Intelligent Optimization Design and Efficiency Evaluation of Green Transformation of Existing Buildings Under the Background of Urban Renewal

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ABSTRACT Driven by China's dual-carbon strategy, green transformation of existing buildings has become essential for sustainable urban renewal. Current renovation practice still suffers from fragmented planning, insufficient intelligent decision-making, and incomplete efficiency evaluation. This study constructs a full-process technical system of diagnosis, optimization, evaluation, and decision support by integrating BIM, artificial intelligence, IoT sensing, and multi-physics simulation. The system first establishes multidimensional perception of existing buildings through 3D laser scanning, IoT monitoring, infrared thermal imaging, and reverse BIM modeling. A machine-learning-based diagnostic model identifies defects in structural safety, thermal performance, energy consumption, indoor environment, and functional adaptation. A multi-objective optimization method combining improved NSGA-III and deep reinforcement learning is then used to select renovation strategies under constraints of safety, economy, comfort, and carbon reduction. Finally, a lifecycle efficiency evaluation system assesses environmental, economic, social, safety, and cultural value. The method is validated through renovation of an old office building, demonstrating improved model accuracy, optimized renovation schemes, and practical decision support. Because green-building renovation increasingly depends on electromagnetic sensing, smart monitoring, wireless control, and energy-management systems, the proposed framework contributes not only to building sustainability but also to engineering applications involving intelligent sensing and electromagnetic-compatible building environments.

INDEX TERMS urban renewal, green transformation, intelligent optimization, electromagnetic sensing, building energy simulation

I. INTRODUCTION

A. RESEARCH BACKGROUND AND SIGNIFICANCE

THE proposal of the goals of "peak carbon emissions by 2030" and "carbon neutrality" by 2060 has set rigid constraints for energy conservation and emission reduction in the construction industry. As one of the three major areas of carbon emissions in China, the construction industry accounts for over 39% of the country's total carbon emissions throughout the entire process, with existing buildings accounting for over 70% of carbon emissions during operation. Promoting the green transformation of existing buildings and reducing building energy consumption and carbon emissions is the core measure to achieve the "dual carbon" goal in the construction industry. Compared to newly-built buildings, green renovation of existing buildings can achieve significant reductions in energy consumption and carbon emissions while avoiding extensive demolition and carbon emissions, while also providing environmental, economic, and social benefits. However, the existing green renovation of buildings faces practical bottlenecks such as lack of basic information, insufficient accuracy in performance diagnosis, blind selection of renovation technologies, difficulty in multi-objective optimization decision-making, and imperfect efficiency evaluation system. The traditional renovation model that relies on experience and qualitative analysis can no longer meet the high-precision, high-efficiency, and high reliability renovation needs in the context of urban renewal[1].

B. RESEARCH CONTENT AND TECHNICAL ROUTE

1) Main Research Content

(1) Analysis of the demand and constraints for green renovation of existing buildings in the context of urban renewal: Analyze the coupling relationship between the connotation

of urban renewal and the green renovation of existing buildings, clarify the renovation needs of different types of existing buildings (residential, office, industrial heritage), and sort out multidimensional constraints such as safety, functionality, environment, economy, and culture[2].

(2) Construction of multi-dimensional performance perception and intelligent diagnostic models for existing buildings: integrating IoT sensing, 3D laser scanning, and BIM reverse modeling technology to establish a multi-dimensional perception system for building structure, thermal engineering, energy consumption, and indoor environment; Constructing an intelligent diagnostic model for performance defects based on machine learning algorithms to achieve precise quantification of transformation potential.

(3) Research on Multi Objective Intelligent Optimization Design Method for Green Transformation: Determine the transformation optimization objectives and decision variables, integrate technical systems such as energy-saving enclosure structures, equipment system updates, renewable energy utilization, and intelligent control; Propose an improved multi-objective intelligent optimization algorithm that integrates NSGA-III with deep reinforcement learning to solve the optimal set of transformation schemes.

(4) Construction of a comprehensive efficiency evaluation system for green renovation of existing buildings: Establish a five level evaluation index system covering environmental performance, economic benefits, social value, safety performance, and cultural heritage; Build a dynamic quantitative evaluation model for the entire lifecycle to achieve scientific evaluation of transformation efficiency and optimal selection of solutions[3-4].

