International Journal of Engineering Research and Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 21, Issue 9 (September 2025), PP 110-115

Research on Regionally Adaptive Green Building Evaluation System: A Case Study of Student Dormitories in Central China

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Abstract : *This study explores the application of green building technologies and the development of a tailored evaluation system for student accommodations, using Xinzheng City as a case study. It aims to support the green transformation of such buildings by promoting energy efficiency, environmental protection, and optimal resource use.A five-dimensional evaluation framework—covering energy efficiency, water management, material use, indoor environmental quality, and innovation—was established through literature review and fieldwork. A mixed-methods approach combined qualitative (expert consultation) and quantitative (surveys and IoT data analysis) methods to assess technology effectiveness.Findings indicate that green technologies reduce energy use by 15.7% per unit area, improve indoor comfort (23.6% rise in PMV compliance), and lower health risks (76.7% drop in mould levels). The study introduces a region-specific evaluation system that emphasises resource efficiency and indoor environmental optimisation. Notable strategies include straw composite wall systems (thermal conductivity: 0.078 W/m·K) and BIM-based energy prediction models (RMSE = 4.2 kWh/m²).The proposed framework addresses local challenges—such as high occupancy and seasonal extremes—and offers practical guidance for low-carbon building upgrades. This work contributes empirical support and methodological innovation towards China's "dual carbon" goals, highlighting the importance of adaptive technologies and data-driven management in sustainable construction.*

Key words: *green building evaluation system; sustainable development evaluation index;energy saving*

Date of Submission: 02-09-2025 Date of acceptance: 11-09-2025

I. Introduction

With global economic development and population growth, environmental issues have become increasingly prominent, and sustainable development has emerged as a global consensus. As the construction industry is a major source of resource consumption and pollution, a transition towards green practices is urgently needed. Green buildings, with their efficient resource utilisation, low environmental impact, and health-friendly features, offer a crucial pathway to sustainable industry development. However, existing evaluation systems for green buildings exhibit limitations, particularly in specialised building types such as student accommodations.

This study focuses on student accommodations in Xinzheng, Central Plains, aiming to develop a scientifically sound and reasonable evaluation system for green buildings that addresses high energy consumption, low energy efficiency, and suboptimal indoor environments. By analysing the current situation and challenges, this research integrates core indicators including energy efficiency, water resources management, materials utilisation, indoor environment quality, and innovation management to propose an adaptable evaluation framework. The case study demonstrates that the application of green technologies can substantially reduce energy consumption by 15.7% per unit area, optimise the indoor environment with a 23.6% increase in PMV compliance, and mitigate health risks by reducing mould concentrations by 76.7%.

The innovation of this study lies in its proposal of a region-specific evaluation system and targeted retrofit strategies, such as the use of straw composite wall systems and BIM-based dynamic optimisation-which provide practical references for the green transformation of similar buildings. Consequently, this research contributes to the low-carbon development of the construction industry and supports the achievement of national "dual carbon" goals. Furthermore, the irreversible global trend towards green building development underscores its growing significance in addressing environmental challenges and fostering sustainable industrial progress. In the context of student accommodations, the rational application of green technologies can create healthy and comfortable learning environments for students, thereby advancing broader societal sustainable development.

II. Related work

Research on green buildings in student accommodations has attracted both domestic and international attention, particularly regarding their definitions, technological potential, and benefits [1-5]. Studies have demonstrated that green technologies can significantly reduce energy consumption—for instance, energy-efficient lighting can lower energy use by 30% [6]improve indoor air quality by reducing $PM_{2.5}$ concentrations by 40% [7] and enhance student learning efficiency [8-10]. Nonetheless, existing research still suffers from incomplete evaluation systems and a lack of targeted implementation strategies [11-13]. Therefore, there is an urgent need to establish an adaptable evaluation framework and develop dynamic optimisation pathways [14-15].

