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Research Article

All-Round Control of High-Rise Buildings by Construction Organization Design Based on Distributed Control System

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The construction of high-rise buildings usually involves many problems. With the increasing population and demand for tall buildings, researchers have also proposed different design approaches for various aspects of tall buildings. The design of traditional construction organization is difficult to cover all systems of high-rise buildings comprehensively and efficiently. Among the high-rise buildings involved, the first important is safety, followed by energy conservation. The high floor and complex structure of high-rise buildings bring hidden dangers to safety, and the large volume brings a burden to energy conservation. In this paper, in order to solve the problems that the system is difficult to fully cover in high-rise buildings and the design of consumables and energy materials, the method of distributed system is adopted. The main aspects of high-rise buildings are studied in an all-round way, and a distributed system model is first constructed in this paper. Then, the lighting, air conditioning, and fire protection systems of high-rise buildings are correspondingly formed under this system. Through the simulation experiment of the B4 building in the business district, it is concluded that the average luminous flux of lighting under the distributed system of this paper is 11385 lm, saving more than 60% of energy. The error of the air-conditioning system is less than 0.2°C, and the energy consumption is saved by 10%. The fire detection window length of the fire protection system exceeds 0.15, which can detect the fire sensitively. In addition, the evacuation pressure of personnel is reduced by more than 20% in emergency situations. The results show that the system establishment of high-rise buildings under the distributed method in this paper can effectively improve the efficiency, save energy consumption, and reduce the pressure of resource utilization. The design of this paper unifies the overall and local control objectives, which can fully meet the needs of comfort and convenience.

1. Introduction

High-rise buildings are currently emerging due to economic growth and urbanization. High-rise buildings are mostly larger integrated systems. The large construction area and high floors of various large buildings such as hotels, high-rise apartments, and commercial buildings have brought problems in power supply and distribution, air conditioning, lighting, fire prevention, and security monitoring. Therefore, construction and design should be combined in the initial design stage to promote the smooth progress of design and construction. For example, a safe and effective monitoring system requires more computer and communication technology assistance. The design of fire protection system also involves more knowledge due to the number of floors in high-rise buildings. It is also difficult to fully control due to the changeable structure of high-rise buildings.

Because of its rapid growth rate, the safety of high-rise buildings has also been questioned by many. In earthquakes, for example, tall buildings are vulnerable to damage because of their large size. Salim conducted research on the seismic performance of high-rise buildings. It compares the seismic performance of a 40-story high-rise building with different outriggers with truss systems and dampers and a conventional building [1]. His research has a certain reference, but it is not practical for a large number of high-rise building designs in nonseismic zones. Lan analyzed the structure of high-rise buildings and proposed that the load transferred from the superstructure to the foundation by the uneven soil under the building foundation is variable [2]. However, most of his research involves buildings with about 10–20 floors, which is not typical. Song et al. proposed an infinite-dimensional system model for describing high-rise building structures with large inertial loads [3]. His model provided some support for the stability of high-rise building construction, but still has limitations in the study of all-round control. Omar advocated that smart building design is the future of the construction industry, while integrating the design of smart buildings into high-rise buildings [4]. However, his system is simpler and cannot handle complex high-rise situations. Kim et al. proposed the design of net-zero energy buildings and suggested its application to high-rise buildings as the main driving force in the future [5]. Although his design supported high-rise buildings from an environmental perspective, the economic cost is too high. Prajapati conducted studies on the wind loads and seismic loads of tall buildings to determine their structural capabilities in safely moving horizontal loads to the ground [6]. His research has helped to improve the stability of high-rise buildings, but the research on internal system control is still lacking. In order to solve the all-round control problem of high-rise buildings, Cho started from researching technology patents and obtained the optimal solution for construction design [7]. However, his research only starts with the technology of other people's research instead of his own research and development, and it is difficult to guarantee the security.

With the continuous development of today's construction industry, a variety of different technologies have also been put into the design of construction organizations. Jurnal first used DCS to control the process equipment of the factory. His proposed DCS can be used to quickly read the response of the factory equipment with installed sensors [8]. Saad proposed a secure control framework for the future smart grid using distributed systems [9]. His design improved the safety of distributed systems and enables the safety structures that the system would otherwise use on the grid to be used in buildings. His design requires a very high configuration. It also results in an excessively high cost of construction. Kazemi implemented and embedded advanced monitoring algorithms directly into the DCS structure, thereby eliminating the need for additional computers connected to the DCS [10]. His design reduces the cost of the system, but also reduces the work efficiency of the system, which is not conducive to practical operation.

This paper adopts the method of distributed system and designs a distributed system model based on the direct digital control method. At the same time, under this system, lighting subsystem, air-conditioning subsystem, and fire-fighting subsystem are established in this paper. It also conducts experiments from these three aspects. After conducting experiments on the total amount of lighting and energy saving, air-conditioning control rate and energy-saving rate, fire sensing sensitivity, and evacuation efficiency, the results of the overall operating efficiency of the high-rise building system under the control of the distributed system are obtained. Under the general framework of distributed system, the innovation of this paper is to use a simple but practical method to study the all-round control of high-rise buildings from three aspects: lighting system, air-conditioning system, and fire-fighting system. Because these three systems work best to take advantage of the distributed control system, they also occupy the main control aspect of most buildings. It can be said that a practical and effective design has been completed by starting from a part and using a concise method.

1.1. Application Method. With the advent of the information age in the 21st century, the popularization of computer networks, and the continuous development of digital control technology, the traditional control system is developing towards the direction of intelligent and networked control. One of the significant differences between distributed control and centralized control is the difference in information flow. Distributed building control no longer relies on the global building, but is based on local areas. It monitors and manages the central refrigeration station, heat exchange station, air-conditioning unit, fresh air unit, air supply and exhaust unit, water supply and drainage, power transformation and distribution, elevator, lighting, and other electromechanical equipment in the building. It adopts the regional controller to realize the sharing of the underlying equipment information in the adjacent area, and all terminal devices are managed and controlled by the regional controller in a unified manner [11]. It is a set of comprehensive control systems that arise with the rise of automated production and increasingly complex manufacturing processes in modern large-scale industries [12].

1.2. Principle and Construction of Distributed System. The complete definition of distributed control system includes the following: the function of the system is mainly based on loop control, and the human-computer interface, communication, and function control all use digital technology. Distributed system (DCS) must have the following parts: communication system network, on-site control station, and operator station (operator station sometimes acts as an engineer station). Figure 1 is the composition of the DCS system structure.

As shown in Figure 1, the DCS system consists of three levels: field level, monitoring level, and management level. The main task of the field-level equipment is to directly control the field, such as controlling the end effector of the field-controlled equipment or collecting and processing the data measured by the sensor. Fieldbus has the remarkable characteristics of openness, decentralization, and data communication. It is mainly used for data communication between intelligent instruments, controllers, actuators, and other equipment in industrial field and digital information interaction between advanced control systems. The number of field-level devices that can be monitored by the monitoring level is limited. From the perspective of high-rise building system integration, the management level is an extremely important part. It can monitor all controlled devices at field level. Its main task is to introduce the control

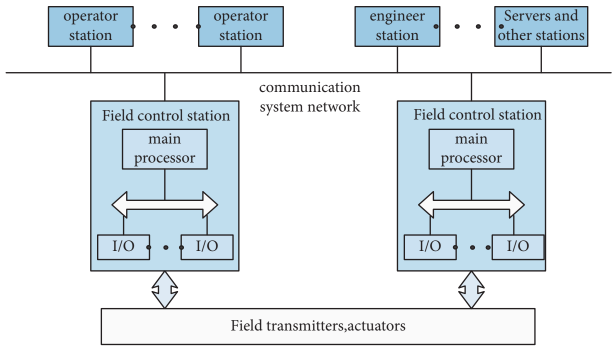

Figure 1: Composition of DCS system structure.

decision of the management department into the control strategy of the monitoring level, so as to realize the coordination and information sharing among the related systems [13].

