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INTELLIGENT MONITORING METHOD FOR OCCUPANTS' BEHAVIOR AND INDOOR ENVIRONMENT USING INTERNET OF THINGS TECHNOLOGY

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•H1:Review the evaluation index for a building environment, which can influence occupant comfort, and develop an intelligent control method.

H2:Sum up the investigation of occupants' preferences and requirements in an office building based on questionnaires.

H3:Construct an intelligent monitoring framework considering occupants' demands and compare it with existing standards.

ABSTRACT

The effects of the indoor environment on people's comfort and health have been increased in public awareness. However, although occupants are often dissatisfied with an indoor environment, they will passively accept their situation. The development of Internet of Things technology can provide users with convenient, comfortable and creative indoor environments in the most effective way and can quickly respond to the user's various requirements to ensure good indoor environment quality in a sustainable environment. However, the intelligent monitoring systems of buildings have mainly been focused on building equipment and energy consumption and are not standardized construction in building environmental monitoring. In this research, take an office building as an example, an intelligent monitoring framework that considers occupants' demands is designed, and the problems of environmental intelligent monitoring methods are analyzed and compared with existing standards in China, based on occupants' evaluation of the indoor environment investigating.

Keywords: *Intelligent Monitoring; Building Environment; Evaluation; Office Building*

1 INTRODUCTION

The importance of indoor environmental monitoring systems for human safety and health is growing, specifically intelligent monitoring and control systems for air cleanliness. Ninety percent of people spend most of their time in buildings, occupant productivity and health are highly influenced by the indoor air quality, and currently, increasingly more attention is paid to the comfort and safety of building environments. Occupant behavior represents one of the largest uncertainties in building energy usage, and it can be optimally managed by indoor sensors and intelligent technology. Intelligent monitoring is an integrative system management technology that can combine real-time sensing with project-specific data processing, event detection, forecast analysis, and collaborative tools for data interpretation and decision making. However, most of the current environmental monitoring systems are not designed to handle real-time data streams, and the best practices for data stream processing and forecast analysis are yet to be established[1-3].

The rapid evolution of Internet of Things technology（IOT）is driving the increased deployment of smart sensors in environmental applications, An indoor environment monitoring system is designed based on the IOT and a cloud platform to establish an evaluation model of indoor air quality (IAQ), but the system does not consider the intelligent feedback control of the system. An intelligent indoor environment monitoring system is proposed which contains ZigBee wireless sensor network technology to store and process environmental data. [4].

The intelligent indoor environment monitoring design includes the monitoring and control of traditional cold and heat sources, heating, ventilation and air conditioning, a water supply and drainage, a power supply and distribution, lighting, elevators and other equipment. The design should also include monitoring basic environmental information parameters such as the indoor temperature, humidity, illumination, CO2 concentration and noise. However, current building environment control is mainly based on a building automation system (BAS), and the design principle is based on an “on-demand” adjustment[5].

Due to the lack of interaction among indoor personnel, control information and building use information during building operation, the operational effect of the BAS is far below the design requirements[6]. Additionally, occupant satisfaction and the evaluation of the indoor environment are key for intelligent indoor environment monitoring to adjust the building environment. A multi-agent framework for intelligent building control with sensors is described, but ignored the impact of occupant activities and demands when setting the system. The specific control approach for each item in a building environment is reviewed, but failed to provide an evaluating index to judge whether it is comfortable for occupants[7]. An indoor environmental quality (IEQ) toolbox for evaluating a building is proposed based on a wireless mesh network. The IEQ toolbox can collect environmental monitoring data and conduct a comfort assessment, but it is not connected to the control system and does not consider human behaviors[8].

Therefore, many problems still exist for intelligent indoor environment monitoring when considering occupant demands, and for different requirements, field testing and the evaluation of indoor environments are different[9]. In this paper, we will discuss this topic further, and the main content is as follows:

•Review the evaluation index for a building environment, which can influence occupant comfort, there are no standards for environmental intelligent monitoring in China now.

•Sum up the investigation of occupants’ preferences and requirements in an office building based on questionnaires, and to know occupants’ requirements for environmental intelligent monitoring system.

•Construct an environmental intelligent monitoring framework which considering occupants’ demands, and the proposal on the environmental intelligent monitoring system will be given.

2 OCCUPANT’S SATISFACTION AND EVALUTIONG FOR BUILDING INDOOR ENVIRONMENTS

2.1 Occupant requirements of an indoor environment

With improving living and working conditions, occupants’ requirements for building environments have been increasing. The users' evaluation of indoor environment comfort is mainly based on subjective and objective aspects. Objective environmental elements mainly consist of the indoor thermal environment, indoor air environment, indoor acoustic environment, and indoor light environment. The subjective factor is related to the human psychological factor, which can cause the intelligent monitoring system to meet an individual’s comfort demand by understanding the subjective demand of the office workers.

Occupants control the applications, such as the air conditioning terminal, lighting, windows, sunshade and other equipment, which are closely related to the subjective feelings of individuals. Different users have different control behaviors due to their different individual needs. Occupants should be able to directly participate in the control of an indoor environment. If the user does not know how to control the indoor environment, it will affect the application effect of intelligent control technology.

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An understanding of methods to control building indoor environments and some intelligent control technologies should be improved.

Based on the requirements of individuals, the indoor environment is divided into meeting functional needs, energy saving requirements, health and comfort and personalized needs. The functional requirement is a basic switch control, and energy saving requirements are based on standard requirements. For the health and comfort of individuals, information such as the user, environment and equipment are integrally considered.

