figure 1. Load forecast process of intelligent building clusters driven by data under various forecast problems

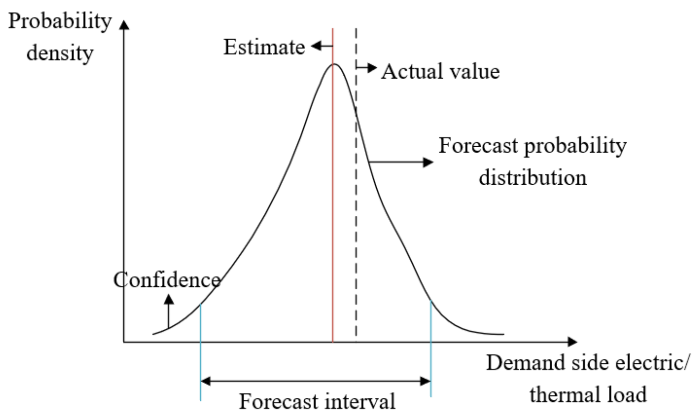

Figure 2. Classification of forecast results

To sum up, the load forecast problem for intelligent buildings needs to be based on the general principles of knowability and systematicness, and follow the basic principles of continuity, similarity and correlation. It is mainly divided into supply-side and demand-side time series forecast problem and multi-factor forecast problem. The forecast content is mainly divided into long-term, medium-term, short-term and ultra-short-term according to the forecast period, and the forecast results are mainly divided into point forecast, interval forecast and probability density forecast according to the detailed information. Its forecast process is not limited to numerical forecast, but also includes data processing, feature processing and data security related to the application of data-driven technology. Figure 1 shows the data-driven load forecast process of intelligent building clusters under reasonable forecast problems.

Due to the early research on load forecast of single energy system, data-driven technology has been widely used in single load forecast, and gradually promoted its extension to interval forecast and probability density forecast. Figure 2 shows the schematic diagram of the forecast results of different types of energy demand. It can be seen that the forecast probability distribution conveys the most information and the least forecast value. In addition, compared with single load forecast, the application scenarios of energy load forecast of intelligent building clusters are more complex, its characteristics are embodied in the setting of input/output data feature sets of various energy supply and demand including DC, AC and heat. Therefore, it is a blank in the current research of electric-thermal load forecast to take typical daily load, holiday load and spatial distribution load as output characteristics, which requires to effectively learn multi-type energy coupling information including DC, AC and heat, and accurately forecast the source-load joint of multi-type energy through big data on both sides of cluster energy supply and demand.

There are few research results on source-load joint forecast of energy system at home and abroad. Therefore, in order to achieve the ideal energy demand-side response effect of intelligent building clusters, referring to the existing statistical methods such as linear regression [15], exponential smoothing [16] and autoregressive differential moving average [17], traditional machine learning methods such as wavelet neural network [18], extreme learning machine [19], feedforward neural network [20] and SVM [21], and data-driven technologies such as gradient lifting decision tree of integrated learning [22], deep belief network of deep learning [23], LSTM network based on RNN [24] and derived bidirectional long-term and short-term memory network [25], it can further innovate the source-load joint forecast model suitable for intelligent building clusters, and explore the application mode of data-driven technology in the load forecast research of intelligent building clusters, which is expected to provide a useful reference for the in-depth development of the dual-side energy forecast system of cluster energy supply and demand.

3. Research Status and Development Trend Analysis of Key Technologies of Energy Supply and Demand Data Security in Intelligent Buildings

The input/output data of various energy supply and demand of intelligent building clusters are generally characterized by wide sources, large scale and complex types. This open, interconnected and shared energy management mechanism will lead to malicious network attacks and false data, which will inevitably pose a great threat to the security of energy utilization, conversion and transaction of intelligent building clusters.

Generally speaking, the energy supply and demand data of intelligent buildings have security attributes such as confidentiality, integrity, availability, authenticity, reliability and non-repudiation. Due to the reasons of the management system itself, the security attributes of data are affected, resulting in certain vulnerabilities, including technical vulnerabilities and management vulnerabilities, such as data authenticity is not verified, data encryption measures are not taken, and reasonable security policies are not configured. The main threats that intelligent building energy supply and demand data may face are storage security threats, network security threats, privacy threats, advanced persistent threats and other threats. In order to maintain the balance of energy supply and demand of intelligent building clusters, it is necessary to ensure the safety of energy supply and demand data from the above aspects.