The following describes the structure model of the distributed control system in this paper. Data acquisition and monitoring management in high-rise buildings are highly regional, and some functions in each system have strong independence, such as data acquisition module, positioning module, and strategy customization module [14]. Therefore, this paper chooses to build distributed control system structure according to data range distribution and function. That is, it manages the equipment and functions of a certain area by a single server or a group of servers, so that the nodes of the platform composed of multiple servers can run independently and work together. The nodes are connected through Ethernet and exchange data according to the distributed communication protocol, so that each area can be controlled independently. It is also convenient for centralized management, which controls the impact of system and equipment failures on the entire system in one area [15]. This decentralized control method greatly decentralized the risk of control. When a control link fails, it will only affect the part and will not pose a fatal threat to the whole production process. Redundant control is introduced into the system. When the local control fails, it can be controlled by other control devices, so as to improve the reliability of the control system and minimize the control risk.

In order to meet the needs of data processing and real-time response, this paper divides the control system according to functions and different areas as follows. The controlled building is divided into several areas according to different parts of the building (such as floors and offices). A decision server and a data server are arranged in each area, and data are exchanged between the servers in each area through Ethernet. They form a pyramid structure, and each decision-making subsystem at the same level can act on the lower level at the same time and be interfered by the higher level at the same time. Subsystems can exchange information with each other through their superiors. Therefore, the distributed control system has a hierarchical control structure. The system structure is shown in Figure 2.

As shown in Figure 2, the functions and connections of the server are described as follows: (1) the main application server acts as a coordinator in this network, and its main functions are receiving and processing user requests and submitting processing result data to users. After submitting data and decisions to the main decision-making center, receive and process decisions and requests from the main decision-making center and store the received equipment data, log information, and alarm information in the database. Then, receive regional application server data (device data, log information, alarm information, policies, etc.) and send commands and cross-regional decisions to the regional application server. (2) The main decision server is mainly responsible for processing the cross-regional strategy and sends the final processing result to the main application server. (3) The regional application server acts as the coordinator of the region, and its main functions are as follows: it collects the data of all devices in the region and sends commands to the device controller. It processes the collected data and sends the data to the regional decision server and the main server; receives and processes the commands of the main server and the decision of the regional decision center; receives and processes the requests of regional users. (4) The regional decision center server is mainly responsible for the localization of the region and the control strategy of the region and sends the decision to the regional application server. When encountering a cross-regional strategy, it sends the strategy to the main decision center server. (5) The control center is mainly responsible for interacting with users and displaying data to users.

Next, computer control needs to be introduced as the basis of the distributed control system in this paper, and Direct Digital Control (DDC) is the most suitable for the basic structure of the DCS system in this paper. The architecture of DDC system is divided into hardware structure, software structure, and network structure. DDC algorithms can be divided into three categories: continuous control, logic control, and sequential control [16]. Commonly used PID control algorithms and model-free adaptive control are the two types of continuous control algorithms that will be further emphasized in this paper.

The first is the PID control algorithm, which is often used in continuous control systems and has the most complete control laws. The PID control algorithm starts out simple, robust, and easy to use. It can achieve the most practical needs and is suitable for different disciplines, with strong algorithm structure [17]. PID is suitable for simple systems, but for complex systems, PID is powerless. At the same time, when the dynamic characteristics of the process change, the parameters of PID controller need to be adjusted frequently. While the operation of a digital PID controller will be more flexible, it is easier to improve and customize, and the PID controller law is

$$u(t) = K_p\left(e(t) + \frac{1}{T}\int_0^t e(t) + dt + T_D\frac{de(t)}{dt}\right). \quad (1)$$

In the formula, $u(t)$ represents the control quantity (controller output), $e(t)$ stands for control bias, K_p stands for scale factor, and T stands for integration time constant.

The corresponding function for the corresponding continuous system migration is

$$D(s) = \frac{U(s)}{E(s)} = Kp + T_i s. \quad (2)$$

$D(s)$ has the function of adjusting and correcting in the system, which is composed of the linear combination of relative, integral, and differential operations on the deviation. In practical applications, the structure of the controlled object can be flexibly changed according to the attributes and control requirements of the controlled object, and a part of it can form a controller, for example, relative integral controller (PI) and relative derivative controller (PD).

Another category is introduced below: model-free adaptive control. It does not contain process identification mechanism and identifier in the system, and it has closed-loop system stability analysis and criterion to ensure the stability of the system. The following takes the SISO (Single Input Single Output) MFA controller as an example to describe it. The main goal of SISO MFA is to replace PID, which can be adjusted according to the actual situation, so as to design and realize the controller of the system in high-rise buildings [18]. The structure of single-loop MFA is relatively simple, including a SISO process, an MFA controller, and a feedback loop.

The core control algorithm of SISO MFA is as follows:

$$\begin{aligned} p_j(n) &= \sum_{i=1}^{N} w_{ij}(n) E_i(n) + 1, \\ q_j(n) &= \phi\left(p_j(n)\right), \\ o(n) &= \left[\phi\left(\sum_{j=1}^{N} h_j(n) q_j(n)\right) + 1\right] = \sum_{j=1}^{N} h_j(n) q_j(n) + 1, \\ v(t) &= K_c[o(t) + e(t)], \\ \Delta h_j(n) &= \eta K_c e(n) q_j(n), \end{aligned} \quad (3)$$

where n is equal to the number of iterations and $o(t)$ is the time transfer function of $o(n)$. $V(t)$ is the gain without analog adaptation, K $(K > 0)$ is the input without analog adaptation, and the weight learning algorithm is as follows:

$$\begin{aligned} \Delta w_\eta(n) &= \eta K_c e(n) q(n)\left(1 - q_j(n)\right) E_j(n) \sum_{k=1}^{N} h_k(n), \\ \Delta K_j(n) &= \phi \sum_{n-1}^{i} e(t) q_j(n). \end{aligned} \quad (4)$$

The goal of updating the weight factor algorithm is to reduce the deviation between the set value and the process variable. Because its effect is consistent with the control goal, the use of weight factor is helpful to reduce the deviation of the controller when the dynamic characteristics of the process change.

MFA can adapt to changes in process dynamics. Today, model-free adaptive controllers tailored to special applications or general-purpose can be easily designed into various platforms, including the distributed control system in this paper.

In this paper, the construction organization design of high-rise buildings is designated as a distributed system. After the detailed introduction of the method of distributed system, before the formal experiment, the following preparations for the construction organization design should be clarified: (1) understand the characteristics of high-rise building construction. High-rise building projects generally occupy a relatively important position in urban architecture. Not only are the buildings high in number and complex in shape, but designers must express functional requirements and styles through various means. Therefore, the construction department must have a sufficient understanding of the characteristics of the high-rise building projects undertaken and make full use of time and space to intersperse and cooperate. (2) Correctly grasp the time for compiling the construction organization design. It is difficult to complete a very comprehensive and specific construction organization design in a timely manner, especially for high-rise buildings, the construction unit must combine the contractor and the design department to prepare the construction. The general design of the organization or the preliminary design of the construction organization determines the main construction methods and mechanical equipment in order to prepare for the organization of materials and technology. (3) Strengthen the cooperation between design and construction. High-rise buildings mostly include large comprehensive systems, and the completion of a house can only be completed through the close cooperation of building structure, construction, and materials. When considering the design plan, the construction plan should be considered, so the construction and design should be combined in the initial design stage, and the corresponding construction organization technical design should be compiled to promote the smooth progress of design and construction.

1.3. Lighting Design Method for High-Rise Buildings in Distributed Systems. The lighting system of high-rise buildings is no different from ordinary buildings according to common sense. However, considering the height of the floor and the complexity of the floor structure and interior, it can easily lead to excessive energy consumption of the lighting system, which will cause unnecessary cost increase in the floor expenditure in the long run. Relying on the advantages of distributed systems here, energy-saving and intelligent lighting systems can be designed in high-rise buildings. It is applied to each floor through experiments in the later stage [19]. Single system software is greatly limited by server performance and geographical location, and the lighting equipment that can be controlled and managed at the same time is limited. Therefore, a distributed lighting control system based on data server, decision center server, and positioning server is designed and established. It makes the system not limited by equipment performance and facilitates system expansion, collaborative work among systems, and unified control and management.