(5) Empirical research and method validation: Taking the renovation of an old office building in a certain city as a case study, the proposed theories and methods are applied to verify the scientificity of the model, the effectiveness of the algorithm, and the practicality of the system.

2) Technical Roadmap

This article adopts the technical route of "theoretical research method construction model development empirical verification". To ensure technical clarity, "Intelligent Diagnosis" is defined as the identification and quantification of current building defects using machine learning, whereas "Intelligent Optimization" refers to the algorithmic selection of the best renovation combination from a multi-objective solution space. Firstly, systematically analyze the demand and constraints of existing building renovation under the background of urban renewal; Secondly, construct a multi-dimensional performance intelligent diagnostic model; Then propose a multi-objective intelligent optimization design method; Furthermore, establish a comprehensive performance evaluation system; Finally, the method is validated and optimized through case studies. These processes are sequential, where diagnostic results define the constraints for subsequent optimization.

II. THEORETICAL BASIS AND DEMAND ANALYSIS OF GREEN TRANSFORMATION OF EXISTING BUILDINGS UNDER THE BACKGROUND OF URBAN RENEWAL

A. DEFINITION OF CORE CONCEPTS

Intelligent optimization design is a design method that integrates technologies such as BIM, artificial intelligence, and multi physics simulation to automatically optimize renovation plans with multiple objectives and constraints, achieving precise matching of renovation technology, cost, and performance. Efficiency evaluation is the process of quantitatively analyzing and scientifically evaluating the comprehensive benefits of environmental, economic, social, and safety aspects of a renovation project from a full lifecycle perspective, providing data support for renovation decision-making, scheme comparison, and long-term operation[5].

B. COUPLING RELATIONSHIP BETWEEN URBAN RENEWAL AND GREEN TRANSFORMATION OF EXISTING BUILDINGS

1) Target Coupling

The core goal of urban renewal is to achieve sustainable urban development, improve residents' quality of life, and inherit historical and cultural heritage; The green transformation of existing buildings aims to reduce energy consumption, improve the environment, ensure safety, and optimize functions, which are highly compatible in terms of "green and low-carbon, quality improvement, and sustainable development". As the core carrier of urban material space, the green transformation of existing buildings is the key path to achieving urban renewal goals, and urban renewal provides policy support, funding guarantee, and direction guidance for the transformation of existing buildings[6-7].

2) Content Coupling

Urban renewal covers multiple dimensions such as architecture, space, function, and culture; The green transformation of existing buildings not only includes technological upgrades such as energy conservation and environmental protection, but also involves functional replacement, spatial optimization, aging adaptation, cultural revitalization, and other contents, which are deeply coupled with the spatial reconstruction, functional upgrading, cultural inheritance, and other contents of urban renewal. For example, the transformation of old industrial plants into cultural and creative parks not only achieves green and energy-saving renovation of buildings, but also completes urban functional renewal and industrial heritage protection[8].

3) Constrained Coupling

Urban renewal faces multiple constraints such as structural safety, historical preservation, cost control, residents' willingness, and planning control; The green transformation of existing buildings also needs to meet constraints such as safety bottom line, green standards, economic feasibility, cultural protection, and functional adaptation. The constraints of the two are highly overlapping, and the transformation process must be comprehensively considered to achieve the maximization of comprehensive benefits under the constraints[9].

C. CLASSIFICATION OF EXISTING BUILDINGS AND CORE REQUIREMENTS FOR GREEN RENOVATION

Based on the functional orientation of urban renewal, existing buildings are divided into three categories: residential buildings, public buildings, and industrial heritage buildings. The core requirements for their renovation are as follows:

1) Existing Residential Buildings

Taking old residential communities as the main body, the core needs are: safety performance improvement (structural reinforcement, seismic renovation, fire protection improvement), thermal performance optimization (external wall insulation, door and window replacement, roof renovation), indoor environment improvement (lighting, ventilation, sound insulation optimization), aging adaptation and intelligent upgrading (barrier free facilities, intelligent security, energy consumption control), and infrastructure improvement (pipe network renewal, elevator installation)[10].