2.2 Evaluation of building indoor environments

The indoor physical environment of a building is very complex and consists of a thermal and humidity environment, a building light environment, an IAQ environment and a sound environment. Each index of the indoor environment has a strict limitation, and the details are as follows.

2.2.1 Thermal and Humid Environment

To control and improve the thermal and humidity environment of buildings, air conditioning systems are employed. At present, all air conditioning systems take the temperature standard value as the reference input and the indoor temperature as the control target. When the indoor temperature meets the standard value, the indoor heat and moisture environment is comfortable. However, a comfortable environment not only needs a suitable temperature but also needs a suitable humidity, wind speed, etc. The predicted mean vote (PMV) index as the control target of the air conditioning system comprehensively reflects the comfort level of the indoor heat and moisture environment[10]. The calculation formula is as follows Eq. (1):

PMV=[0.303exp(-0.036M)+0.0275]×{M-W-3.05[5.733-0.007(M-W)-Pa]-0.42(M-W-58.2)

-0.0173M(5.867-Pa)-0.0014M(34-ta)-3.96×10fcl[(tcl+273)-(+273)]-fclhc(tcl-ta)} (1)

The thermal sensation scale is shown in Table 1 from the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).

Table 1 Thermal sensation scale based on the PMV

Thermal Sensation	hot	warm	slightly warm	neutral	slightly cool	cool	cold
PMV value	+3	+2	+1	0	-1	-2	-3

Using intelligent control technology, the PMV value of an indoor environment can be predicted on-line in real time, and the PMV deviation value can be calculated as the control input of the air conditioning system, thus controlling the actions of the end devices of the air conditioning system and creating a comfortable thermal and humidity environment.

2.2.2 Indoor air quality (IAQ)

For the IAQ of buildings, the concentration of main pollutants affecting the IAQ can be improved by controlling the doors, windows and ventilation equipment. In the actual control process, the main pollutant types to be monitored should be determined according to the building function and the activities of the individuals. Generally, a comprehensive index method is used for the evaluation. The subindex is defined as the ratio of the pollutant concentration Ci to the index upper limit value Si, which can be found from the index data in the existing standards, and its reciprocal is regarded as its weight coefficient, which vividly represents the distance between a certain pollutant concentration and its standard upper limit value. The comprehensive index, organically combined by subindex, reflects the condition of the indoor air quality as shown in Eq. (2)[11].

$$\text{Comprehensive index:} I = \sqrt{\left(max\left|\frac{C_1}{S_1},\frac{C_2}{S_2},\dots,\frac{C_n}{S_n}\right|\right)\cdot\left(\frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{S_i}\right)} \quad (2)$$

According to the comprehensive index, the IAQ is divided into five levels, as shown in Table 2.

Table 2 Five levels of IAQ

Comprehensive index	≤0.49	0.50-0.99	1.00-1.49	1.50-1.99	≥0.49
IAQ level	I	II	III	IV	V
Description	clean	unpolluted	lightly polluted	moderately polluted	heavily polluted

According to the collected data of the indoor air evaluation factors, the operation state of doors, windows, ventilation and air conditioning equipment can be controlled, and the indoor air is reasonably organized so that the concentration of each indoor pollutant is below the standard value and the comprehensive index is required to reach the standard.

2.2.3 Luminous Environment

For the luminous environment of a building, intelligent technology is adopted to improve the lighting mainly from the illuminance level and illuminance uniformity. The daylighting coefficient is usually used to evaluate the building light environment. The daylighting coefficient C is defined as the ratio of the natural illuminance En at a certain indoor point to the outdoor illuminance Ew at the same time. It's shown in Eq. (3). In the daylighting standard, outdoor illuminance refers to the diffuse light in the sky when the sky is full of clouds.

$$\text{Daylighting coefficient } C = \frac{E_n}{E_w} \times 100\%. \quad (3)$$

The standard values of the lighting coefficient are shown in Table 3.

Table 3 Standard values of the lighting coefficient

Visual work classification	Visual working characteristics		Daylighting coefficient (%)	
	Accuracy	Identify dimensions	Side lighting	Top lighting
I	Extremely accurate	d≤0.15	5	7
II	Very accurate	0.15<d≤0.3	3	5
III	Accurate	0.3<d≤1.0	2	3
IV	Normal	1.0<d≤5.0	1	2
V	Rough	d>5.0	0.5	1

The illuminance level of the main indoor functional areas is monitored in real time, and the indoor illuminance average level and illuminance uniformity are obtained through data processing; these values are compared with the indoor required illuminance and illuminance uniformity standard values. If the illuminance level is lower than the standard value, then the angle of the sun visor and the blinds can be controlled by linkage so that natural light fully irradiates into the room. If the illuminance level is higher than the standard value, then the reverse action will be taken. If the illuminance level is satisfied but the illuminance distribution is uneven, the action of the reflector can be controlled by the linkage, and its rotation angle is calculated according to the solar altitude angle of the area where the lowest illuminance level is collected[12].

2.2.4 Acoustic Environment

For the building acoustic environment, common evaluation methods include the noise rating (NR)

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curve method and a sound level standard. The NR curve is a group of noise evaluation curves recommended by the International Organization for Standardization and has a wide range of applications. The allowable indoor noise levels of various buildings are shown in Table 4.