First of all, in a specific area, it is assumed that the reflected light from the indoor walls and floors has very little

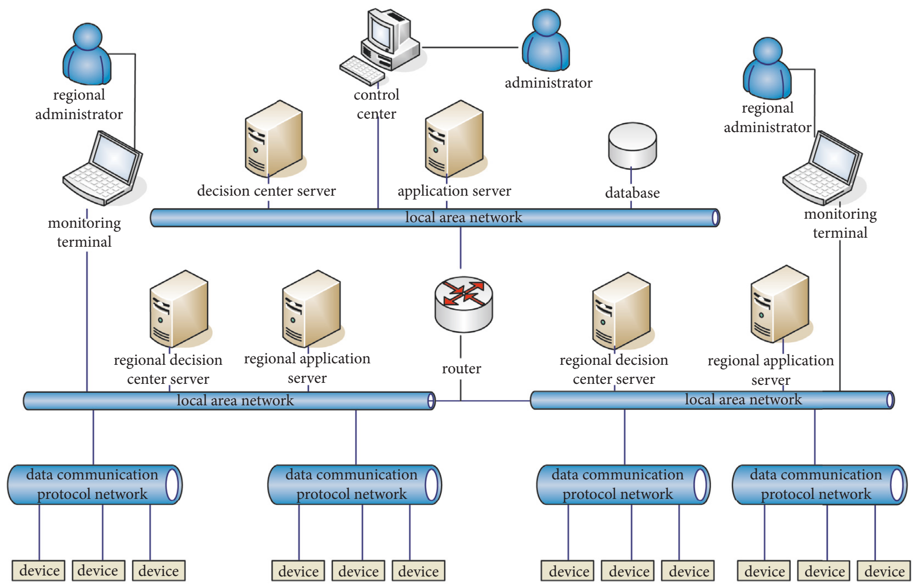

FIGURE 2: System distributed model.

influence on the illuminance of the inspection point. The diffuse reflectance of the ceiling to the light is μ, and the reflected light source is evenly distributed in space, and the natural light of the window is used as a fixed-point light source and a plane light source. The illuminance of each indoor point is the linear combination of the illuminance of each lamp at that point. The calculation of the illuminance generated by the luminaire at point P is shown in Figure 3 and the following formula:

$$\begin{aligned} E_i &= \frac{(\mu+1)I_i(\theta)\cos\theta}{H^2}, \\ \cos\theta &= \frac{H}{\sqrt{H^2+L^2}}, \\ H &= Z_i - Z_j\,(i,j=1,2,3,\ldots), \\ L &= \sqrt{\left(x_i-x_j\right)^2+\left(Y_i-Y_j\right)^2}\,(i,j=1,2,3,\ldots). \end{aligned} \tag{5}$$

Among them, $I_i\theta$ represents the light intensity in the θ direction of the light distribution curve of lamp L_i; E_i represents the illuminance generated by lamp L_i at P_j position; H represents the vertical distance from the lamp L_i to the P_j point; L refers to the horizontal distance between lamp L_i and P_j; (Xi, Yi, Zi) is the coordinate of lamp L_i; (x_i, y_i, z_i) is the coordinate of point P_j; and the illuminance of lamp light source is

$$\begin{aligned} v_i(t+1) &= v_i(t) + c_1 r_1\left[pbest_i(t) - x_i(t)\right] \\ &\quad + c_2 r_2\left[gbest(t) - x_i(t)\right], \\ &\left\{v_{ij} = v_{\max}, if_{ij} \geq v_{\max}.\right. \end{aligned} \tag{6}$$

The illuminance of the natural light source of the window is obtained by the illuminance meter, so the obtained illuminance value is affected by the illuminance of the lamp. Assuming that the coordinate of the window is (x_k, y_k, z_k), the value of the illuminance meter is E_0, and E_i is the illuminance of the lamp L_i at point (x_k, y_k, z_k). The actual illuminance E_k of the window light source is

$$E_k = E_0 - \sum_{i=1}^{n} E_i^k\,(k,n=1,2,3,\ldots). \tag{7}$$

In order to simplify the illuminance model, it is assumed that the window is not directly illuminated by sunlight, and its light source comes from the diffuse reflection of sunlight in the air. Therefore, the window can be regarded as a uniform diffuse light source, and the normal of the illuminated surface is perpendicular to the window. φ is the illumination direction angle of the light source, and then the total illuminance of point p_j can be approximately calculated by

$$E_{pj} = \sum_{i=1}^{n} E_i + \sum_{k=1}^{m}\left(\frac{E_k\cos\varphi}{\left(x_k-x_j\right)^2+\left(Y_k-Y_j\right)^2+\left(Z_k-Z_j\right)^2}\right). \tag{8}$$

According to the basic principle of particle swarm optimization algorithm, each lighting device is regarded as a dimensional space and each group of potential feasible solutions is regarded as a particle [20]. Assuming that the number of lighting devices in the control area is D, the population searches for the optimal solution in d-dimensional space. There are m users entering the control area. The illumination demand of users is $U_j(j=1,2,\ldots,m)$, and the unit is LX; the number of natural light sources in the control area is n. Each lighting device can adjust the light intensity within the range of $[0, i_d]$. Then, the fitness evaluation model and constraint function of the lighting strategy in the control area are shown in the following formula:

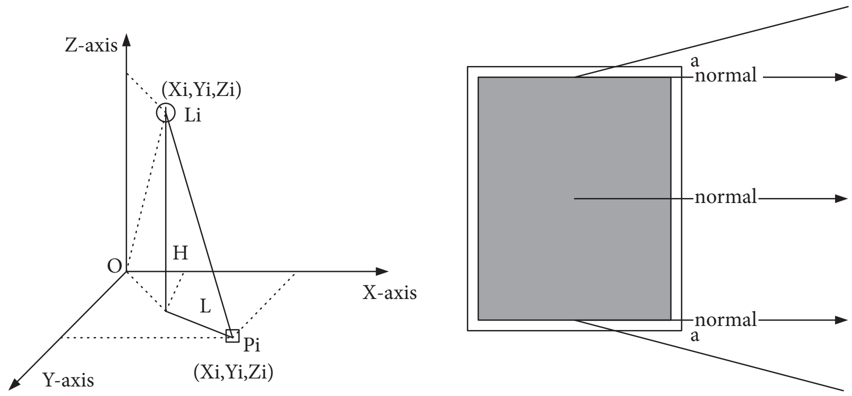

FIGURE 3: Schematic diagram of light source and illuminance calculation.

$$\min f(x) = \sum_{d=1}^{D} x_d \,(d = 1, 2, 3, \ldots, D),$$
$$s.t. \left\{ \sum_{i=1}^{D} E_i + \sum_{i=1}^{n} \left(\frac{E_k \cos\varphi}{\sqrt{\left(x_k - x_j\right)^2 + \left(Y_k - Y_j\right)^2 + \left(Z_k - Z_j\right)^2}} \right) = U_j, \, (j = 1, 2, \ldots, m). \right. \tag{9}$$

1.4. Design Method of High-Rise Building Air-Conditioning System in Distributed System. In high-rise office buildings, air conditioning can usually consume more than half of the energy consumed by the whole building. Among them, cooling system, water pump, and internal mechanical structure spend the most energy. Therefore, if users require high comfort in use, they have to work hard in the control center and start from the core to reduce consumption [21]. Under background, this paper decides to adopt the design of variable air-conditioning system under DSC controller to study the effective distribution and energy-saving use of air-conditioning system.