Traditional energy linkage modes can be divided into centralized and decentralized [26]. At present, the related research and engineering practice mainly focus on centralized scheduling mode, that is, the central operation layer is constructed for centralized calculation and energy distribution. Because of the high communication pressure and low operation efficiency in the decision-making process system, this model is not suitable for the application in the supply-side and demand-side energy management scenarios of intelligent buildings studied in this article. However, without a central organization, the decentralized energy linkage mode can realize the independent operation and collaborative management of operators. Although it can be applied to the research scenario in this article, it lacks supervision and cannot resist malicious attacks.

A large number of researchers have gradually explored the application and prospect of blockchain in the fields of power transaction market and even energy internet. It is considered that alliance blockchain or private blockchain is a highly distrusted and decentralized database, in which the calculation process can be transparent, the information cannot be tampered with, the shortcomings of decentralized energy linkage can be made up, various threats to energy supply and demand data of intelligent buildings can be effectively avoided, and the sharing, availability, security traceability and high efficiency of supply and demand data can be realized. However, the related research results mainly focus on power systems, such as decentralized coordinated control among distributed sources in microgrids [27], auditing the integrity and effectiveness of energy flow and financial transactions [28] and decentralized energy interaction and capital flow optimization among multiple microgrids [29]. Few scholars have studied the application of blockchain technology in different energy interaction and linkage including DC, AC and heat.

Moreover, in the supply-side and demand-side energy linkage model of distributed intelligent buildings, the sub-models of thermal and electrical system have equal status. The operating parameters of all sub-models are independent of each other, and only the consistency variables in the collaborative computing process need to be exchanged. According to the advantages and disadvantages of decentralized linkage model, the similarity and complementarity of blockchain technology are shown in Table 1. From the table, it can be seen that blockchain technology is expected to become the underlying technical framework for building energy linkage between supply-side and demand-side of decentralized intelligent buildings. Based on the characteristics of blockchain technology, this article analyzes the feasibility of applying blockchain technology to the research scenario in this article, and summarizes the specific technical advantages in the following four aspects:

1) Improve the security level and stability of energy utilization, conversion and transaction of intelligent building clusters, and ensure the property safety of buyers and sellers of energy transactions.

2) Solve the privacy leakage problem of energy supply and demand data of intelligent buildings, and improve the privacy of transactions on the premise of ensuring the efficiency of energy transactions.

3) Realize the efficient and perfect energy transaction matching mechanism and supervision mechanism, and promote the interconnection of hardware data acquisition equipment of IoT in intelligent buildings.

Table 1. Feasibility of applying blockchain in decentralized energy linkage model

Contrast items	**Blockchain technology**	**Decentralized energy interaction**
Similarity	Encryption algorithm can encrypt the user's identity information, other nodes can't view the user's identity information, but can only read the corresponding digital signature.	Operators do not need to disclose their own system parameters and equipment operation.
	There is no whole management organization in the network, and the data is jointly maintained and supervised by nodes.	There is no central operation layer in the system, and operators communicate with each other and cooperate with each other.
	All running rules are written into the intelligent contract, and the execution command is automatically triggered when the condition is reached.	Each operator needs to execute commands according to the operation model and algorithm.
Complementarity	Encryption algorithm ensures that the identity information corresponds to the digital signature one by one. If the identity information changes, the signature will be invalid.	The internal information of the system is easy to be calculated and changed privately.
	The operation process of intelligent contract is open and transparent, and nodes can view the operation data at any time.	The fairness of the leadership or aggregation process is difficult to verify.

Therefore, in order to improve the reliability and stability of power generation and power supply of intelligent buildings as much as possible, promote more energy transactions of intelligent building clusters, and improve the energy management efficiency of intelligent buildings, referring to the relevant achievements of blockchain in solving the problems of energy proximity transactions [29], preventing false transactions [30], preventing transaction information from being tampered with [31], data single point failure [32], preventing privacy leakage [33], and unauthorized access traceability [34], it is necessary to verify the matching, efficiency, transaction security and real-time service of the negotiation mechanism of intelligent building energy service system supported by blockchain, and complete the authenticity verification and security protection of energy supply and demand data of intelligent buildings based on blockchain, which also provides theoretical basis for further constructing scientific distributed energy transaction decision-making research of intelligent building clusters.

