Enhancing Sustainability in Educational Buildings through Retrofitting:

Case Study of a School in Mira Bhayandar, Maharashtra

Sub theme: **Goal 7-Affordable and Clean Energy**

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Date of Submission: 16-11-2024 Date of Acceptance: 16-11-2024

Abstract

India's rapid urbanization has led to increased greenhouse gas emissions, particularly from buildings, which account for 37% of the nation's energy consumption. In Mira Bhayandar, this project focuses on retrofitting three selected schools to enhance sustainability and resilience, targeting a minimum 20% improvement in energy and water efficiency. These schools were chosen based on factors such as structural stability, student population, building orientation, and their potential to serve as emergency shelters during crises. Heat reduction measures include applying solar reflective index (SRI) paint on the roof to reduce solar heat gain, complemented by passive cooling strategies that naturally lower indoor temperatures. Energy efficiency is aimed to be improved through the installation of LED lighting and BLDC fans, while water conservation measures include installation of dual flush cisterns and aerators. The project involves key stakeholder's local government, community members, and students, who will engage in capacity-building initiatives to understand the benefits of green retrofitting. Educational workshops on energy conservation and climate awareness will empower students to adopt sustainable practices. The interventions will be evaluated using the EDGE certification framework to ensure compliance with global green standards. A financial feasibility analysis will assess the payback period for these upgrades. This case study aims to serve as a replicable model for sustainable retrofitting across India's educational institutions, contributing to low carbon development and community resilience.

Keywords

EDGE certification; Energy efficiency; Greenhouse gas emissions; Green Retrofitting; Sustainability; Water efficiency

1. Introduction

As awareness of environmental challenges continues to expand, the necessity for the adoption of sustainable practices has become increasingly apparent in all aspects of life. One of the most significant challenges is the overreliance on fossil fuels, which not only contributes to global warming but also intensifies the problem of energy shortages (Zhao et al., 2015). To facilitate the practice of sustainability and engagement with habitats, it is imperative that educational systems undergo a process of reform (Ferrer-Balas et al., 2010). The existing built environment presents a significant challenge in addressing energy efficiency and sustainability goals. In recent years, there has been a notable increase in the emphasis on sustainability, which has also affected institutional buildings. Schools are at the vanguard of this movement, serving as both educational hubs and community role models for sustainability.

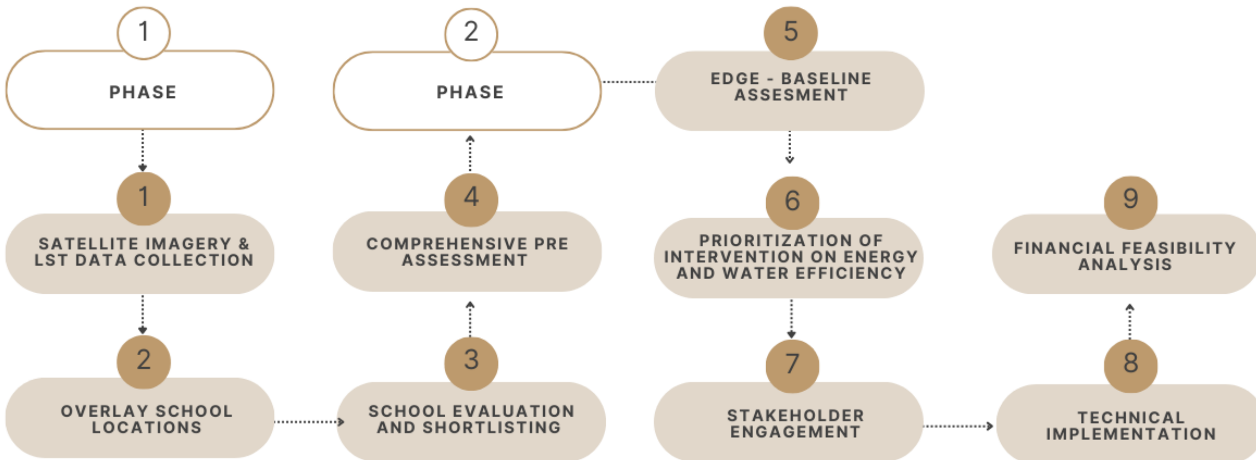
Retrofitting is the practice of adding modern elements, materials, and technologies to existing buildings to increase the building's performance in terms of energy and water efficiency (Wan et al., 2022). Retrofitting of existing educational buildings presents a feasible solution to promote sustainability, reduce energy consumption, and create healthier learning environments for learning. Educational institutions can use retrofitting to turn existing buildings into models of environmental sustainability and energy efficiency in order to meet sustainability goals and lower their carbon footprints (Javid et al., 2019).

