TOWARDS CARBON NEUTRALITY IN CONSTRUCTION PROJECTS BASED ON LIFE CYCLE ASSESSMENT

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Abstract - The construction industry is among the largest global consumers of natural resources and contributors to greenhouse gas emissions. This paper aims to evaluate current environmental standards and propose a new framework for reducing greenhouse gas emissions, targeting carbon neutrality in construction projects. The study employs the Life Cycle Assessment (LCA) methodology to assess the environmental impacts of civil buildings throughout their lifecycle, including material production, construction, operation, and disposal. Data were obtained from the IMPRO-Building project, which analyzed 72 building samples across three distinct climate zones in Europe. The findings indicate that high-rise buildings demonstrate greater energy efficiency compared to single-storey and multi-storey structures. Furthermore, climatic conditions significantly influence energy consumption, with cold climates exhibiting higher energy demands. The study recommends adopting LCA-based standards to mitigate environmental impacts, thereby promoting the sustainable development of the construction industry.

Key words - Carbon neutrality; Life cycle analysis; Residential buildings; Greenhouse gas emission potential; Primary energy consumption

1. Introduction

The construction industry is one of the largest resource-consuming sectors and a major contributor to global greenhouse gas emissions. While it accounts for approximately 23% of global energy consumption 17% from residential buildings and 6% from service buildings - the direct and indirect CO2 emissions associated with energy use and operational activities in this sector have reached approximately 0.4 Gt CO2, representing 38% of total global emissions. Additionally, the production of building materials contributes about 11% of global greenhouse gas emissions [1]. Given the escalating climate crisis, reducing emissions and improving resource efficiency within the construction sector has become imperative. The transition toward carbon-neutral buildings is not only an inevitable necessity but also a crucial long-term strategy for ensuring the sustainable development of the global environment.

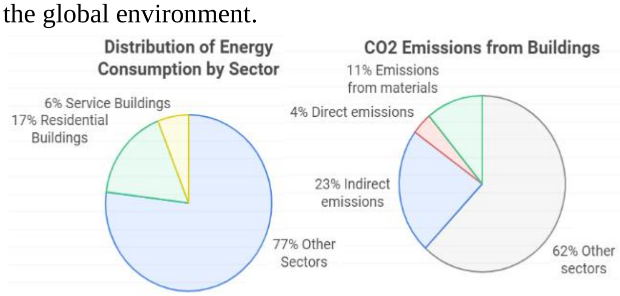

Figure 1. *Energy consumption and emissions of buildings*

Currently, standards such as LOTUS (Vietnam), LEED (USA), HQE (France), and BREEAM (UK) offer frameworks for assessing and enhancing the energy performance of buildings. However, these systems primarily focus on the operational phase, while the environmental impacts associated with the full life cycle of building materials and structures remain insufficiently addressed. This highlights the urgent need for the development of new environmental standards that encompass the entire life cycle of buildings - from resource extraction, production, and construction, to operation and disposal.

In Vietnam, nearly 500 buildings and structures, covering a total area of approximately 11.5 million m², have attained green certifications, with EDGE accounting for 44% of the projects, LEED for 37%, and Green Mark for 11%. Each certification type entails varying levels of criteria and requirements. Depending on the function and scale of the project, costs can increase by 1-3%, and in some cases, by 5-6%, when adhering to higher-level LEED criteria. The application of standards that are tailored to specific climate conditions and construction methods contributes to cost reduction and facilitates progress toward carbon neutrality [2].

This paper aims to evaluate existing environmental standards in the construction industry and propose new indicators to guide buildings toward carbon neutrality. The research focuses on developing a standard system based on the Life Cycle Assessment (LCA) method [3], with the goal of minimizing the environmental impact of buildings. By employing the LCA method, the study identifies key environmental indicators and establishes standards that are applicable to the construction industry in the long term, ensuring sustainable development and reducing ecological footprints.

This study contributes to the development of a new framework for assessing the environmental performance of buildings, with the ultimate goal of achieving carbon neutrality. Specifically, the paper proposes the application of tailored standards to various building types, ranging from single-family homes to high-rise structures. These indicators are derived from data collected through the IMPRO-Building project and include a comparative analysis across different climatic zones in Europe. The study offers recommendations for the establishment of environmental standards in sustainable design and construction, aiming to reduce the environmental impact of the construction industry.