Table 4 Allowable indoor noise levels of various buildings

Type of building	NR (noise rating number) curve	A sound level /dB(A)
Broadcasting studio, voice room	15~20	20~25
Concert hall, theater	20~25	25~30
Cinema, conference hall	25~30	30~35
Office and reading room	30~35	35~40
Restaurants, gymnasiums, shopping malls	35~45	40~50
Waiting hall for airplanes, cars or ships	40~45	45~55
Cleaning workshop	50~60	55~65

Noise is generated from a noise source, propagated through a propagation medium, and finally reaches the receiver's ear. Therefore, noise control can begin at the noise source and propagation path. Noise sources are located throughout distributed monitoring devices. If the outdoor noise is too large, then the doors and windows will be controlled to play a certain role in sound insulation[13].

3 THE INVESTIGATION OF OCCUPANTS' PREFERENCES AND REQUIREMENTS IN AN OFFICE BUILDING

3.1 The investigation of occupant satisfaction in indoor environments

Via the comprehensive influence factors, the characteristics of user environmental control behaviors are analyzed by a questionnaire survey. Occupant satisfaction under indoor environmental conditions is investigated in the Baishu office building. Because the office building will be renovated in the future, the occupants' environmental preferences and control methods should be known. Therefore, some questions are designed, and 96 questionnaires are collected from individuals who occupy the office building, namely, 45 females and 51 males at ages ranging from 30-50 years old.

In a building environment, with respect to shading, lighting, air conditioning and windows, the characteristics that the occupants most like to control in the office room are analyzed, and the results are shown in Fig. 1. From the pie chart, the results are similar for every product, with percentages ranging from 20% to 30%. When the participants are asked about acoustic, luminous, thermal environment and air quality in an office room, the results in Fig. 2 show that the IAQ is 56.4%, the hot and humid environment is 18.8%, the luminous environment is 17.1%, and acoustic environment is 7.7%. From the pie chart, we can see that the occupants are more concerned with the air quality.

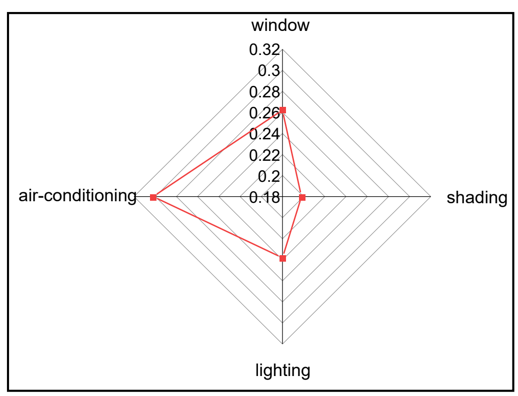

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Fig. 1 Comparison of different office room characteristics

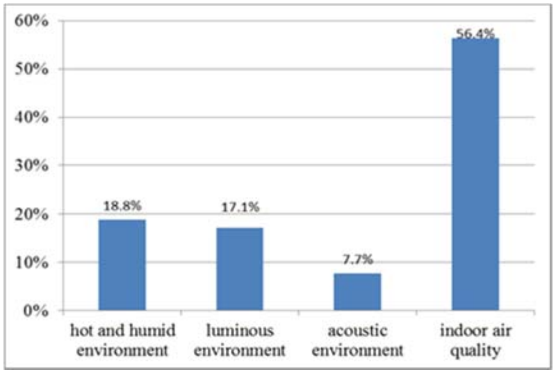

Fig. 2 The type of indoor environment of most concern

For the purpose of building environment control, the requirements that occupants most like to control are analyzed, and the results are shown in Fig. 3. From the picture, we can see that health and comfort needs are the maximum demand. For the question of how to control the indoor environment of the building, the intelligent way is the best one, 55.1%, as shown in Fig. 4.

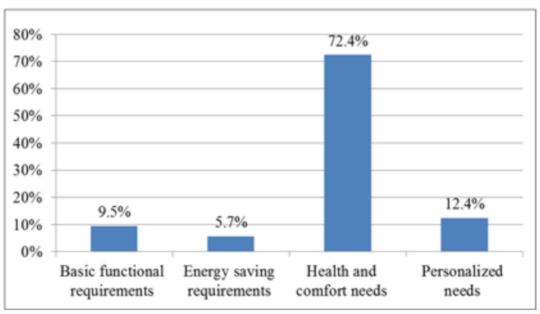

Fig. 3 The requirements of indoor environment control

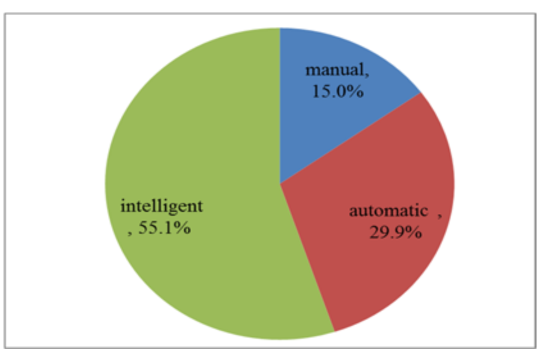

Fig. 4 The method of indoor environment control

For the control method of indoor light and heat environment, the participants were asked about their preference for the main method for indoor light control, and the results are shown in Fig. 5. The combination of lighting and natural lighting is a popular method, with a result of 77.8%. Regarding how to control the indoor thermal environment, the method is turning on the air conditioning or controlling the windows and shading, which according to peoples' preferences, it is 70.8%. The results are shown in Fig. 6.

