Investigation on Sustainable analysis of Building System from LCA-Emergy-Carbon emission perspective

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Abstract. Currently, in the context of carbon neutrality, research on the ecological sustainability of building systems holds significant importance. This paper evaluates the sustainability of building systems by integrating the concepts of ecological emergy theory and carbon emissions calculation with systems engineering principles. The results indicate that the operational phase of buildings is the key contributor (accounting for approximately 79.6% of the total emergy and 97.9% of the overall carbon emissions), representing the highest amounts of emergy and carbon emissions within the entire building system. To enhance the ecological sustainability of building systems, the exploration and consideration of renewable energy subsystems have been conducted. This contributes to achieving low-carbon sustainable building practices and helps mitigate global climate issues.

Keywords: Building system; Ecological emergy; Carbon analysis; Sustainable design.

1 Introduction

In the face of global climate change, adopting a low-carbon approach is crucial for mitigating its impacts. As the primary infrastructure of cities, the building system holds significant importance in terms of ecological sustainability and low-carbon practices [1-4]. However, maintaining the ecological sustainability of building systems requires continuous support from resources, energy, and service systems, which inevitably leads to increased carbon emissions [5-6].

2 Method and Case

2.1 Emergy theory

As a methodological approach for evaluating the ecological sustainability of various systems, Emergy theory can be applied to assess multiple types of systems such as agriculture, urban systems, industry, materials, regions, and buildings [7-26]. The

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indicators for emergy assessment include environmental load ratio(ELR), emergy yield ratio(EYR), and emergy sustainability indicator(ESI).

2.2 Carbon emission perspective

In the context of carbon neutrality, low-carbon building design is an imperative. Currently, adopting low-carbon practices has become a national strategy, and the calculation of carbon emissions throughout the entire lifecycle follows national standards[27].

2.3 Case

The architectural case is derived from a commercial complex building consisting of a five-story commercial center and a twelve-story hotel, with a total area exceeding 50,000 square meters(Figure 1). The entire building complex adopts a classical design strategy, with the facade adorned with roof component elements.

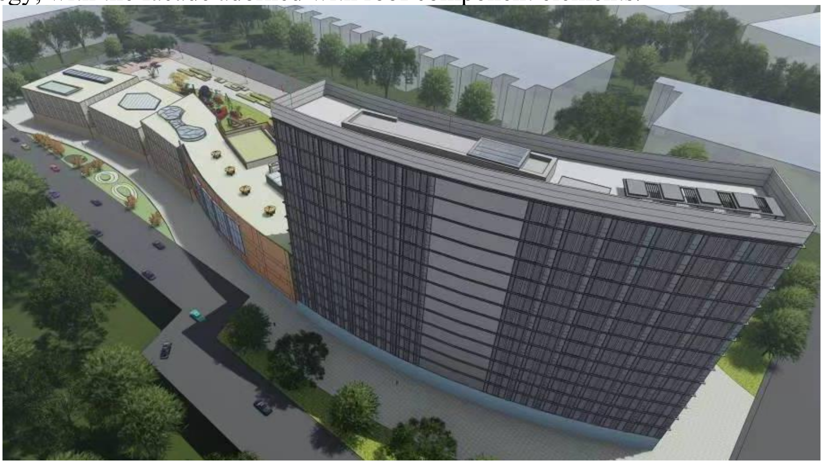

Fig. 1. Study case.

3 Results and discussion

3.1 LCA-Emergy analysis

This paper studied and discussed the entire life cycle of the building, which consists of five stages. Firstly, the largest contribution of emergy comes from the operational phase of the building, as the paper calculated the emergy for a 20-year operational period (6.09E+20sej). The second-largest contributor is the emergy in the building materials stage (8.73E+19sej), followed by the building construction stage (5.55E+19sej), building demolition stage (1.12E+19sej), and building renewal stage (1.42E+18sej) as shown in Figure 2.

