Energy Consumption Monitoring System of the Large-scale Building Using Insect Intelligent Building Technology

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Abstract: In this paper, the methodology using Insect Intelligent Building (I^2B) technology for establishing energy consumption monitoring system of public buildings is prevailed. The computing process node and distributed algorithm are utilized to implement the energy consumption collection and data transmission and data pre-processing. Taking a commercial building as a case study, CPNs are applied to set up the building energy consumption monitoring system, with the Spanning Tree Algorithm for generating network topology， and BPNN method for solving abnormal data and recovering missing data. The research results demonstrate the proposed method can effectively improve the performance of plug-and-play and self-identified and self-configuration of energy consumption monitoring system.

Keywords: Energy consumption monitoring system; Building energy conservation management; Insect Intelligent Building technology; Computing process node; Insect intelligent algorithm

1 Introduction

According to the *Statistics of the Annual Development Report on Building Energy Conservation in China 2018*, construction operation accounts for about 20% of the total energy consumption with the rapid development of new urbanization in China [1]. As shown in Fig.1, the proportion of building energy composition is the second largest energy consumption terminal after industrial and increasing by years. Building energy conservation is extremely urgent.

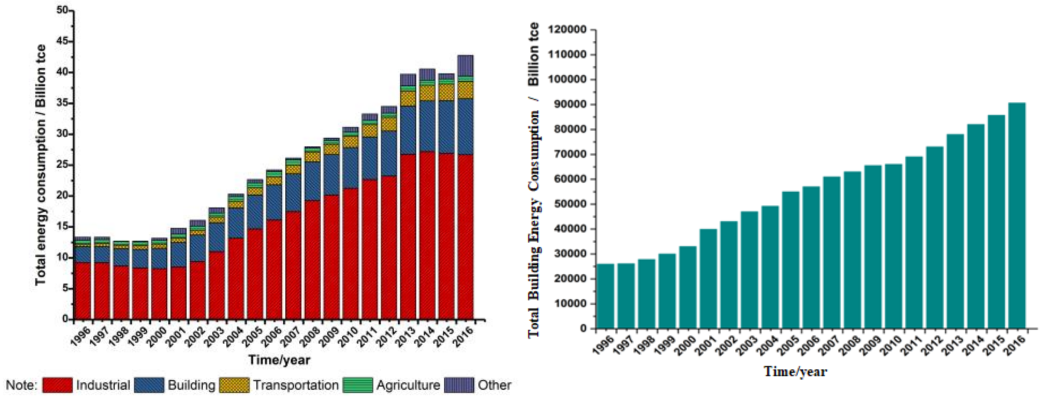


Fig.1 Energy consumption in different areas of China (1996~2016)

Building energy monitoring system refers to the hardware system and software system for the public buildings, which used the remote transmission and other means to collect energy consumption data to realize the online monitoring and dynamic analysis of building energy consumption [2]. From 1972 to 1977, Princeton University conducted building energy consumption measurement for townhouses of Twin Rivers in New Jersey. They studied the influences of room temperature, energy consumption and other conditions to American building energy consumptions [3], [4]. Professor Karlin put forward the building energy monitoring system in the 1980s, and gave the methods to improve the energy efficiency of the building electromechanical system from the aspects of planning, design, installation and operation [5]. At the end of last century, European and American countries established energy consumption statistical databases to ensure the maximum energy efficiency of buildings through energy audit of existing buildings. Later, the UK and the US established NDBS (Non-Domestic Building Stock) database [6], [7] and CBECS (Commercial Buildings Energy Consumption Survey) database [8], [9]. Comprehensive statistics on the energy consumption and carbon emission of various types of buildings based on the database are carried out. On the one hand, it is used for the calculation of carbon emission in international regulations; on the other hand, it is used to test the implementation effect of building energy conservation. In recent years, green building and intelligent building develop rapidly. Professor Brooks of Massachusetts Institute of Technology introduced multi-agent system into indoor comfort control for the first time [10]. Cai et al. proposed a general multi-agent control method, which applied the plug and play mode to the optimization of building energy system and verified the feasibility of the algorithm through an example of air-conditioning system [11]. Labeodan et al. applied multi-agent technology in building operation to coordinate energy supply of buildings and smart grid [12]. Alberto et al. used multi-agent technology to simulate the distributed energy network in cities, aiming to get the best distributed energy design strategy [13]. Xu et al. plan, schedule, and coordinate all the storage devices together with schedulable loads in a building facilitated by microgrid technology [14].

However, various building energy consumption monitoring systems generally have poor performance in actual operations [21]. The large-scale public construction energy consumption monitoring system under the hierarchical centralized structure completes the system configuration of building energy consumption monitoring points according to the current building entity. But the whole life cycle of building including the phase of planning, design, bidding, construction, completion acceptance and property management. Its business format, functional division, system structure and operation mode of the building are all changing process. The current building management system exist problems: (1) Energy consumption data format disorder. (2) Difficult to upgrade. (3) Poor expansion of energy consumption system. For post-reconstruction building, it is difficult to install monitoring system and the renovation project will damage the finished product.

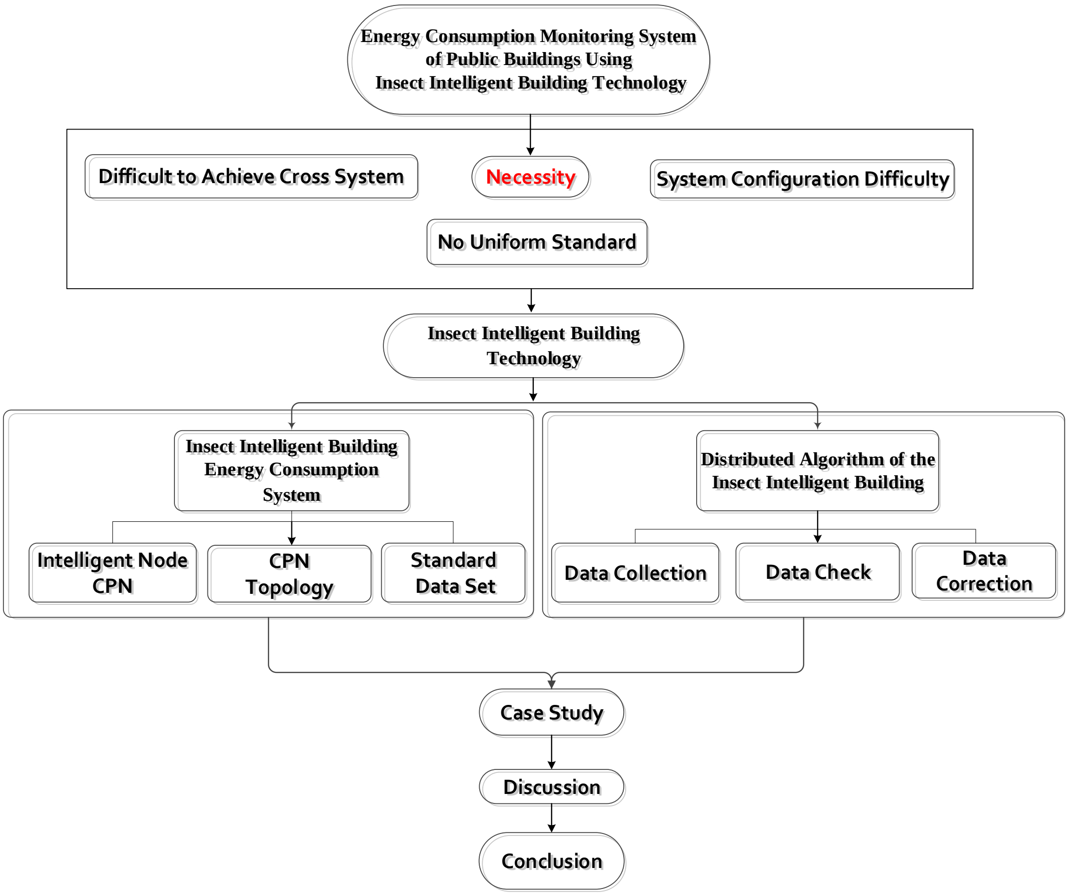


Fig.2 Structure of the paper

A building energy consumption monitoring structure with characteristics such as easy extension, plug-and-play and convenient implementation has never been more expected. Hence, in this paper, energy consumption monitoring system of public buildings base on Insect Intelligent Building (I^2B) technology is proposed with energy consumption estimation of building zones and equipment. In Fig 2. The paper is organized as follows: Section 2 introduces the principle and architecture of building energy consumption monitoring system. Section 3 describes the proposed devices deployment optimization method. In the Section 4, a case using the proposed method is studied, which is a commercial building. And, performances of the conventional method and the proposed novel methodology are discussed. Finally, conclusions are provided in Section 5.