Existing research has explored various technologies for improving energy efficiency in building retrofits, such as solar water heating systems (Liu et al., 2021) and envelope improvements (Hong et al., 2019). However, there remains a significant gap in understanding the combined impact of implementing multiple energy and water-saving technologies simultaneously. Most studies have focused on individual technologies in isolation, overlooking the potential for cumulative benefits from a more integrated approach. (Madushika et al., 2023). While numerous energy retrofit technologies are available, there is limited empirical data on their long-term performance and cost-effectiveness, particularly when integrated into diverse climatic conditions. (Madushika et al., 2023) (Shaikh et al., 2017) (Zhao & Mo, 2023) (Hong et al., 2019). Existing literature highlights the potential of building retrofitting to reduce energy consumption and improve resilience, but the specific challenges and optimal strategies for achieving these benefits remain underexplored. Attaining sustainability in the built environment requires a comprehensive approach to building retrofits. Frameworks like EDGE have been successfully applied to evaluate green retrofitting projects in diverse settings (Isimbi & Park, 2022). However, there is a lack of case studies focusing on Indian schools, particularly in urban context. This research aims to bridge that gap, providing a replicable model for sustainable retrofitting in educational institutions.

In a city like Mira-Bhayandar, where development is happening at a rate which is uncomprehensible, it is essential we look at solutions which provide with the most sustainable solution for existing buildings. Given that the buildings in Mira-Bhayandar are already being built at a rapid rate, its essential for architects to look for solutions which are more sustainable than resorting to demolition of the buildings. Green retrofitting in existing buildings becomes a solution with least timeconsuming process and least waste generated and a process which is both sustainable in terms of finance and materials in the longer run.

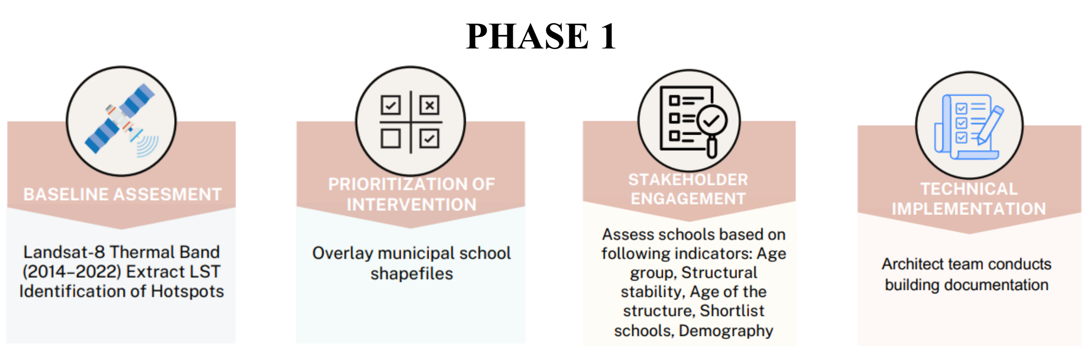
2. Methodology

Figure 1: Methodology for implementing green retrofitting solutions



We have used a structured and phased methodology to identify the green retrofitting solutions for the schools in Mira Bhayandar. The methodology is divided in two phases. Phase 1 is about the selection of schools in Mira Bhayandar based on the scientific approach. After selecting the school, a team was formed to carry out the energy and water audit. In phase 2, data collection, selection of green retrofitting measures and assessing their financial viability was the next step. For demonstration purposes, the demolition of existing schools was considered an unsustainable approach. Instead, the strategy was to retrofit the existing structures to enhance sustainability and efficiency.