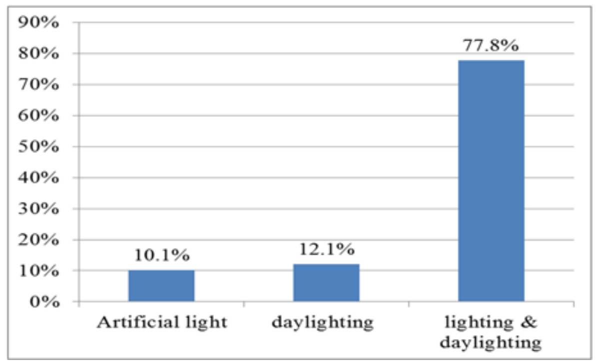

Fig. 5 The method for indoor light environment control

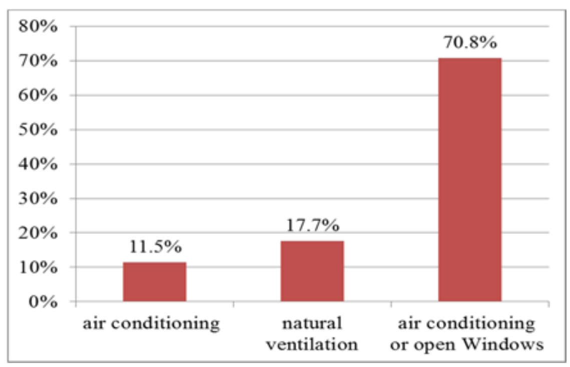

Fig. 6 The indoor thermal environment

From the survey results, we know that occupants like to switch the shading, windows, lighting and air conditioning in an office room, they care more about the IAQ, and they hope the indoor environment can be intelligently controlled according to their preferences. For the light environment, the occupants hope to combine lighting and natural lighting, and for the thermal environment, they hope to switch on the air conditioning or open

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the windows and adjust the shading according to their own preferences.

3.2 Occupant' behavior of building environment control

The occupant's behavior for controlling the indoor environment is also investigated in the Baishu office building via a questionnaire. The used time and control of the air conditioning, lighting, windows, and shading are surveyed, and the results are shown as follows.

In an office building, when the air conditioner is switched on, the participants were asked about their preference for the air conditioning control method. The results are shown in Fig. 7 and Fig. 8. From the graphics, the reason for air conditioner control is because of the occupants' requirement, and the automatic method is the best choice.

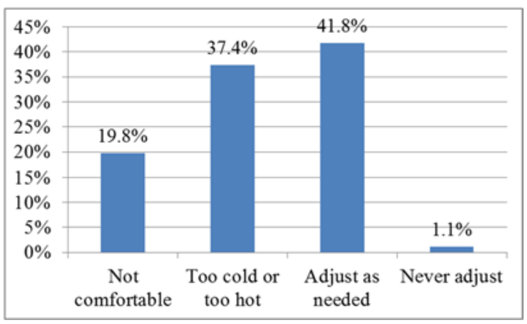

Fig. 7 The reason for air conditioner control

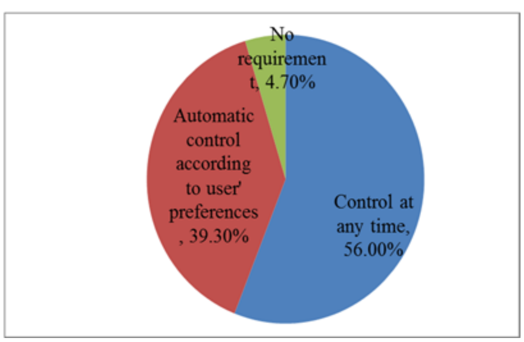

Fig. 8 Control method for the air conditioner

For the lighting switching, the participants were asked about their preference for what time of the day the office lighting is usually turned off, and what is the most popular method. Fig. 9 and Fig. 10 show the results. The results show that the occupants in the office room do not like to turn the lighting down, and they hope that the lighting can be adjusted in an intelligent manner.

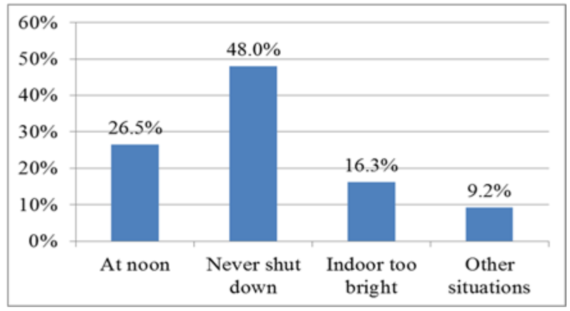

Fig. 9 Time to switch off the light

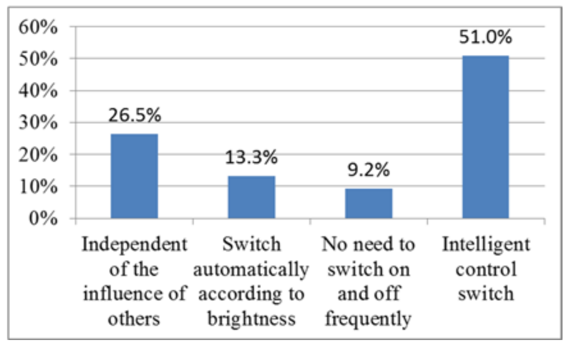

Fig. 10 Method for adjusting the lighting in an office room

For windows and shading, the participants were asked about how these factors influence each other and are they controlled for the same reason. The results for opened or closed window preferences and the method of window opening and closing are shown in Fig. 11 and Fig. 12, respectively. The seasons for window opening and closing are different, and the occupants hope to adjust the windows randomly.

