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Research on Low-Carbon Operation and Maintenance and Fire Emergency Coordination Management for Commercial Buildings in the Jidong(Eastern Hebel) Region based on BIM Technology

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Abstract

Under the dual imperatives of achieving carbon peaking and carbon neutrality alongside ensuring construction safety, commercial buildings in the eastern Hebei region face industry-wide challenges: fragmented low-carbon operations and maintenance (O&M) from fire emergency management, coupled with outdated management practices. As the core city in eastern Hebei, Tangshan's commercial buildings exemplify regional characteristics in climate conditions, functional layouts, and O&M models. This study examines representative commercial buildings in Tangshan, leveraging BIM technology to construct a comprehensive building information model across all disciplines. It adopts a research framework centered on problem identification-Solution Optimization-Collaborative Strategy as its research framework. Through BIM model information extraction, clash detection, and visualization analysis, it systematically identifies critical carbon emission points during building operations and fire emergency management risks. Ultimately, it proposes collaborative management strategies across three levels-scheme, information, and response-providing practical insights and technical references for green and safe management of similar commercial buildings in the Jidong region.

Keywords

BIM Technology; Commercial Buildings; Low-Carbon Operations and Maintenance; Fire Emergency Management; Collaborative Management.

1. Introduction

The deepening advancement of China's dual-carbon strategy and the continuous refinement of building safety management systems impose dual demands on the construction industry for green, low-carbon operations and fire safety management. As a typical industrial and commercial hub in northern China, the Jidong region features commercial buildings characterized by high occupancy density, complex functionalities, significant operational energy consumption, and substantial fire prevention pressures. Current building management practices in the area commonly suffer from issues such as separate systems for low-carbon operations and fire emergency response, insufficient application of digital technologies, and conflicting management strategies, all of which hinder the advancement of green and safe building development.

Tangshan City, as the economic and commercial hub of the Jidong region, exhibits highly representative characteristics in terms of commercial building structures, operational features, and climate adaptation needs. BIM technology, serving as the core tool for integrated information management and visualization throughout a building's lifecycle, enables the consolidation of data on building components, mechanical and electrical equipment, energy consumption, and fire safety measures. This provides an effective pathway to address the separation of these two management systems. This study examines a typical commercial building in Tangshan City. Integrating the climatic characteristics and management requirements of eastern Hebei, it explores BIM-based collaborative management for low-carbon operations and fire emergency response. Using a BIM multi-disciplinary information model as the analytical foundation, the research employs techniques such as information mining, parameter extraction, and spatial verification to to identify specific challenges in low-carbon building operations and fire emergency management. This process culminates in the design of targeted optimization solutions and the formulation of collaborative management strategies, offering practical insights and technical references for similar buildings in the Jidong region.

2. Research Subjects and BIM Model Construction

2.1 Research Subjects

This study examines a typical multi-story frame-structured commercial building in Tangshan City, Jidong region. The building houses diverse commercial functions including retail and leisure, representing a common high-occupancy commercial complex in the area. During the building operation and maintenance phase, it faces low-carbon optimization demands including high winter heating energy consumption, low energy utilization efficiency, and coarse-grained equipment operation control. Concurrently, it requires fire emergency prevention and control measures due to complex evacuation routes, uneven distribution of firefighting facilities, and disjointed emergency response procedures. In terms of architectural form, operational model, and climate adaptation, this research subject represents the fundamental characteristics of most similar commercial buildings in eastern Hebei. The research findings provide a foundation for promoting and applying these insights to similar buildings within the region.

2.2 BIM Model Construction and Information Integration

This study employed Guanglianda GTJ Civil Engineering Quantity Takeoff and GQI Installation Quantity Takeoff software to establish a comprehensive BIM model encompassing all disciplines: civil construction, plumbing, HVAC, electrical lighting, and fire protection systems. The modeling process strictly adhered to the architectural design standards of the Jidong region, ensuring the model aligns with the actual building's structure, layout, and equipment configuration[3].

