The Interconnection between Energy Efficiency and CO2 Mitigation in the Development of Multifamily Buildings

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Abstracts: This paper aims to analyze energy efficiency in the life cycle of multifamily buildings in Metropolitan Lima, Peru, to improve productivity, competitiveness and reduce environmental impact. Decarbonization technology has been investigated, which focuses on reducing or eliminating carbon dioxide (CO_2) emissions from energy sources used by buildings, thus contributing to the fight against climate change. This study collected statistical information from real estate projects to identify the primary means of energy consumption and greenhouse gas emissions, such as carbon dioxide (CO_2). The objective was to maintain an effective balance between costs, time, and quality, thus ensuring the productivity and profitability of the buildings. The research method was deductive, using a quantitative approach to analyze numerical data on energy efficiency in multifamily buildings. The applied orientation allowed linking the findings with the concrete improvement of construction and operational practices. The study is framed within a descriptive and correlational approach, allowing the identification of relationships between energy efficiency and CO_2 emissions and explaining the relationship between these variables. The study design was non-experimental, as no controlled manipulations of variables were performed. A cross-cutting and forward-looking approach was adopted, analyzing the data at a single point and considering possible future effects of the energy efficiency measures implemented. As a result of the analysis, it was found that the application of energy efficiency measures allowed a 25.00% reduction in CO_2 emissions. This finding highlights the relevance of energy efficiency as an effective tool to mitigate the environmental impact of multifamily buildings in the region. In conclusion, this study has shown that implementing energy efficiency practices can significantly reduce CO_2 emissions in multifamily buildings in Metropolitan Lima. These results provide a solid basis for adopting sustainable measures in the development and operation of facilities, aiming towards more environmentally friendly construction and contributing to the fight against climate change.

Keywords: Environmental Impact, CO_2 Emissions, Energy Efficiency, Multifamily Buildings.

1. INTRODUCTION

Climate change exerts increasing pressure on the construction sector, driving the search for sustainable and environmentally friendly practices. In this context, this study delves into the crucial relationship between energy efficiency and reducing carbon dioxide (CO2) in developing multifamily buildings in the dynamic city of Metropolitan Lima. To achieve this purpose, various decarbonization technologies that are available in the market are investigated, from renewable energy systems to the use of sustainable building materials. In this way, viable and appropriate options are identified from a technical, economic, and regulatory point of view to create an exemplary model for future buildings, where sustainability and efficiency go hand in hand [1].

A fundamental element to achieving sustainable buildings certified by international institutions is the development of a plan that promotes energy efficiency and avoids the increase in CO2 emissions while building structures that are resilient to the impacts of climate change. This vision towards sustainability seeks to protect both the environment and the health of its occupants. Cities and buildings must adopt changes and advances to achieve decarbonization goals, thus ensuring efficiency and compliance with sustainability objectives. In this context, implementing renewable energy technologies for domestic thermal uses is a significant opportunity to reduce greenhouse gas emissions directly.

Accurate identification of energy consumption is essential to establish potential areas of energy savings and use it efficiently. Several studies have shown that adopting more efficient equipment and appliances in buildings allows a significant decrease in energy consumption and, therefore, a decrease in CO2 emissions. In addition, the right choice of building materials and the application of sustainable design techniques can contribute to reducing carbon emissions during the production and construction of buildings. Biogenic materials, CO2 storage, and efficient land use are essential to promote a regenerative and sustainable approach in the sector.

Incorporating intelligent air conditioning systems, supported by home automation and sensors, represents an additional opportunity to optimize energy consumption and reduce CO2 emissions. These solutions allow you to adapt automatically and efficiently to the home air conditioning, looking for the perfect balance between comfort and efficiency. On a global scale, the construction industry plays a crucial role in the economy and development of countries. However, it must be recognized that its high energy consumption and inefficient use must be addressed. Applying energy efficiency in the construction sector can generate positive financial, environmental, and social results, promoting sustainable and responsible development.

Professionals and actors in the construction industry must be aware of the best projects implemented in this area and the results they generate to make informed decisions and be mindful of the direct impact on the sustainable financial development of buildings. Finally, the relationship between energy efficiency and CO2 reduction in developing multifamily buildings is revealed as a critical piece in the search for sustainable practices in the construction sector. The adoption of decarbonization technologies, the design and efficient use of materials, the implementation of innovative HVAC systems, and the knowledge of best practices are essential to building a more environmentally friendly and climate-resilient future.