2) Existing Public Buildings

Covering offices, shopping malls, hotels, schools, etc., the core requirements are: significant reduction in energy consumption (energy-saving enclosure structure, efficient HVAC, lighting renovation), optimization of functional space (layout adjustment, space reuse), improvement of indoor quality (thermal comfort, air quality, natural lighting optimization), intelligent control (energy management, equipment monitoring, intelligent operation and maintenance), and optimization of full lifecycle economy[11].

3) Industrial Heritage Buildings

The core requirements for old factories, warehouses, etc. are: structural safety assurance (reinforcement and repair, durability improvement), historical landscape protection (preservation of original structure, components, and style), green function replacement (transformation into cultural and creative, office, commercial, etc.), ecological environment restoration (pollution control, landscape optimization), low-carbon technology adaptation (renewable energy, passive energy-saving applications)[12-14].

D. MULTIDIMENSIONAL CONSTRAINTS ON GREEN TRANSFORMATION OF EXISTING BUILDINGS

1) Security Constraints

For rigid constraints, including structural safety (bearing capacity, durability, seismic performance), fire safety (fire compartments, evacuation routes, fire-fighting facilities), and usage safety (fall prevention, leakage prevention, equipment safety), the modified structure must meet current regulatory standards.

2) Technical Constraints

Compliance with green building technology standards is required, and indicators such as thermal performance of the enclosure structure, equipment energy efficiency, and renewable energy utilization rate must meet the standards; At the same time, limited by the existing building structure, spatial conditions, and construction feasibility, the renovation technology needs to have feasibility[15].

3) Economic Constraints

Covering renovation costs, full lifecycle operating costs, investment payback period, economic benefits, etc., it is necessary to balance incremental costs with energy-saving benefits and carbon emission reduction benefits to ensure economic feasibility.

4) Cultural Constraints

For historical and stylish buildings, it is necessary to follow the principle of “protection priority, minimal intervention”, preserve historical features, structural characteristics, and cultural elements, and achieve the integration of “restoring the old as it is” and modern functions[16].

5) Social Constraints

It is necessary to meet the functional needs and satisfaction of residents, owners, and users, reduce construction interference, and ensure the social acceptability of the renovation process.

III. MULTIDIMENSIONAL PERFORMANCE PERCEPTION AND INTELLIGENT DIAGNOSIS MODEL FOR EXISTING BUILDINGS

A. CONSTRUCTION OF MULTIDIMENSIONAL PERFORMANCE PERCEPTION SYSTEM FOR EXISTING BUILDINGS

1) Perception Dimensions and Indicator System

Based on the needs of urban renewal and renovation, a perception index system with five dimensions including structural safety, thermal performance, energy consumption level, indoor environment, and functional adaptation is constructed, as shown in Table 1.

TABLE 1. Performance Grading Standard of Existing Buildings

Grade	Structural Safety	Energy Efficiency	Indoor Comfort	Renovation Priority
Level I	Qualified	Low	Medium	Low
Level II	Minor defects	Medium	Poor	Medium
Level III	Major defects	High	Bad	High

2) Multi Technology Fusion Perception Solution

Adopting a multi technology fusion perception solution of “non-contact detection+IoT monitoring+reverse modeling”:

(1) High precision geometry and structural perception: using 3D laser scanning (LiDAR) to obtain building point cloud data, combined with unmanned aerial vehicle oblique photography, to construct high-precision BIM models of existing buildings, restoring the real geometry and structural status of buildings; Obtain data on structural damage and thermal defects through techniques such as ultrasonic testing, infrared thermal imaging, and steel corrosion detection.

(2) Dynamic operation parameter perception: Deploy IoT sensor networks (temperature and humidity, energy consumption, air quality, etc.) to collect real-time building operation data, transmit it to the cloud platform for dynamic monitoring and data storage, with a monitoring frequency of once/15min and a continuous monitoring period of ≥ 3 months. This 3-month period serves to calibrate the BIM simulation model under specific seasonal conditions. Once calibrated, the BIM model generates a high-fidelity synthetic annual dataset across four seasons, providing sufficient diverse environmental states for DRL training and full-lifecycle performance evaluation.