4. Research Status and Development Trend Analysis of Distributed Energy Transaction Strategy of Intelligent Building Clusters

The energy linkage mode between the supply-side and the demand-side of intelligent buildings is decentralized, which produces small transactions, frequent transactions and involves many users. At the same time, the energy on the supply-side is also characterized by intermittence and fluctuation, so it faces problems such as real-time energy price fluctuation, dynamic adjustment of power consumption plan and frequent electricity bill settlement. In this case, facing the users who can consume as well as produce energy, the intelligent building energy transaction of traditional centralized management can neither effectively protect the interests of all users involved in the transaction, nor coordinate the power consumption behavior of all users. So there is an urgent need for an equal and efficient transaction mechanism that can adapt to the characteristics of distributed energy transaction to deal with the rapid changes of information and energy prices in the transaction process. P2P transaction is a new transaction mode based on the concept of computer overlay network. Because it helps to lower the threshold of power transaction and the cost of users using energy, it has been widely studied to help users realize free power transaction. At present, it has been demonstrated and applied in Britain, Germany, the United States and other countries [35-37]. Previous studies have shown that through demand-side management, the consumption of clean energy can be increased by 2% ~ 15% [38]. At present, although some literatures have considered the influence of demand-side response factors in the research of P2P transaction mode [39-41], the transaction process is shown in Figure 3. However, they failed to analyze the impact of regulation strategy and alliance unified pricing on energy consumption and transactions in combination with specific load carriers, and failed to consider how to accurately describe the relationship between participants in each link of transactions and the impact of distributed transactions on the operation of intelligent buildings. Therefore, the related results are not applicable to the supply-side and demand-side energy management scenarios of intelligent buildings studied in this article.

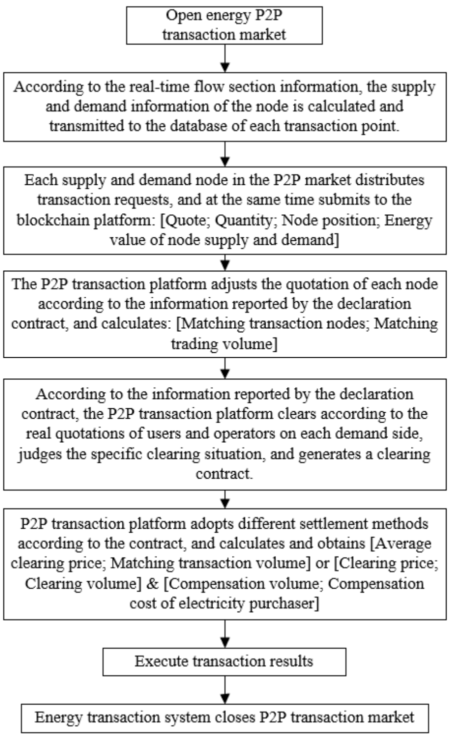

Figure 3. P2P transaction process considering demand-side response factors

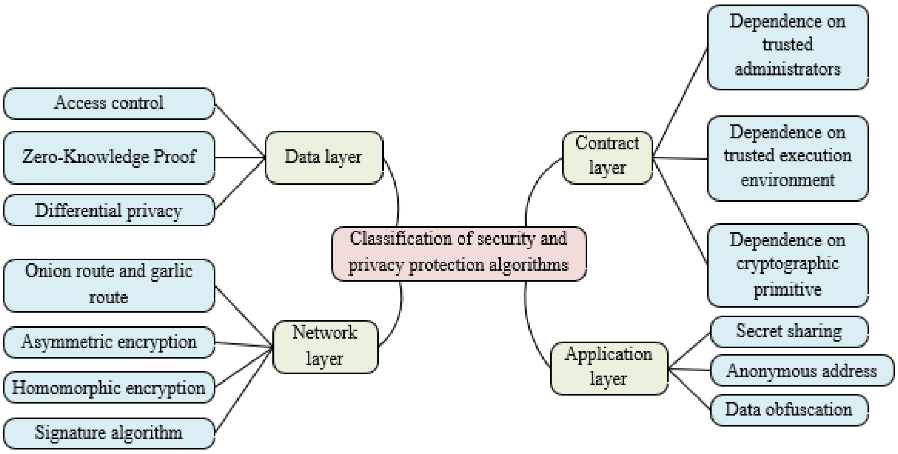

Figure 4. Classification of security and privacy protection algorithms for distributed energy transaction system of intelligent building clusters