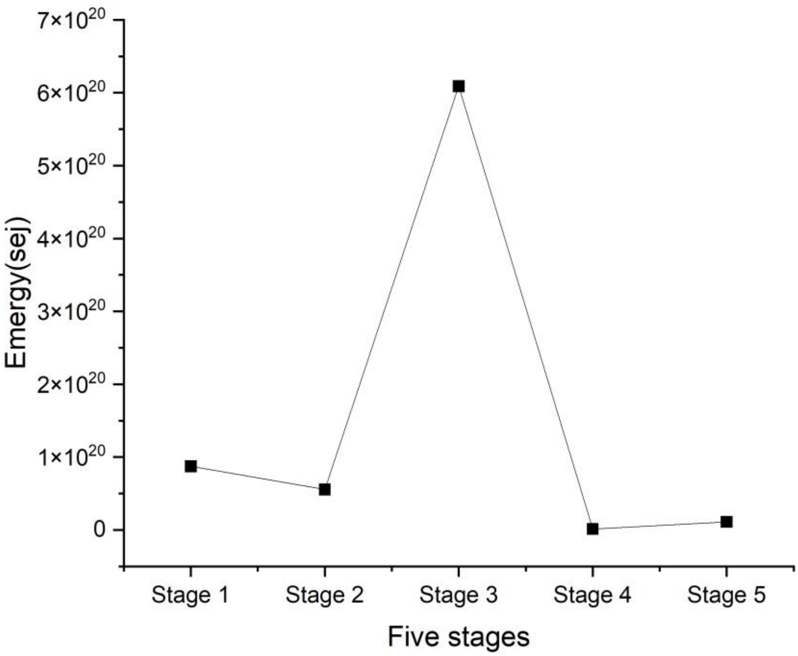

Fig. 2. Comparative analysis

3.2 Indicator analysis

Compared to renewable inputs and emergy feedback inputs, nonrenewable resource inputs play a dominant role. The calculated values for Emergy Yield Ratio (EYR) and Environmental Load Ratio (ELR) are 69.1 and 81.4, respectively. The Emergy Sustainability Indicator (ESI) is then computed and its value is 0.849. According to the sustainability standard (with a threshold of 1), the ESI value approaching 1 indicates that continuous improvement is required for the overall building system to enhance its sustainability level.

3.3 Sensitivity analysis

To ensure the stability and accuracy of the research results, the sensitivity of the sustainable parameters was calculated and analyzed.

Hypothesis: During the operational stage of the building, it is necessary to investigate six subsystems, including environmental inputs, water supply and sewage treatment facilities, heating and cooling systems, electrical installations, telecommunications systems, and elevator systems. The emergy of each subsystem will be varied by 10%, and subsequently, the extent of change in the final sustainability indicator will be examined.

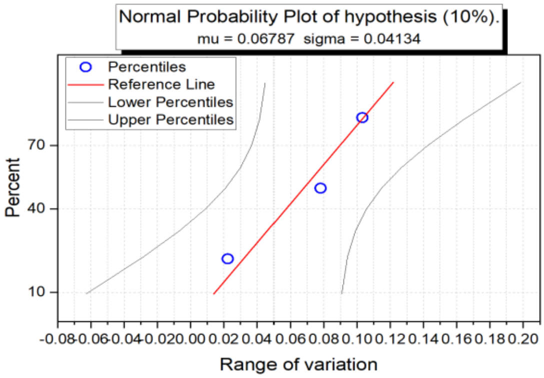

Fig. 3. Uncertainty analysis

Figure 3 presents the sensitivity analysis conducted for hypothesis 1. With a 10% variation, three sustainability indexes exhibit a consistent deviation that closely follows a linear trend, indicating the reliability of the calculated results. Among them, EYR (10.32%) shows a more pronounced difference compared to ELR (7.8%) and ESI (2.24%) under the 10% change scenario.

3.4 LCA- carbon emission analysis

According to the analysis of a 20-year service life, the operational phase has the largest carbon footprint, reaching 1.14E+07tCO2. The next in line is the building material production stage with emissions of 1.02E+05tCO2, followed by the building demolition stage (6.83E+04tCO2), building construction stage (5.87E+04tCO2), and building renewal stage (5.33E+03tCO2). Figure 4 illustrates this trend by comparing the carbon emissions across these five stages. It is worth noting that the operational phase contributes significantly higher carbon emissions compared to the other four phases, accounting for approximately 97.9% of the total emissions.

