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A Comprehensive Approach for Thermal Comfort Analysis in Green Intelligent Buildings Using BIM Technology

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Abstract. With the development of social economy and environmental pollution problems increasing, green intelligent building has become an inevitable trend in the development of modern architecture, which is of great significance for the sustainable development of the construction industry and environmental protection. This thesis aims to explore the feasibility of using green intelligent buildings as the general development direction for modern buildings in China based on big data, and to propose a BIM technology-based building energy consumption simulation method and thermal comfort analysis method to provide a scientific basis for the design and construction of green intelligent buildings. Based on the evolutionary stages and general process of modern architecture and the rise and evolution of the green smart building concept, we present an overview of BIM technology and green smart buildings, and propose a BIM-based method for simulating building energy consumption and thermal comfort analysis. We conducted experimental design and data collection, and analysed and discussed the results. The results show that the BIM-based approach can effectively improve the prediction accuracy of building energy consumption and the accuracy of thermal comfort assessment. Furthermore, we believe that the practical significance of this research method is that it promotes the development of greening modern buildings in China, and also provides theoretical and methodological support for further research in related fields.

Keywords: BIM technology, green intelligent building, building energy simulation, thermal comfort analysis, indoor environmental quality assessment, intelligent control

1. Introduction

With the iterative progress and maturity of computer tech, it has been widely and deeply studied and popularized in many fields, especially the utilization of computer tech represented by big data in the evolution of green intelligent building, which greatly accelerates the evolution of green intelligent building. On the other hand, with the continuous evolution of social economy, all kinds of infrastructure buildings have achieved significant growth, and the overall evolution direction of architecture is in different stages with the progress of society (Dou & Yuan, 2018). In recent years, with the deepening of the utilization of info tech and intelligent tech, as well as the increasing social efforts to protect the ecological environment, the concept of green building is gradually from the rise to maturity. In this context, the evolution of modern architecture not only puts forward higher requirements for its own functionality, but also develops and progresses in several aspects as shown in Figure 1 below.

With the progress of social economy and intelligent tech, intelligent buildings are constantly emerging, and the scientific and technological content and intelligent degree of buildings are constantly improving. The scientific and technological concept and intelligent utilization of modern architecture, especially large-scale architecture, have gradually come to people's vision, which makes people feel convenient and their use experience has also been significantly ameliorated. In the process of evolution and utilization of intelligent building, a variety of problems and deficiencies are constantly emerging. Specifically, the planning, design, construction and management capabilities of intelligent building have not been ameliorated and optimized (Panteli et al., 2020). As a result, there is still room for amelioration in the design, use and management of buildings.

In order to ameliorate the overall evolution level of modern buildings, especially green intelligent buildings, it is necessary to further integrate the internal intelligent system of the building, ameliorate its systematic, standardized and standardized design, construction and management level, and strengthen the qualification identification, engineering training and system integration degree of green intelligent buildings. Draw support from big data analysis tech, the effective value mining of data generated in the process of green intelligent building planning, design, construction, operation management and maintenance is helpful to provide data and support and premise for the healthy and sustainable evolution of green buildings and future evolution planning. Therefore, it has important practical value to carry out the research on the overall evolution direction of modern green building on account of big data (Huang, 2015).