Figure 2: Phase one for selection of schools in Mira Bhayandar



The stepwise and detailed methodology is given below:

- To find the heat hotspots in Mira Bhayandar, we used Landsat-8 satellite imagery to extract Land Surface Temperature (LST) data for peak summer periods from 2014 to 2022. Then, annual LST data was overlapped to calculate the mean temperature, identifying heat hotspots as per IMD. This was done by mapping on arc GIS. We overlaid the location of schools on heatmaps. Then, we got the schools which were in the high stressed zones.

- The selected schools were chosen based on specific green retrofitting principles, age group of the students, structural stability, age of the structure, demography and vulnerability of the residents residing around the schools. Following a thorough evaluation, schools number 3, 11, and 35 were identified as the most suitable schools for the study.
- A team comprising structural engineers and architects was formed for the comprehensive assessment and baseline data collection.
- Now, next step is to evaluate the energy and water consumption of the school. With this purpose, an energy audit was conducted in the school and collected the data on following things:

Table1: List of Parameters

S.No.	Parameters	Data collected	Units
1	Electricity consumption	Yes	kWh
2	Expenses on electricity consumption	Yes	INR
3	Solar electricity generation	No	
4	LPG consumption	Yes	Kg
5	LPG bills	Yes	INR
6	Diesel consumption	Yes	L
7	Diesel Bills	Yes	INR
8	Water consumption	Yes	L
9	Water Bills	Yes	INR

Reference: Audit's findings

- Next step is to identify the solutions. To do this, a combination of result of the audits and EDGE analysis was used. After considering the CAPEX, payback period, Climatic conditions and baseline data, we proposed SRI paint, BLDC fans, motion light sensors and dual flush system. Also, local authorities and school management communities were engaged early in the process. The long-term economic benefits of the interventions were assessed to justify their scalability and replication in similar situations.

Figure 3: Phase two for identification of solutions.

PHASE 2

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floors and totaling 1,689 m^2 has an occupancy density of 25.21 persons/ m^2. The EDGE analysis projects that the implementation of BLDC fans would result in significant energy savings. These fans, which consume 58% less electricity consumption, would require an initial investment of ₹1,92,000 but could generate annual savings of ₹46,080.

The analysis projected payback period of 4.17 years with potential energy savings of 6.55%. The effectiveness of the SRI paint depends on the location where it is applied. Application of SRI paint on roof yields a good results having a payback period of 6.09 years. The EDGE analysis shows that with ₹1,20,934 of investment, the savings on electricity bills is ₹19,843 annually. But the analysis for wall application suggests less favorable outcomes. It would require a higher initial investment of ₹3,53,378 and lead to lower annual savings of ₹7,686. This results in a longer payback period of 45.98 years which makes it an expensive green retrofitting measure. According to the EDGE analysis, installing water-efficient faucets and implementing dual flush toilets, which would cost ₹32,000, would save ₹33,858 each year. This means the investment would be paid back in 0.95 years. These projections indicate `water efficiency improvement between 47% and 60%. Additionally, the analysis of motion sensor lights shows some potential benefits. The analysis shows that with an investment of ₹45,600, these systems could save ₹13,229 each year. This means they would pay for themselves in 3.45 years. The water efficiency improvements demonstrate the most favorable projected returns, while energy-saving measures demonstrate varying degrees of cost-effectiveness in the analysis. The EDGE analysis particularly highlights BLDC fans and roof SRI paint application as promising energy-saving solutions that balance initial investment with long-term benefits.