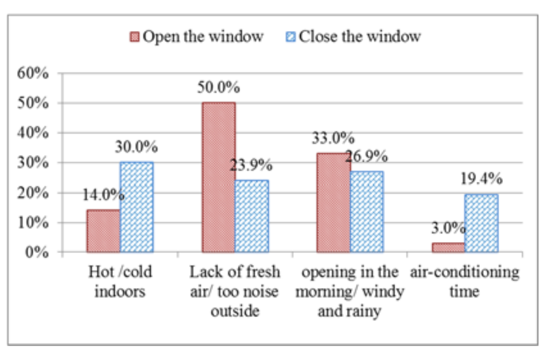

Fig. 11 The reason for an opened or closed window

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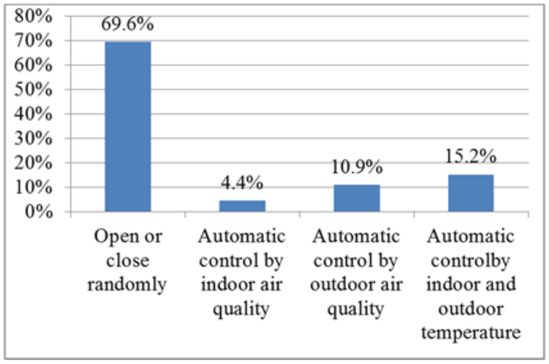

Fig. 12 The method of window opening and closing

The reasons for shading control and the methods of shading control are shown in Fig. 13 and Fig. 14, respectively. The reason for shading control is different from that for window control. Shading is used to mitigate the glare in an office room, and the occupants prefer intelligent shading control.

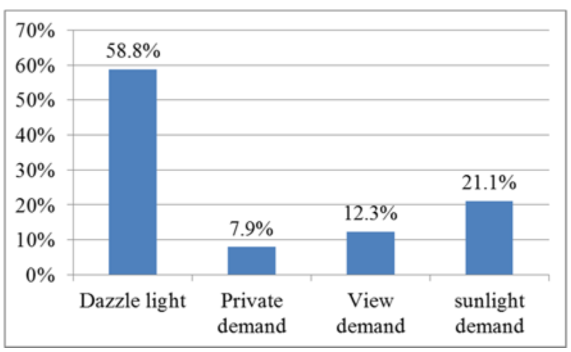

Fig. 13 The reason for adjusting the shading up and down

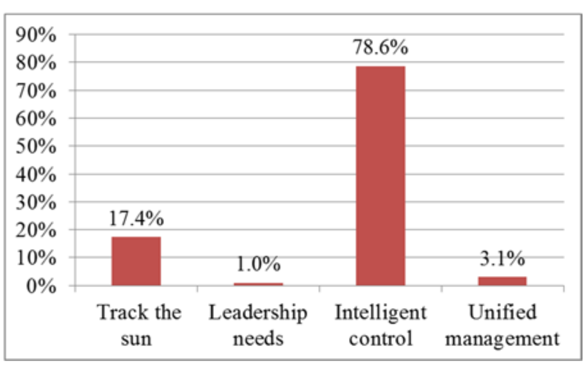

Fig. 14 The method of shading control

For the different types of equipment and because the functions and user demands are different, the control behavior varies. The air conditioning is controlled in accordance with the thermal and humidity environment, the shading and lighting are adjusted for the light environment requirement and the opening and closing of a window mainly affect the IAQ. With respect to the control method for the equipment, except for the windows, the occupants prefer intelligent control.

However, current control systems of building environments do not meet occupant requirements, and users' demands have not been considered. Therefore, building control systems are underutilized. Thus, in the future, occupant demands must be considered for an intelligent monitoring system and user preferences must be known to control an office environment.

4 DESIGN CASE FOR AN ENVIRONMENTAL INTELLIGENT MONITORING

4.1 Field test method for indoor environment parameters

There are many standards for the field testing of indoor environments, such as the temperature, humidity, wind speed, CO2 concentration, illuminance and noise, as shown in Table 5.

From the standards, we know that the measuring points of indoor environment parameters are mainly based on the size of the building room area. For the temperature and humidity, the height of the measuring points is from 0.8 m to 1.6 m and should not be less than 0.5 m from the wall and heat source. The CO2 concentration test is also based on the size of room area and condition, and the height of the measuring point should be consistent with the height of the breathing belt, which is from 0.5 m to 1.5 m. The measuring points of indoor environment parameters are shown in Table 6.