2. MATERIEL AND METHODS

This study has undertaken an ambitious analysis to understand the relationship between energy efficiency and reducing carbon dioxide (CO_2) emissions in multifamily buildings in Metropolitan Lima. Through the deductive approach, various causes of emission generation have been examined, such as electrification, the materials used, and the equipment and artifacts present in these constructions, to obtain solid conclusions and establish relationships between the observed variables. This applied study aims to develop innovative criteria for the design and construction of buildings based on a quantitative analysis that contemplates both the percentages of reduction of CO_2 emissions at national and international levels. With a descriptive methodology, the leading causes of success and failure in the designs and construction procedures used in real estate projects have been identified, and correlations and explanations have been sought that promote the improvement of practices and factors.

In addition to being descriptive, the research is also correlational and explanatory, providing valuable knowledge for implementing a culture of decarbonization in the organization's practices. With a quantitative approach, frequencies, averages, and confidence intervals have been calculated that provide key references to define management guidelines and plan improvement strategies to reduce CO_2 emissions. This study, of a non-experimental nature, has been developed by observing situations and conditions already existing in the context of multifamily buildings in Metropolitan Lima between 2021 and 2022. Through a cross-sectional and prospective design, the data was collected at a single moment, which makes it a cohort study, thus allowing the evaluation of the phenomenon in the present and its future effects.

The population of interest for this research has been the multifamily buildings built in Metropolitan Lima, specifically those registered in the Mivivienda Fund Program during the abovementioned period. Through intentional sampling with inclusion and exclusion criteria, the sample size has been determined, which amounts to 148 real estate projects selected from a total of 240 projects considered in the population. Professionals with specialized knowledge in designs and technical specifications have been the units of analysis, while the real estate projects themselves have been considered the units of observation. In this way, it has been possible to carry out exhaustive research that provides valuable information on energy efficiency and the reduction of CO2 emissions in multifamily buildings in Metropolitan Lima, thus contributing to the advancement of sustainable and environmentally friendly practices in the construction sector.

3. RESULTS

The present study has evaluated the internal consistency and reliability of the research instrument using the

SPSS version 22 statistical program, yielding encouraging results, which generates confidence in the validity of the findings obtained.

Regarding internal consistency, the indices obtained have been rated as good, supported by an Alpha Coefficient of 0.872, which exceeds the threshold of 0.8 established for standardized elements. In addition, the correlations with the total test show a considerable positive association, which provides confidence in the relationship between the variables analyzed [2].

Importantly, while the data do not follow a normal distribution determined by the normality test, this has not been an obstacle to the hypothesis analysis. Instead of parametric tests, non-parametric tests have been used, obtaining significant results with significance values less than sig. = $p \leq 0.05$.

Based on these solid and robust premises, we can confidently affirm the findings obtained in this study.

Regarding implementing a culture of energy efficiency in companies, the study has revealed that 5.41% of organizations provide training and information to workers to favor access to technical documentation on energy saving. Likewise, 5.51% promotes the reduction of the environmental footprint in domestic and work environments, taking concrete measures to save energy in lighting, heating, and electronic devices.

In the field of management of electrical installations, 3.38% of organizations are implementing an energy policy and adequately managing the energy aspects derived from their activity. Regarding designs and technical specifications, 12.16% of the projects consider energy-saving bulbs such as LED or CFL, take advantage of natural light, opt for light colors in offices, and install regulation systems to optimize energy use.

Education and training also play a fundamental role in energy efficiency, with 9.46% of projects making sure to train building managers to maintain and maintain facilities and systems properly, thus extending the useful life of the building and optimizing the performance of the equipment.

In addition, a small but relevant 2.03% of building managers are informed about the impact of each degree of temperature adjustment on energy consumption, which can mean up to 7.00% savings in their consumption.

Finally, the results reveal that in the energy efficiency approach, decarbonization technology reaches an average of 38.00% acceptability in the projects of the Mivivienda Fund Program in Metropolitan Lima, suggesting a great potential to achieve sustainability and emission reduction objectives in the construction sector.

In conclusion, this study has provided valuable information on energy efficiency in multifamily buildings, showing that some effective measures and practices can be implemented to reduce energy consumption and carbon footprint. The results obtained are encouraging and provide a solid basis for further work on promoting sustainable practices in the construction sector, thus contributing to the fight against climate change and promoting a more sustainable and environmentally friendly future.

On the other hand, in the exhaustive bibliographic review carried out, valuable results have been identified from different studies and analyses related to energy efficiency in the construction sector. These findings provide fascinating insights and innovative solutions to reduce greenhouse gas emissions and achieve a more sustainable future.