Figure 4: Payback period for different measures

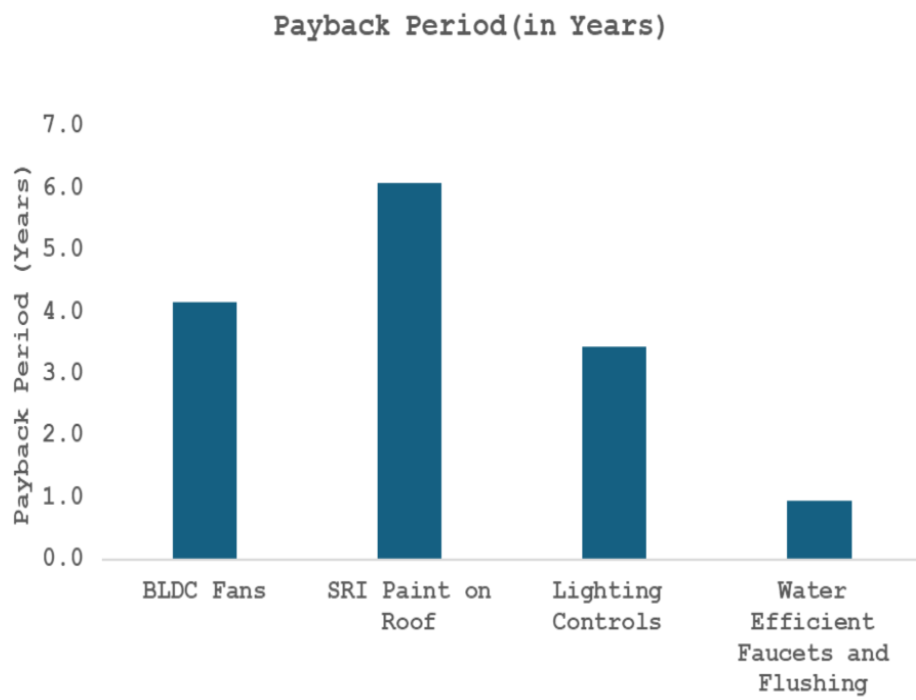


Table 2: EDGE Analysis for different measures

S.No.	Measure	Measure Description	Impact	CAPEX Cost (INR)	Annual Savings (INR)	Payback (in years)

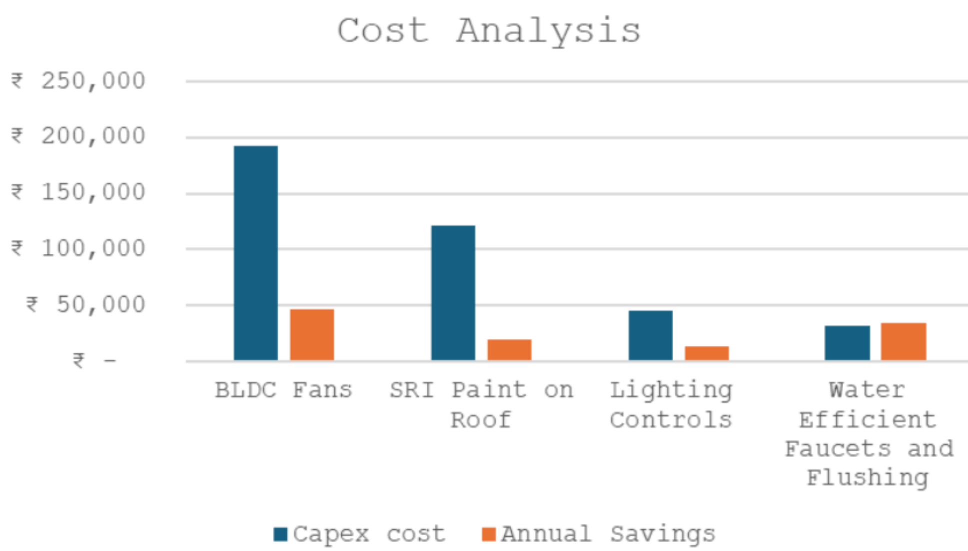
1	Energy Reduction Measure	BLDC Fans	BLDC Fans consume 1/3 of electricity compared to conventional fans, thereby making an important energy reduction measure.	192,000	46,080	4.17
2	Energy Reduction Measure	SRI Paint on Roof	SRI paint reflects solar radiation, reducing heat absorption and cooling costs. It lowers energy consumption, mitigates urban heat islands, and decreases greenhouse gas emissions. Additionally, it enhances surface durability and is versatile for various applications, including roofs and walls.	120,934	19,843	6.09
3	Energy Reduction Measure	SRI Paint on Walls		3,53,378	7,686	45.98
4	Energy Reduction Measure	Lighting Controls - Daylight Sensors with Occupancy Control	Since there is enough daylight but a lack of awareness in general, installing daylight with occupancy sensors will help reduce energy consumption.	45,600	13,229	3.45
5	Water Efficiency Measure	Water Efficient Faucets and Dual Flush Cisterns	Install dual flush external flush tank with full flush of 6L and half flush of 3L or only full flush of 5L.	32,000	33,858	0.95