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Table 5 The field testing standards of indoor environments

No.	Parameter	Detection method	Reference
1	Temperature	Glass liquid thermometer method	GB/T 18204.13
		Digital thermometer method	
2	Humidity	Ventilation psychrometric method	GB/T 18204.14
		Hair hygrometer method	
		LiCl hygrometer method	
3	Wind speed	Hot - bulb anemometer method	GB/T 18204.15
		Digital anemometer method	
4	CO2 concentration	Non - spectral infrared gas analysis	GB/T 18204.24
		Gas chromatography	
		Volumetric titration	
5	Illuminance	Illumination meter method	GB/T 18204.21
6	Noise	Sound level meter method	GB/T 18204.22

Table 6 Measuring points of the indoor environment parameters

Temperature and Humidity	Indoor Area Measuring Point	≤16 m^2	16~30 m^2	30~60 m^2	≥60 m^2
	Number	1	2	3	5
	Height	0.8~1.6 m			
Wind Speed	Indoor Area Measuring Point	≤16 m^2	16~30 m^2	30~60 m^2	≥60 m^2
	Number	1	2	3	5
	Height	0.8~1.6 m			
CO2 Concentration	Indoor Area Measuring Point	≤50 m^2	50~100 m^2		≥100 m^2

	Number	1~3	3~5	≥5
	Height	0.5~1.5 m		
Illuminance	Indoor Area Measuring Point	Normal Size	Large Areas	
	Number	5	10 points/100 m^2	
	Height	0.8~0.9 m		
Noise	Indoor Area Measuring Point	≤100 m^2	>100 m^2	
	Number	3	1	
	Height			

4.2 Case study of indoor environment monitoring

To show that the demand for measuring the point layout of a building environment intelligent monitoring system is different from that of engineering detection, taking the building in which the questionnaire was carried out as an example, the following two charts give two layout methods of measuring points. Fig. 15 shows the layout of the measuring points required by the national standard of China, and Fig. 16 shows the layout of measuring points required by the comfort requirements of intelligent monitoring.

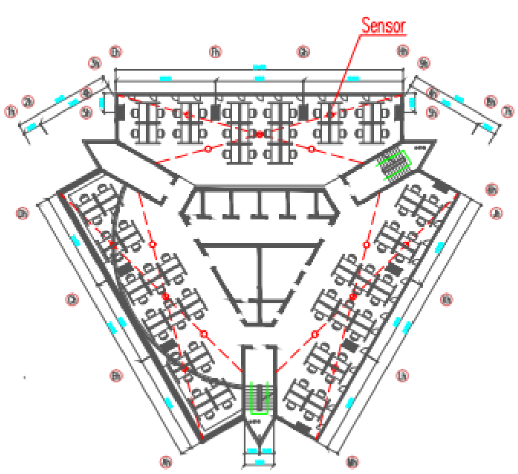

Fig. 15 Chinese national standard of intelligent monitoring

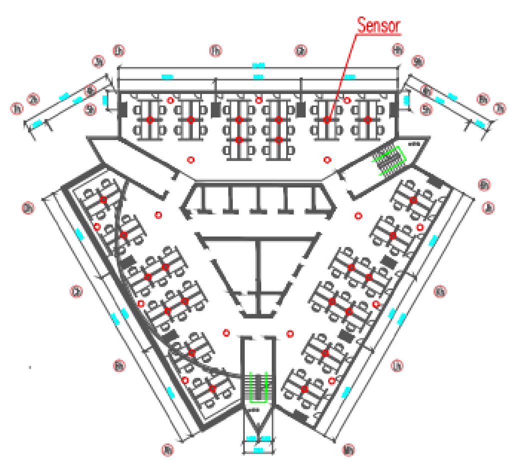

Fig. 16 Comfort requirements of intelligent monitoring

As shown in the comparison figure, the number of sensors meeting the comfort requirements will be greater, and the installation position will be more conducive to intelligent monitoring of the environment. In office rooms, occupants sit for a long period of time and require high comfort. To carry out intelligent regulation and control, the parameter collection of the desk and its surrounding environment must be timely and accurate. When the indoor environment is precisely regulated, the measuring point layout should be able to realize indoor environment control. Accordingly, with regard to the location of the monitoring points, the following recommendations are made:

(1) On the premise of meeting the national standards, the number of monitoring points should be increased to further meet the comfort requirements, and the economic costs should also be considered.

(2) More attention should be paid to the locations where environmental parameters are prone to change, such as those areas that are near and far from windows. As office buildings are mostly glass curtain walls, the locations close to windows are more likely to be affected by outdoor environmental parameters. Therefore, locations close to windows need more monitoring points.

(3) The layout that meets the requirements of comfort is no longer divided according to the area only, but according to the location and density of the office staff. As shown in Fig. 8, at least one integrated sensor is shared by every four stations of the office building so that the monitoring results of environmental parameters in the office area can be more accurate and meet the follow-up intelligent regulation.

Therefore, the indoor environment test and evaluation standards are not only used to meet the project acceptance requirements but also are used to meet the occupant environment requirements. In addition to the real-time monitoring of environmental parameters, such as temperature and humidity, wind speed, and illumination, it is also necessary to understand the environmental needs of users, as well as their demands for air conditioning, lighting, windows and shading, to achieve user comfort, to control equipment at any time and to meet other higher requirements.

5 PROPOSAL ON THE ENVIRONMENTAL INTELLIGENT MONITORING SYSTEM

5.1 Problems

The testing methods from these current standards are mainly used for accepting building completion or for evaluating the air conditioning environment, mainly with manual testing. However, there are some problems in the intelligent control system of building environments; that is, the occupants' real needs, the influence factors of the wireless sensor application, and the environmental control needs are all ignored[14].

(1) The monitoring standard does not meet the needs of personnel. At present, the automatic monitoring methods used in engineering are more traditional and conservative and seldom consider the influence of indoor personnel activities and the needs of different building environments. Personnel needs should be taken into account and will be considered in the new monitoring standards.

(2) A systematic evaluation standard does not exist. The current evaluation standard for building environment monitoring is not systematic and leads to confusion in the quality management of design and construction. As a result, the design drawings are not standardized, the service life of the intelligent building system is short, the intelligent building is underutilized, the system failure is frequent, and the energy consumption is high.