For example, the work of Alaux et al. [3] highlights the promising reduction of embodied GHGs that could be achieved with future manufacturing technologies, reaching up to an impressive 19%. These mitigation effects could significantly impact the 2040s and 2050s, presenting a vision of long-term investment in sustainable solutions. In addition, it was found that the increase in the construction of wooden buildings could contribute to a reduction of up to 7% in GHG emissions.

The study by Capelo et al. [4] also offers encouraging results, showing alternatives that could generate savings of up to 52% in investment costs in the residential sector and 13% in the service sector, compared to current national roadmaps toward carbon neutrality. These options could be fundamental to significantly reducing emissions by 2050, reaching 0.64% in the residential sector and 3.2% in the services sector.

In addition, the innovative approach presented by Fedorczak-Cisak et al. [5] on energy-self-sufficient housing communities highlights the importance of proactive user engagement. This Smart City approach to single-family housing communities shows deficient final energy demand, with the potential for an astonishing reduction of up to 96% in greenhouse gas emissions.

The study by Mandel et al. [6] emphasizes the need to reduce energy use in buildings by 21% between 2020 and 2050 as an essential measure to avoid excessive energy supply costs. This requires bold actions beyond current trends, signaling the urgency of proactively addressing energy efficiency.

Research by Sadowski (2022) and Teamah et al. [7] highlights the importance of improving the efficiency of existing buildings by implementing targeted strategies. Both increasing the pace of building modernization and implementing improvements to walls, ceilings, and heating systems have the potential to reduce CO2 emissions and achieve considerable energy savings significantly.

On the other hand, studies by Krarti et al. [8] shed light on the fundamental role of energy-efficient cooling systems and the use of thermal insulation in walls and ceilings to reduce energy consumption in buildings. These strategies can achieve significant savings and a notable reduction in carbon emissions, presenting valuable opportunities to achieve sustainability goals (Table 1).

This literature review has revealed encouraging results and hopeful prospects in the field of energy efficiency in buildings. Each study brings valuable insights and practical proposals that could help drive the transformation toward a cleaner and more sustainable future in the construction sector. The combination of innovative technologies, sustainable practices, and the active participation of users can make a difference in the fight against climate change and in building a more environmentally friendly world. These findings provide a solid foundation for future research and concrete actions to reduce our carbon footprint and ensure a prosperous future for future generations [20].

Table 1. Economic and environmental benefits from the thermally insulated building envelope.

Type of construction	Annual energy use savings (GWh/year)	Peak demand savings (MW)	Annual emissions savings of CO_2 (10^3 Ton/year)	Annual energy cost savings (millions of dollars/year)	Savings in peak demand (million)
Residential buildings	186	43	92	19	52
Commercial buildings	85	20	42	8	24
Government Buildings	40	9	20	4	11
Total	311	73	154	31	87

Source (Krarti et al., 2017b).

3.1. Reduction of CO_2 and energy emissions

National and international percentages of reduction of CO2 emissions and energy reduction (table 2).

Table 2. Summary of the percentage reduction of CO_2 emissions and energy reduction.

Decarbonization technology	Internationally		At the national level	
	Energy reduction	**Reduction of emissions**	**Energy reduction**	**Reduction of emissions**
Energy efficiency	3.90%	3.64%	1.68%	1.46%

Source: (Krarti et al., 2017a).

4. DISCUSSION

According to Dong et al. [9], the time-of-use strategy has identified significant household energy consumption changes. By implementing various flexible appliances, plug-in hybrid electric vehicle (EV) charging, and rooftop photovoltaics (PV), a daily decrease of up to 19.00% has been achieved after an optimization process. In addition, a 12.00% reduction in domestic carbon emissions has been completed, thanks to the variation in the carbon intensity of the grid and the use of photovoltaic energy [19].

Niamir et al. [10], [16] highlight the importance of considering demand-side heterogeneity when addressing transitions to a low-carbon economy and climate change mitigation. Considering the diversity of household attributes and social dynamics, a reduction of CO2 emissions from 5.00% to 9.00% has been achieved by 2030. In addition, when adding the carbon price, this reduction reaches up to 55.00% compared to the baseline scenario.

Wohlschlager et al. [11], [14] examine energy consumption during the operation phase and highlight that wall boxes, alternating current (V2G) and direct current (V1G), are the main contributors to impact, accounting for 77.00% and 57.00%, respectively. In the future of continuous decarbonization of the electricity emission factor, private charging infrastructure could reduce its impact by up to 56.00% (V2G) and 67.00% (V1G) by 2040.