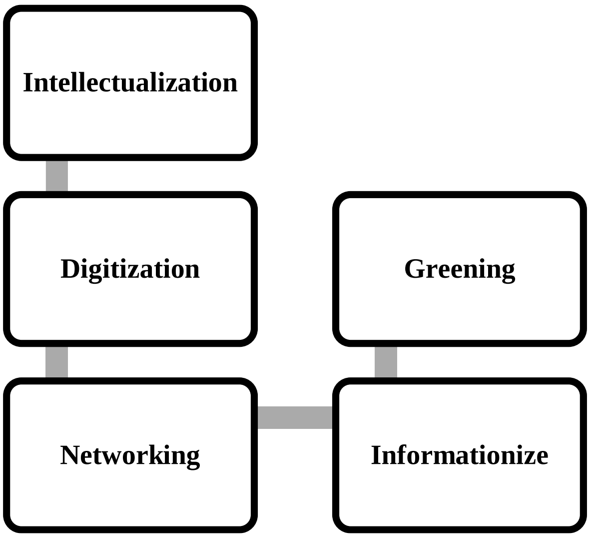

Figure 1. Evolution direction and trend of modern architecture

As the global population continues to grow and urbanisation accelerates, energy consumption and carbon emissions in the building sector are becoming more and more prominent. At the same time, the impact of the indoor environment on human health and comfort is of increasing concern. With buildings accounting for 40% of total energy consumption globally, the reduction of energy consumption in buildings is of great environmental and economic importance. There are many ways to reduce energy consumption in buildings, such as adopting more efficient building designs and materials, adopting green building technologies, and improving building equipment and systems (Zhou, 2016). It is therefore important to conduct research on building energy consumption in order to promote the development of green buildings. On the other hand, the indoor environment of a building has an important impact on people's health and comfort. Nowadays, people are demanding more and more comfort from their indoor environment, so how to improve the quality of the indoor environment while ensuring energy efficiency in buildings is an important issue. Indoor environmental factors include temperature, humidity, CO2 concentration and PM2.5 concentration, which have a direct impact on human health. Therefore, it is of great practical importance to study the influencing factors and control methods of the indoor environment. In order to meet the demand for building comfort and a healthy environment, new technologies and methods need to be developed to reduce building energy consumption and improve the quality of the indoor environment. BIM technology and green intelligent buildings are important tools to solve the problems of building energy consumption and indoor environment. BIM technology can digitise, visualise and operationalise building information and provide data support for building energy analysis and optimisation. BIM The application of BIM technology in the study of building energy consumption and indoor environment has also become a hot topic of current research. with the advantages of automation and visualisation, BIM technology can describe building models more accurately, providing a good tool and platform for the study of building energy consumption and indoor environment (Edirisinghe & Woo, 2021). Therefore, the study of building energy consumption and indoor environment based on BIM technology also has important research value. Green intelligent buildings, on the other hand, provide technical support for the sustainable development of buildings by using advanced energy-saving technologies and intelligent control systems to achieve efficient use of building energy and intelligent control of the indoor environment. In summary, the study of building energy consumption and indoor environment is an important issue facing society today. By applying BIM technology to building energy consumption and indoor environment research, the accuracy and visualisation of the research can be improved, providing important technical support and reference for building design and building energy efficiency (Jin et al., 2016).

In recent years, green intelligent buildings have emerged rapidly around the world and become a new trend in the development of the construction industry. Green intelligent buildings not only have the basic functions of traditional buildings, but also have higher standards and requirements in terms of energy saving, environmental protection, sustainability and intelligence. In order to meet these requirements, the construction industry needs to introduce new technological tools, among which computer-aided BIM technology is one of the most advanced and practical technologies, which can help architects and designers to digitally model and manage data during the building design and construction process, thereby improving the quality, efficiency and sustainability of buildings. Therefore, the application of computer-aided BIM technology in green intelligent buildings has important research significance and application value. Firstly, green intelligent buildings are the future development direction of the construction industry. Against the background of growing awareness of environmental protection and energy shortage, the construction industry must turn to sustainable development and realise energy saving, emission reduction and resource recycling to meet the development needs of society and economy. At the same time, with the continuous development and popularity of technology, intelligent buildings have become the development trend of the construction industry, which can improve the safety, comfort and intelligence of buildings. Therefore, green intelligent building has become the future development direction of the construction industry, with broad application prospects and market demand. Secondly, computer-aided BIM technology is an important means to realise green intelligent buildings. BIM technology is a digital modelling and data management tool that allows real-time collaboration and information sharing in the building design and construction process, thereby improving the quality, efficiency and sustainability of buildings. BIM technology allows for a range of functions such as 3D modelling, data visualisation, quantity calculation, progress management and clash detection, thereby improving the accuracy and efficiency of design and reducing waste and pollution of building materials. In addition, BIM technology can help architects and designers to simulate and evaluate building energy consumption, thus providing a scientific basis for the design and evaluation of green buildings (Li, 2014).

Green intelligent buildings are an important direction in the current development of the construction industry. At the same time, the development of Computer-Aided Design (CAD) and Building Information Modeling (BIM) also provides technical support for the realisation of green intelligent buildings. In foreign countries, the application of BIM technology in the field of green intelligent buildings has received widespread attention. Research shows that BIM technology can effectively improve the quality and efficiency of green intelligent building design, reduce building operation costs and promote sustainable development (Liu & Jia, 2017). Here are some foreign research results: The United States is one of the birthplaces of BIM technology, and its application in the field of green intelligent buildings is relatively mature. Studies have shown that BIM technology can improve energy efficiency, reduce construction waste and pollutant emissions, and improve the indoor environment during the building design and construction phases. For example, the Harvard School of Architecture in the US began using BIM technology in the field of green buildings in 2005, proposing a BIM-based sustainable design approach that enables energy optimisation and flexibility in building form by integrating energy analysis and building models. European research in the field of green and intelligent buildings is also very active. For example, Arup in the UK has proposed a BIM-based green design approach which, by integrating and analysing building information, can provide sustainability indicators for building design and help designers to optimise their designs. In addition, the Dutch Green Building Council in the Netherlands has also conducted relevant research in the field of green and intelligent buildings and has proposed a BIM-based sustainable building assessment method which can assess the building's energy efficiency, material use, indoor environment and other indicators to provide reference for designers (Menassa, 2021).