Variable air-conditioning system is a kind of all air-conditioning series. It includes the following parts: central management controller, communication network, field controller, VAV terminal device, sensor, transmitter, and actuator. Its core is a new technology developed by applying energy-saving technology to air conditioning. Because it is developed on the basis of fixed channel air-conditioning system, it is superior to other air-conditioning systems and can work with high energy efficiency and high quality. Indirect hot and cold gas exchange is affected by the load in the working area during gas conversion. This makes the exchange of cold and hot air in the air-conditioning system strictly and accurately controlled. Only when the technical management is in place can the smooth work of the core system be guaranteed [22]. Figure 4 is the structure diagram of variable air-conditioning system designed for high-rise buildings in this paper.

As shown in Figure 4, the variable air-conditioning system designed for the experiment of high-rise buildings in this time, according to the distributed principle and the general working methods of variable air conditioning, includes controlling the temperature, controlling the air pressure, controlling the exchange temperature of cold and hot air, controlling the exhaled air volume, and ensuring the pressure balance in the area. The dotted arrow in the figure represents the output signal from the DDC controller to the driver, and the solid arrow represents the input signal from the sensor to the DDC controller.

The five control systems are independent of each other, and there is a strong connection between the cycles. Therefore, the control requirements of VAV system are higher than those of constant air volume system.

1.5. Design Method of High-Rise Building Fire Protection System under Distributed System. In this paper, the special control equipment such as fire control and security designed by distributed system can be called by all control tasks, which significantly improves the control effect. For example, in a fire scene, each area can identify the status of the area through the camera in the predefined area types, such as evacuation and refuge area (corridor, elevator lobby, etc.), manned area, and unmanned area. The distributed control system can adopt different control strategies to improve the safety level of buildings and personnel on the basis of self-control and interregional negotiation. The unmanned partition system can open windows for smoke exhaust and turn off lighting and air-conditioning devices to save energy. The evacuation refuge area or manned partition system can turn on the lighting device to reduce personnel panic, open the window and air conditioner, and discharge the smoke in time to ensure personnel safety, as shown in Figure 5.

According to Figure 5, under the centralized control mode, air conditioning, fire protection, and security systems rely on their own special control units to operate independently, and different systems and equipment cannot interact directly. In the building distributed evacuation system, the building is divided into several zones.

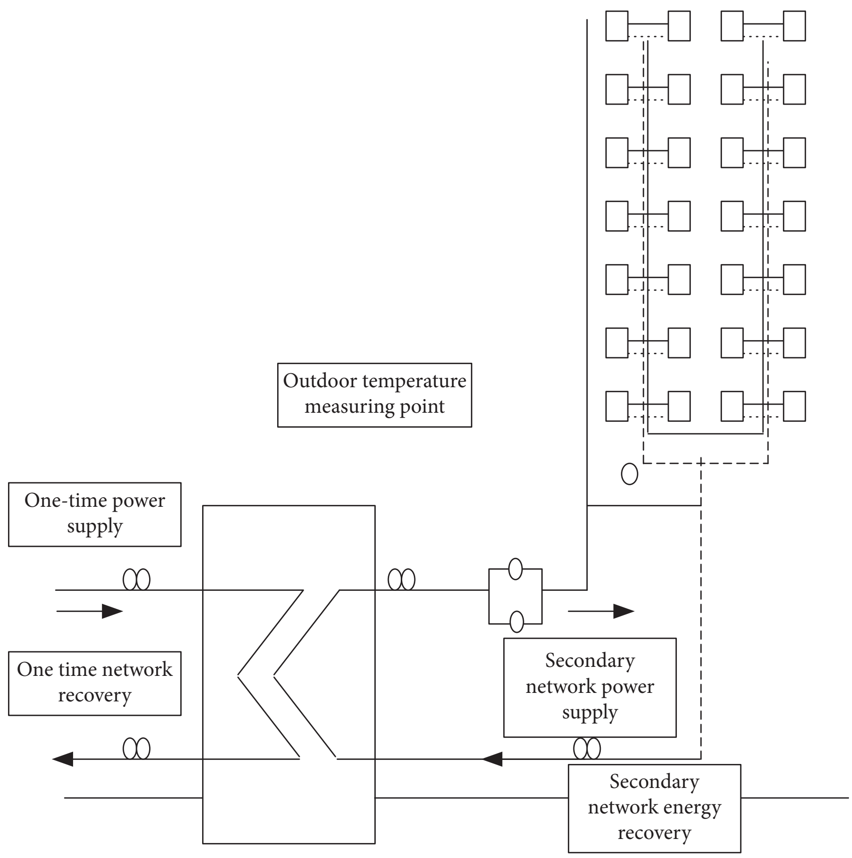

Figure 4: Building physical structure of variable air-conditioning system.

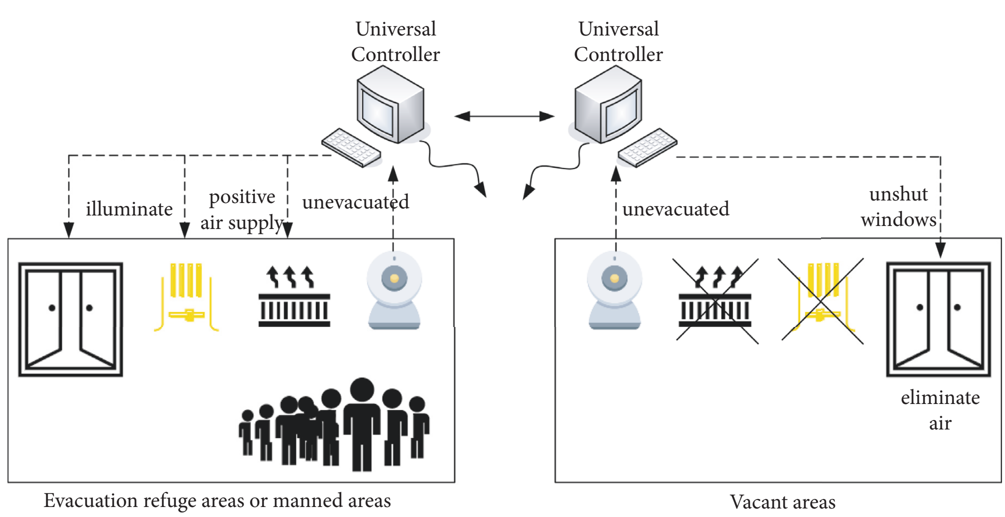

Figure 5: Schematic diagram of fire-fighting strategy of distributed system control.

Each zone is equipped with sensors, general controllers, and other basic data acquisition and processing equipment and dynamic evacuation indication signs. The smoke temperature composite sensor in the zone can monitor the fire information in real time. When a fire occurs, the general controller calculates the fire source location information, fire source intensity information, and fire development trend information according to the monitored fire information.

At the same time, the personnel monitoring equipment installed in the zone includes radio frequency identification system, access control system, and video system. It can monitor the location distribution information of personnel in each division and estimate the personnel density information in each region. The dynamic evacuation indication sign is different from the traditional static evacuation indication sign, which can change the direction according to the demand. It can effectively guide the decision-making of trapped people and guide them to choose the best evacuation direction and path.

The working principle of the distributed evacuation system is as follows: when the controller of a partition detects a fire through a sensor, the controller of the partition transmits this information to the adjacent area. After receiving this information, the adjacent area will also forward it to the neighbor and so on. The information of fire spread through the whole network in this form of "flooding." When the fire information is received in the area where the evacuation exit is located, the area will initiate a distributed operation to solve the generalized shortest path problem. The basic idea of distributed algorithm is that each partition controller continuously receives the information of adjacent controllers. It also estimates the generalized distance to the emergency exit when each adjacent area is selected as the evacuation direction [23]. The algorithm compares the generalized distance to the exit when each adjacent area is selected as the evacuation direction. It takes the adjacent area with the shortest generalized distance as the direction of evacuation indication, then outputs the evacuation indication of each zone, displays the evacuation direction through dynamic evacuation signs, and guides personnel to evacuate.

2. Experimental Simulation and Analysis

The design object of this experiment is B4 building in a business district, which is a comprehensive commercial office. It is positioned as a boutique department store and office building, with a total of 30 floors and a building height of about 109 meters. According to the common criteria of civil building design, the building is a high-rise building. Refuge floors are set on the 15th and 31st floors of the building. The computer room of the system management center is located on the first floor. The experiment will be carried out in different rooms or floors according to different categories to arrange equipment or simulate the actual situation.