2 Insect intelligent building energy consumption monitoring system

This section focuses on the research progress of the national key research and development project *New Building Intelligent System Platform Technology*. The theoretical problems of intelligent node and its topological structure design, building energy consumption standard data set, parallel energy consumption data calculation mode in the energy consumption system of intelligent buildings are analyzed in turn.

2.1 Energy consumption monitoring system and intelligent nodes

Building energy monitoring refers to the comprehensive monitoring and management analysis of energy plan, prediction, equipment, quality, production scheduling and logistics scheduling through the collection, processing and analysis of energy data. Its main management links include energy input, energy conversion, energy consumption analysis and energy-saving technology progress [22].

Buildings serve their users, while the building space and various electromechanical equipment and electromechanical systems distributed in the building space. The centralized building energy consumption monitoring system is based on the longitudinal monitoring of building energy consumption data of electromechanical systems (such as lighting system, air conditioning system, water supply and drainage system, etc.). However, the building functions often take the space as the horizontal function (such as meeting room, office, dormitory, toilet, etc.). Difference with traditional building energy consumption system was shown in Fig.3

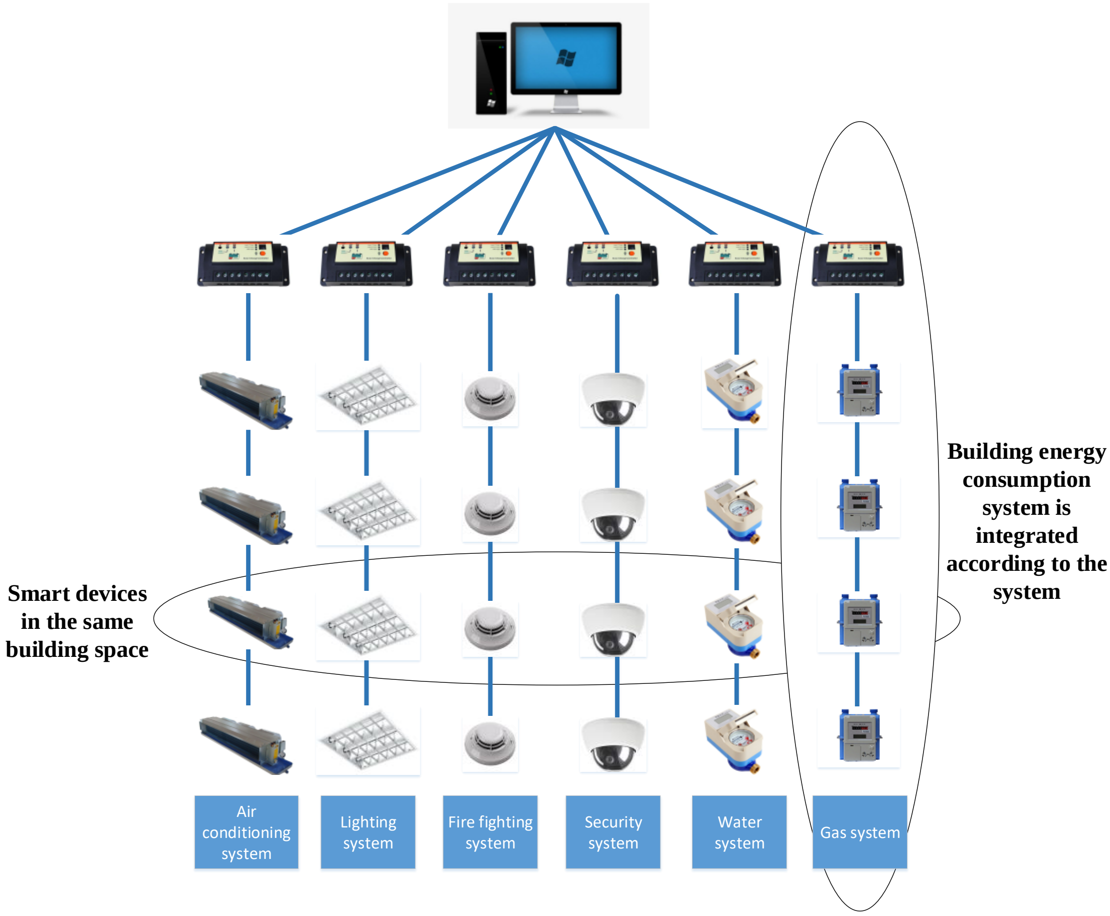


Fig.3 Difference with traditional building energy consumption system

The insect intelligent building energy consumption monitoring system consists of a large number of intelligent nodes CPN (Computing Process Node). Through mapping the standard data set of building energy consumption, the collection of building energy consumption data is completed. According to the operation mechanism of the building, each CPN node is connected to each other through six RJ45 network ports to form a group of intelligent building energy consumption monitoring system as shown in Fig.4.

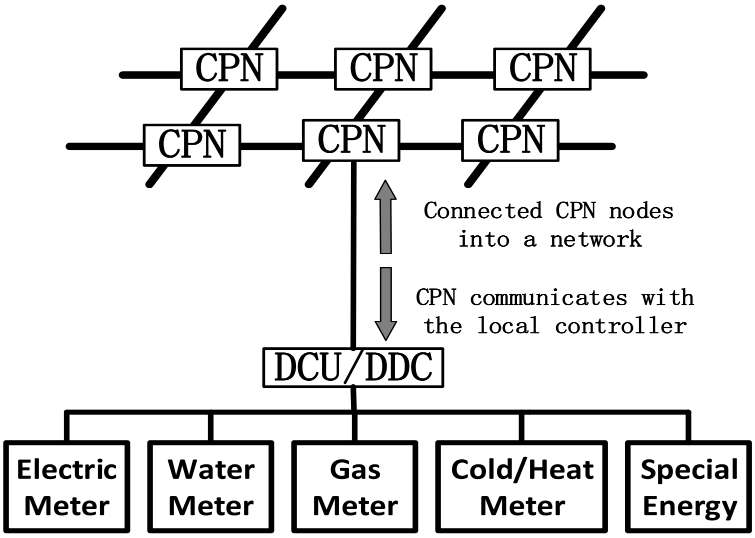


Fig.4 Schematic diagram of insect intelligent building energy consumption monitoring system

2.2 Topology of intelligent node CPN

2.2.1 Two types of basic unit

There are two types of basic units in building energy consumption monitoring system. The first one is building space unit called smart zone, and the other is electromechanical equipment called smart zone. The CPN nodes monitor various energy consumption of the building space units or electromechanical equipment information. Multiple CPN nodes are connected to each other to form an insect intelligent building network, collaboratively complete building energy monitoring, so how to divide building space units and electromechanical equipment is particularly important [23].

Current, the smart zones could be office rooms, conference rooms, lobbies and corridors, etc. The device zone refers to chillers, pumps, fresh air units, elevators and so on. Although the function, size and inside devices of a zone may be different, but the principles of the division are:

(1) The devices type and relationship in a zone are similar.

(2) Standard smart zones should be defined with a recommend size varies from 20 m^2 to 50 m^2.

(3) The standard information should be set according different types and devices.

The designers can divide a building into lots of pieces according the principles with the standard space unite and devices. In the process of designing an intelligent building system, designers can divide the building space into a unit that can assign equipment to different units, and link the operating parameters of the equipment to the standard information set. The unit of design can only be a subset of one of the standard units.