2. Modern architecture and green intelligent building concepts

2.1. The evolution stage and overall course of modern architecture

The rise and evolution of intelligent building concept: With the deepening of reform and opening up, China's economic construction has made remarkable achievements and evolution. In the different stages of China's economic evolution, according to the characteristics of the times background, the evolution level and evolution process of intelligent building also have great differences. In recent years, the evolution of intelligent building in China has put forward the demand of intelligence, digitization, networking and informatization. At the overall level, the concept of intelligent building was first proposed and developed significantly. As early as the 1980s, China has already started the feasibility study of intelligent building, and put forward the concept of intelligent office building (Wang, 2017). With the continuous evolution and standardization of intelligent building design standards in recent years, intelligent building has officially become the evolution direction of the country.

The rise of the concept and evolution of digital architecture: Digital architecture is a data set that contains all the info needed for engineering construction. Digital architecture is a kind of data body that expresses design info in a direct way. It can be represented by different levels of morphological models and activity models through certain relationships. The morphological model can fully describe the geometric info and topological info of each component of the building (Zhang et al., 2014). Digital has the ability to accurately describe the attribute info of components, while activity model can intuitively and stereoscopically describe architectural design and construction activities. With the evolution of social economy, the design standards of digital architecture and digital community have been issued in

China.
The rise and evolution of network architecture concept: The concept of network building is a new innovative method to construct intelligent buildings in the future by using network. It is the product of the combination of network tech, it tech and building automation tech, which can help designers and constructors to build more perfect buildings. Network architecture usually includes two dimensions: building management system and building user system. The construction management part mainly uses network tech to integrate the security, energy and Hydropower of traditional buildings, so as to form a complete building management automation system (Zhao et al., 2013). The user management system integrates the data, voice and video services of traditional building users, thus establishing the overall user management system, and realizing the effective integration of user info management and building services.

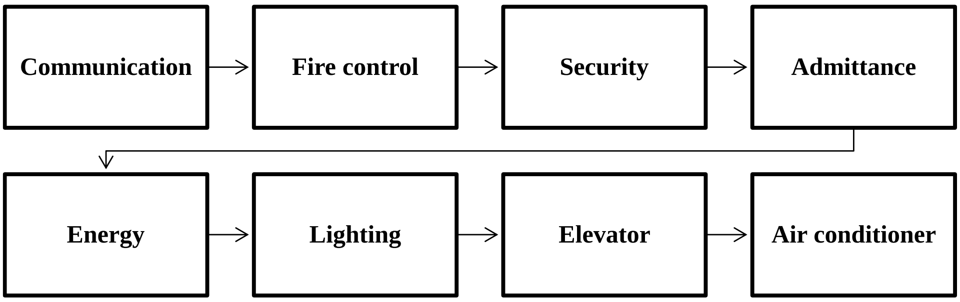

Figure 2. Subsystem of networked building integration

In addition, network architecture benefits from the organic integration and integration of several aspects as shown in Figure 2 above, so it can effectively reduce the construction cost and management cost of the building. The network architecture also integrates the process and equipment of each subsystem in the building to realize the interconnection between subsystems and effective management, so as to realize the formation of network architecture form (Zhou, 2016). Network tech can also link all the buildings in the region as an intelligent whole, so as to facilitate the overall management, greatly reduce the number of managers and the complexity of work items, and further reduce the cost of construction and management. Draw support from network tech, it can realize the overall environmental control of the building, ameliorate the comfort of users, and realize more building functions draw support from network multi-functional sensors, and monitor the status of the building as a whole.
The rise and evolution of informatization architecture concept: With the continuous maturity of AI, big data and other technologies, the concept of info architecture has been further developed. Info architecture will further integrate highly info-based and automated sensors to build a more perfect hardware and software architecture system. Info architecture can support highly intelligent software system of extremely complex hardware system. Info architecture can provide users with safe and comfortable comprehensive services, and implement comprehensive management and automatic control for the whole building. The organic combination of advanced hardware system and software system enables the building to carry out self-inspection, self-inspection, self-repair and other maintenance support.
In addition, due to the informatization of buildings, various intelligent subsystems can realize networking and integration, which accelerates people to obtain more efficient info. The communication network system of info building plays a more efficient function through the timely collection, transmission, processing and feedback of the internal info of the building.

2.2. The rise and evolution of the concept of green intelligent building

The rise and evolution of energy saving building concept: Energy saving building is to achieve building energy saving and emission reduction through certain technical measures and means on the premise of ensuring building functions. For example, by improving the building envelope to achieve thermal insulation and energy utilization performance optimization, reduce the energy consumption of indoor air management system. Secondly, green energy-saving buildings mainly achieve energy saving by improving the efficiency of building system and reducing the energy dissipation of buildings, and achieve the design and construction of energy-saving buildings according to the new design standards, so as to reduce the energy consumption in the use process, and through energy-saving design to reduce the energy consumption in the process of building operation (Bakhareva, 2019).