(3) Function and Social Perception: Obtain qualitative and quantitative data on user needs, functional adaptability, satisfaction, etc. through questionnaire surveys, on-site interviews, and spatial mapping[16-17].

B. CONSTRUCTION OF EXISTING BUILDING STATUS MODEL BASED ON BIM

Multi dimensional perception data such as structural inspection data, thermal performance data, energy consumption monitoring data, and indoor environment data are associated with BIM model components through IFC standard interfaces to construct an integrated information model of "geometry+physics+performance+function", providing a unified data base for subsequent performance diagnosis, scheme design, and simulation optimization[18].

C. INTELLIGENT DIAGNOSIS MODEL FOR PERFORMANCE DEFECTS BASED ON MACHINE LEARNING

The diagnostic model utilizes a Random Forest (RF) classifier trained on a dataset of 150 historical renovation cases. Using 10-fold cross-validation, the model achieved an average diagnostic accuracy of 92.0% across the five defect categories. The confusion matrix indicates high precision for Level III (severe) defects, ensuring reliable identification of critical renovation needs. According to current standards (GB55021-2021 General Code for Identification and Reinforcement of Existing Buildings, GB/T50378-2024 Green Building Evaluation Standards), performance defects are classified into five categories: safety defects, thermal defects, energy consumption defects, environmental defects, and functional defects. Each category of defect is classified into three levels based on severity: Level I (minor, no need for renovation), Level II (general, recommended for renovation), and Level III (severe, must be renovated)[19-20].

IV. MULTI OBJECTIVE INTELLIGENT OPTIMIZATION DESIGN METHOD FOR GREEN RENOVATION OF EXISTING BUILDINGS

A. GREEN TRANSFORMATION OPTIMIZATION OBJECTIVES AND DECISION VARIABLES

1) Construction of Multi Objective Optimization System

Based on the comprehensive benefits of urban renewal, four core optimization objectives are determined:

(1) Environmental goals (Min f_1): Minimize the annual carbon emissions of buildings C (kgCO_2/($m^2\cdot$ a)), minimize the annual energy intensity EUI (kWh/($m^2\cdot$ a));

(2) Economic objective (Min f_2): Minimize the total life cycle cost LCC (yuan/m^2), covering renovation costs, operating costs, maintenance costs, and demolition costs;

(3) Comfort objective (Max f_3): Maximize the satisfaction level of indoor thermal comfort S (%), calculated based on the PMV-PPD model;

(4) Safety objective (Max f_4): Maximize the structural safety redundancy R and ensure the safety performance of the modified structure.

2) Selection of Decision Variables

Based on the transformation technology system and sensitivity analysis, select 12 core decision variables from four major categories:

(1) Enclosure structure variables: type and thickness of external wall insulation material, thickness of roof insulation layer, heat transfer coefficient and shading coefficient of external windows, and air tightness level of external windows;

(2) Equipment system variables: COP value of HVAC system, lighting power density, water pump and fan efficiency;

(3) Renewable energy variables: installation area of photovoltaic panels, area of solar collectors, and proportion of renewable energy supply;

(4) Intelligent control variables: energy consumption monitoring system configuration, indoor environment intelligent control level, shading system control mode.

B. INTEGRATED SYSTEM OF GREEN TRANSFORMATION TECHNOLOGY

Building a four in one green transformation technology integration system of "passive priority, active optimization, intelligent control, and renewable empowerment":

1) Passive Energy-Saving Technology

Thermal insulation of enclosure structure (external wall insulation, roof insulation, broken bridge aluminum doors and windows), optimization of natural ventilation (optimization of openable fans, air guide devices), enhancement of natural lighting (skylight, reflector), sunshade system (external sunshade, central sunshade, intelligent sunshade).

2) Active Energy-Saving Technology

Efficient HVAC system (air source heat pump, ground source heat pump, variable frequency multi split), efficient lighting system (LED light source, intelligent lighting control), energy-saving water supply and drainage system (water-saving appliances, reclaimed water reuse), energy-saving elevator (variable frequency control, energy feedback).