Similar definitions apply to purchased equipment, like coolers, air handling equipment, power stations, pumps, cooling towers, elevators, etc. The information set for standard devices describes only the information related to the control of the build system and no internal parameters are included. The same type of equipment from different manufacturers can be described by a standard device. For a particular device, its parameters override a subset of the standard information set. Typically, 10 to 20 standard devices may cover the most common devices in a building.

With standard space units and standard equipment, designers can divide the smart building into several blocks, which are basic units or simplified basic units. The standard information set of each unit is the standard model of different components of the building system, which is the basis of plug-and-play, self-identification and self-configuration.

2.2.2 CPN network and communication

As defined above, all basic cells have the property of location. A three-dimensional network will be formed if basic units are connected to adjacent units according their location. The structure of network can be the architectural space or mechanical system. The characteristics of the above network are:

(1) All nodes are equal because of no center network, and nodes can only communicate with neighbors.

(2) The network can be extended. Extending the network by connecting nodes to neighboring

nodes in the network is very flexible.

According to analysis, the impact of most physical processes in a building is short-term, it makes sense to communicate only with adjacent nodes. The network does not require global IP, so the network layer protocol is unnecessary. For each node, only six relative addresses are required, which represents six possible neighbors. Corresponding to the direction of space, they can be: in front, behind, left, right, above and below. The underlying protocol can adopt common communication standards such as Ethernet [24].

2.2.3 Computing and control of decentralized system

Since there is no central node in the system, decentralized computation is required. In a traditional system, central nodes collect data and perform calculations, much like the brain. However, in a decentralized system, computation is done through the collaboration of all nodes, such as a neuron system. In general, a control strategy can be thought of as a series of discrete computations. If decentralized computation is feasible, decentralized control is feasible [22].

2.3 Building energy consumption structure

The building energy consumption standard data set is the basis for the CPN node to be able to interact with adjacent CPN nodes. The building energy consumption standard information set is the collection of building space, electromechanical equipment information in the building. They are the corresponding information of each building space and electromechanical equipment, and both of them are stored in a fixed address [21]. Based on the building energy consumption standard data set, the group intelligent building system has the following advantages:

(1) Cross-system building energy consumption information exchange.

(2) Avoid global configuration of terminal monitoring point address.

(3) System adaptability enhancement.

2.4 Decentralized algorithm of the Insect Intelligent Building Monitoring System

The CPN nodes in the intelligent building energy monitoring system are connected into a network according to the construction space unit structure and the electromechanical system pipe network relationship. The whole network constitutes a *Supercomputer* to monitor the running state of the building. The system is consistent with the function of the original centralized building energy consumption monitoring system, except that the system data processing task is dispersed to each CPN node, and distributed parallel computing method is adopted, which reduces the performance of building energy consumption monitoring equipment and improves the flexibility, expansibility and reliability of the system [24].

2.4.1 Decentralized building energy consumption data collection

The distributed intelligent building energy consumption monitoring system can give full play to the computing capacity of each CPN nodes. CPN nodes only need to do local data processing and update the calculation results to complete the integration of energy consumption information of the whole network. Compared with the centralized building energy consumption monitoring system, this parallel computing model can not only improve the speed of information collection, but also improve the accuracy of system operation because each CPN node will check the data when receiving the information from the neighbor node.

In the large public building energy saving monitoring technology based on insect intelligent platform, data driver DCU (Drive Control Unit) collects the energy consumption information of building space units or electromechanical equipment. CPN nodes map the building energy consumption standard data set in DCU and connect to a group of intelligent network to realize the summary of building energy consumption information. When receiving the summary instruction of building energy consumption information, the undirected graph of related spatial units and mechanical and electrical equipment CPN nodes was converted into an ordered minimum tree by using the generative tree algorithm, and then the energy consumption data was summarized by using the distributed sum algorithm. In the Insect Intelligent Building Monitoring system, we mainly use the spanning tree algorithm

As shown in Fig.5, the spanning tree algorithm refers to a spanning tree in which all sub-graphs of a connected graph G contain all the vertices of G in the field of graph theory, and the spanning tree is a minimum connected subgraphs containing all the vertices in the connected graph [25].

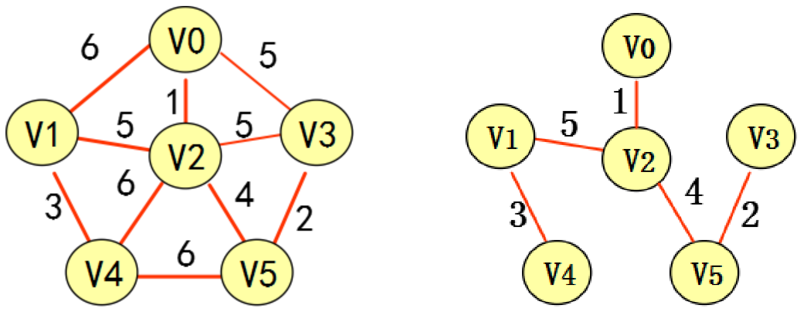


Fig.5 Spanning tree algorithm

When a CPN node initiates a building energy consumption information summary instruction, such as "7-layer space unit building energy consumption collection", the group intelligent building energy-saving monitoring system uses an automatic topology recognition algorithm to establish a 7-layer space unit CPN node topology of a building. Structure undirected figure $G(V,E)$, where V represents all CPN nodes in the undirected graph and E represents the connection connecting all CPN nodes in the undirected graph. Using the spanning tree algorithm to establish the minimum tree with the CPN node as the root node, the building energy consumption collection can be equivalent to the summation problem f, so the building energy consumption information is as shown in equation (1):

$$Q = f(x_1, x_2, x_3, \ldots x_n) \qquad (1)$$

Where *x* represents the *i* energy consumption data of the corresponding CPN node building energy consumption standard data set, $x_i \subseteq V$.

Based on the spanning tree algorithm to achieve building energy consumption information collection, the overall calculation efficiency can be effectively improved. It can be deduced that the relationship between the number of steps S and the number of participating CPN nodes n using the distributed spanning tree algorithm is obtained in equation (2):

$$S = \frac{2\ln(B-1)n}{\ln B} \sim o(\ln n) \qquad (2)$$

However, if the hierarchical energy consumption monitoring system is used to collect the building energy consumption data, all the energy consumption data are transmitted to the root CPN node for calculation, and the relationship between the number of calculation steps S and the number of participating CPN nodes n is obtained in equation (3):

$$S = 2[B + (B-1)(n-1)] \sim o(n) \qquad (3)$$

Where B is the number of adjacent CPN nodes, $1 \leqslant B \leqslant 6$.

The energy consumption data collection of building energy consumption monitoring system based on group intelligence mainly has the following steps:

Step 1: According to the division principle of building space units and mechanical and electrical equipment, complete the setting of CPN node topology structure. CPN node network should cover not only all kinds of traditional energy systems of buildings, but also all kinds of building energy consumption equipment. Topological connections between CPN nodes in the plane were completed according to architectural functions or mechanical and electrical equipment. Topological connections between CPN nodes in different floors were completed through Wells and stairwells.

Step 2: DCU is set in each building space unit. DCU obtains the corresponding data through Ethernet, ZigBee, WiFi and other communication methods and smart electricity meters, smart water meters, smart gas meters and cold/heat meters arranged in the building space. The mechanical and electrical equipment shall be equipped with a built-in DCU unit to collect energy consumption information related to the equipment and store it in the building energy consumption standard data set. CPN node completes the collection of energy consumption information of the spatial unit or electromechanical equipment by mapping the building energy standard data set in DCU.

Step 3: When a CPN node initiates the collection of energy consumption information, the local related CPN nodes retrieve the energy consumption data of the corresponding position from the building energy standard data set according to the instruction. Based on CPN node topology spanning tree, "one hop" data transfer method is adopted. After receiving the information, the neighbor CPN node will also complete the information transmission or retrieve the local energy consumption data according to the original instruction and sum with the data from the neighbor. Then, the processed information will be transmitted to the next neighbor CPN node. Iteration by iteration, when no more CPN nodes are passing information, the task is completed. The CPN node that ultimately initiates the task receives the corresponding instruction result.