2. Data and Research Methodology

This study employs the Life Cycle Assessment (LCA) method to comprehensively evaluate the environmental impacts of civil buildings across their entire life cycle, from raw material production and construction to usage and end-of-life disposal. LCA serves as a tool to quantify these environmental impacts, facilitating the development of environmental standards aimed at achieving carbon neutrality in construction projects.

The scope of the LCA in this study focuses on the structural systems of buildings, including construction materials such as concrete, steel, and wood. The life cycle of a building is divided into distinct stages: material production (A1-A3), construction, operation (B1-B5), and decommissioning (C1-C4). The application of the LCA method enables a clearer identification of the factors that have the most significant impact on greenhouse gas emissions and energy consumption in civil buildings (Figure 2).

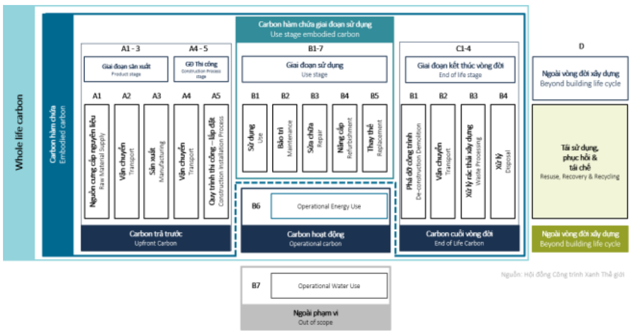

Figure 2. *Stages in the life cycle of a building*

The data for this study were sourced from the IMPRO-Building project [4], a European research initiative aimed at exploring the environmental improvement potential of residential buildings within the EU-25. The project's database comprises 72 residential building samples, including 31 single-family houses (SI), 32 multi-family buildings (MF), and 9 high-rise buildings (HR). These samples are categorized into three primary European climatic zones: Z1 (Southern European countries), Z2 (Central European countries), and Z3 (Nordic European countries).

Table 1. *Number of projects and types of projects*

Zone	Single family home		Multi-storey house		High-rise building	
	existing	new	existing	new	existing	new
Z1	8	3	8	3	2	1
Z2	8	3	8	3	2	1
Z3	7	2	8	2	2	1
Total	**31**		**32**		**9**	

The collected data includes key metrics such as Global Warming Potential (GWP), which measures the potential greenhouse gas emissions over the life cycle of a building (in kg CO_2 equivalent), and Primary Energy (PE), which refers to the total energy consumed. PE is further divided into two categories: embodied impacts (material impacts) and operational impacts. These data are normalized by building area (in m² per year) to enable meaningful comparisons across different building types and climate zones.

The analytical approach primarily employs descriptive statistics and comparative analysis to establish standard environmental indicators for various building types. Specifically, mean values, variances, and standard deviations are calculated for each building group (single-family, multi-family, and high-rise) across the three climate zones.

3. Results and discussion

This study analyzes three main building types: single-family houses, multi-family buildings, and high-rise buildings. The analysis results are presented based on two key criteria: Global Warming Potential (GWP) and Primary Energy consumption (PE), both calculated over the entire life cycle of the buildings. These results are provided for the three corresponding climatic zones: Z1 (Southern European countries), Z2 (Central European countries), and Z3 (Nordic European countries).

Table 2. *GWP and PE calculation results for area Z1*

Generic	Index	Medium	Standard
Single family home	GWP	9.87	9.32
	PE	162.12	154
Multi-storey house	GWP	8.62	8.06
	PE	124.58	112.45
High-rise building	GWP	7.51	6.21
	PE	100.86	82.25

Table 3. *GWP and PE calculation results for area Z2*

Generic	Index	Medium	Standard
Single family home	GWP	6.77	7.4
	PE	134.65	131.83
Multi-storey house	GWP	7.28	7.26
	PE	112.53	105.25
High-rise building	GWP	6.17	6.57
	PE	83.86	88.89

Table 4. *GWP and PE calculation results for area Z3*

Generic	Index	Medium	Standard
Single family home	GWP	9.17	8.94
	PE	180	133.89
Multi-storey house	GWP	7.69	8.07
	PE	124.82	116.86
High-rise building	GWP	6.17	6.57
	PE	84.36	88.91

The analysis results reveal significant variations in environmental impacts across the three building types. Single-family homes exhibit the highest average GWP and PE values, primarily due to their larger area and higher resource demands. Factors such as low building density and large surface-to-volume ratios contribute to substantial energy consumption, particularly for heating and operational needs. Multi-family buildings, while demonstrating lower GWP values compared to single-family homes, still exhibit higher environmental impacts than high-rise buildings. This reflects an intermediate level of resource use and operational energy consumption per unit area. Notably, high-rise buildings display superior resource efficiency, with the lowest GWP and PE values. This efficiency is largely attributed to optimized space utilization and shared resources between units, which significantly reduces energy consumption and greenhouse gas emissions per unit area. These findings provide a critical foundation for evaluating and selecting sustainable construction solutions in the context of growing urbanization.