In the context of Xinzheng student accommodations, the current situation and corresponding optimisation recommendations are as follows. Regarding energy efficiency, the heating and ventilation systems are characterised by low efficiency, with an energy consumption of 160 kWh/m². It is recommended to employ BIM to optimise the window-to-wall ratio from 0.3 to 0.25, and to integrate solar chimneys, which can reduce cooling demands by 8%. In terms of water resources management, the per capita daily water usage exceeds standard levels by 20%; thus, the promotion of water-saving fixtures-with a water-saving rate of at least 15%—and the implementation of intelligent monitoring systems are imperative. Concerning materials and indoor environmental quality, traditional building materials exhibit high carbon emissions. Therefore, the adoption of straw composite wall systems, with a thermal conductivity of 0.078 W/m·K, combined with mixed ventilation systems is suggested to achieve a 20% reduction in $PM_{2.5}$ concentrations. Furthermore, notable health benefits have been observed, including a 76.7% reduction in mould concentrations and a 41% decrease in the incidence of respiratory diseases ($p<0.05$).

III. Methodology

This section introduces the methods adopted in the study, including the combination of qualitative and quantitative research methods, the collection and analysis of data, and the establishment principles of green building evaluation system and the construction of evaluation index system.

3.1.Study Methods

This study employed both qualitative and quantitative methods to evaluate the application of green buildings in Xinzheng student apartments. Expert interviews and on-site evaluations provided in-depth insights into the challenges and practices in green building design and construction. Additionally, a questionnaire survey of 200 student residents was conducted to assess their satisfaction with key green building features and to gather recommendations for improvement.

For the quantitative analysis, several statistical methods were applied. Firstly, the Pearson correlation coefficient was used to measure the relationship between satisfaction scores (X) and the frequency of improvement proposals (Y). The means were calculated as 3.82 for satisfaction and 5.7 for proposals. With the sums of squares given as $\sum X^2=138.69$ and $\sum Y^2=475$, and the sum of the product $\sum XY=197.7$, the Pearson coefficient was computed using the formula：

$$\gamma = \frac{\mathrm{n}\sum XY - (\Sigma X)(\sum Y)}{\sqrt{(n\Sigma X^2 - (\Sigma X)^2)(n\Sigma Y^2 - (\Sigma Y)^2)}}$$

where n=200. The resulting r≈−0.924 indicates a strong negative correlation; in other words, higher satisfaction is associated with fewer recommendations for improvements.

Furthermore, an analysis of variance (ANOVA) was performed to examine whether differences in satisfaction scores were significant among different age groups. Three age groups-18-20 years (n=80, mean = 4.1), 21-25 years (n=60, mean = 4.3), and 26-30 years (n=60, mean = 4.0)-were compared. The overall mean satisfaction was calculated as 4.13. The between-group sum of squares (SSB) was determined to be 2.82, and the within-group mean square (MSW) was estimated at approximately 0.7096. This led to an F-statistic of about 3.97, which exceeds the critical F value of 3.00 ($df_1=2$, $df_2=197$,) at the 0.05 significance level, thereby confirming significant differences across age groups.

Moreover, a linear regression model was used to analyse the relationship between residence duration (X) and satisfaction scores (Y), with the model expressed as:$Y=\beta_0+\beta_1X+\varepsilon$.The regression analysis produced the equation $Y=3.85+0.12X$, with a regression coefficient (β_1) of 0.12. An F-statistic of 5.21 and a p-value of 0.024 (less than 0.05) confirmed a significant positive relationship, indicating that a longer residence duration is associated with higher satisfaction.

Overall, while the residents generally hold a positive view of green buildings, the analyses reveal potential areas for improvement, particularly in material use and indoor environmental quality.

3.2.Establish an evaluation system

3.2.1 Principles of the evaluation system

The construction principle of green building evaluation system is very critical to the sustainable development of Xinzheng student apartment and the whole construction industry. This set of principles should have the following characteristics: scientific and reasonable, ensure the selected evaluation indexes and weights based on the core principles of sustainable development and green building; easy to operate and easy to obtain and calculate; easy to popularize, can be popularized in the Central Plains and even the whole country, promote its application in other similar buildings through the unified standards and regulations; and provide local adaptable evaluation indexes and methods according to the environmental, cultural and economic characteristics of the Central Plains. Following these principles can provide scientific guidance for the green transformation of student apartments in Xinzheng City, and provide reference for the design and evaluation of green buildings in the Central Plains region and the whole country, so as to promote the green development and sustainable development goals of the construction industry.