2.4.2 Decentralized building energy consumption data check

Accurate building energy consumption data is the basis of building energy consumption data statistics. If the statistical data is mixed with abnormal values, the corresponding analysis data deviation will increase, and even lead to the chaotic operation of the building energy consumption control system, so the building energy the verification of data consumption is of great significance.

The building energy consumption data is based on the energy conservation law, the thermal equilibrium law and other related constraints. So there is a correlation between several variables of the building energy consumption data. Therefore, the check of the data can be realized by the equality constraint of the equation (4) and the inequality constraint.

$$\begin{aligned} h_i(x_i, x_{i1}, x_{i2} \cdots x_{im}) \le 0 \\ g_i(x_i, x_{i1}, x_{i2} \cdots x_{im}) = 0 \end{aligned} \quad (4)$$

In the building energy-saving monitoring algorithm based on the insect intelligent platform, the equality constraint is that the sum of the corresponding energy consumption data of each space unit or electromechanical device CPN node should be equal to the monitoring value of the energy consumption data of the region or system CPN node as shown in formula (5):

$$f(x_n) = f(x_{n1}) + f(x_{n2}) + f(x_{n3}) + \ldots + f(x_{nn-1}) \quad (5)$$

The inequality constraint adopts the RAYDA criterion (the 3σ principle), that is, in the standard normal distribution, the probability that the data falls within the interval $(\mu - 3\sigma, \mu + 3\sigma)$ is greater than 99.7% as shown in Fig.6, and the probability that the sampled data is not within the range is less than 0.3% [26], so when the data is not in the interval $(\mu - 3\sigma, \mu + 3\sigma)$, the data can be considered as an outlier, and the local CPN node is used to store the historical energy consumption data, and the formula (6) and the formula (7) are used to find the data.

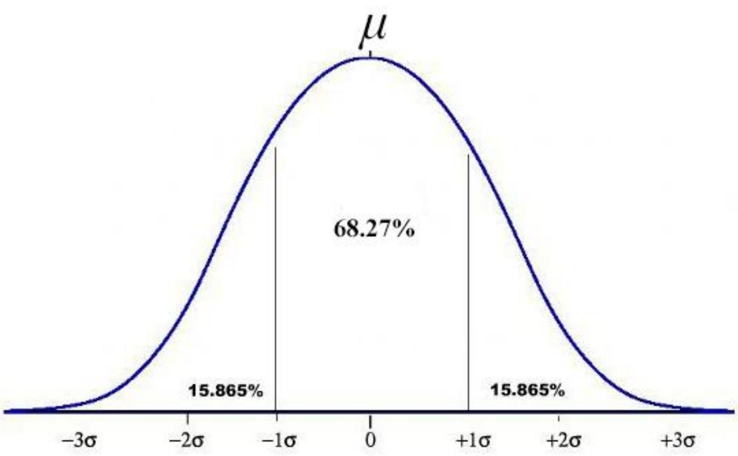


Fig. 6 RAYDA criterion

$$\mu = \frac{x_{i1} + x_{i2} + x_{i3} + \ldots + x_{in}}{n} \quad (6)$$

$$\sigma = \sqrt{\frac{(x_{i1}-\mu)^2+(x_{i2}-\mu)^2+(x_{i3}-\mu)^2+...+(x_{in}-\mu)^2}{n}} \quad (7)$$

Where x_{in} is the historical data of the corresponding energy consumption data of the CPN nodes.

2.4.3 Decentralized building energy consumption data correction

Common data correction methods include mean interpolation method, deductive estimation method, modeling prediction method, random interpolation method, maximum likelihood estimation and regression interpolation method [27]. The current building energy monitoring system does not set a missing completion algorithm for energy consumption data. When the data is found to be missing, the property personnel often supplement the data by experience.

Among the above methods, the mean interpolation method is the simplest and most widely used. According to the distance measurability of the sample attributes, this method uses the mean interpolation method to complete the missing data [28]. However, due to the influence of many factors on the building energy consumption, the randomness is relatively strong and presents a strong non-linear, so this method has a large error, which is not suitable for the correction and completion of building energy consumption data. Machine learning algorithms for its outstanding nonlinear mapping, adaptive, strong fault tolerance and other characteristics, widely used in construction load dynamic prediction [29, 30], the most widely used BP neural network model, its principle as shown in Fig.7: Firstly, the input signal by the input layer, hidden layer and output layer forward step by step, get the output value of each layer. Secondly, the output layer reverses the errors between the output value and the true value through the output layer, the hidden layer and the input layer, and corrects the unit weights in each layer with the minimum output error as the optimization objective [31]. According to the principle of short time series similarity of building energy consumption data [32], BP network is trained with historical data, energy consumption data are used to predict and fill in the energy consumption data of this time.

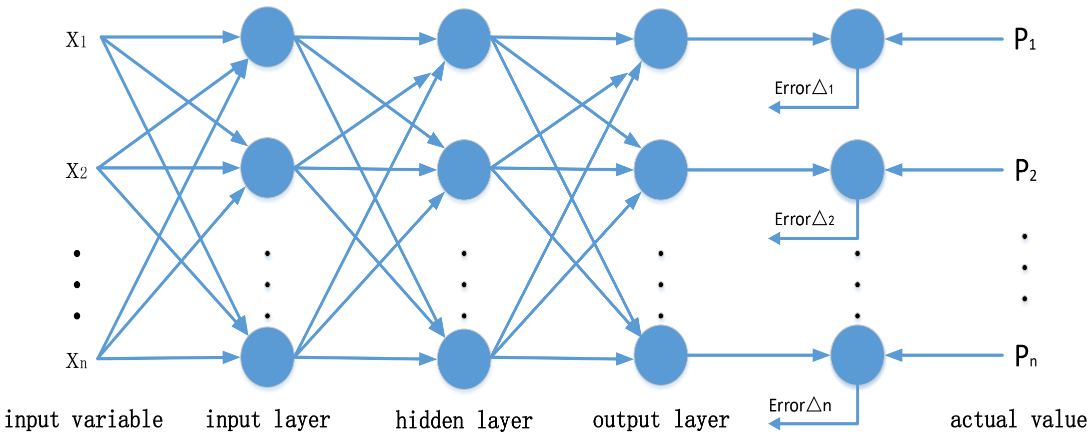


Fig.7 BP neural network schematic

3. Case Study

In order to test the insect intelligent building energy-saving monitoring system algorithm, this chapter focuses on the distributed energy consumption data collection, energy consumption data check and energy consumption data correction in the case of a commercial building energy monitoring algorithm based on insect intelligent building (I^2B) energy consumption platform. Tab.1 displays information about the building. It is a commercial building and located in 34°23′N, 108°89′E, China.

Tab.1 The information of case study buildings

Photos	
Building type	commercial
Location	34°23′N;108°89′E
Floor area(m^2)	300000

Structure type	concrete shear wall
Exterior wall	solid clay brick
External wall insulation	external insulation
Exterior window	type hollow three-layer glass window
Air conditioning	fan coil + fresh air system
Heating	radiator heating

3.1 Building space unit CPN topology

The building space units are naturally divided according to the spatial layout of the building, with the following principles:

(1) The building space unit must be continuous. The division of space units should meet the understanding of technical personnel of different majors, and intuitively correspond to the building entities as shown in Fig.8. There are 26 CPNs setting in the room and 9 CPNs setting in the corridor and 2 CPNs setting in the stairs.

(2) There shall be no overlapping spaces in any two building space units, reducing the building energy consumption error caused by redundancy and double counting of CPN nodes.

(3) There must be no missing space in the entire building, and the energy consumption information in the building will be completely counted.