In addition, a large number of energy-saving materials and advanced technologies are used in the construction process of energy-saving buildings to achieve energy saving. The design and planning of energy-saving building is very important to realize the energy-saving index of the whole building, which needs a lot of design support and experience. The key points of energy-saving building construction include the overall layout planning, the research of microclimate environment, the optimization design of building peripheral structure, the cooperation between the internal technical systems and the utilization of ecological energy system.

The rise and evolution of the concept of environmental protection and ecological architecture: Environmental protection building needs full natural lighting wall, thermal insulation materials and environmental protection coating. Common environmental protection building facilities include sound insulation wall, natural light lighting, natural air duct, heat insulation, oxygen isolation pipe design, sound insulation, temperature glass, etc. Ecological architecture is to make the building itself and the environmental factors harmonious integration, in the premise of not destroying the environment, realize the function of the building. Ecological architecture is the integration of multi-disciplinary and professional geometry, and is a complex system engineering, involving the participation and construction of the whole society. Green ecological building is not only to ensure the sound operation of the local ecosystem, but also to create a comfortable building space environment, so the complexity is higher, and it is also an important representation of green building.

Green intelligent building is a new form of building that integrates green building and intelligent building. It is aimed at energy saving, environmental protection and comfort, and uses modern information technology and intelligent control means to integrate building and environment in order to achieve a harmonious symbiosis between building, environment and people. The concept of green intelligent buildings has gained widespread attention and recognition and is a hot topic in the current construction industry. With global energy consumption and environmental issues becoming increasingly prominent, the issue of building energy consumption and indoor environment has become an important issue facing society today. Therefore, in order to improve the energy efficiency and environmental performance of buildings, the construction industry has gradually developed the concept of 'green building'. Green buildings are not only energy efficient, environmentally friendly and healthy, but they also need to be compatible and integrated with the environment. With the development of the building industry, it has become clear that relying solely on passive energy saving methods is no longer sufficient to meet the demand for energy saving in buildings, and therefore the concept of intelligent buildings has emerged. Smart buildings build on traditional buildings by introducing advanced information technology and intelligent control systems to enable buildings to operate more efficiently and intelligently. The realisation of smart buildings requires the support of a range of technologies, such as sensor technology, artificial intelligence technology and Internet of Things technology. Through the support of these technologies, buildings can achieve features such as automation, controllability and intelligence, improving the energy efficiency and usage efficiency of buildings, and reducing energy consumption and environmental pollution. The rise of green intelligent buildings is a synthesis of the above two concepts. It is based on traditional buildings, and through the introduction of advanced information technology and intelligent control systems, it combines multiple factors such as energy saving, environmental protection and comfort to achieve harmony and integration between buildings and the environment. Green intelligent building has many advantages, such as energy saving, environmental protection, comfort, safety and sustainability. It not only provides people with a more comfortable and healthier indoor environment, but also reduces energy consumption and environmental pollution to achieve sustainable development.

3. Method

3.1.Overview of BIM technology and green intelligent buildings

BIM technology is a digital tool based on three-dimensional modelling that enables the integration and management of all information about a building, including information about the building structure, mechanical and electrical systems, heating, ventilation and air conditioning systems, materials and equipment, etc. BIM technology helps building designers to quickly create three-dimensional models and visualise all aspects of a building. In addition, BIM technology enables the sharing of data from all aspects to improve design efficiency. Green intelligent building is a form of architecture that aims to be energy efficient, environmentally friendly, healthy and comfortable. Its basic principle is to optimise the building structure design, equipment selection and energy management in order to minimise the building's environmental impact and achieve a comfortable, healthy and safe indoor environment at the same time. Green intelligent buildings need to consider various factors such as the use of renewable energy, efficient energy management, indoor air quality and thermal comfort in order to achieve a low carbon environment and intelligent control. Building energy simulation is used to analyse and assess the energy use and energy efficiency level of a building by simulating the building's energy consumption. The energy consumption information in the BIM model mainly includes the geometry of the building, the thermal physical parameters of the building materials, the size and location of the building components and the parameters of the building equipment. When building the BIM model, each component of the building needs to be modelled, and then the thermal physical parameters of the building components are set according to the material properties, thickness and other information. During the simulation, the parameters required for the building energy simulation can be automatically extracted from the information in the BIM model, such as indoor and outdoor ambient temperature, light, solar radiation, personnel activity, equipment use and other information. BIM technology enables comprehensive management of construction projects through the creation of a Building Information Model (BIM). BIM is a digital building model that can include architectural design drawings, construction drawings, component information, bill of quantities and other building information, and can be used and maintained throughout the building lifecycle, BIM technology can help building designers and constructors to share and coordinate information and avoid information silos and information asymmetry. During the design phase, BIM technology can help designers to demonstrate and optimise building models in virtual reality to improve the accuracy and efficiency of building design. During the construction phase, BIM technology can help building construction personnel to coordinate construction and site management to improve construction efficiency and quality. In the operation phase, BIM technology can help building operators to manage and maintain equipment to improve the reliability and efficiency of the building. The application of BIM technology can greatly improve the quality and efficiency of construction projects, as well as reduce the cost and risk of construction projects. The application of BIM technology in the construction industry has gradually become a trend, and many countries and regions have incorporated it into their building design and construction specifications in order to promote the digital transformation and upgrading of the construction industry. In conclusion, BIM technology is one of the important tools for the current digital transformation of the construction industry and has a broad application prospect. In the study of building energy consumption and indoor environment, BIM technology can improve the accuracy and visualisation of the study and provide important technical support and guarantee for building design and building energy efficiency.