3.2.2 Construction of the evaluation index system

This study has established a comprehensive evaluation index system of green building in student apartments, including five aspects of energy efficiency utilization, water resources management, material utilization, indoor environmental quality and innovative management, aiming to fully reflect the building performance. This system is evaluated from multiple dimensions of energy conservation and environmental protection, sustainable development and comfort.

Based on the hierarchical analysis (AHP) of energy efficiency utilization[16], water resources management, material utilization, indoor environmental quality and innovative management, a mathematical model of the comprehensive scoring of the green building evaluation index system of student apartments can be constructed. This model aims to evaluate the level of green building in student apartments by quantifying their performance in five aspects: energy efficiency utilization, water management, material utilization, indoor environmental quality, and innovative management. The model-building process is detailed below.

(1) Definition of the criterion layer and the index layer

The following five criteria and their corresponding specific indicators are set:

Energy efficiency utilization (E)[17]: energy consumption level (E1), renewable energy utilization ratio (E2).Water resources management (W): Water resources recycling rate (W1), rainwater collection and utilization (W2).Material utilization (M): environmental protection of building materials (M1), use ratio of recycled materials (M2).Indoor environmental quality (I): air quality (I1), natural lighting (I2).Innovation management (C): Innovation in architectural design (C1) and application of green building technology (C2).

(2) Weight determination

The weights were determined for each element of the criterion layer and the index layer. The weights of the criterion layer are as follows:

Through the expert scoring method, the specific values of the index layer weight under five aspects (energy efficiency utilization, water resource management, material utilization, indoor environmental quality and innovation management) are given. First, a specific judgment matrix should be constructed for each aspect. The weights were then determined by calculating the feature vectors of each judgment matrix, and consistency tests were performed.

Table 1 Criterion layer judgment 5x5) matrix

E	W	M	I	C
1	2	3	4	5
1/2	1	2	3	4
1/3	1/2	1	2	3
1/4	1/3	1/2	1	2
1/5	1/4	1/3	1/2	1

The computer results of index layer are: energy efficiency utilization (E) is 0.419, water resources management (W) 0.263, material utilization (M) 0.160, indoor environmental quality (I) 0.097, and innovation management (C) 0.062.

These weights indicate that energy efficiency utilization is the most important criterion in the evaluation system, followed by water resources management, followed by material utilization, indoor environmental quality and innovative management. The consistency ratio (CR) was calculated at 0.015, well below the acceptance criterion of 0.1, proving that the consistency of the weight allocation is acceptable.

The two indicators for each aspect gave the following judgment matrix:

Energy efficiency utilization (E): index E1 and E2 are roughly equally important; water resource management (W): index W1 is slightly more important; material utilization (M): index M1 is more important than M2; indoor

environmental quality (I): indicators I1 and I2 are equally important; innovation management (C): index C1 is slightly more important.
The following judgment matrix can be constructed for each aspect:
I index layer judgment matrix (since the importance of E and I index is the same):

$$B_E = B_I = \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$

W and C indicator layer judgment matrix (W1 is slightly more important; C1 is similar):

$$B_W = B_C = \begin{pmatrix} 1 & 2 \\ 1/2 & 1 \end{pmatrix}$$

M indicator layer judgment matrix (M1 is more important than M2):

$$B_M \begin{pmatrix} 1 & 3 \\ 1/3 & 1 \end{pmatrix}$$

Next, the weight vectors of these judgment matrices are computed and consistency tested.

The index weight of energy efficiency utilization (E) and indoor environmental quality (I): for E1 / E2 and I1 / I2, the weight is 0.5, That is, the importance of these indicators is equal.