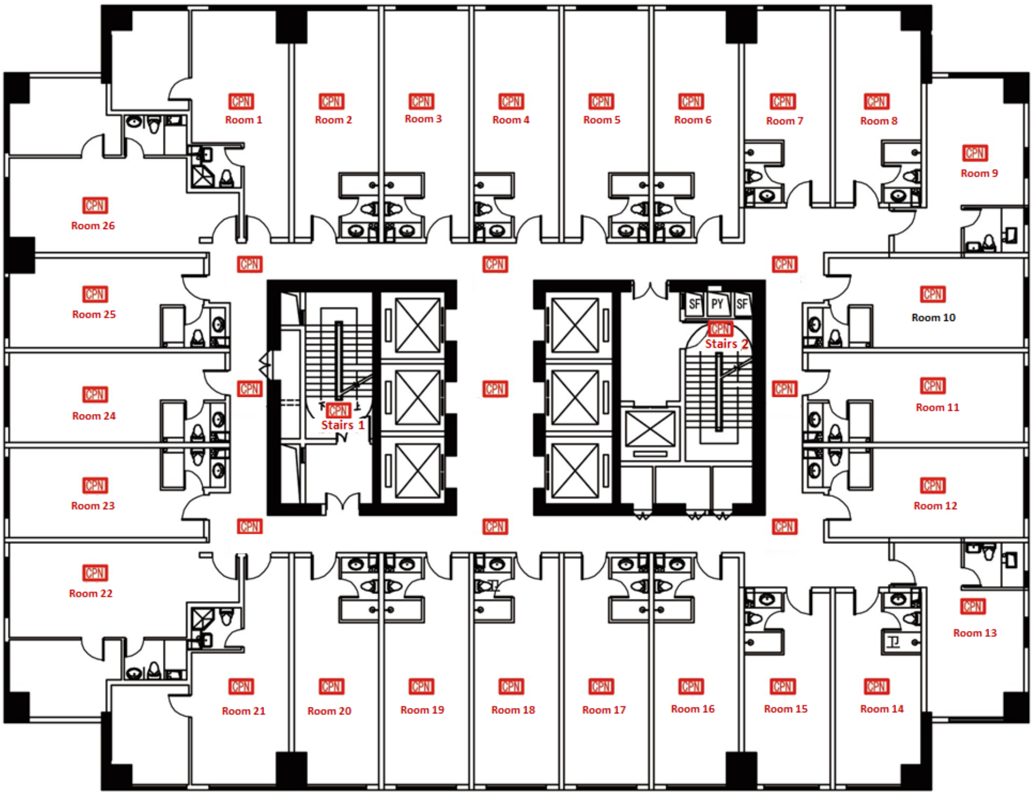


Fig.8 Topology of CPN Node in Building Plane

3.2 Electromechanical equipment CPN topology

The CPN node of the electromechanical device corresponds to the basic integrated unit of the electromechanical system. The basic unit is not simply dividing the isolated electromechanical device, but the device group surrounding the electromechanical device, which is the basic unit after the electromechanical system splitting. Electromechanical devices of a freezing station are shown in Fig 9 and Fig 10.

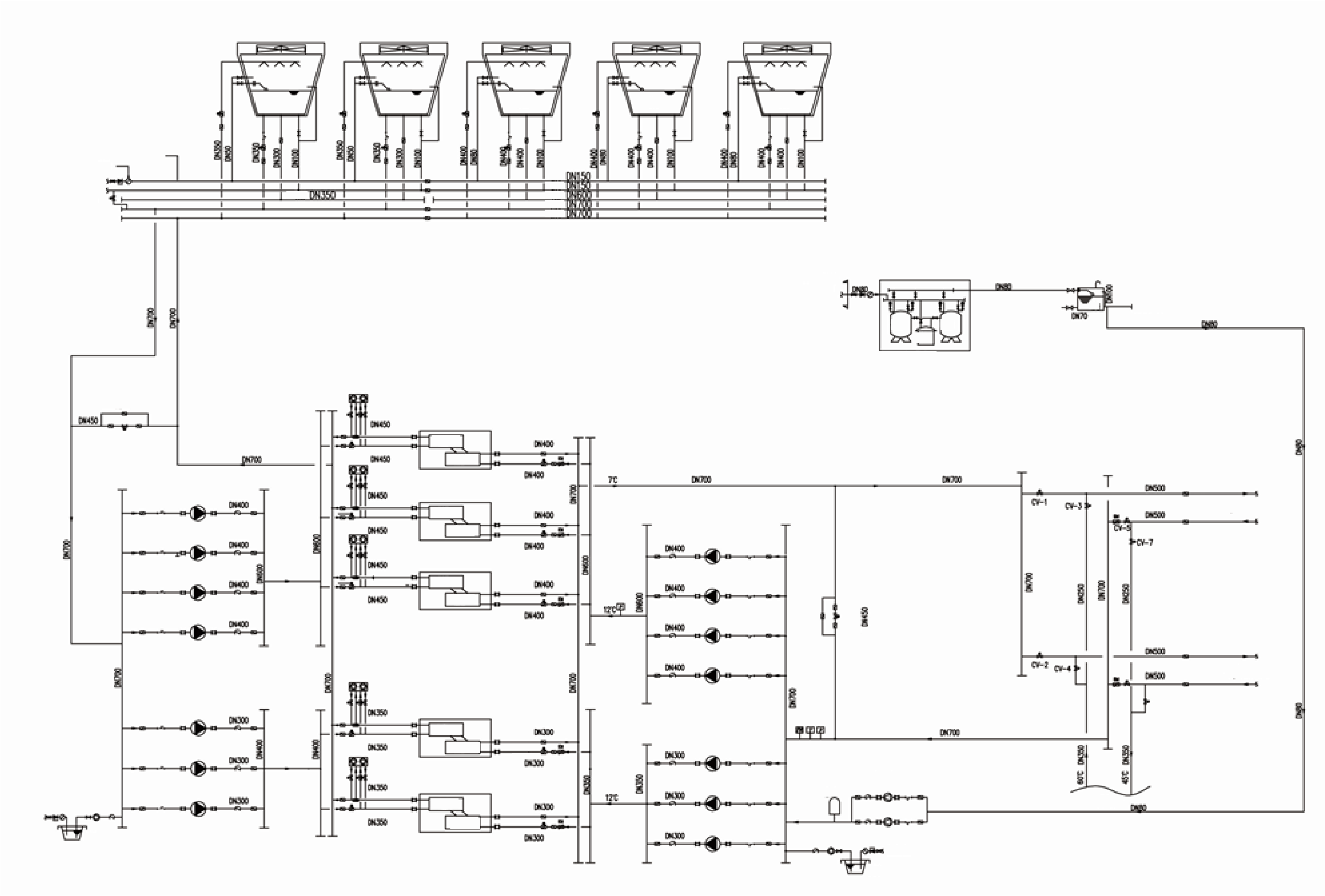


Fig.9 Building freezing station

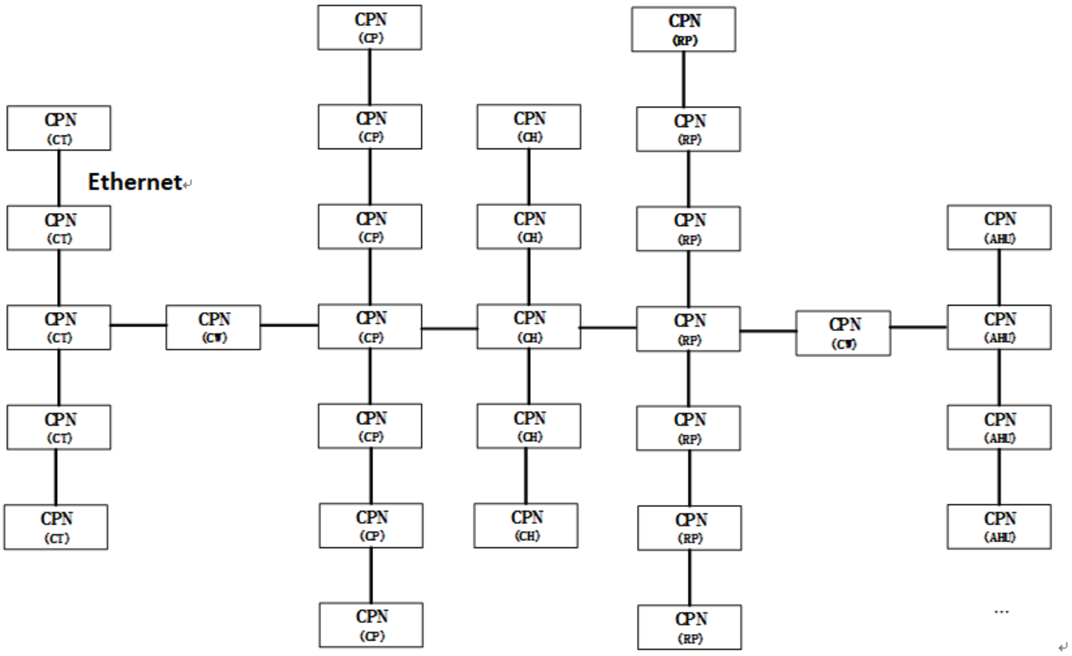


Fig.10 Topographical structure of CPN of electromechanical equipment in freezing station