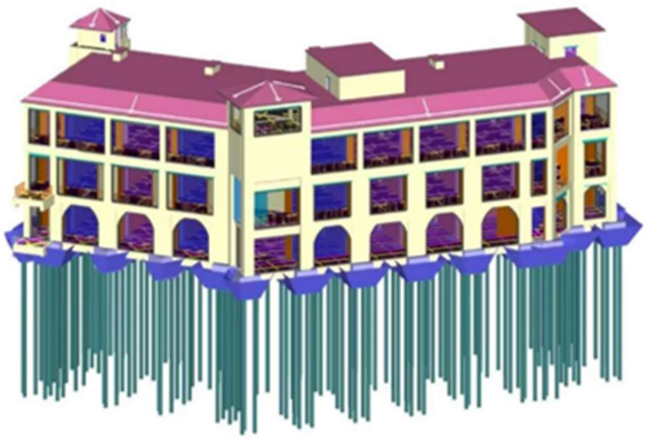

Fig. 1 Full Professional BIM Model Rendering

Based on the comprehensive professional model, it integrates core information required for low-carbon operations and maintenance as well as fire emergency management. This includes fundamental properties of building materials, energy consumption parameters of mechanical and electrical equipment, locations and types of fire protection facilities, and layouts and dimensions of

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evacuation routes. Simultaneously, through BIM model clash detection, spatial conflicts between pipelines and components are eliminated, ensuring the model's integrity and usability. This lays the foundation for subsequent issue identification and analysis.

3. Design of Low-Carbon Building Operation and Maintenance Solutions based on BIM Technology

Leveraging the established BIM multi-disciplinary model, this approach focuses on three core energy consumption areas during building operations and maintenance: building envelope, HVAC systems, and lighting systems. Through model information extraction, parameter analysis, and performance comparison techniques, energy consumption issues are identified. Subsequently, targeted low-carbon operations and maintenance optimization design solutions are developed, achieving full-process BIM technology application from model information mining to energy consumption optimization.

3.1 Identification of Key Factors Affecting Carbon Emissions During the BIM-Based Operations and Maintenance Phase

Using BIM models as the core data foundation, this study examines and analyzes the composition of carbon emissions during the operation and maintenance phase of commercial buildings in accordance with the calculation requirements for carbon emissions during this phase outlined in the "Standard for Calculation of Carbon Emissions from Buildings" (GB/T 51366-2019)[1]. The following data is accurately extracted from BIM models:

(1) Envelope: Thermal conductivity and heat transfer coefficients of insulation materials for exterior walls, roofs, and doors and windows;

(2) HVAC: unit models, rated power, air distribution paths, and operating duration;

(3) Lighting systems: luminaire types, power density, and operating duration;

(4) Plumbing: Pump parameters and circulation system operating modes. Using building performance analysis software, we identified that the primary sources of carbon emissions during the building's operation and maintenance phase are electricity consumption and thermal energy consumption. Among these, the HVAC system, the thermal performance of the building envelope, and the lighting system configuration are the three key factors influencing carbon emissions.

3.2 BIM-Based Low-Carbon Operation and Maintenance Optimization Measures

Considering the climate characteristics of the Jidong region-with its cold winters and extended heating season-alongside the operational features of commercial buildings that operate around the clock and exhibit significant variations in energy consumption across different zones, we utilized a building performance analysis platform to conduct spatial analysis, parameter comparisons, and energy consumption simulation predictions on the BIM model. This process identified three major issues currently present during the building's operation and maintenance phase:

(1) Unreasonable HVAC air outlet layout resulting in ineffective air distribution;

(2) Lighting systems lack zoned design based on daylighting conditions, resulting in low natural light utilization;

(3) Envelope insulation materials exhibit high thermal conductivity coefficients, leading to substantial heating and cooling loads.

To address these issues, targeted low-carbon operation and maintenance optimization solutions were proposed based on the BIM model[5]:

(1) HVAC System Optimization: Utilizing BIM visualization capabilities to optimize air vent layout and airflow paths, reducing short-circuited airflow zones and eliminating energy wastage. Pre-setting zone-based temperature control strategies based on spatial layouts and operational characteristics of different functional areas to enable demand-based cooling/heating for retail spaces, corridors, equipment rooms, etc., thereby enhancing energy efficiency;

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(2) Lighting System Optimization: Analyze daylighting surface distribution and natural illumination conditions across building zones via BIM modeling to plan lighting zones prioritizing natural light utilization. Simultaneously replace high-energy-consumption fixtures with LED energy-saving lighting and optimize wiring layouts to achieve precise control of lighting energy consumption[2].