(3) The level of intelligence is not high. At present, to achieve the desired goal, the BAS is mainly adopted to control the equipment in the building environment. It is only the primary stage of intelligent buildings, and for the advanced stage, artificial intelligence technology, such as self-adaptation, self-diagnosis and self-repair, should be used to realize higher-level intelligence.

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5.2 Proposal

5.2.1Sensor requirement

A large number of sensors are needed in the intelligent monitoring system of building environments, and wireless sensing technology has been developed and applied. The acquisition and transmission of wireless sensing technology is the key to the successful establishment of building environmental monitoring systems. At the same time, the sensors must have certain precision to meet the monitoring system requirements. The accuracy requirements of common sensors for building environments are shown in Table 7.

There are many kinds of sensors for building environment monitoring, and an increasing number of problems are beginning to be exposed. Sensor devices from different manufacturers need to be interconnected and interference with existing systems need to be avoided. Different sensors use different protocols, such as IEEE 802.15.4 and ZigBee. Based on the wireless sensors used, some factors should be considered for the measurement points of building environment monitoring, as follows:

(1) Node location. The location and number selection of network nodes are the first problem to be considered for the wireless communication network. Due to the complex structure of the building, a reasonable location for the transmitters, repeaters and receivers are key for ensuring the robustness of the network. For communication between nodes, the best position for the nodes is within a visual distance to ensure the stability of communication and connection between nodes.

(2) Transmission distance. There are three reasons for the difference between the actual transmission distance and the ideal state in buildings: ①The signal attenuation caused by the transmission distance; ② the signal attenuation caused by the obstacles in the transmission process; and ③ electromagnetic interference from other equipment. When there is an unobstructed visual path between the transmitter and the receiver, the attenuation of the received signal intensity is inversely proportional to the square of the transmission distance. In practical applications, due to the existence of obstacles and the interference of signal emission, the power exponent of the distance is usually greater than 2, and it is approximately 2~4[15] Therefore, when the sensor nodes are arranged in the building, the transmission distance should be evaluated correctly according to the environment to ensure the effective transmission of information.

(3) Electromagnetic interference. The wireless communication network of the building environment monitoring system will be interfered by wireless waves from mobile phones, computers and other electromagnetic equipment in the building. Spread spectrum technology is used to transmit signals, and the ability of anti-interference is enhanced. However, when wireless nodes are designed, they should be kept at a certain distance from electromagnetic devices. At the same time, the electromagnetic field of wireless nodes should not interfere with other devices.

(4) Signal strength detection. The purpose of signal strength detection is to confirm whether the node location is correct and whether the communication between the nodes is stable and reliable. Through signal intensity detection, the robustness of the network will be enhanced by changing the location of each node reasonably or appropriately by adding a repeater[16]. The weak spots in the wireless network are located and adjusted in time.

Therefore, the influence of the above factors on the layout of measuring points should be taken into account when building an intelligent monitoring system, and the wireless protocols of all sensors should be uniform.

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Table 7 The sensor accuracy requirements of indoor environment monitoring

Serial number	Environment parameter	Measuring sensor	Accuracy requirement	Measurement range	Recommend wireless standard protocol
1	Temperature and humidity	PT100 thermal resistance	±0.5℃	≥16 m	IEEE 802.15.4, ZigBee, Bluetooth, WirelessHART, ISA100, WIA-PA, 6LowPAN
		Lithium chloride humidity sensor	±3% RH		
2	Wind speed	Ultrasonic wind speed sensor	±0.2 m/s	≥16 m	
3	CO2 concentrations	Infrared carbon dioxide sensor	±40 ppm	≥16 m	
4	PM2.5	Laser particulate matter (PM) sensor	$\pm 10\mu g / m^3$ $(0 \sim 100\mu g / m$	≥16 m	
5	PM10		$\pm 10\%$ $(100 \sim 1000\mu g$	≥16 m	
6	Volatile organic compounds (VOCs)	Gas sensor	±25 ppm	≥16 m	
7	Total volatile organic compounds (TVOCs)			≥16 m	
8	Illuminance	Photosensitive diode	±7% (25℃)	≥16 m	
9	Luminance	Photosensitive resistor sensor	±7%	≥16 m	
10	Noise	Electret condenser microphone	±0.5 dB	≥16 m	
11	Identification of human behavior	Ultra-wide band (UWB)	10 cm	30-50 m	

5.2.2 System requirements

The influencing factors of indoor environmental comfort are diverse, and the standard parameters of comfort rating are unclear; the comfort rating standard of indoor environment is different for different scenarios and different users. Taking comfort and energy savings as the goal, intelligent monitoring of indoor comfort environments in office buildings can be realized through self-control by recognizing the scene[17]. Through indoor environmental parameters, such as temperature, humidity and illumination, which are monitored by sensors and controlled by users or historical data, the comfort degree is evaluated by the technology of context awareness[18]. According to a well-designed control strategy, building energy conservation and environmental comfort can be realized.

(1) Intelligence. The system should be able to judge the current environmental comfort and feed it back to the central processing unit and then intelligently adjust the equipment to improve the environment comfort.

(2) High accuracy and high stability. The error of the monitoring data should be as small as possible. The monitoring equipment should have good stability and not need frequent maintenance or need to be replaced. The equipment should reduce operating costs and never need human intervention.