According to the design of the electromechanical system of the building, the CPN node is set for each data collector, and the energy consumption data of the original data collector is uploaded to the CPN node network to establish an insect intelligent building energy consumption monitoring system, as shown in Fig.11.

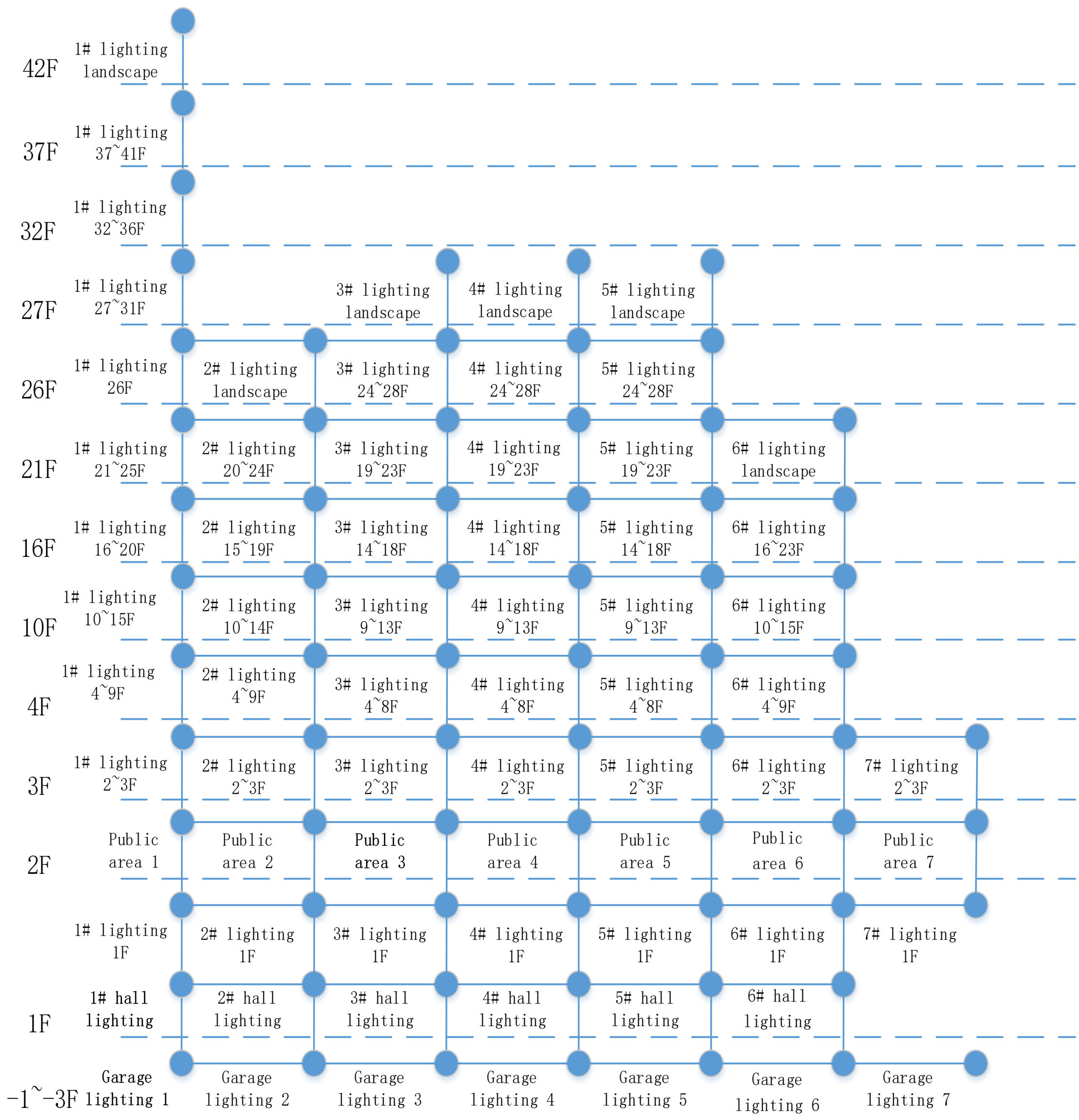


Fig.11 Commercial Building-A CPN Node Network Topology

3.3 The building energy consumption structure

3.3.1 Building space energy standard data set

Relevant domestic and foreign related literatures show that basic building information, enclosure structure information, indoor personnel activities, indoor environmental factors, outdoor meteorological factors, and operational status of building electromechanical equipment are important influencing factors affecting building energy consumption. The description of the above various types of information are shown in Tab.2.

Tab.2 Building space unit energy consumption standard data set classification

Information classification	Subclass information	Quantity
CPN name		1
Basic		1
Structural		1
Personnel		1
Indoor environmental		1
Outdoor environmental		1
Electromechanical Equipment	Lighting	16
	Socket	20
	Sun visor	4
	Power window	12
	Fan coil	4
	VAV box	4
	Radiator	6
	New fan	6
	Tap water	1
	Hot water	1
	Gas	1

Building basic information includes building function, geometric size and so on. Building envelope structure information includes information like building door and window material, heat transfer coefficient, window to wall ratio. Personnel information refers to the number of personnel etc. Indoor environmental information mainly includes indoor environmental quality; outdoor environmental information mainly refers to outdoor meteorological parameters. Mechanical and electrical equipment operating status information mainly includes switch status, energy consumption in the past one or fifteen minutes, and data format, content description are shown in Tab.3.

Tab.3 Building energy consumption standard information set (part)

Classification	Content	Data type	Unit	Description
Space unit basic information	function	int	/	0:room; 1:corridor; 2:entrance
	size	float	mm	space length
		float	mm	space width
		float	mm	space height
	coordinate	float	/	space relative x coordinate
		float	/	space relative y coordinate
		float	/	space relative z coordinate
Enclosure structure information	wall size	float	/	include roofing and ground
	wall material	float	/	data the material
	wall thermal conductivity	float	/	
	door size	float	mm	door width
		float	mm	door height
	window size	float		window width
		float		window height
	window to wall ratio	float	/	
	window transmittance	float	/	
	orientation	int	/	1: East; 2: West; 3:South; 4: North
Personnel information	number of people	int		enter: +1, leave: -1
	personnel density	float		current number/space area
	personnel identity	int		1: resident staff; 2: outsiders
Indoor environmental information	temperature	float	℃	
	relative humidity	float	%RH	
	lighting power density	float	w/m^2	
	CO_2 concentration	float	ppm	
	PM2.5 concentration	float	ppm	
Outdoor weather parameters	temperature	float	℃	
	relative humidity	float	%RH	
	wind speed	float	m/s	
	solar radiation	float	w/m^2	

3.3.2 Electromechanical equipment energy consumption standard data set

Considering that the internal control of various electromechanical devices is quite mature, and has excellent control capabilities, and commercial technology privacy between vendors, the CPN node network is only responsible for the communication of the device with other devices without directly controlling the electromechanical device. Therefore, in the building energy consumption standard data set, the information only needs to be interacted with the neighbor CPN node and the information parameters that only occur on the local device are not included in the building energy consumption standard data set. Tab.4 shows the standard energy consumption data set for pump equipment.