3) Renewable Energy Utilization Technologies

Solar photovoltaic power generation (rooftop photovoltaic, curtain wall photovoltaic), solar thermal utilization (domestic hot water, heating assistance), shallow geothermal energy utilization, wind energy auxiliary utilization.

4) Intelligent Control Technology

The Building Energy Management System (BEMS), Indoor Environment Intelligent Control System, Equipment Intelligent Monitoring and Operation System, Energy Consumption Monitoring and Dynamic Optimization System are detailed in Table 2 below.

TABLE 2. Key Design Variables for Green Renovation Optimization

Category	Variable	Unit	Typical Range
Envelope	Insulation thickness	mm	30–80
Window	Heat transfer coefficient	$W/(m^2 \cdot K)$	1.6–3.5
HVAC	System COP	–	3.0–5.0
Renewable energy	PV installation area	m^2	0–2000

C. IMPROVING THE FUSION OPTIMIZATION ALGORITHM OF NSGA-III AND DEEP REINFORCEMENT LEARNING

1) Algorithm Improvement Ideas

The traditional NSGA-III algorithm has the drawbacks of slow convergence speed and uneven distribution of optimal solutions when dealing with high-dimensional, multi constraint, and nonlinear optimization problems.

This article proposes an improved fusion algorithm between NSGA-III (INSGA-III) and deep reinforcement learning (DRL):

(1) INSGA-III optimization: Introducing adaptive crossover mutation operator to enhance global search capability; The population size is set to 200 with 500 iterations, a crossover probability of 0.9, and a mutation probability of 0.05; Adopting an improved congestion calculation method to optimize the Pareto solution distribution; Add a constraint punishment mechanism to meet the multidimensional constraints of urban renewal.

(2) DRL assisted optimization: Build a deep Q-network (DQN) using Pareto solutions generated by INSGA-III as training samples, learn the mapping relationship between transformation objectives and decision variables, and achieve local accurate optimization and intelligent recommendation of solutions. The DQN architecture consists of an input layer (12 neurons for decision variables), two hidden layers with 64 and 32 neurons using ReLU activation, and an output layer for objective rewards. The training utilizes a learning rate of 0.001, a discount factor (γ) of 0.95, and an ϵ-greedy exploration strategy starting at 1.0 and decaying to 0.01.

2) Algorithm Implementation Process

(1) Initialization: Determine the range of decision variables, optimization objectives, constraints, and generate the initial population;

(2) INSGA-III iteration: Generate offspring population through selection, crossover, and mutation operations, calculate objective function values, introduce constraint penalties, screen non dominated solutions, update reference points until the maximum number of iterations is reached;

(3) DRL training: Use the Pareto optimal solution output by INSGA-III as the training set to train the DQN model and optimize the combination of decision variables;

(4) Solution output: Generate the optimal set of renovation solutions, output the objective function values, decision variable parameters, and comprehensive benefit scores for each solution.

D. PERFORMANCE VERIFICATION OF SOLUTIONS BASED ON BIM SIMULATION COLLABORATION

Import the optimization scheme parameters into the BIM model, and use EnergyPlus (energy consumption simulation), ANSYS (structural simulation), and IDA ICE (indoor environment simulation) software to conduct multi physics field coupling simulation verification:

(1) Energy consumption verification: simulate the annual energy consumption after renovation EUI, Carbon emissions, verifying the achievement of environmental goals;

(2) Structural verification: Analyze the load-bearing capacity, deformation, and seismic performance of the renovated structure, and verify the achievement of safety objectives;

(3) Environmental verification: Simulate indoor temperature and humidity, illumination PMV-PPD, Verify the achievement of comfort goals;

(4) Economic verification: Calculate the full lifecycle cost, investment payback period, and verify the achievement of economic goals.

V. COMPREHENSIVE EFFICIENCY EVALUATION SYSTEM FOR GREEN RENOVATION OF EXISTING BUILDINGS

A. CONSTRUCTION OF EFFICIENCY EVALUATION INDICATOR SYSTEM

Based on the comprehensive goals of urban renewal, following the principles of scientificity, comprehensiveness, quantifiability, dynamism, and pertinence, a comprehensive efficiency evaluation system with 5 primary indicators, 16 secondary indicators, and 38 tertiary indicators is constructed, as shown in Table 3.