2.1. Experiment of High-Rise Building Energy-Saving Lighting System under Distributed System. Equipment selection and system layout of lighting system: this test adopts CC2530 2.4 G active RFID read-write RFID development kit. The power of the reader is less than 400 MW, and the working frequency is 2.400 ghz-2.4853 ghz ISM band. It can read up to 300 m, and the air transmission rate can reach up to 250 kbps. It has the ability of received signal strength detection (RSSI). The receiving sensitivity is 105 dbm, the recognition speed is up to 200 km/h, and the RS232/RS485 interface is supported. The lighting equipment adopts energy-saving dimmable LED bulb with bulb shape, working voltage of 220 V, maximum power of 8 W, warm yellow light, E27 lamp cap interface, and service life of 25000 hours. The initial maximum luminous flux is 470 lm, and the adjustable light range is 0%~100%.

Two adjacent rooms with a width of 10 m, a length of 15 m, and a height of 2.5 m are selected as the experimental site. The walls in the middle are opaque. Each room has three shutters, one ventilation window, and two double doors. The door and ventilation window face the middle aisle, and the shutter faces the outside. An RF reader is arranged on the middle ceiling of each room, 2.0 m above the ground; The bulbs are separated by 2.5 m and 2.2 m from the ground; the interval between reference labels is 1.5 m. The equipment layout is shown in Figure 6.

Positioning data and analysis of lighting system: in this experiment, the signal transmission cycle of reference label and positioning mark is 1 s, the data acquisition cycle of server is 1 s, the initial brightness of LED lamp is 0, and the light tolerance of the system is 1LX. In the experiment, user A and user B enter the control area with positioning labels, respectively, in which user A enters the area from door 1 and user B enters the area from door 2.

This paper analyzes the actual position and measured position of user A and user B, respectively. From the error distribution between the actual position and the measured position, it can be seen that the error between the measured value and the real value of each point is within 0.4 m, and the measured position at the critical point is always in the same space with the actual position, which meets the requirements of positioning accuracy in personalized lighting control. The data of some measurement points of the user's actual position and predicted position are shown in Table 1.

According to Table 1, combined with the data of each point, the predicted value of each point of user A and user B is compared with the actual value. The accuracy range of the predicted value of user A's walking route is 0.85 m, and the accuracy range of the predicted value of user B's walking route is 0.55 M. The user's actual route is basically the same as the predicted route. The distance difference between the predicted position and the actual position increases near the turn of the route, and its accuracy is still within the scope of personalized lighting demand.

Experimental results and analysis of lighting system: Figure 7 shows the comparison between the total luminous flux and illuminance of the lighting system. Experiments show that when the intelligent control strategy is introduced, when the natural light source is not used, the light source provided by the lighting system is larger. It can not only meet the needs of users for lighting but also the energy consumption of the equipment will not increase.

According to Figure 7, in three cases, the average luminous flux of indoor lighting equipment and the average illuminance of the user's point are as follows: without the traditional lighting strategy of distributed system, the average luminous flux of lighting equipment is 11280 lm. The average illuminance of user A is 128.4 lux and that of user B is 130.2 lux. Under the lighting strategy under the distributed control system, the average luminous flux of the equipment is 11385 lm. Under almost the same luminous flux, the average illuminance of user A is 61.1 lux and that of user B is 40.2 lux. Compared with the two cases without distributed control strategy, the energy savings of the two cases with distributed system strategy are about 63.9% and 68.5%, respectively. Therefore, the lighting strategy of the distributed control system designed in this paper not only saves lighting resources but also meets the lighting comfort requirements of users.

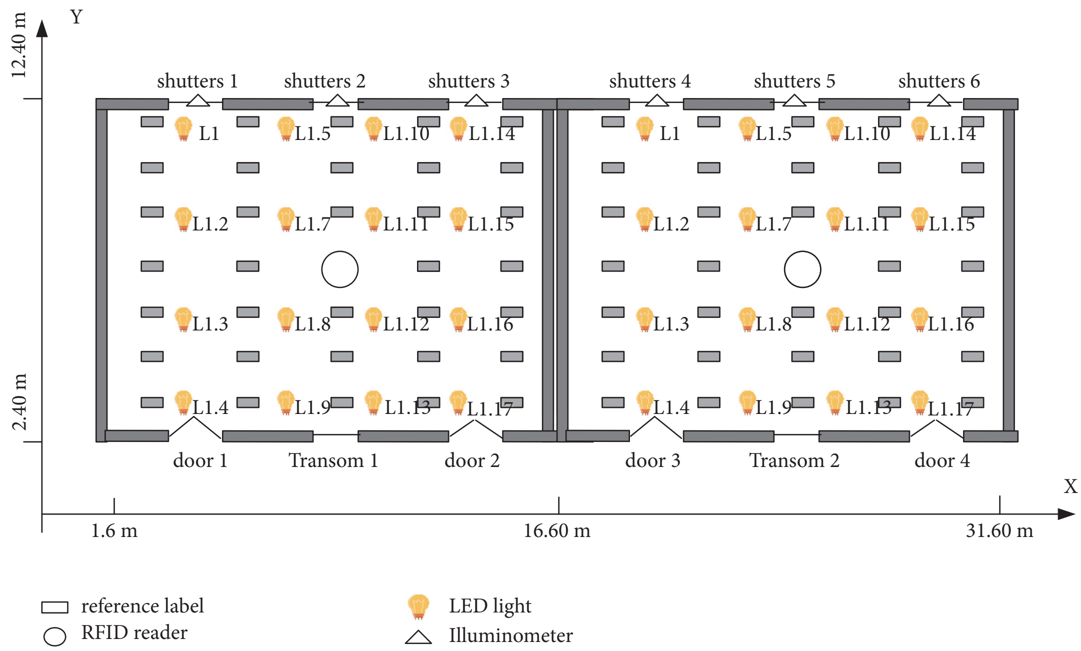

Figure 6: Layout of lighting system experimental equipment.

Table 1: Comparison between user's actual position and measurement position.

Time	User A location			User B location		
	Actual location	Positioned location	Predicted location	Actual location	Positioned location	Predicted location
2	(4.15, 3.17)	(4.16, 3.31)	(3.95, 3.84)	(13.03, 2.69)	(13.13, 2.79)	(12.90, 3.13)
5	(3.51, 5.31)	(3.63, 5.45)	(3.36, 6.26)	(12.71, 5.06)	(12.86, 5.31)	(13.13, 4.51)
9	(3.04, 8.09)	(3.10, 8.34)	(2.99, 9.13)	(14.36, 7.60)	(14.42, 7.87)	(15.16, 8.19)
13	(4.31, 10.50)	(4.40, 10.65)	(5.01, 11.09)	(16.20, 9.35)	(16.00, 9.36)	(15.63, 9.29)
17	(7.23, 10.46)	(7.46, 10.75)	(8.18, 10.51)	(14.00, 10.17)	(14.28, 10.40)	(13.59, 10.45)
21	(9.92, 9.29)	(10.12, 9.55)	(10.80, 9.21)	(11.00, 10.20)	(11.26, 10.30)	(10.56, 10.18)