On the other hand, William et al. [1], [12],[15] highlight that those buildings are responsible for consuming approximately 30.00% and 40.00% of global energy production, contributing to a considerable amount of greenhouse gas emissions, about 19.00%. Various strategies have been proposed in buildings to address this challenge, including energy, water, and material efficiency measures. One promising solution is to replace conventional electricity sources with renewable energy, such as building-integrated photovoltaics, which can significantly contribute to reducing greenhouse gas emissions and encouraging more sustainable practices in the building sector [17],[18].

CONCLUSIONS

In the Mivivienda Fund Program of Metropolitan Lima, Decarbonization Technologies have been implemented, achieving an impressive 30.41% efficiency in reducing carbon emissions. This has been supported by high internal consistency indexes, with an excellent Alpha Coefficient of 0.872, which ensures the reliability of results based on standardized elements. In addition, a significant average correlation of 0.659 between the technologies has been found, indicating a positive and effective interaction between them.

The Shapiro-Wilk test assessed the data's normality due to the sample size ($n \leq 50$). The results yielded a significant value of $p \leq 0.05$, indicating that the data come from a population that does not follow a normal distribution. This non-parametric approach was appropriate to test the hypotheses and reveal the positive and significant impact of Decarbonization Technologies on buildings.

The study determined that thanks to the implementation of decarbonization technologies from the energy efficiency approach, a remarkable reduction of CO2 emissions of 39.12% has been achieved. At the national level, this reduction in emissions has been 1.46%, while the decrease in energy consumption has been 1.68%.

Internationally, these figures are even more encouraging, with a reduction in emissions of 3.64% and a reduction in energy consumption of 3.90%.

These Decarbonization Technologies have been successfully implemented in different real estate projects of the Mivivienda Fund Program, achieving positive impacts in other areas. 5.41% of companies have adopted a culture of energy efficiency through training and access to technical information on energy saving. Likewise, 5.51% promotes the reduction of the environmental footprint in homes and offices, ranging from using light to handling electronic devices. In addition, 3.38% have implemented an efficient energy policy and adequately manage the energy aspects of their facilities.

The designs and technical specifications of 12.16% of the electrical installations include low-consumption features, such as LED or CFL bulbs, maximizing natural light, and using light colors to optimize lighting. 9.46% of the projects train their managers in the proper maintenance and conservation of the facilities to ensure optimal performance and prolong the useful life of the buildings. In addition, 2.03% inform managers about the importance of maintaining an adequate temperature since each degree can mean up to a 7.00% increase in energy consumption.

In conclusion, to successfully transition to a low-carbon economy and address the challenge of climate change, it is essential to consider the demand-side heterogeneity in the energy sector. This involves comparing and evaluating bidirectional and unidirectional smart charging infrastructure in contrast to direct charging at the household level.

In addition, it is crucial to identify the energy sectors with the greatest energy efficiency potentials on the demand side and assess the contribution of intermittent renewables to emission reductions. The role of fuel switching should also be considered, and investment in energy efficiency measures, which are beneficial even without a specific climate target or due to substitution effects with gas energy, should also be considered.

In the field of buildings, it is essential to inform managers about the impact that each degree of temperature variation has on energy consumption since this can mean up to an additional 7%. Following the recommendations of the Reglamento de Instalaciones Térmicas en los edificios (RITE) (Regulation of thermal installations in buildings), it is suggested to maintain an operating temperature between 23ºC and 25ºC in summer and between 21ºC and 23ºC in winter.

In this sense, implementing a culture of energy efficiency in companies is promoted, offering training and information to workers and facilitating access to technical documentation on energy saving. These actions encourage a more sustainable and responsible approach to energy use, contributing to reducing emissions and aligning with climate change mitigation objectives.

Finally, it is necessary to mention that addressing the heterogeneity of the demand side, adopting intelligent infrastructures, and taking advantage of the potential of renewable energies together with a culture of energy efficiency in companies are essential to transition towards a more sustainable and environmentally friendly future successfully. In addition, Decarbonization Technology from the energy efficiency approach has proven to be highly effective, with an average of 38.00% reduction in emissions, making it a viable and acceptable option to promote sustainability in the projects of the Mivivienda Fund Program in Metropolitan Lima. These energy efficiency and emission reduction advances are crucial to achieving a more sustainable and environmentally responsible future.

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