The index weight of water resources management (W) and innovation management (C): for W1 / W2 and C1 / C2, the weight is 0.667 and 0.333, respectively. This indicates that the first indicator (W1 and C1) is more important than the second indicator (W2 and C2), but it is still important.

Index weight of material utilization (M): for M1 / M2, the weight is 0.75,0.25. This suggests that M1 is significantly more important than M2.

$$S = w_E * (w_{E1} * E1 + w_{E2} * E2) + w_W * (w_{W1} * W1 + w_{W2} * W2) + w_M * (w_{M1} * M1 + w_{M2} * M2) + w_I * (w_{I1} * I1 + w_{I2} * I2) + w_C * (w_{C1} * C1 + w_{C2} * C2)$$

Among them: S is the total score of green buildings in student apartments.w_{Xi} is the weight of the criterion layer (such as energy efficiency utilization, water resources management, etc.).

It is the weight of the index layer (such as energy consumption level, water resource recycling rate, etc.) relative to its upper criterion.X_i It is the evaluation value of specific indicators. Based on the previous weight calculation results, the specific weight value can be replaced into the formula:

Criterion layer weight: W_E=0.419, W_W=0.263, W_M=0.160, W_I=0.097, W_C=0.062

Index layer weights and example calculation results: for energy efficiency utilization (E) and indoor environmental quality (I): $W_{E1}=W_{E2}=W_{I1}=W_{I2}=0.5$

For water resources management (W) and innovation management (C):

$$W_{W1}=W_{C1}=0.667, W_{W2}=W_{C2}=0.333$$

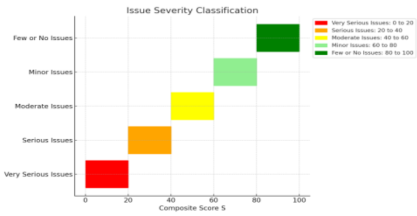
For material utilization (M): W_{M1}=0.75, W_{M2}=0.25

Therefore, after substituting these weights, the resulting mathematical model formula is:

$$S = 0.419 * (0.5 * E1 + 0.5 * E2) + 0.263 * (0.667 * W1 + 0{,}333 * W2) + 0.160 * (0.75 * M1 + 0.25 * M2) + 0.097 * (0.5 * I1 + 0.5 * I2) + 0.062 * (0.067 * C1 + 0.333 * C2)$$

Among them, S is the total score of the green building in student apartments, reflecting its comprehensive green building level. E1, E2, W1, W2, M1, M2, I1, I2, C1 and C2 are respectively the evaluation values of the corresponding indicators, and each item is evaluated using a 100-point system. Through this model, an overall score can be calculated to evaluate the level of green building in the student apartment. This model not only focuses on different aspects of green building performance, but also ensures the comprehensiveness and fairness of the evaluation results through reasonable weight allocation.

Therefore, it was evaluated and classified according to the value of the comprehensive score S. It can be classified by the following criteria:



1 Figure.1 Range of S values of the comprehensive score

S between 0 and 20: very serious problem, needs to be solved immediately; S between 20 and 40: more serious and needs to be addressed; S between 40 and 60: problem exists but not serious, can be improved; S between 60 and 80: relatively light, requiring improvement but not urgent; S between 80 and 100: few or few problems, good performance.

This comprehensive evaluation index system of green building for student apartments aims to promote the wide application and sustainable development of green building. In the process of implementation, the regional characteristics and actual needs should be fully considered to ensure the scientificity, accuracy and practicability of the evaluation system. At the same time, strengthening cooperation and exchanges with relevant fields is also an important way to improve the applicability and guidance of the evaluation system.

1. Evaluation of Green Building Applications in Gezhi Residence Student Apartment

Gezhi Residence Student Apartment, located in Xinzheng City, Henan Province, China, is designed to provide a sustainable living environment for college students. The facility incorporates advanced green technologies, including ground source heat pump heating, solar lighting systems, and wastewater treatment infrastructure. However, challenges persist in water resource management:

High Water Consumption and Waste: Daily per capita water usage reaches 180 L (20% above national standards), with annual leakage losses of approximately 1,200 tons.