Tab.4 Pump standard energy consumption data set

Classification	Content	Data type	Unit	Description
Set value	pump frequency	float	Hz	
	pump start and stop status setting	int	/	0:off;1:on
	pump head	float	m	
	water flow	float	m^3/s	
Operating status	pump head	float	m	
	water flow	float	m^3/s	
	start-stop status	int	/	0:off;1:on
	pump efficiency	float	/	
	pump power	float	W	
	pump frequency feedback	float	Hz	
	1# pump in the past 15min cumulative power consumption	float	Wh	cumulative power consumption in the past 15 minutes
Performance parameter	rated lift	float	m	initialize settings according to different devices
	limited Data	float	m^3/s	
	rated power	float	W	
	rated efficiency	float	/	
	pump performance curve	float	/	
	diameter of impeller	float	mm	

3.4 The building energy consumption monitoring system based on I^2B

3.4.1 The commercial building energy consumption data collection

The building is divided into five sections: 4~8 floors, 9~13 floors, 14~18 floors, 19~23 floors and 24~28 floors. With "4 # building on December 7, 2018 (Friday) energy collection" as the research object, its power consumption including 4 # floor hall lighting, commercial lighting, public lighting, layer lighting power consumption, elevator shaft power consumption (including ordinary elevator and fire elevator), roof landscape lighting power consumption, commercial air conditioning power consumption, business and high water consumption and thermal energy consumption.

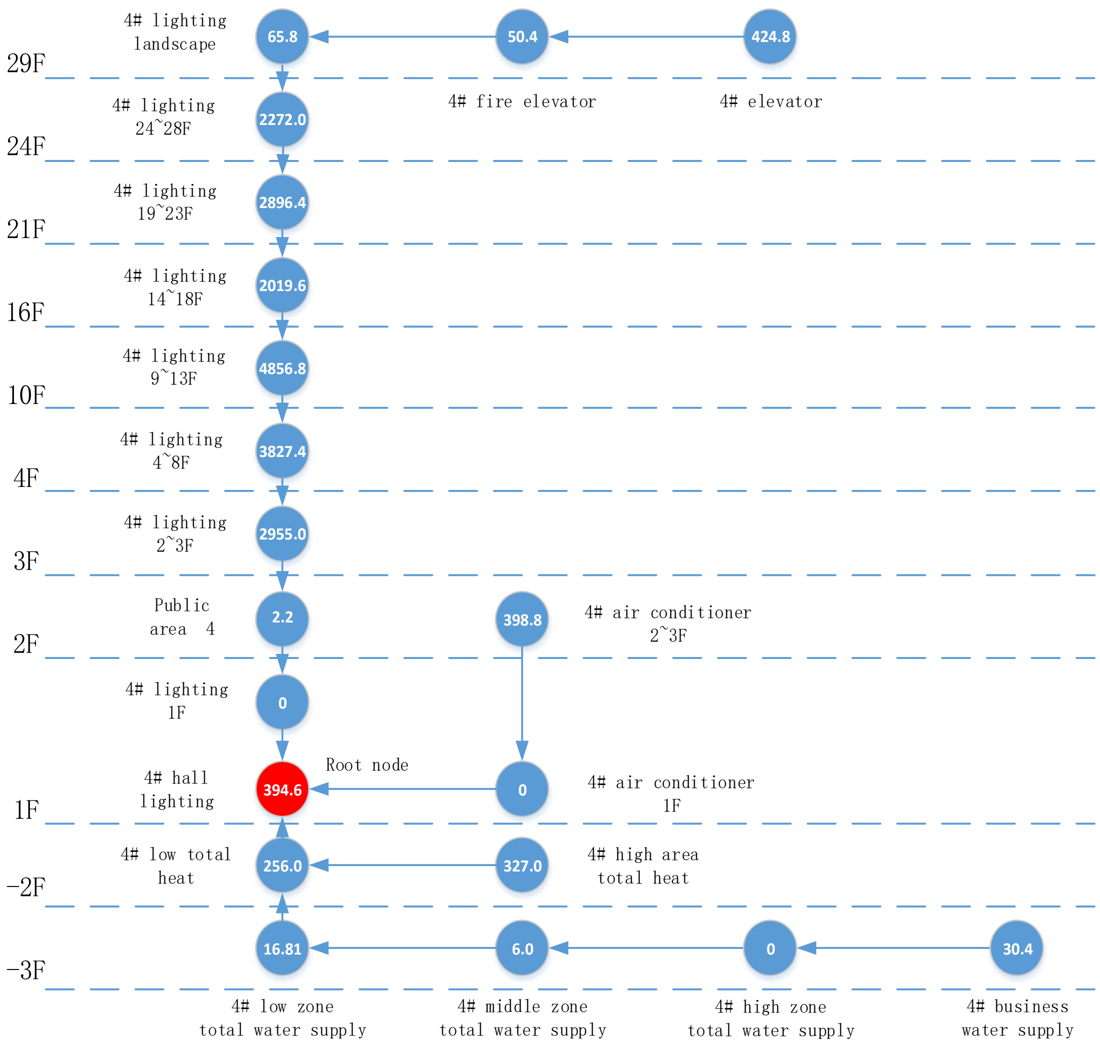


Fig.12 4# Building CPN Node Tree

When the Root CPN node in the group intelligent building energy consumption monitoring system initiates the “4# building energy collection” command, based on the group intelligent topology identification algorithm, all relevant 4# building energy consumption information CPN nodes in the group intelligent network are identified and adopted. The spanning tree algorithm generates a minimum tree of CPN nodes as shown in Fig.12. Each CPN node calls the corresponding power consumption information of the building energy standard data set, and the energy consumption iterative calculation is performed by the path in the figure. Each CPN node receives the energy consumption data transmitted by the child node, and is converted by energy equivalent, and then with the local energy consumption data. The sum is passed to the upper node, and each CPN node is calculated according to the same algorithm. The energy consumption of all CPN nodes in the spanning tree is as shown in Tab.5.

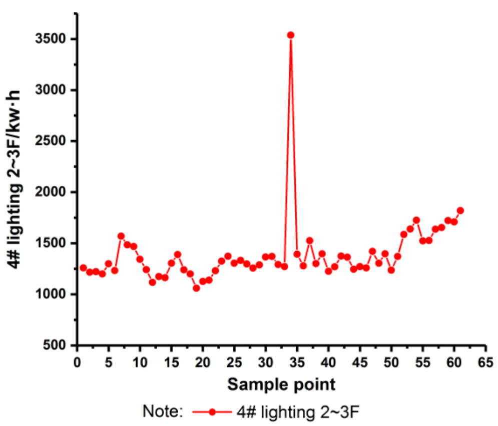
Tab.5 Commercial Building-A-4# Building December 7, 2018 Energy Consumption (tce)

Energy type	Consumption	Standard coal	Discounted coal	Energy ratio
Electricity（kW·h）	20163.8	12290 tce /kW·h	2.48	11.09%
Thermal （GJ）	583.0	0.0341 tce/GJ	19.88	88.87%
Water （t）	0.0053	24290tce/t	0.013	0.04%
Total energy consumption（tce）	-	-	22.37	100.00%

3.4.2 The commercial building energy consumption data check

Using the data check algorithm to verify the correctness of the collected data is an important procedure for large public construction to achieve energy-saving monitoring. Taking "4# energy consumption" as an example, the power consumption data from September 15th, 2018 to November 14th, 2018 is used as sample information as shown in Fig 13.