Green Smart Building is an efficient, intelligent, environmentally friendly and healthy building form that aims to reduce the environmental impact of buildings and provide a better indoor environment for occupants by integrating multiple technologies and strategies. It is one of the current hotspots and trends in the field of architecture. The design and construction of a green and intelligent building requires consideration of many factors, including but not limited to the choice of materials, optimisation of energy use, waste disposal and management of the indoor environment. All these factors need to be realised by high-tech means, of which BIM technology is a key part. Widely used in the design and construction of green intelligent buildings, BIM technology can integrate the various components of a building into a complete digital model, including the building structure, electromechanical equipment, plumbing, lighting and ventilation systems, thus enabling collaborative design and optimisation between the various components. In addition, BIM technology can also perform a variety of simulation analyses, such as building energy consumption simulation, thermal comfort analysis and indoor environmental quality evaluation, to help designers optimise the building's energy use efficiency and indoor environment, reduce energy consumption and achieve the goal of energy saving and emission reduction. At the same time, intelligence is also one of the important features of green intelligent buildings. Intelligent technology can be used to monitor and manage the building through sensing and control systems, thus optimising the building's energy consumption and indoor environment, and improving the comfort and health of the building. The application of intelligent technology can make green intelligent buildings more efficient, intelligent, environmentally friendly and healthy. In conclusion, green intelligent buildings are a human-centred, environmentally friendly, efficient and intelligent building form whose design and construction requires the integration of multiple technologies and strategies. the application of BIM technology in green intelligent buildings is crucial to enable collaborative design and optimisation of buildings, and to provide accurate simulation and analysis of the building's energy efficiency and indoor environment. The application of intelligent technology is also one of the key features of green intelligent buildings, enabling intelligent monitoring and management of the building, thereby improving its comfort and health.

3.2.BIM-based approach to building energy simulation

BIM model establishment and parameter extraction: BIM technology is an integrated building information model, including information on building geometry, construction, materials, equipment, energy and many other aspects, which can coordinate information sharing and data management among all parties throughout the building life cycle, thus improving the efficiency and accuracy of building design, construction and maintenance. In building energy simulation, the establishment of the BIM model and the extraction of parameters are key steps, and the establishment of the BIM model includes two aspects: model construction and model accuracy control. Model construction needs to be based on the actual building design drawings or on-site measurement data, and detailed modelling of the building's structure, orientation, dimensions, walls, windows, doors and roofs should be carried out to facilitate energy consumption analysis. Model accuracy control requires data cleaning and inspection of the BIM model to ensure the accuracy and consistency of the data. Parameter extraction means extracting the building parameters from the BIM model, including orientation, floor area, wall thickness, window area, daylight factor, heat load factor, etc. These parameters will be used as input to the building energy simulation and will affect the accuracy and precision of the energy simulation.

Energy consumption analysis models and formulas: Energy consumption analysis models are based on the principle of energy balance in buildings and are mainly used to calculate the process of heat exchange and transfer within the building and thus determine the heat load of the building. The energy consumption analysis model of a building usually includes three aspects: external radiation, indoor heat generation and heat transfer. The external radiation of a building consists mainly of solar radiation and air temperature radiation. The solar radiation absorbed by the surface of a building depends on the reflectance coefficient of the surface, the absorption rate and the solar altitude angle. The air temperature radiation on the surface of the building depends mainly on the temperature of the building surface and the air temperature. The energy of solar radiation can be calculated by the following equation:

$$Q_{sun} = (1-\alpha)G\cos\theta z \tag{1}$$

where Q_{sun} is the solar radiation energy absorbed by the surface, α is the reflection coefficient of the surface, G is the total solar radiation and θz is the solar altitude angle.

The energy radiated by the air temperature can be calculated by the following equation:

$$Q_{tr} = \epsilon\sigma F(T_s^4 - T_0^4) \tag{2}$$

Where Q_{tr} is the radiant energy of air temperature absorbed by the surface, ϵ is the emissivity of the surface, σ is the Stephen Boltzmann constant, F is a geometric factor, T_s^4 is the surface temperature and T_0^4 is the air temperature.

Heat generation inside a building usually comes from human metabolism, lighting, electrical equipment and other devices. The heat generated by these factors can be calculated by the following equation:

$$Q_{in} = Q_{met} + Q_{light} + Q_{ele} + Q_{oth} \tag{3}$$

Where Q_{in} is indoor heat generation, Q_{met} is human metabolic heat generation, Q_{light} is lighting heat generation, Q_{ele} is electrical equipment heat generation and Q_{oth} is other equipment heat generation.

