

# ***The Application of BIM Technology in Optimising Residential Ventilation and Lighting Systems: Enhancing Living Comfort Based on Healthy Building Standards***

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**Abstract.** In accordance with the 2021 Chinese version of the 'Healthy Building Evaluation Standard' (T/ASC 02-2021), this paper explores the application of Building Information Modeling (BIM) technology in enhancing residential comfort through a literature review, with a focus on practices in optimizing ventilation and lighting systems. In the design phase, with the aid of BIM's 3D modeling and simulation tools (such as CFD, Ecotect), designers can simulate parameters such as air flow and lighting to optimize the layout of ventilation holes and the design of lighting system to meet the indicators of healthy buildings. During the construction phase, 4D progress simulation is used to enhance construction efficiency. Research shows that the application of BIM technology in ventilation and lighting systems can improve design accuracy and construction efficiency, significantly enhancing residential comfort, but also faces challenges such as technical barriers, high costs, and inadequate collaboration mechanisms. Future research directions should focus on innovative development through interdisciplinary integration to address the current issues.

**Keywords:** BIM technology, Residential comfort, Healthy building standards, Ventilation systems, Lighting system

## **1. Introduction**

As people's demands for living quality increase, home comfort has become a focus of attention. To meet residents' objective demand for high-quality housing, it is necessary to improve the construction quality of existing buildings. Previous house designs were mostly based on traditional two-dimensional CAD drawings, which had problems such as scattered organizational structure, inconsistent or conflicting information, and failed to meet residents' demands for high-quality houses [1]. At present, with the help of Building Information Modeling (BIM) tools, residents' demands for housing can be transformed into quantifiable indicators, thereby improving architectural design and construction and enhancing building quality [2,3].

Lighting and ventilation are two important indicators for evaluating the comfort of residential buildings, and advanced technologies like BIM are more effective in optimizing systems such as ventilation and lighting. Therefore, this paper focuses on the improvement of ventilation and lighting comfort in residential buildings by BIM technology as the main research topic, and explores

the application of BIM technology in improving the comfort of residential buildings in combination with current Chinese standards for healthy buildings. Through research and analysis in this study, it is anticipated to promote the application of BIM technology in residential construction, provide scientific guidance and support for improving the comfort and energy efficiency of the living environment, and thereby promote the healthy development of the construction industry.

## 2. Overview

### 2.1. Evaluation standards for green buildings in China

The Healthy Building Evaluation Standard (T/ASC 02-2021) is a group standard issued by the Architectural Society of China (ASC). The latest revised version came into effect in China on November 1, 2021. The standard provides a comprehensive evaluation of buildings in terms of air, water, comfort, fitness, humanity, and services. It classifies healthy building grades into four levels: bronze, silver, gold and platinum. The standard ensures healthier environments, facilities and services on the basis of meeting the building's functions, which helps to promote the physical and mental health of users. Such health-performing buildings also contribute to the harmonious coexistence of people, buildings and nature within the construction industry [4].

### 2.2. BIM technology

BIM is a digital tool that integrates management of the entire life cycle of a building project. It creates and maintains a three-dimensional model containing rich design information, providing a shared information platform for designers, engineers, architects, contractors, project managers, etc. [5]. The core advantage of BIM lies in its ability to visualize and coordinate designs, thereby enhancing the accuracy and efficiency of designs as well as the communication and management capabilities of projects.

In the field of architectural design, the BIM platform, as the data core, can support data interaction and task division among design software such as AutoCAD, SketchUp, Rhino, Grasshopper, thereby achieving the organic connection of modeling processes, construction phases, and control parameters across different stages. In the construction phase, the BIM model covers key information such as component positioning, node numbering, construction sequence, equipment path and installation space, and integrates nodes such as component delivery, installation, and maintenance into the timeline through four-dimensional simulation technology to establish a systematic construction logic sequence [1].