(3) Envelope Optimization: Importing thermal insulation material parameters into BIM models and building performance analysis platforms, we compared core metrics including thermal conductivity, insulation effectiveness, and regional suitability. This led to the selection of low-thermal-conductivity materials such as 90mm-thick rock wool insulation boards, autoclaved aerated concrete blocks, and triple-pane ultra-clear insulated glass. Simultaneously, optimize the thermal design of building exteriors, doors, and windows to enhance thermal performance of the envelope. This reduces heating and cooling loads, thereby minimizing operational energy consumption at the source.

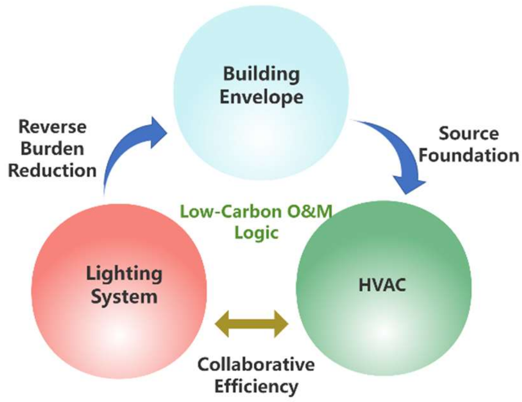

Fig. 2 BIM-Based Low-Carbon O&M Optimization Logic Diagram

4. Design of Building Fire Emergency Management Solutions based on BIM Technology

Leveraging the information integration, spatial visualization, and positioning measurement capabilities of BIM models, we conduct fire scenario analysis, evacuation route verification, and fire protection coverage calculations. This identifies existing hazards in building fire emergency management, enabling targeted optimization of fire emergency response plans to enhance the scientific rigor and operational feasibility of fire emergency management in commercial buildings.

4.1 BIM-Based Low-Carbon Operation and Maintenance Optimization Measures

Import the BIM model into analysis software. Focusing on core areas such as the ground floor, atriums, and evacuation stairwells, conduct fire scenario analysis based on the characteristics of commercial building fires in Tangshan City and the Jidong region, where fires frequently occur in ground-floor shops, dining areas, and passage intersections. By extracting spatial dimensions, combustible material distribution, and ventilation conditions from the BIM model in high-risk zones, we analyzed fire propagation pathways and smoke diffusion patterns. Simultaneously, leveraging model data on occupancy density, evacuation corridor widths, and exit locations, we mapped primary evacuation routes during fires. This identified three critical existing hazards in building fire emergency management:

(1) Limited visibility at certain evacuation corridor turns, prone to causing congestion;

(2) Coverage gaps in fire protection systems within select areas;

(3) Unclear operational logic for emergency equipment, lacking unified command protocols.

4.2 Optimization Measures for Fire Emergency Management based on BIM

Based on fire emergency management hazards identified through BIM model analysis, and in accordance with the Building Design Fire Protection Code and fire safety management requirements for buildings in the Jidong region, targeted optimization solutions for fire emergency management are proposed across three key areas: evacuation routes, fire protection facilities, and emergency procedures:

(1) Evacuation Path Optimization: For bottleneck areas identified in simulations, re-plan the layout and quantity of evacuation signage within the BIM model. Install luminous evacuation signs at corridor turns and blind spots to clarify optimal evacuation routes. Simultaneously, optimize the placement of obstacles within evacuation corridors based on the model to ensure unobstructed pathways throughout, facilitating rapid and orderly evacuation[4].

(2) Fire Protection Facility Verification and Optimization: Utilize the BIM model's spatial positioning and distance measurement capabilities to verify the coverage range of fire hydrants, sprinkler heads, smoke detectors, and other fire protection facilities, ensuring compliance with fire safety regulations. For areas within the model showing insufficient coverage, propose supplementation and location adjustment plans to achieve comprehensive, dead-zone-free coverage of fire protection facilities;

(3) Emergency Process Optimization: Integrate multi-system information-including building fire protection systems, electrical equipment, and ventilation systems-based on the BIM model. Clarify fire emergency response protocols and establish standardized contingency procedures with equipment activation sequences. During a fire, managers can rapidly make emergency decisions and issue operational commands using the BIM model's spatial layout, equipment distribution, and evacuation path data, thereby creating favorable conditions for personnel evacuation and fire rescue operations.