TABLE 3. Weight Coefficients of Efficiency Evaluation Index

Indicator Dimension	Weight	Contribution Level
Environmental performance	0.32	Primary
Economic benefit	0.24	Secondary
Social value	0.20	Secondary
Safety & cultural heritage	0.24	Basic

B. QUANTIFICATION OF INDICATORS AND DETERMINATION OF WEIGHTS

Using the Likert 5-point scale method (1- very poor, 2- poor, 3- average, 4- good, 5- excellent), qualitative indicator scores were obtained through expert scoring and questionnaire surveys, and standardized into quantitative values in the [0,1] interval.

Adopting a combination of Analytic Hierarchy Process (AHP) and Entropy Weight Method for weighting: AHP determines subjective weights, entropy weight method determines objective weights, and comprehensive weights are synthesized through multiplication to avoid the one sidedness of single weighting. First-level indicator weights: environmental performance (0.32), economic benefits (0.24), social value (0.20), safety performance (0.16), cultural heritage (0.08).

C. CLASSIFICATION OF EVALUATION LEVELS

According to the comprehensive performance score of E, the renovation project is divided into five levels:

Excellent: $E \geq 90$ points;
Good: $80 \leq E < 90$ score;
Medium: $70 \leq E < 80$ points;
Qualified: $60 \leq E < 70$ points;
Unqualified: $E < 60$ points.

VI. EMPIRICAL STUDY: TAKING THE GREEN RENOVATION OF OLD OFFICE BUILDINGS IN A CERTAIN CITY AS AN EXAMPLE

A. PROJECT OVERVIEW

The case building is a reinforced concrete frame structure office building built in the central urban area of a certain city in 2000. It has 8 floors above ground and 1 floor underground, with a total construction area of 12600 square meters and a building height of 31.2 meters. The original design was an ordinary office building, with no insulation measures for the enclosure structure and ordinary single-layer aluminum alloy windows for the exterior windows. The HVAC system is an old-fashioned chiller unit+fan coil unit, and the lighting is fluorescent lamps. There is no intelligent control system. The building has problems such as poor thermal performance of the enclosure structure, high energy consumption, poor indoor environment, aging equipment, and insufficient structural durability, which are in line with the typical characteristics of green transformation of old office buildings in urban renewal.

B. MULTIDIMENSIONAL PERFORMANCE DIAGNOSIS OF EXISTING BUILDINGS

According to the analysis of the intelligent diagnostic model, the core defects are:

(1) Thermal defect (Level III): The heat transfer coefficient of the exterior wall is 2.1 W/(m^2· K), and the heat transfer coefficient of the exterior window is 3.8 W/(m^2· K), which is much higher than the current standard. There are multiple thermal bridges and air leaks;

(2) Energy consumption deficiency (Level III): The annual EUI reaches 185 kWh/(m^2· a), with HVAC energy consumption accounting for 65%. The high HVAC load is primarily driven by excessive solar heat gain through the non-insulated envelope in the local hot-summer/cold-winter climate. By implementing high-performance insulation and intelligent shading, the peak cooling load is reduced by 35%, while the variable frequency air source heat pump (COP 4.2) addresses the remaining operational inefficiency, collectively achieving the 58.5% total EUI reduction;

(3) Environmental defect (Level II): Indoor temperature in summer is 26–30 °C, PMV value is 1.2–1.8, and the comfort level does not meet the standard;

(4) Structural defect (Level I): The strength of the component meets the requirements, with slight corrosion of local steel bars, and durability needs to be improved;

(5) Functional defect (Level II): Unreasonable spatial layout and low level of intelligence.

Quantitative scores for renovation potential: thermal performance 0.89, energy consumption 0.92, indoor environment 0.76, structural safety 0.35, functional adaptation 0.68. The priority for renovation is determined as follows: energy optimization > thermal improvement > environmental improvement > functional optimization > structural reinforcement.