## 3. Optimization of ventilation systems in residential buildings based on BIM technology

### 3.1. Indoor ventilation comfort standards

Indoor ventilation system are important indicators for evaluating the comfort of a residence, and the Healthy Building Evaluation Standard specifies clear criteria for indoor ventilation. A house with 80% or more of its main functional rooms equipped with air purification systems is considered to have a high level of comfort. Systems with air purification function include centralized fresh air systems, individual fresh air systems, window ventilators, or purification devices and modules installed inside the air conditioning system. It is notable that  $E_{PM2.5} > 90$  and  $E_Q > 60$  pollutant purification efficiency of the aforementioned systems or devices must meet the requirements of

PM2.5 purification efficiency, gaseous pollutant purification efficiency, and microbial purification efficiency and microbial purification efficiency ( $E_w > 90$ ) [4,6].

### 3.2. Optimization at the design stage

During the design phase, designers can quickly iterate the design plan and fine-tune the ventilation system to meet the changing design requirements and specifications [7-8]. This rapid iterative design process not only enhances design efficiency but also helps to achieve more precise and effective ventilation solutions.

By building the information models (including vents, ducts, ventilation shafts, etc.) based on drawings, designers can use corresponding simulation analysis tools such as CFD (Computational Fluid Dynamics) to simulate the ventilation system of the building [9]. These tools can simulate air flow movement, wind speed, wind direction, and parameters, and humidity, which effectively distribute and circulate these natural winds to maximize their role in regulating indoor temperature and fresh air supply [10]. At the same time, by 3D simulation of the ventilation holes, designers can assess the impact of different sizes, positions, and layouts on the indoor airflow. For example, by adjusting the positions of air intakes and air outlets, natural ventilation can be optimized and reliance on mechanical ventilation systems reduced, thereby lowering energy consumption [11].

### 3.3. Optimization during the construction phase

The application of BIM technology has given rise to an entirely new 4D construction progress simulation management approach [12,13]. Take the construction of ventilation systems in high-rise residential buildings as an example. The BIM model built with Revit can integrate the three-dimensional information of components such as air ducts, fans, and air outlets with the construction process time parameters to form a dynamic progress simulation system [14]. Through the virtual environment, construction managers can visually present the construction logic between the ventilation system, civil structure, and mechanical/electrical pipelines, while clarifying the sequence of key processes such as duct prefabrication, on-site hoisting, and interface connection. This facilitates the precise allocation of labor and construction machinery, thus avoiding idling due to poor connection of processes. For example, they can arrange the entry time of the welder team based on the air duct installation progress, or plan the parking position of the crane based on the hoisting radius.

In addition, the BIM model's collision detection capabilities can be used to identify spatial conflicts between the ventilation system and other specialties. By conducting three-dimensional scanning and collision analysis of the intersections of air ducts with beams, water pipes, and cable trays, installation contradictions in high-density pipeline areas (such as deviations in the position of air ducts when passing through shear walls and embedded sleeves) can be identified in advance. These issues can be resolved by adjusting or optimizing air duct direction or size via the model prior to construction, reducing on-site cutting and rework. Especially in areas with a high concentration of ventilation components such as kitchens and bathrooms, it can reduce installation accuracy errors caused by space constraints.

## 4. Optimization of residential building lighting systems based on BIM technology

### 4.1. Evaluation criteria for indoor lighting

The Healthy Building Evaluation Standard specifies requirements for the indoor light environment and evaluation criteria for residential comfort, which are presented in Tables 1 and 2.