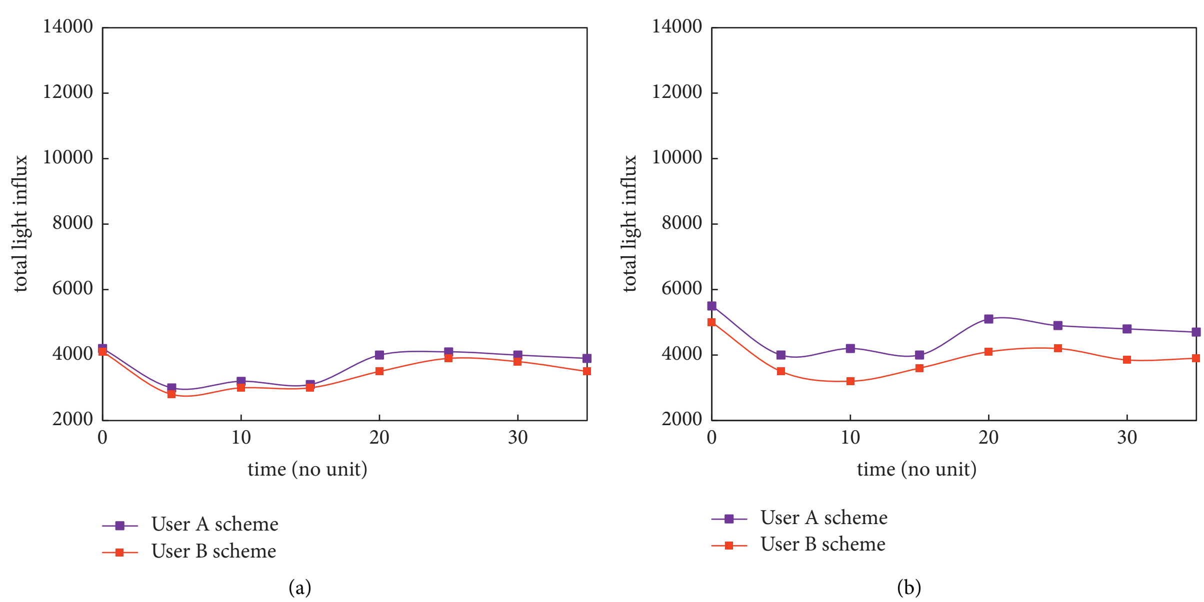

Figure 7: Comparison of total luminous flux and illuminance of lighting system: (a) results under traditional system and (b) results under DCS.

2.2. Control Experiment of High-Rise Building Air-Conditioning System under Distributed System. Operation and environment setting of air-conditioning system: according to Section 2, the variable air-conditioning system will be divided into five operation modules to control the temperature, control the air pressure, control the exchange temperature of cold and hot air, control the air volume, and ensure the pressure balance in the area. The operating environment and parameter settings of the air conditioner are shown in Table 2.

Layout and experimental flow of air-conditioning system: the steps of variable air conditioning in this experiment are shown in Figure 8. First, we initially determine the start of the air conditioner in the system and then carry out three steps: fault detection, automatic and manual emergency, and then carry out five subroutines: temperature control, air pressure control, cold and hot gas exchange temperature control, air volume control, and pressure balance program in the area. The system enters the program and then controls the air-conditioning cycle with variable air volume to execute each control program. DDC collects the status data of field sensors and equipment, converts the data into digital signals, and feeds back to the upper computer of DCS control system. It realizes the distributed control of DCS control system on the site.

Experimental results and analysis of air-conditioning system: after the experiment of the above process, the system realizes the start and stop control of equipment, the monitoring and display of equipment operation status, parameter detection and display, accident and abnormal state alarm, data recording, printing, and so on. It completes the real-time monitoring of the whole system, the room temperature, air supply static pressure, and indoor positive pressure are analyzed, and their analysis results are shown in the form of Figure 9.

According to Figure 9, when the initial temperature of the room temperature curve is about 29°C, the set temperature is 24°C, the adjustment time is 20 min, and the overshoot is 0, the stability error of the air-conditioning system is about 0.2°C. The error is less than the average level of 0.5°C of most air-conditioning systems. The set value of air supply temperature is 20°C, and the actual air supply temperature reaches the original value after 4 minutes and tends to balance to achieve the expected effect. Also, this value is within the range of energy conservation and emission reduction. According to the international energy-saving standards, the energy consumption can be reduced by more than 10%. From the analysis, we can conclude that the design of the air-conditioning system not only has small control error but also can effectively save energy. It can be used in the design of high-rise buildings.

3. Experiment of High-Rise Building Fire Protection System under Distributed System

In this paper, the fire protection experiment of high-rise buildings is carried out in two steps. First, the response sensitivity of sensors to fire in distributed system is tested. The second is the evacuation experiment under the guidance of the system. Because of the particularity of the fire, the field experiment cannot be carried out, so the simulated combustion chamber is used for this experiment. Table 3 shows the parameters of the simulated combustion chamber.

Under the distributed fire protection system in this paper, multisensor fire detection technology improves the sensitivity and anti-interference of fire detection by using the combination of various characteristics of fire. Figure 10 shows the analysis of fire detection results by sensors under different systems.

As shown in Figure 10, when the window length of 0–0.3 is adopted, the PNN sensor in the distributed system is more sensitive to sensor changes than other traditional models. It can detect more fires, with a maximum value of 0.15, far exceeding the value of about 0.1 in other traditional models. In the error rate of fire detection, the sensor under the distributed control system also has the lowest error value and is the most stable in the detection of error value. Therefore, it can be concluded that the fire sensor in the distributed system has the highest efficiency.

After the experiment of fire detection, the next step is the experiment of distributed evacuation indication system and fire evacuation drill. The fire evacuation is divided into four groups. In the experiment, it is assumed that the fire point is the stairwell from the third floor to the fourth floor, and the impact of fire situation development on other zones is not considered. Therefore, only the stairwell between the third and fourth floors is not available in the evacuation drill. Before each experiment, the initial distribution of personnel is known. Table 4 shows the distribution of personnel on each floor before the experiment.

For comparison, STEPS software is used to simulate the number and time of evacuation at each exit with or without evacuation instructions provided by the distributed system under the experimental conditions in Table 4. According to the characteristics of personnel activities, building space is divided into two categories: room and channel. The former refers to the area where personnel stay for a long time. The latter refers to the areas such as corridors and staircases that are only used as passageways and can be used as evacuation routes in case of emergency. In the simulation, it is assumed that the pedestrian evacuation speed on the plane is 1 m/s, the pedestrian flow speed at the main exit is 3 people per second, and the pedestrian flow speed at other exits is 1 person per second. At the same time, since the evacuation speed and height of the staircase are known, the evacuation time of each staircase is set as 14 s. The experimental and simulation results are shown in Table 5.

It can be seen from Table 5 that the total evacuation time under the first two groups of simulations is 99 and 71 s without and with instructions, respectively. The total evacuation time under the following two groups of simulations is 136 and 129 s without and with instructions, respectively. This shows that providing evacuation instructions can shorten the total evacuation time. Comparing the drill and simulation results without instructions and those with instructions, it can be seen that the number of evacuees at each exit is the same during the simulation and drill, but the evacuation time at each exit is relatively

Table 2: Operating environment and parameter setting of air-conditioning system.

	Temperature (°C)	Humidity (%)	Static pressure (Pa)	Positive pressure (Pa)
Indoors	28	50	300	5
Outdoors	31	54	250	7
System parameters	30	58	270	9
Other systems	30	51	280	6

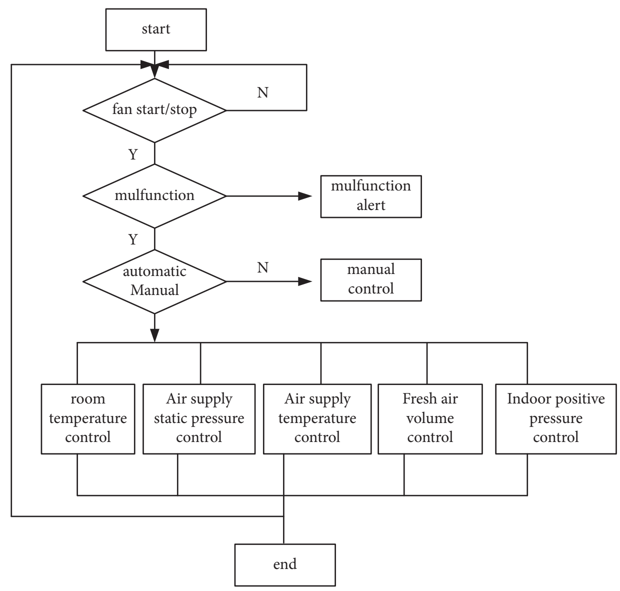

Figure 8: Flowchart of air-conditioning system control experiment.