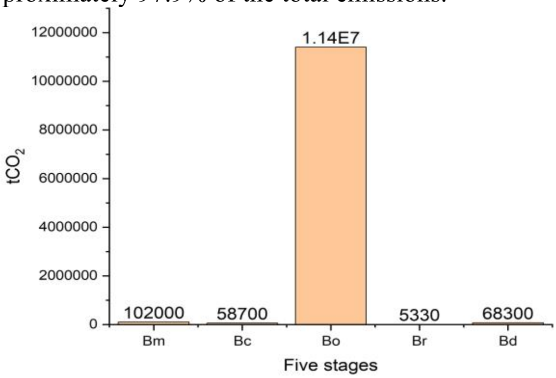

Fig. 4. Carbon emission analysis

4 Comprehensive analysis

From the perspective of life cycle assessment (LCA) based on energy valuation, the operational phase of a building is the primary influencing factor, followed by the production phase of building materials. This is similar to the research findings based on LCA focusing on carbon emissions. It indicates that both the operational phase and the building materials phase are significant factors from an ecological or carbon emissions perspective. Furthermore, the renovation phase of a building, based on LCA for energy valuation and carbon emissions, serves as a complementary factor in validating the consistency of energy valuation and carbon emissions results when considering the entire life cycle of a building system.

However, there is a difference in terms of sustainability assessment. With LCA based on energy valuation, a range of sustainability indicators can demonstrate the sustainability status. On the other hand, LCA based on carbon emissions primarily calculates and analyzes carbon emissions for each phase, without assessing sustainability through indicators.

Currently, there is a lack of academic research combining energy assessment studies with carbon emissions calculations. For instance, a study conducted in Spain focuses on reducing the carbon emissions of building systems from the perspective of energy retrofitting. The analysis reveals obstacles to implementing energy retrofitting, such as economic factors, lack of awareness among building owners, and construction sound insulation. In Romania, researchers extensively discuss transforming inefficient buildings into smart buildings to achieve low-carbon and efficient structures. They contribute to exploring innovative energy-saving systems in buildings by conducting comparative analyses of energy consumption before and after the use of new insulation materials. Analysis of research related to energy and buildings using the Web of Science Core Collection database demonstrates scholars' strong interest and recognition in this field.

To summarize the aforementioned research, a comprehensive analysis can be achieved through the framework of life cycle assessment involving energy valuation and carbon emissions. It considers both ecological sustainability and carbon emissions, enabling more accurate and holistic research on building systems and providing corresponding improvement strategies. However, this study also has limitations, and further research is needed to explore the integration of these two approaches, mechanisms, and models to obtain more precise results on the sustainability of building systems.

5 Conclusions

The aim of this study is to analyze the entire lifecycle of building systems from a sustainability perspective through the calculation and evaluation of emergy and carbon emissions. Lifecycle assessment using emergy value analysis reveals the sustainable state of building systems, with the operational phase being the primary contributor that requires greater attention. It is necessary to refine the indicators of energy value sustainability and verify them from the perspective of unit energy value.

Similar findings are derived from the lifecycle assessment of carbon emissions, where the operational phase of the building system accounts for the highest carbon emissions, consistent with the results of the energy value analysis. However, there are also differences, such as the contradiction observed when introducing new energy subsystems that can reduce the overall sustainability level of the building system while increasing carbon emissions, from an environmental sustainability standpoint.

In conclusion, the lifecycle assessment integrating emergy value and carbon emissions methods is feasible and provides valuable insights for architects and designers. Achieving a higher level of sustainable systems goes beyond reducing carbon emissions in the operational phase alone, necessitating comprehensive considerations. This offers new perspectives for future researchers, indicating that the evaluation of sustainable building systems can go beyond singular approaches based solely on energy or carbon emissions and instead integrate both methods. Further research could focus on exploring long-term sustainability indicators of building systems and utilizing machine learning techniques to predict their trends, enabling comprehensive monitoring and verification of buildings throughout their lifecycle.

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