RAYDA criterion was adopted for verification, and the distribution of data sample points was shown in Fig.14. The sample data set obeys the normal distribution $N(1390.94,104094.50)$. Therefore, according to the LAIDA criterion, the confidence interval is $[1068.30,1713.58]$. After checking the consumption data of October 18 is wrong in preliminary conclusion. Using the above insect intelligence parallel energy consumption statistical algorithm, the all-day power consumption of 4# building on October 18 was 21895.7 kW · h, while the real value was 20984.5 kW · h, and the power consumption data on October 18 was judged to be wrong. The analysis as follows: firstly, the terminal power consumption will not be higher than the metering value of the transformer room due to the power loss in the transmission process. Secondly, the data of each CPN node in Fig.11 were also checked by the LAIDA criterion, and it was concluded that the data of other nodes were correct, so it could be determined that the data was wrong.



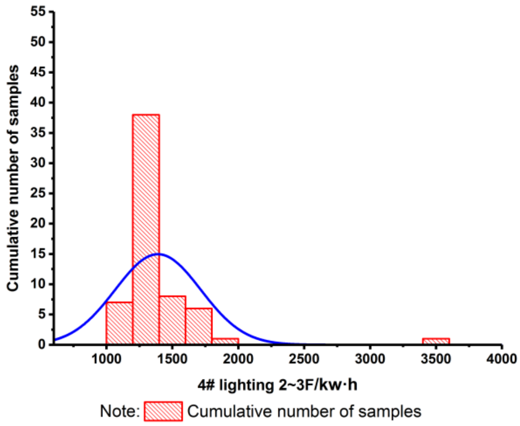


Fig.13 4# lighting 2~3F sample power consumption **Fig.14 Sample normal distribution**

3.4.3 The commercial building energy consumption data correction

For the abnormal value of the power consumption data of the above sampling points, the BP neural network is used to predict the power consumption value of the point. The algorithm parameters are set as follows:

1) Using a three-layer BP neural network structure, the input factor is the power consumption information of the three time points before the time point, so the number of neurons in the input layer is 3; the output value is the power consumption value at the time point, so the number of neurons in the output layer is 1, and the number of neurons in the hidden layer is set by the literature

[28] using the formula (8). The hidden layer node uses the *TANSIG* transfer function, and the output layer node uses the *PURELIN* transfer function.

$$nl = \begin{cases} n + 0.618 * (n - m) & n \geq m \\ m - 0.618 * (m - n) & n \leq m \end{cases} \quad (8)$$

Where *nl* is the number of neurons in the hidden layer. *n* is the number of neurons in the input layer, and *m* is the number of neurons in the output layer.

2）The activity range of the neural network training function is [0, 1], the input data is processed by the standardization of the deviation of the formula (9):

$$x = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \quad (9)$$

3）The neuron learning efficiency η was set to 0.31 using equation (10), the number of iterations was set to 1000, and the acceptable error was set to 0.001.

$$\eta = \frac{1}{\sqrt{n1}} \quad (10)$$

From May 1, 2018 to September 30, 2018, the power consumption data of "4# lighting 2~3F" is 153 groups of data. Using the above energy consumption data checking algorithm, 10 groups of data were obtained as abnormal data to be eliminated, and the remaining 143 groups of data were used to train the above BP neural network. The data from October 1, 2018 to October 15, 2018 were used to verify the accuracy of the prediction algorithm. The comparison between the model predicted value and the real value is shown in Fig.15. It can be concluded from the prediction error Fig.16 that the prediction error of the model is relatively less, and RMSPE (Root mean square percentage error) (equation 11) is adopted to calculate the RMS relative error of the prediction model.

$$RMSPE = \frac{\sqrt{\frac{1}{N}\sum_{i=0}^{N}(y(i) - \hat{y}(i))^2}}{\bar{y}} \quad (11)$$

Where $y(i)$ is the true value of the monitoring point at i time points; $\hat{y}(i)$ is the predicted value of the monitoring point at i time points; $\bar{y}$ is the average value of the sample points and RMSPE=2.19%. Using the above model, the electricity consumption of “4# lighting 2~3F” on

October 18th, 2018 is 1321.5kw·h, so the electricity consumption of 4# building should be 19680.7kW·h, and the real value is 20984.5kW·h.The error rate is 6.21%, which conforms to the transmission loss of the system energy consumption.

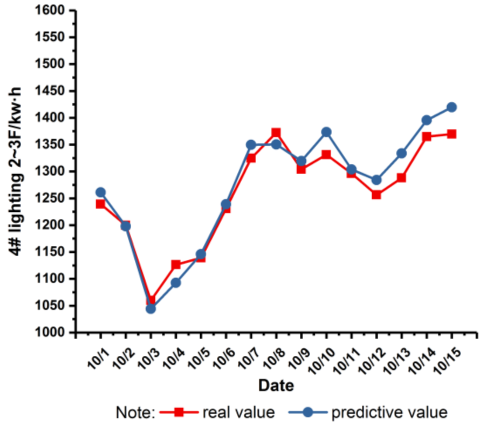


Fig.15 Comparison of predictive value and real value

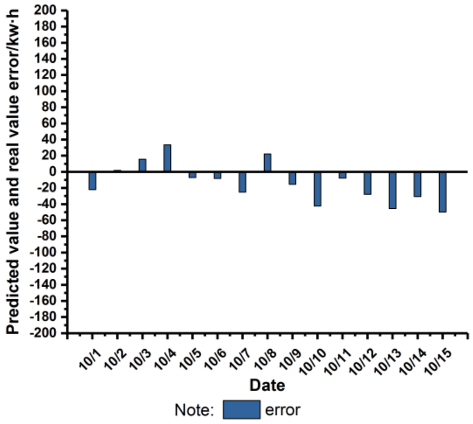


Fig.16 Model prediction error map

4. Discussion

The prevailed Energy Consumption Monitoring System of the large-scale Building using Insect Intelligent Building technology can address the existing problem of traditional method. This paper studies the basic theory, distributed algorithm and data checking theory. First, the common CPN nodes of buildings under the group intelligent network architecture were divided into two categories, one is the spatial unit according to area, and the other is the electromechanical unit according to the equipment. Then, the standard data set of energy consumption monitoring system is define, and distributed energy consumption collection and processing algorithm of intelligent buildings is deep studied with a specific building experimental supported. The novel method can improve the performance of plug-and-play and self-identified and self-configuration of energy consumption monitoring system.

In the future, building energy consumption based on I^2B technology needs to be improved. First, in this paper, the division of architectural space units is mainly aimed at common large civil buildings similar to commercial buildings. Due to the great gap between industrial buildings and civil buildings in terms of functions and personnel requirements, the division method of spatial units need to be further studied and refined.

Besides, the data collection, verification and correction methods proposed in this paper under the group intelligence architecture are more traditional, so the data processing algorithm of artificial intelligence building energy consumption using I^2B technology can be further studied. In order to improve this insect intelligent building energy consumption monitoring system, one of the most important issues is that more case studies should be done in the next step so as to check the operability of this system.

In general, the system has standardized data sets. So the insect intelligent building has the characteristics of plug-and-play. The construction of CPN will not cause damage to the installed buildings, and can perfectly make up for the shortage of centralized buildings. What's more, the cost is lower than the Energy consumption acquisition device of centralized system. All of the above advantages can benefit the government and users. However, its application in high space still has some limitations, and all current researches are mainly in experiments, so it will take some time for its practical application and popularization.

4. Conclusion

A novel idea for a building energy consumption monitoring based on insect intelligence building (I^2B) platform is proposed. According to the platform, the traditional devices can be upgrade and transformed into smart device. The distributed algorithm and accurate model can be written into the chips. Based on the CPN node of building space unit and electromechanical equipment and the building energy consumption standard data set, the parallel building energy monitoring technology is used to realize building energy monitoring operation. The smart devices CPN communicate with their neighboring nodes and work collaboratively to perform the building energy consumption monitoring. Besides, the key issues of distributed energy consumption data collection, energy consumption data check, energy consumption data correction are studied. The feasibility of the above algorithm is verified by an example. It is proved that in this case, field-site modeling, configuration, communication and development work can be simplified as the communication among different CPNs, which can be plug-and-play, and can adapt to the feasible situation of subsystems. The proposed method meets the requirements of the current energy consumption monitoring system and is adaptive to large-scale buildings. And the present study can lay a foundation for the further research of decentralized system.

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