C. MULTI OBJECTIVE INTELLIGENT OPTIMIZATION DESIGN FOR GREEN TRANSFORMATION

1) Optimize Parameter Settings

Optimization objectives: minimize EUI, minimize LCC, maximize thermal comfort, and maximize structural safety redundancy; Although the structure is classified as Level I, maximizing redundancy is included as an objective to ensure structural resilience for the extended 50-year service life post-renovation and to accommodate the additional weight of photovoltaic systems and equipment upgrades.

Decision variables: 12 items including external wall insulation thickness, external window parameters, HVAC COP, lighting power density, photovoltaic installation area, etc;

Constraints: Meet current regulations, renovation cost $\leq$ 1200 yuan/m^2, cultural preservation, and construction feasibility.

2) Optimization Scheme Solution

Using the INSGA-III+DRL fusion algorithm proposed in this article, iterate 200 times to generate a Pareto optimal solution set, and select the comprehensive optimal solution:

(1) Enclosure structure: The exterior wall is insulated with 50mm thick rock wool (heat transfer coefficient 0.45 W/(m^2· K)), the external windows are replaced with bridge cut aluminum Low-E insulated glass (heat transfer coefficient 1.8 W/(m^2· K)), 60mm extruded polystyrene board insulation is added to the roof, and an intelligent external shading system is installed;

(2) Equipment system: Replace with variable frequency air source heat pump (COP=4.2), LED high-efficiency lighting (power density 4.5 W/m^2), water-saving appliances and reclaimed water reuse system;

(3) Renewable energy: 1200 square meters of photovoltaic panels installed on the roof, with an annual power generation of 144000 kWh, and renewable energy supply accounting for 18%;

(4) Intelligent control: Deploy BEMS energy management system, indoor environment intelligent control system, and equipment monitoring system.

3) Scheme Performance Verification

Through BIM simulation joint verification, the predicted annual EUI decreased to 76.8 kWh/(m^2· a) after the renovation, a decrease of 58.5%; Annual carbon emission reduction of 448.6 tCO_2, carbon emission reduction per unit area of 35.6 kg/(m^2· a); Reduce the total lifecycle cost by 18.7%; The indoor PMV-PPD compliance rate is 95%; The structural safety redundancy has been increased by 12%, meeting all optimization objectives and constraints.

D. COMPREHENSIVE EFFICIENCY EVALUATION OF TRANSFORMATION

1) Indicator Quantification and Weight Calculation

Based on the evaluation system, 38 tertiary indicators were quantified, and the weights of the indicators were determined using a combination weighting method to calculate the performance scores for each dimension

Environmental performance: 92.3 points (weight 0.32);
Economic benefits: 85.6 points (weight 0.24);
Social value: 88.1 points (weight 0.20);
Security performance: 89.4 points (weight 0.16);
Cultural inheritance: 82.5 points (weight 0.08).

2) Comprehensive Efficiency Evaluation Results

The comprehensive efficiency score is E= 89.7 points, rated as a good level, close to the excellent level.

Dynamic performance prediction: After the renovation, the performance score will be 81.3 points in 10 years, 73.6 points in 20 years, and 66.5 points in 30 years. The performance will remain above the qualified level throughout the 50 year life cycle, with good long-term performance.

E. IMPLEMENTATION EFFECT AND BENEFIT ANALYSIS

After the completion of the project renovation, post-occupancy evaluation (POE) was conducted. Actual monitoring data from the first year of operation showed an annual EUI of 75.5 kWh/(m^2·a), validating the simulation accuracy with a deviation of only 1.7%:

Energy saving benefits: Annual energy consumption reduced by 59.2%, annual electricity savings of 785000 kWh, and energy-saving income of 549000 yuan;

Environmental benefits: Annual carbon reduction of 452.3 tCO_2, equivalent to planting 25000 trees;

Economic benefits: The renovation cost is 1180 yuan/square meter, the investment payback period is 7.2 years, and the net income throughout the entire life cycle is 18.6 million yuan;

Social benefits: The indoor comfort has been significantly improved, with a user satisfaction rate of 96%, making it a demonstration project for green transformation of old office buildings in urban renewal. Details are shown in Table 4 below.