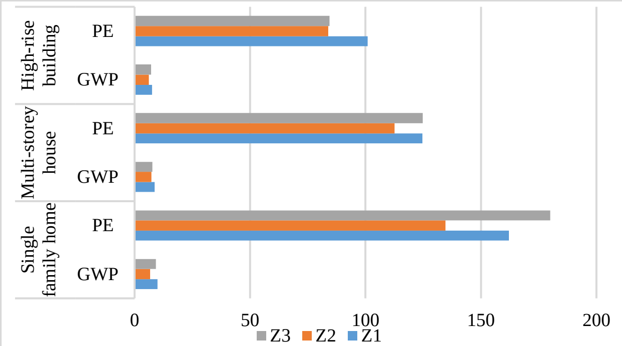

Figure 3. *Correlation between PE and GWP index*

The study results indicate that climatic conditions play a critical role in determining the energy efficiency of buildings. Notably, buildings located in the cold climate zone (Z3) exhibit significantly higher PE values compared to those in other zones, primarily due to increased energy demands for heating during colder seasons. While existing standards, such as LEED [5] and LOTUS [6], predominantly assess energy consumption during the operational phase of a building, this study adopts a more comprehensive approach by applying Life Cycle Assessment (LCA). This method evaluates the entire life cycle of a building, including stages such as material production and post-life disposal.

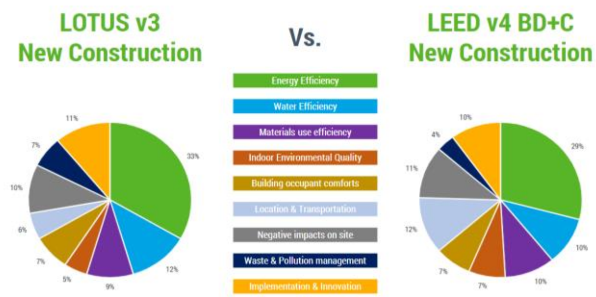

Figure 4. *Comparison of LOTUS and LEED standards [7]*

Systems such as LEED and LOTUS often overlook the environmental impact of building materials and fail to account for factors such as energy consumption during the production and transportation of these materials, despite the fact that these stages can significantly contribute to a building's overall greenhouse gas emissions. The findings of this study highlight the importance of assessing non-operational factors, including material production and end-of-life disposal, as essential components for achieving comprehensive carbon neutrality goals.

The carbon neutrality of buildings is influenced not only by construction materials but also by several key factors, including climate zone, building type, and operational energy use.

Climatic zones: In colder climates, such as Z3 (Northern Europe), energy demand for heating is significantly higher, resulting in elevated Primary Energy (PE) values. This necessitates the implementation of more stringent energy efficiency measures in design and energy management, such as enhanced insulation and the integration of renewable energy sources.

Building type: Different building types exhibit varying environmental impacts. Single-family homes typically have higher GWP and PE values compared to multi-story and high-rise buildings due to their lower density and larger footprint. In contrast, high-rise buildings benefit from shared resources and infrastructure across multiple floors, enhancing their potential for carbon neutrality.

Operational energy use: Buildings designed with energy-saving features, such as natural ventilation, solar energy systems, or smart energy management technologies, are more likely to achieve carbon neutrality through reduced operational energy consumption.

4. Conclusion

This study utilized a Life Cycle Assessment (LCA) approach to evaluate the environmental impact of carbon-neutral buildings. The findings indicate that high-rise buildings have the potential to utilize resources more efficiently than single-family and multi-storey buildings, particularly in the context of increasing urbanization. Additionally, climatic conditions play a critical role in determining energy consumption, with cold climates exhibiting significantly higher energy demands. Consequently, the development of sustainable construction standards must encompass the entire life cycle of a building - from raw material extraction to end-of-life disposal - rather than focusing solely on the operational phase, as many current rating systems do.

Selecting appropriate assessment criteria not only helps reduce costs but also contributes to broader sustainable development goals. In the context of Vietnam, the application of the LOTUS assessment criteria may be considered as a viable option.

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