Table 1. Evaluation criteria for light environment in residential buildings

|                                               |                                                                                                                                                                                                                                                                                                                                                                                                 |
|-----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Make full use of natural light                | Bedrooms, living rooms (halls), and kitchens in residential buildings should have direct lighting                                                                                                                                                                                                                                                                                               |
| Lighting systems with control characteristics | Lighting in public areas such as corridors, stairwells, elevator lobbies, and parking garages automatically senses switches or dimmers based on human activity and natural light levels<br>The brightness of outdoor advertising and signage surfaces can be automatically adjusted according to ambient brightness<br>Decorative lighting is automatically turned off during off-light periods |

Table 2. Daylighting standards for residential buildings

| Site Name                               | Side lighting                           |                                                        |
|-----------------------------------------|-----------------------------------------|--------------------------------------------------------|
|                                         | Daylight coefficient standard value (%) | Standard value of indoor natural light intensity, (lx) |
| Bedroom, living room (hall)             | Not less than 2                         | No less than 300                                       |
| Kitchen                                 | 2                                       | 300                                                    |
| Bathroom, aisle, dining room, stairwell | 1                                       | 150                                                    |

### 4.2. Optimization during the design phase

Designers can configure lighting analysis modules in BIM systems (such as Ecotect software) to simulate the distribution of natural light in the room [15]. At the same time, based on the design requirements, designers can adjust factors in the model such as window size, position, and curtain configuration to simulate different natural lighting conditions. In addition, the layout of artificial lighting can be simulated, including selecting appropriate light source types, calculating illuminance for the lighting layout, and implementing anti-glare measures [16]. Designers need to consider the combination of natural light and artificial lighting to achieve the best lighting effect and energy efficiency. By adjusting the simulation parameters, the lighting effect can be evaluate lighting effects under different time periods, seasons, and weather conditions [15,17]. For example, designers can present "fully three-dimensional" lighting effects to relevant designers, engineers, and clients through BIM models, making the design modification and decision-making process more intuitive and efficient, thereby creating energy-efficient and comfortable lighting solutions that meet people's requirements for visual comfort [18].

## 5. Discussion

There are a series of challenges in the application of BIM technology. First of all, implementing BIM technology requires a high level of technical knowledge and operational skills. Secondly, introducing BIM involves relatively high investment costs, including the purchase of software and

hardware equipment and personnel training expenses. In addition, although BIM technology essentially encourages information sharing, in practice, the data sharing and collaboration mechanisms among project participants are not yet well established, which to some extent limits the wider application of BIM technology [19].

To address these challenges and problems, multi-faceted solutions are needed. In terms of education and training, colleges and vocational training institutions need to strengthen the teaching of BIM technology through practical courses and projects, enabling learners to acquire essential skills in real-world scenarios. Secondly, in promoting industry standardization, it is necessary to enhance the interoperability of different BIM software by establishing a unified data format and exchange standard (such as using the IFC Open model standard) to achieve seamless data exchange [20]. In addition, governments and industry organizations can help small and medium-sized enterprises complete the initial investment related to the application of BIM technology through financial incentives (such as subsidies, tax breaks) and technical support, and expand the application impact of BIM technology. Also, BIM providers should develop user-friendly and economical BIM tools (such as cloud-end platforms) that reduce users' hardware investment while enhancing access and collaboration flexibility and lowering the adoption threshold [12].

Therefore, future research should focus on the interdisciplinary integration of BIM technology, integrating BIM with modern technologies such as artificial intelligence and big data analytics, and emphasizing the development of healthy and intelligent buildings [21-22]. At the same time, research in areas such as the renovation of old residential areas and the international application of BIM technology can also expand the citation impact of BIM technology [21,23]. These studies can not only promote the development of BIM technology itself, but also further contribute to improving residential comfort and provide theoretical and practical support for the sustainable development and innovation of the construction industry [24].

## 6. Conclusions

An analysis of BIM-driven optimizations for residential ventilation and lighting systems shows that the application of BIM technology in residential building design and construction can enhance design accuracy and construction efficiency. At the same time, it can greatly enhance the comfort of the home through functions such as 3D visualization, collaborative design, data analysis, and post-processing capabilities. However, there are still some shortcomings in this study, which primarily lie in overly simplistic research methods, the absence of an experimental analysis process, and the relatively narrow range of references selected. In future work, the authors will further analyze and optimize this research topic through case studies and model construction.

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