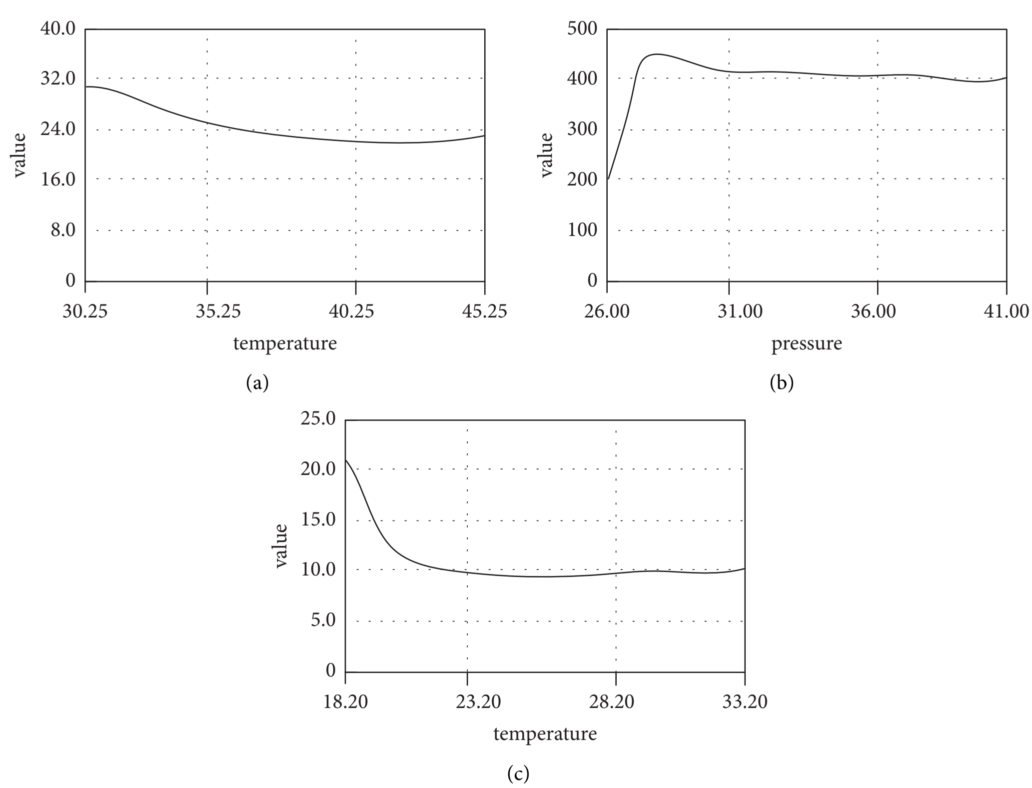

Figure 9: Experimental results of different parameter control of air-conditioning system. (a) Room temperature curve; (b) supply air static pressure curve; (c) supply air temperature curve.

Table 3: Parameter setting of combustion chamber.

	Size (m)	Material	Flaming time (s)	Sensitivity
Walls	3.6 m × 2.4 m × 2.4 m	pp&pe	500	15
Doors	3 m × 3 m	pp&pe	400	20
Windows	1.5 m × 1.5 m	pp&pe	300	30

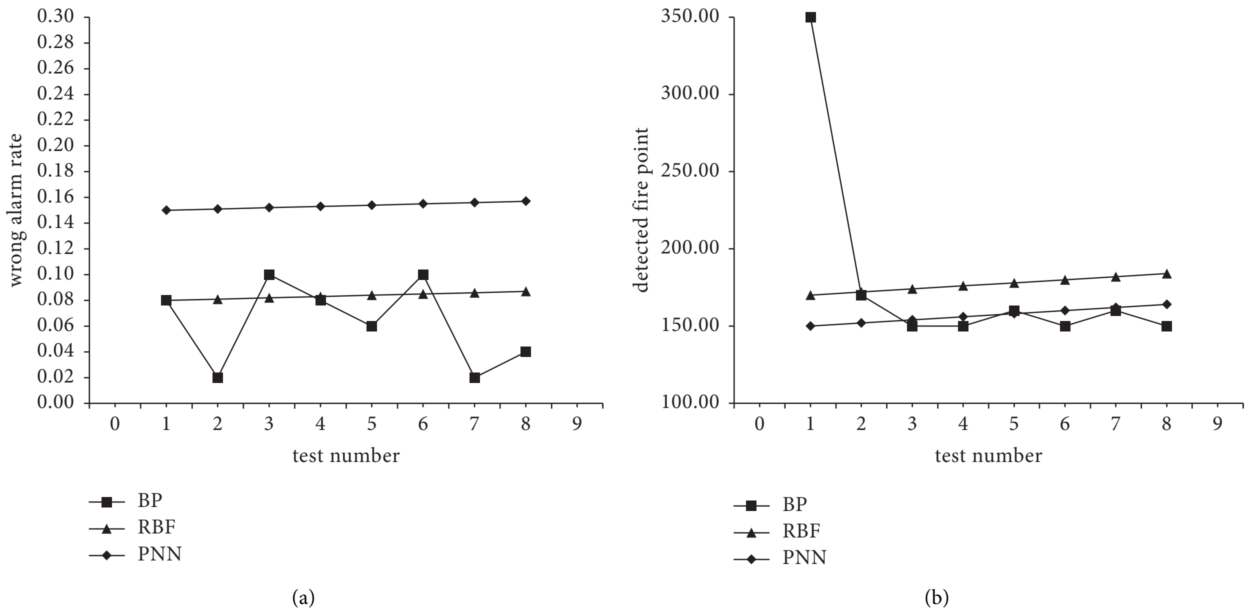

Figure 10: Analysis of fire detection results by sensors under different systems. (a) Detect spot; (b) detect error.

Table 4: Personnel distribution on each floor of the experiment.

Group	10th floor	15th floor	20th floor	25th floor
Group 1	23	33	42	20
Group 2	27	40	22	35
Group 3	40	42	34	34
Group 4	39	38	31	26

Table 5: Simulation of evacuation number and time at each exit.

Group	Experiment type	Instructions	People evacuated from the main exit	Main exit evacuation time (s)	People evacuated from the roof	Rooftop evacuation time
Group 1	Drill	None	68	99	7	80
Group 2	Simulation	None	68	71	7	62
Group 3	Drill	None	41	136	34	68
Group 4	Simulation	None	39	129	52	129

short under the simulation. The main reason is that the extra time caused by evacuation congestion is not considered in the simulation. Figure 11 shows the evacuation situation without distributed system and with distributed system guidance.

It can be seen from Figure 11 that, in the simulation results in Experiment 1, in the absence of instructions, the two groups that completely evacuated within the specified time are the first group and the third group. The number of people in the first group who chose the main exit, steel ladder, and roof accounted for 71.58%, 7.37%, and 21.05% of the total number of people, respectively. The third group chose the main exit, steel ladder, and roof, accounting for 63.74% and 36.26% of the total, respectively. In the simulation results of Experiment 2, under the guidance of the distributed system, all four groups of personnel were evacuated within the specified time. Among them, the first group of people who evacuated the fastest chose the main exit, steel ladder, and roof, accounting for 43.16%, 35.79%, and 21.05% of the total number, respectively. The number of people choosing the main exit and steel ladder accounted for 42.86% and 57.14% of the total number, respectively.