(3) Low power. Modern office buildings are basically green buildings, which have higher requirements for energy consumption. Therefore, the principle of system construction nodes can operate with low power consumption and ensure a long network working life

(4) Real time. The response of the environmental acquisition system should be changed in a timely manner, and the current temperature and humidity and illumination information can be queried at any time.

(5) Anti-interference. There are many wireless signals in modern office buildings; to ensure the monitoring data accuracy, the system must have strong anti-interference performance.

Therefore, in practical applications, intelligent control systems should not only realize intelligent monitoring but also take into account the system's low energy consumption, high stability, high precision, anti-interference ability and so on.

6 CONCLUSIONS AND DISCUSSION

This paper attempts to elucidate the importance of intelligent indoor environmental monitoring, and it is different from engineering testing. The occupant’s preferences and the characteristics of sensor and network protocols should be taken into consideration.

In this study, although indoor environmental assessments are very complicated, the results of the questionnaire are confirmed. For the controlling method of the equipment, the intelligent method is more popular. Therefore, the construction of intelligent indoor environment monitoring systems should integrate wireless sensors and different functional requirements to develop monitoring strategies. Additionally, standardized monitoring methods should be considered to provide a basis for the sustainable development of intelligent building environments, and also occupants’ behavior in building environments.

However, the measuring point numbers for indoor environmental monitoring do not meet the intelligent requirements, and a case study of a building intelligent monitoring system is shown. According to different levels of building requirements, the test points of the building environment intelligent monitoring system are set. When satisfying the user's comfort requirement, the layout of measuring points should be based on the user's station characteristics, rather than just according to the area.

Our case study is limited to popularization and application, and many more case studies are needed to develop standards. Furthermore, the related technical parameters will be quantified, and a standard system will be established for intelligence monitoring systems in future work.

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REFERENCES:

[1] Alexander Y. Sun, Zhi Zhong, Hoonyoung Jeong, Qian Yang. Building complex event processing capability for intelligent environmental monitoring Environmental Modelling and Software， 2019（116）：1–6

[2] Bing Dong, Prakash, Fan Feng, Zheng O'Neill. A review of smart building sensing system for better indoor environment control. Energy & Buildings，2019（199）：29-46

[3]Chao-Tung Yang, Shuo-Tsung Chen, Walter Den, Yun-Ting Wang, Endah Kristiani. Implementation of an Intelligent Indoor Environmental Monitoring and management system in cloud. Future Generation Computer Systems，2019 (96) ：731–749

[4] Ming Jin, Shichao Liu, Stefano Schiavon, Costas Spanos. Automated mobile sensing: Towards high-granularity agile indoor environmental quality monitoring. Building and Environment，2018 (127)： 268–276

[5]Cui Ran, Ma Xudong, Peng Changhai. Design of building environmental monitoring system based on wireless sensing tec hnology [J]. Modern electronic technology,2010,33(07):53-58.

[6] Zhang shuai,He Weiping,Chen Dengkai,Chu jianjie,Fan Hao,Duan Xiaosai. Thermal comfort analysis based on PMV/PPD in cabins of manned submersibles[J]. Building and Environment,2018.

[7]Laura Bellia,Francesca Fragliasso. Automated daylight-linked control systems performance with illuminance sensors for side-lit offices in the Mediterranean area[J]. Automation in Construction,2019(100):145-162.

[8]Ivan Sarwar. Noise Pollution and Control Measure: In the Case of Dhaka City[A]. Chinese Academy of Sciences, State Environmental Protection Administration, Swiss Academy of Engineering Sciences, Switzerland,2005:1.

[9] Shahryar Habibi.Smart innovation systems for indoor environmental quality (IEQ). Journal of Building Engineering ,2016 (8) 1–13

[10] Mitja Košir, Aleš Krainer, Živa Kristl. Integral control system of indoor environment in continuously occupied spaces. Automation in Construction ，2012 (12) ：199–209

[11] D.Kolokotas, G.Saridakis, K.D.alamagkidis, S.Dolianitis,I.Kaliakatsos. Development of an intelligent indoor environment and energy management system for greenhouses. Energy Conversion and management, 2010 (51)155-168

[12] Da Li, Carol C. Menassa∗, Vineet R. Kamat. Personalized human comfort in indoor building environments under diverse conditioning modes. Building and Environment， 2017 (126)： 304–317

[13] A. Wierzbicka, M. Bohgard, J.H. Pagels, A. Dahl, J. L€ondahl, T. Hussein ,E. Swietlicki, A. Gudmundsson. Quantification of differences between occupancy and total monitoring periods for better assessment of exposure to particles in indoor Environments. Atmospheric Environment， 2015 (106) ：419-428

[14] Christopher O.Muller. Energy Conservation and Improved IAQ with Existing Ventilation Standards[A]. Tianjin University、Dalian University of Technology,2008:8.

[15] KINTNER M M,CONANT R.Opportunities of wireless sensors and controls for building operation[J]. Energy Engineering Journal,2005,102(5):27-48.

[16] Zhu Yuanbin. Research on the construction and application of indoor health environment monitoring system [D]. Dalian university of technology,2017.

[17] Wang Yu. Design and implementation of indoor comfortable environment energy-saving monitoring platform for public buildings [D]. Hunan university of technology,2014.

[18] Du Yuansheng. Design and implementation of indoor environment monitoring system based on wireless sensor network [D]. Nanjing university of aeronautics and astronautics,2013.