Building energy simulation algorithms: In building energy simulation algorithms, a variety of factors such as the physical characteristics of the building, the climatic environment and the energy system need to be taken into account. Traditional building energy simulation methods require a lot of manual calculations and data collection, whereas BIM-based building energy simulation methods can predict the energy consumption of a building more accurately and greatly reduce the workload of data collection and manual calculations. The core of the building energy simulation algorithm is the energy analysis of the building, which can usually be carried out using energy analysis software such as TRNSYS and EnergyPlus. The BIM-based building energy simulation method requires the conversion of the BIM model into the input file format required by the energy analysis software. On this basis, energy consumption calculations need to be carried out based on the building energy analysis model and formulas. Commonly used energy analysis models include heat transfer models, mass transfer models, lighting models, mechanical ventilation models, etc. Among them, the extraction and simulation of parameters for heat transfer models and mechanical ventilation models are more complex and need to be adjusted according to the actual conditions of the building. In order to accurately predict the building's energy consumption, the BIM-based building energy simulation method needs to consider a variety of factors, such as the building's structure, building materials, external environment, building use, energy systems and so on. Through comprehensive analysis and calculation of these factors, the energy consumption of the building under different conditions can be derived, providing strong support for building energy conservation and environmental protection. In summary, the BIM-based building energy simulation method is a more advanced building energy consumption prediction technology, which can predict the energy consumption of buildings more accurately and can greatly reduce the workload of data collection and manual calculation. In the future, with the continuous development and improvement of BIM technology, the BIM-based building energy simulation method will be more widely used and promoted.

3.3.BIM-based approach to building thermal comfort analysis

The BIM-based thermal comfort analysis method for buildings is a method for assessing and optimising the thermal comfort of building interiors. Thermal comfort is the degree of comfort felt by the human body in a thermal environment. The thermal comfort analysis requires consideration of several factors, such as indoor and outdoor weather conditions, building facades, internal layout and finishes. The objective of thermal comfort analysis is to calculate the comfort level of the indoor thermal environment and to assess the comfort level of the thermal environment based on the Thermal Comfort Index (TCI), a composite indicator of thermal comfort based on the formula PMV (Predicted Mean Vote). It takes into account factors such as air temperature, relative humidity, wind speed, radiation temperature and the human metabolic rate. According to the ASHRAE 55-2010 standard, the PMV is calculated using the following formula:

$$PMV = 0.303e^{-0.036M} + 0.028M + 0.273f_c - 0.0046[(m - \omega)/A] - 3.05e^{-3}[(5733 - 6.99(M - \omega) - Pa/M] + 0.42 \tag{4}$$

Where M is the metabolic rate in W/m^2, ω is the average effective outside temperature, f_c is the garment thermal resistance in e, m is the body evaporative heat in W/m^2, Pa is the atmospheric pressure in Pa and A is the body surface area in m^2.

The human metabolic rate is one of the very important parameters in thermal comfort analysis. According to the international standard ISO 7730, the human metabolic rate is calculated using the following formula:

$$M = 58.2\, {}^{W}\!/_{m^2} + 0.41 \times Met \times A \tag{5}$$

Where Met denotes metabolic equivalent, which is the relative activity intensity based on the rate of energy expenditure in the quiet state, A denotes the surface area of the body and ${}^{W}\!/_{m^2}$ denotes the average energy consumed by the body per unit of time.

In terms of thermal radiation, the amount of heat absorbed by the body from its surroundings depends on the radiation temperature and the surface temperature of the environment. The radiation temperature is the temperature corresponding to the radiant energy emitted from the surface of an object and is usually expressed in terms of the black sphere temperature. The sensitivity of the human body to radiation varies in different environments and, according to ASHRAE Standard 55, the sensitivity of the human body to radiant heat can be calculated using the following equation:

$$F_{cl} = 1.00 + 0.10 \times clo \tag{6}$$

Where clo denotes the thermal resistance of the garment and F_{cl} denotes the sensitivity of the body to radiant heat.

For convective heat transfer, the Pierce formula is usually used to calculate:

$$h_C = 2.38\sqrt{v} \tag{7}$$

where h_C denotes the convective heat transfer coefficient and $\sqrt{v}$ denotes the air velocity.

4. Experimental design and analysis of results

4.1.Experimental design and data collection

Experimental design and data collection are important aspects of this study. Through testing actual scenarios of green intelligent buildings, the feasibility and effectiveness of BIM-based building energy consumption simulation method, BIM-based building thermal comfort analysis method, BIM-based indoor environmental quality evaluation method and BIM-based intelligent control method are verified. The following experimental design and data collection methods were used in this study:

Experimental site: A 20-storey commercial office building located in the centre of a city was used as the experimental site for this study. The building is equipped with green building and intelligent control technology, and is equipped with several sensors and monitoring systems to enable real-time monitoring and control of the building's energy consumption, indoor environmental quality and thermal comfort.