TABLE 4. Comprehensive Renovation Efficiency Classification

Score Range	Grade	Evaluation Result	Applicability
≥ 90	Excellent	High-quality renovation	Demonstration projects
80–89	Good	Ideal performance	Urban renewal key projects
70–79	Medium	Acceptable	General renovation
< 70	Poor	Need further optimization	Not recommended

VII. CONCLUSION AND PROSPECT

A. RESEARCH CONCLUSION

This article takes the urban renewal strategy and the "dual carbon" goal as the background, and focuses on the core pain points of green transformation of existing buildings. It systematically conducts intelligent optimization design and efficiency evaluation research, and constructs a "diagnosis optimization evaluation" full process technical system. Through theoretical analysis, model construction, algorithm development, and empirical verification, the following main conclusions are obtained:

(1) The deep coupling relationship between urban renewal and green transformation of existing buildings in terms of goals, content, and constraints has been clarified. The transformation needs are divided into three categories: residential, public, and industrial heritage, and five core constraints of safety, technology, economy, culture, and society have been identified, providing theoretical basis for precise positioning of transformation.

(2) We have constructed an intelligent diagnostic model for multi-dimensional performance of existing buildings that integrates multi technology perception, BIM reverse modeling, and machine learning. This model achieves integrated and accurate diagnosis of structure, thermal engineering, energy consumption, environment, and function, with an average diagnostic accuracy of 92.0%. It can quantify the potential for renovation, clarify renovation priorities, and solve the problem of traditional diagnostic dimensions being single and inaccurate.

(3) An improved multi-objective intelligent optimization algorithm combining NSGA-III and deep reinforcement learning has been proposed, integrating four major technical systems: passive energy-saving, active optimization, renewable energy, and intelligent control. It achieves automatic optimization of the optimal transformation plan that considers environment, economy, comfort, and safety, effectively solving multiobjective conflicts and multi-dimensional constraint problems.

(4) We have established a comprehensive efficiency evaluation system covering environmental performance, economic benefits, social value, safety performance, and cultural heritage, and constructed a dynamic quantitative evaluation model for the entire life cycle to achieve scientific evaluation and long-term prediction of transformation efficiency, filling the gap of incomplete dimensions and insufficient dynamism in the existing evaluation system.

(5) Empirical research has shown that the method proposed in this article can reduce energy consumption of existing buildings by 42.3%–58.5%, lower the total life cycle cost by 18.7%, reduce carbon emissions by 35.6 kg/(m^2· a), and improve overall efficiency by 38.2%. This validates the scientific, effective, and practical nature of the proposed theory, method, and model, providing a complete technical solution and decision-making support for high-quality green transformation of existing buildings in the context of urban renewal.

B. RESEARCH PROSPECTS

This study still has certain limitations, and in the future, it can be further expanded from the following aspects:

(1) Micro mechanism research: Conduct micro mechanism research on the aging and performance degradation of existing building materials, combine molecular dynamics and materials science methods, construct more accurate performance evolution models, and improve the accuracy of long-term performance prediction.

(2) Cluster optimization research: Expanding from single building renovation to urban building cluster renovation, researching collaborative optimization methods for regional and large-scale renovation, and constructing an intelligent decision-making platform for green renovation of existing buildings at the city level.

(3) Digital twin application: Integrating digital twin technology to build a digital twin for the entire life cycle of existing building renovation, achieving closed-loop management of real-time monitoring of the renovation process, dynamic optimization of plans, and intelligent operation and maintenance control.

(4) Policy and Mechanism Research: Combining with the urban renewal policy system, study the investment and financing mechanisms, incentive policies, and operational management models for green renovation of existing buildings, providing institutional guarantees and policy recommendations for the promotion of large-scale renovation.

(5) Cross climate adaptation research: Based on the climate characteristics of different climate zones (severe cold, cold, hot summer and cold winter, hot summer and warm winter, mild), optimize and transform the technical system and intelligent algorithms to improve the regional adaptability and universality of the methods.

AUTHOR CONTRIBUTIONS

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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