Fig. 3 BIM-Based Fire Emergency Management Optimization Logic Diagram

5. Cooperative Management Strategy for Low-Carbon Operations and Fire Emergency Response

Leveraging the integrated advantages of BIM's multi-disciplinary information model, this approach breaks down the barriers between independent systems for low-carbon operations and fire emergency management. Addressing common challenges such as conflicting strategies, information silos, and disjointed response protocols in both management processes, it establishes an integrated collaborative management strategy across three core levels: solution design, information management, and emergency response. This framework achieves information sharing, process integration, and unified objectives between the two management systems.

5.1 Scheme Coordination: Integrated Design of Optimization Measures

Integrate low-carbon operations and maintenance with fire emergency optimization solutions within the BIM model to prevent conflicts between these measures.

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(1) Spatial Coordination: When optimizing the layout of HVAC vents, lighting fixtures, and energy-saving equipment, strictly avoid obstructing fire evacuation routes and all types of fire protection facilities. Ensure the integrity of evacuation spaces and the visibility and accessibility of fire protection equipment to meet fire safety code requirements.

(2) Equipment Coordination: During HVAC and electrical equipment selection and configuration, simultaneously consider low-carbon energy efficiency alongside fireproofing, explosion-proofing, and emergency operation requirements. This ensures equipment operates safely and effectively under both routine maintenance and fire emergency conditions.

(3) Zone Coordination: Align low-carbon operation control zones with building fire compartments and smoke control zones. This achieves spatial unity between energy management areas and emergency response zones, facilitating zone-specific management and plan execution.

5.2 Information Collaboration: BIM Model Data Integration and Sharing

Using the BIM model as a unified data carrier, integrate low-carbon operation and maintenance information with fire emergency response data to establish a comprehensive, standardized information database, enabling centralized information management and efficient retrieval.

(1) Data Integration: Integrate building energy consumption parameters, equipment technical information, fire protection system configurations, evacuation route planning, and other content into the BIM model to form a complete information system;

(2) Standardized Updates: Periodically update equipment ledgers, energy consumption statistics, and fire protection facility inspection records during operations to ensure BIM model data aligns with on-site conditions;

(3) Visual Management: Leverage BIM's 3D visualization capabilities to intuitively display energy consumption distribution, fire protection facility locations, evacuation routes, and other critical information, providing visual evidence for management decisions and optimization strategies.

5.3 Disposal Coordination: Integration of Operations and Maintenance with Emergency Response Mechanisms

Establish a management mechanism linking low-carbon operations and maintenance with fire emergency response, clearly defining the boundaries, processes, and responsibilities for both tasks to ensure orderly execution of routine management and emergency handling.

(1) Routine Management Integration: During daily operations and maintenance, concurrently conduct energy consumption control and fire protection facility inspections. Incorporate fire safety requirements into the low-carbon operations and maintenance management system to achieve unified hazard identification.

(2) Emergency Process Integration: Develop fire emergency response plans specifying operational procedures for non-fire power shutdowns, emergency system activation, and HVAC equipment switching during emergencies to ensure orderly transition between operational and fire protection systems.

(3) Post-Incident Optimization Integration: Following emergency resolution, analyze energy consumption data changes and response actions to refine low-carbon operation plans and fire emergency protocols, thereby enhancing management effectiveness.

6. Conclusion and Outlook

This study examines typical commercial buildings in Tangshan City, applying BIM technology to investigate the integrated management of low-carbon operations and fire emergency response. The following conclusions are drawn:

(1) BIM technology effectively consolidates information across all building disciplines, enabling information exchange between low-carbon operations and fire emergency management to break down management barriers;

ISSN: 2414-1895 DOI: 10.6919/ICJE.202603_12(3).0039

(2) Through BIM model information extraction, spatial analysis, and parameter optimization, core issues in both management areas can be precisely identified, enabling targeted optimization proposals to enhance management scientificity;

(3) The established three-dimensional collaborative management strategy-integrating plans, information, and response protocols-achieves unified oversight of low-carbon operations and fire emergency management, aligning with the green and safe development needs of commercial buildings in the Jidong region.

Future developments may integrate IoT and big data technologies to establish a smart management platform, enabling real-time monitoring and intelligent early warning for building energy consumption and fire safety conditions. Simultaneously, expanding the scope of research subjects will refine collaborative management solutions for diverse commercial building types, driving the digital and intelligent upgrade of green and safe management in commercial buildings across the Jidong region.

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