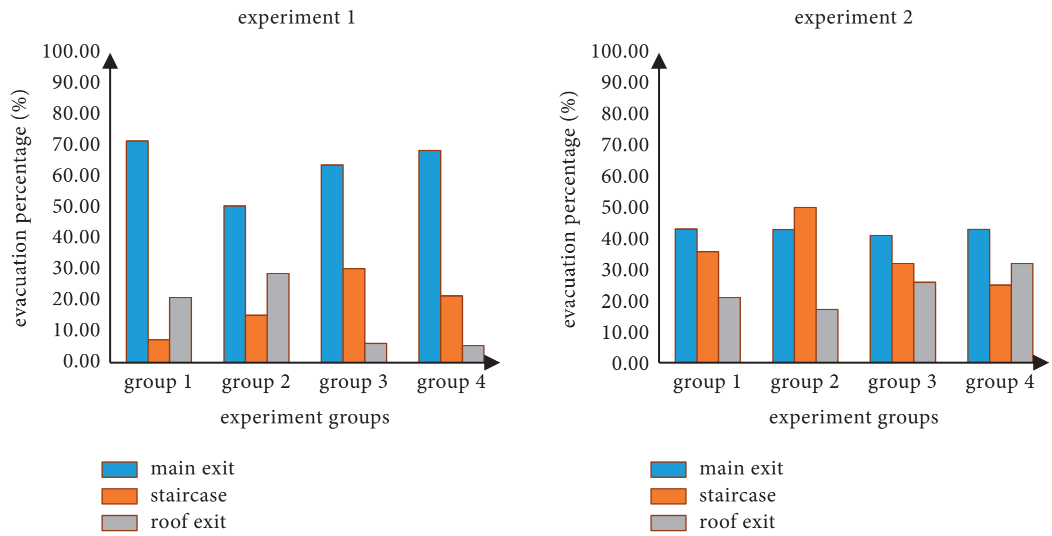

Figure 11: Personnel evacuation without and with distributed system guidance. (a) Experiment 1. (b) Experiment 2.

The two groups of experimental results show that the evacuation indication provided by the distributed system can effectively reduce the evacuation pressure of the main exit, and the number of people choosing each exit is more balanced. From the analysis results, it can be seen that the evacuation indication based on distributed building control strategy can effectively balance the number of people evacuated at different exits. It can avoid congestion, reduce evacuation time, and ensure the effective evacuation in case of emergency.

4. Conclusion

This paper studies the construction design of high-rise buildings through distributed system. The design of construction organization involves many aspects. High-rise buildings are more difficult to design because of their many floors and complex structure. This paper makes use of the advantages of distributed system to carry out a basic all-round control of high-rise buildings. This paper starts with lighting, air conditioning, and fire control, and the results show that the methods and models designed in this paper can achieve good results in high-rise buildings. Because the length of the article is limited, the article cannot be studied from more aspects. This paper only makes a basic all-round control, the research is not deep enough, and some detailed methods are still lacking. In the future, the author expects to expand the construction organization design of high-rise buildings to more aspects and make the design methods more specific and subtle.

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 no conflicts of interest.

References

[1] S. R. Salim, B. Sapkota, and T. M. Jayasree, “Comparative study on seismic performance of high-rise building with energy dissipation and outrigger belt truss system,” *International Journal of Civil Engineering and Technology*, vol. 8, no. 4, pp. 1539–1545, 2017.

[2] L. Lin, A. Hanna, A. Sinha, and L. Tirca, “High-rise building subjected to excessive settlement of its foundation: a case study,” *International Journal of Structural Integrity*, vol. 8, no. 2, pp. 210–221, 2017.

[3] Y. Song, W. He, X. He, and Z. Han, “Vibration control of a high-rise building structure: theory and experiment,” *IEEE/CAA Journal of Automatica Sinica*, vol. 8, no. 4, pp. 866–875, 2021.

[4] O. Omar, “Intelligent building, definitions, factors and evaluation criteria of selection,” *Alexandria Engineering Journal*, vol. 57, no. 4, pp. 2903–2910, 2018.

[5] D. Kim, H. Cho, J. Koh, and P. Im, “Net-zero energy building design and life-cycle cost analysis with air-source variable refrigerant flow and distributed photovoltaic systems,” *Renewable and Sustainable Energy Reviews*, vol. 118, no. Feb, Article ID 109508, 2020.

[6] M. K. Prajapati, “Analysis of a high rise building frame considering lateral load resisting members: a review,” *International Journal of Civil Engineering and Technology (Ijciet)*, vol. 12, no. 3, pp. 12–15, 2021.

[7] H. P. Cho, H. Lim, D. Lee, H. Cho, and K.-I. Kang, “Patent analysis for forecasting promising technology in high-rise building construction,” *Technological Forecasting and Social Change*, vol. 128, pp. 144–153, 2018.

[8] R. T. Jurnal and D. C. S. Analisa, “(D. I. S. T. R. I. B. U. T. E. D. Control System) Analisa dcs (distributed control system) pada proses polimerisasi,” *Sutet*, vol. 7, no. 1, pp. 54–62, 2018.

[9] A. A. Saad, S. Faddel, and O. Mohammed, “A secured distributed control system for future interconnected smart grids,” *Applied Energy*, vol. 243, pp. 57–70, 2019.

[10] Z. Kazemi, A. A. Safavi, S. Pouresmaeeli, and F. Naseri, “A practical framework for implementing multivariate monitoring techniques into distributed control system,” *Control Engineering Practice*, vol. 82, no. JAN, pp. 118–129, 2019.

[11] O. Bekdash, A. Hamdy, and H. El-Ghitany, "Design and implementation of emergency response notification for distributed control system," *The International Conference on Electrical Engineering*, vol. 11, no. 11, pp. 1–13, 2018.
[12] E. Meex, A. Hollberg, E. Knapen, L. Hildebrand, and G. Verbeeck, "Requirements for applying LCA-based environmental impact assessment tools in the early stages of building design," *Building and Environment*, vol. 133, no. APR, pp. 228–236, 2018.
[13] C. Maluk, M. Woodrow, and J. L. Torero, "The potential of integrating fire safety in modern building design," *Fire Safety Journal*, vol. 88, pp. 104–112, 2017.
[14] M. Alwetaishi and A. Balabel, "Numerical study of micro-climatically responsive school building design in Saudi Arabia," *Journal of King Saud University - Engineering Sciences*, vol. 31, no. 3, pp. 224–233, 2019.
[15] H. S. Ahmed and J. Caelen, "The command of comfort in an intelligent building by speech classification and image classification for energy optimization," *International Journal on Smart Sensing and Intelligent Systems*, vol. 13, no. 1, pp. 1–28, 2020.
[16] S. Singaravel, J. Suykens, and P. Geyer, "Deep-learning neural-network architectures and methods: using component-based models in building-design energy prediction," *Advanced Engineering Informatics*, vol. 38, no. OCT, pp. 81–90, 2018.
[17] T. Thepmanee, A. Julser Ee Wong, and S. Pongswatd, "Integration of hart and FF H1 devices into distributed control system for feedforward control in revamping existing plants," *International Journal of Innovative Computing Information and Control*, vol. 15, no. 1, pp. 407–415, 2019.
[18] L. M. Domínguez Lacarte and J. Fan, "Modelling of a thermally activated building system (TABS) combined with free-hanging acoustic ceiling units using computational fluid dynamics (CFD)," *Building Simulation*, vol. 11, no. 2, pp. 315–324, 2018.
[19] H. I. Shaheen, "Control system design of a virtual microgrid for Tishreen University Hospital using a distributed control strategy based on fuzzy logic controller," *Tishreen University Journal for Research and Scientific Studies*, vol. 42, no. 4, pp. 1–26, 2020.
[20] D.-W. Kim and H. J. Park, "Development of distributed control system for interpreter-based educational robot," *Journal of The Korean Society of Manufacturing Technology Engineers*, vol. 29, no. 3, pp. 235–242, 2020.
[21] I. Othman, H. Mohamad, M. Napiah, Z. Hashim, and Z. Cai, "Integration of building information modelling (bim) and industrialized building system (IBS)," *International Journal of Engineering Technologies and Management Research*, vol. 5, no. 12, pp. 92–100, 2020.
[22] J. Omran, "How to achieve sustainable building design and operation with building information modeling," *Tishreen University Journal for Research and Scientific Studies*, vol. 42, no. 2, pp. 217–232, 2020.
[23] H. Sheward, "BIM based normative calculations for early stages of building design," *American Journal of Civil Engineering and Architecture*, vol. 9, no. 5, pp. 181–202, 2021.