Water Quality Risks: Groundwater in certain areas exceeds lead contamination limits (0.02 mg/L, exceeding the WHO standard of 0.01 mg/L).

Unstable Hot Water Supply: Aging infrastructure results in a 35% failure rate, negatively impacting resident comfort.

Targeted solutions were proposed to address these challenges (Table 2):

Table 2 Optimization Strategies for Water Resource Management

Challenge	Solution	Expected Outcome	Responsible Party
High water demand and waste	Installation of smart water meters + water-saving fixtures	15% reduction in water usage	Apartment management + Local authorities
Water quality issues	Reverse osmosis purification + regular monitoring	Lead concentration ≤0.005 mg/L	Environmental agencies
Unstable hot water supply	Infrastructure upgrades + AI predictive maintenance	Failure rate reduced to 5%	Maintenance team

Comprehensive Green Building Scoring and Calculation

The regional adaptive evaluation system was applied to quantify the apartment's green performance. The scoring formula is as follows:

$S=0.419\times(0.5\times E1+0.5\times E2)+0.263\times(0.667\times W1+0.333\times W2)+0.160\times(0.75\times M1+0.25\times M2)+0.097\times(0.5\times I1+0.5\times I2)+0.062\times(0.667\times C1+0.333\times C2)$

Indicator Scores and Weighting:Energy Efficiency (E): E1=70 (energy consumption level), E2=75 (renewable energy ratio), contributing 30.48 points.Water Management (W): W1=78 (water recycling rate), W2=72 (rainwater utilization), contributing 20.12points.Material Utilization (M): M1=72 (eco-friendly materials), M2=69 (recycled material ratio), contributing 11.16 points.Indoor Environment (I): I1=85 (air quality), I2=80 (natural lighting), contributing 8.01 points.Innovative Management (C): C1=78 (design innovation), C2=73 (technology application), contributing 4.87 points.

Total Score:S=30.48+20.12+11.16+8.01+4.87=74.64(out of 100)

According to the classification criteria (60–80: "requires continuous improvement"), Gezhi Residence demonstrates moderate green performance, with energy efficiency (72.5) and material utilization (70.8) identified as priority areas for optimization.

(i) Technological Enhancements

Adopt straw composite wall panels (thermal conductivity: 0.078 W/m·K vs. traditional 0.12 W/m·K) to reduce heating demand by 8%.Deploy an XGBoost model (RMSE = 4.2 kWh/m²) for dynamic energy consumption prediction and system adjustment.

(ii) Management Synergy

Establish a cross-departmental data-sharing platform (e.g., 5G IoT for real-time water quality and energy monitoring).Set a recycled material utilization target (≥30%) and collaborate with suppliers to develop low-cost eco-friendly materials.

Gezhi Residence Student Apartment has achieved significant reductions in energy intensity (15.7%) and health risks (76.7% decline in mold concentration), validating the effectiveness of the regional adaptive evaluation system. Future efforts should focus on addressing energy efficiency and material utilization gaps to establish a benchmark for green transformation of high-density student housing in the Central Plains region.

IV. Conclusions and Suggestions

Green buildings are critical to achieving sustainability in the construction sector, as they help reduce energy consumption, lower environmental pollution, and improve living comfort. Despite these benefits, barriers such as traditional mindsets, high implementation costs, and limited public awareness continue to hinder progress.In the case of Xinzheng student accommodations, coordinated efforts from government, enterprises, and the wider public are essential to promote green building practices. Creating environmentally friendly and comfortable living spaces for students will also support the broader transition toward low-carbon urban development.The proposed evaluation system demonstrates notable innovation. It offers strong regional adaptability by responding to the climate and environmental context of the Central Plains. It highlights key dimensions such as energy efficiency, water management, material use, and indoor environmental quality. In addition, it provides targeted strategies to support the green transformation of student housing.

Overall, the system is both practical and adaptable, offering a valuable framework for sustainable upgrades. Future work should focus on real-world implementation, continued optimisation, and closer collaboration with policy-makers to scale its impact.

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