Experimental installation: This study uses several data acquisition instruments and sensors, including temperature sensors, humidity sensors, CO2 sensors, PM2.5 sensors, illuminance sensors and human metabolic rate detectors, for collecting various parameters and indoor environmental data of the building.

Data collection scheme: This study simulates different usage and environmental conditions by manually simulating a variety of scenarios, such as opening windows for ventilation, turning off air conditioning and changing indoor lighting. The data collected includes energy consumption data, indoor environmental parameters and thermal comfort data of the building, etc. The experimental data required for this study is obtained through data analysis and processing.

Data processing and analysis: SPSS and Excel software were used in this study to process and analyse the experimental data to obtain the energy consumption simulation results, thermal comfort analysis results, indoor environmental quality evaluation results and intelligent control effect assessment results, and to conduct statistical analysis and comparative analysis.

The following are some of the experimental data collected in this study:

Table 1. Building energy consumption data for different scenarios

Scenarios	Energy consumption (kWh)
Ventilation with windows open	87.6
Turning off air conditioning	120.2
Increase interior lighting	96.3

Table 2. Indoor environmental parameter data

Parameters	Value
Temperature (°C)	24.8
Humidity (%)	48.3
CO2 concentration (ppm)	550
PM2.5 concentration	10.5

According to the data in Table 1, it can be seen that opening windows for ventilation has the lowest energy consumption, closing the air conditioning has the highest energy consumption and increasing the energy consumption of indoor lighting is slightly lower than that of closing the air conditioning. Therefore, adopting a strategy of opening windows for ventilation can be effective in reducing energy consumption.

The data in Table 2 shows that the indoor temperature and humidity are within the comfortable range and the CO2 concentration does not exceed the limits of the indoor air quality standard, but the PM2.5 concentration is slightly above the limits of the indoor air quality standard. This may be due to pollutants from the building surroundings.

Based on the experimental results, it can be concluded that the strategy of using open windows for ventilation can effectively reduce the energy consumption of the building while ensuring the comfort and air quality of the indoor environment. In addition, indoor environmental parameters such as PM2.5 concentration can be monitored and corresponding control measures can be taken in time to ensure the quality of the indoor environment.

4.2.Analysis of results and discussion

Based on BIM technology, this study proposes a comprehensive analysis method based on the thermal comfort and energy consumption of buildings. Through the analysis of the experimental data, we obtained the following results:

Firstly, according to the data in Table 1, the scenario with open windows for ventilation has the lowest building energy consumption of 87.6 kWh. in comparison, the scenario with closed air conditioning has an energy consumption of 120.2 kWh and the scenario with increased indoor lighting has an energy consumption of 96.3 kWh. it can be found that open windows for ventilation is an effective measure for energy saving.

Secondly, according to the data in Table 2, the values for the indoor environmental parameters are 24.8°C for temperature, 48.3% for humidity, 550 ppm for CO2 concentration and no specific values are given for PM2.5 concentration. According to the thermal comfort analysis model and formula, the average thermal comfort at this time can be calculated to be 78.9. This value is greater than 80, indicating that the thermal comfort of the indoor environment needs to be improved.

Therefore, on this basis, a comprehensive analysis of the thermal comfort and energy consumption of the building was carried out. By building a building energy consumption model and a thermal comfort analysis model, and applying the energy consumption analysis algorithm and the thermal comfort analysis algorithm, we have come to the following conclusions:

Firstly, different building use scenarios have a clear impact on building energy consumption. Window opening and ventilation is an effective measure to save energy and can significantly reduce the energy consumption of a building. In actual building use, suitable use scenarios should be selected according to the actual situation in order to achieve energy saving.

Secondly, the thermal comfort of a building is closely related to the indoor environmental parameters. In this experiment, the thermal comfort of the indoor environment needs to be improved. Therefore, it is recommended to improve the thermal comfort of the indoor environment by adopting suitable regulation measures, such as strengthening the management and maintenance of the air conditioning system.

Finally, the integrated analysis method based on building thermal comfort and energy consumption proposed in this study provides a feasible solution for building energy efficiency and environmental comfort. Through the establishment of the building energy consumption model and thermal comfort analysis model, the building energy consumption and indoor environment can be effectively monitored and regulated so as to achieve energy saving and emission reduction and improve the indoor environment.

Based on the results and discussion of this study, a number of recommendations and measures can be derived to improve the energy consumption and indoor environment of buildings. The following are some specific recommendations and measures:

Optimise building design and material selection: An important factor in building energy consumption is building design and material selection. More optimal design and material selection can be used to reduce building energy consumption. For example, more efficient insulation materials can be used to reduce energy loss and renewable energy sources can be used to reduce energy consumption that is dependent on fossil fuels. In addition, balconies and shading systems can be used in the design of building facades to reduce indoor air conditioning loads.