Table 2. Landing projects of energy transaction systems in various countries

Project Name	Country	Blockchain	Scale	Security technology	Characteristics
Brooklyn Microgrid	US	*TransActiveGrid*	Small	Ledger encryption	Encrypted distributed ledger technology: scalable intelligent contract
Sunchain	France	*Hyperledger*	Small	/	The share of electricity produced and consumed can be traced back.
Power Ledger	Australia	*Powerledger*	Large	Cryptocurrency	Pay with POWR and Sparkz tokens
Sun Exchange	South Africa	*Blockchain*	Small	Cryptocurrency	Transact with the specified SUNEX token
ElectronConnect	Britain	*Electron*	Large	Role-based access control	Establish a distributed natural gas and power computing system
Interbit	Canada	*Blockchain*	Small	Cryptocurrency	Transaction information on blockchain can be verified by experiments and traced.
TransActive Grid	US	*Ethereum*	Small	/	Use Ethereum blockchain: Transact automatically and safely
Distributed electricity transaction	China	*Hyperchain*	Large	Zero—Knowledge Proof, Ledger encryption	Support multiple energy transactions: avoiding complex iterations of large-scale distributed devices

Energy transactions conducted in an isolated way in intelligent buildings will not rely too much on central organizations, which makes it possible to create energy transactions based on blockchain, which, as an open distributed account book, can not only protect the energy supply and demand data of intelligent buildings, but also effectively, verifiably and permanently record the transaction behavior between the two parties of energy transaction in intelligent buildings.

At present, the energy transaction system based on blockchain is no longer a theoretical topic, and there are many landing application projects for reference [42], see Table 2. Figure 4 summarizes the classification of security and privacy protection algorithms of distributed energy transaction system of intelligent building clusters applied in existing cases. Existing cases all use blockchain technology to provide transaction channels or platforms for distributed energy, while continuous two-way auction mechanism is mainly adopted in transaction mechanism [43]. This transaction mode easily leads to different prices of energy purchased or sold in different transaction rounds in the same transaction cycle, and poor fairness of the transaction market and adequacy of distributed energy consumption. Other distributed energy transaction mechanisms or transaction models based on blockchain technology lack matching intelligent contracts, which is not conducive to practical engineering.

According to the above analysis, it can be known that it is a relatively important research content to use blockchain technology as the infrastructure construction platform to complete P2P electric energy transaction of distributed energy in intelligent building clusters. Therefore, referring to the existing background analysis of P2P electric energy transaction [44], it is necessary to verify the feasibility of combining blockchain with distributed energy transaction of intelligent building clusters. It's essential to construct a P2P electric energy transaction mode suitable for distributed energy transaction of intelligent building clusters under blockchain, provide the authorization mechanism of the corresponding transaction network, the consensus mechanism and intelligent contract in different transaction scenarios, and complete the architecture design and development of decentralized application. The above key research steps are the core content of building a reasonable distributed energy transaction strategy under the isolated island mode in intelligent buildings, and are also an important way to transform this research from theory to technology.

5. Conclusions

According to the retrieved data at present, although a lot of research work has been done on load demand response, data security and distributed energy transaction methods at home and abroad, there are still the following challenges when directly applied to the energy management of intelligent building clusters:

(1) The existing energy demand forecast models of intelligent buildings ignore clean energy power generation and DC load, and do not fully explore the application mode of data-driven technology, so it is impossible to realize the true source-load joint forecast and accurate electric-thermal load response.

(2) The security of different types of energy supply and demand data, including DC, AC and heat, cannot be guaranteed, which affects the interaction and linkage of energy between supply-side and demand-side of intelligent buildings, and further leads to energy waste.

(3) The technical performance advantages of existing blockchain are restricted by the energy types and transaction links on the supply-side and demand-side of distributed intelligent buildings. Therefore, it is necessary to establish a more efficient distributed energy P2P electric energy transaction model.

To sum up, introducing the existing energy blockchain technology into the energy management of intelligent building clusters deserves in-depth study. This article argues that it is necessary to innovate the source-load joint forecast model of intelligent building clusters. The valuable research directions in the future are to expand the application mode of data-driven technology in the load forecast research of intelligent building clusters, verify the matching, high efficiency, transaction security and real-time service of the intelligent building energy management negotiation mechanism based on blockchain, realize the authenticity verification and security protection of energy supply and demand data, use blockchain technology as the infrastructure construction platform to complete P2P electric energy transaction of distributed energy in intelligent buildings, and transform related research from theory to technology. The above research directions are cross-cutting and novel, and have important theoretical significance and practical value.

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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 they have no conflicts of interest.

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