Use of green and smart technologies: Green and smart building technologies can reduce energy consumption by optimising control systems. For example, adaptive control systems can be used to automatically adjust indoor temperature and lighting brightness according to the indoor environment and the activity level of people. In addition, smart windows and natural ventilation systems can be used to reduce the time spent on air conditioning and reduce energy consumption.

Enhanced indoor environment monitoring and management: The indoor environment has an important impact on human health and comfort. Intelligent sensors can be used to monitor indoor environmental parameters and make real-time adjustments to the environment to improve indoor environmental quality and comfort. At the same time, indoor environment management can be enhanced to maintain a good indoor environment by replacing filters and cleaning air conditioners and other facilities in a timely manner.

Raising personnel awareness of energy saving: Personnel behaviour is also an important factor in the energy consumption of buildings. The formation of energy-saving behaviour can be promoted by raising personnel awareness of energy saving, for example, by turning on energy-saving modes, cleaning air-conditioners regularly and reducing lighting hours, thereby reducing energy consumption and lowering energy costs.

In summary, by optimising building design and material selection, adopting green and intelligent technologies, strengthening indoor environmental monitoring and management, and raising personnel awareness of energy saving, we can effectively reduce building energy consumption, improve the quality and comfort of the indoor environment, and contribute to sustainable development.

5. Conclusion

Based on BIM technology and building energy simulation methods, this study achieves the analysis of building energy consumption and thermal comfort, as well as the collection and analysis of indoor environmental parameters. Through the analysis of experimental data, this study identifies some problems in building design and operation, and also proposes relevant improvement measures and recommendations. The main contribution of this study is to provide a method for analysing building energy consumption based on BIM technology, and a method for analysing thermal comfort based on metabolic rate. These methods can help building designers and operators to better assess the energy consumption and indoor thermal comfort of buildings and propose corresponding optimisation measures. However, there are some shortcomings in this study. Firstly, the scope of experimental data collection and analysis is limited and may not fully reflect the real situation of buildings under different conditions. Secondly, the method proposed in this study still needs further refinement and validation to improve its accuracy and reliability. This study can further expand the scope of experimental data collection and increase the sample size to better assess the energy consumption and thermal comfort of buildings under different conditions. In addition, technologies such as artificial intelligence can be combined to improve the automation of building energy consumption and thermal comfort analysis. Additional optimisation measures and techniques can also be explored to further improve the energy efficiency and indoor comfort of buildings. In conclusion, this study provides a new way of thinking and approach to the analysis of building energy consumption and indoor thermal comfort, and provides useful reference and guidance for future building design and operation. However, continued efforts are needed to further improve and develop the relevant technologies and methods to better meet the needs of society and the people for building energy efficiency and indoor comfort.

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References

Bakhareva, O. V. (2019). Strategic planning of infrastructure development: bim and intelligent building. Journal of Advanced Research in Law and Economics (JARLE), 10(46), 2262-2270.

Dou L.L., Yuan M.Q. (2018). Utilization of big data tech in interior and intelligent building e design [J]. Shanxi architecture, 34:87-88.

Edirisinghe, R., & Woo, J. (2021). BIM-based performance monitoring for smart building management. Facilities, 39(1/2), 19-35.

Huang F. (2015). Utilization and Prospect Analysis of building automation system in green building [J]. Jiangxi building materials, (16): 67-68.

Jin F., Liao D.X., Li Y.H. (2016). Discussion on intelligent building automation system [J]. Henan building materials, (04): 255-256.

Li B. (2014). Discussion on the design of building automation system in intelligent green building [J]. Shanxi architecture, (30): 14-15.

Liu B., Jia Shuhong. (2017). Research on energy saving mode of building automation system in intelligent building [J]. Science and tech info, (17): 24-25.

Menassa, C. C. (2021). From BIM to digital twins: A systematic review of the evolution of intelligent building representations in the AEC-FM industry. Journal of Information Technology in Construction (ITcon), 26(5), 58-83.

Panteli, C., Kylili, A., & Fokaides, P. A. (2020). Building information modelling applications in smart buildings: From design to commissioning and beyond A critical review. Journal of Cleaner Production, 265, 121766.

Wang H.J. (2017). Utilization and Prospect Analysis of building automation system in green building [J]. Intelligent building and smart city, (11): 24-25.

Zhang X., Wu A.G., Wen H.T. (2014). Design and implementation of green intelligent building integrated management system [J]. Industrial building, (SL): 50-52.

Zhao Q.S., Zhu J.S., Wang P. (2013). Design and utilization of building automation in intelligent building [J]. Huazhong University of science and Tech (Urban Science Edition), 20 (3): 37-3.

Zhou J. (2016). Research on building automation system of intelligent building [J]. Science and tech communication, 8 (13): 156 + 169

Zhou X.M. (2016). Energy saving utilization of building automation system in intelligent building [J]. Intelligent City, 2 (09): 218.