4. Disscussion

The findings from the energy and water audits conducted in selected schools in Mira Bhayandar, combined with projections from the EDGE analysis, demonstrate significant potential for sustainable retrofitting in educational buildings. The analysis provides valuable insights into prioritizing retrofit strategies, particularly in warm and humid climates. Energy consumption patterns show that lighting and cooling systems use most of the electricity in these schools. This is in line with what other studies have found, which is that these systems are important targets for making schools more energy efficient. (Hong et al., 2019; Zhang et al., 2021). The high humidity levels typical of the coastal climate in Mira Bhayandar pose considerable challenges to maintaining thermal comfort. While passive cooling strategies remain ideal for addressing these challenges (Gondal et al., 2019; Kumar et al., 2022), the adoption of BLDC fans presents a promising and practical solution. These fans consume less energy compared to conventional models and consistent with efficiency gains documented in retrofitted institutional buildings in tropical climates (Abidin et al., 2019; Patel & Singh, 2023). The EDGE analysis further supports this intervention indicating a payback period of 4.17 years, highlights its financial viability. This finding aligns with earlier research emphasizing payback periods of less than five years as a critical factor for the adoption of retrofitting measures in educational institutions (Ma et al., 2012). The results of application of SRI paint on roof are consistent with the previous studies (Abdullah & Alibaba, 2017; Chen et al., 2024). In contrast, the SRI application on wall shows a longer time period for payback period that implies it is not a cost effective and viable solution .

The implementation of dual-flush systems and aerators is projected to achieve a 47-60% improvement in water efficiency with a rapid payback period of 0.95 years. This result surpasses typical performance metrics reported in existing literature (Madushika et al., 2023). The impacts of these measures are more profound where water scarcity is there. Also, rain water harvesting along with the above mentioned water efficient measures can be a significant step in water efficiency. In addition to the previously mentioned measures, the orientation of school buildings plays an important role in maximizing natural light and ventilation. Schools built with north-south orientation can significantly reduce heat gain, so they don't need artificial lighting or cooling systems. Proper shading devices such as overhangs and louvers can further enhance energy efficiency. This problem can be addressed by a variety of strategies including the use of solar panels on the rooftops to cover energy requirements, the implementation of rainwater collection systems in order to lower reliance on city water resources, and the use of energy-saving equipment, and lighting systems.

Figure 5: Economic viability of measures



4.1 Implications and Benefits:

These retrofitting measures have a big impact in many areas. For example, they reduce energy and water consumption, which means less carbon emissions and water conservation. If we retrofitted buildings, we could cut carbon emissions by 30-50% every year (WEF,2024). And the economic benefits go beyond saving on utility costs. Green retrofitting in schools has many benefits. One of the best parts is that it can save money. Sustainable buildings are often cheaper to operate and maintain in the long run. This is because they use less energy, water, and manage waste better. This can free up money that can be used for other things in the school. Green retrofitting can also improve the health and well-being of the school's occupants. Sustainable buildings often have better indoor air quality, lighting, and ventilation systems, which can contribute to a healthier and more comfortable learning environment. This, in turn, can lead to improved student and teacher productivity, as well as reduced absenteeism.The social and environmental benefits of green retrofitting in schools are also noteworthy. Long-term resilience is another crucial benefit. Buildings equipped with energy-efficient systems and water conservation measures are better prepared to handle climate-related stresses and utility cost fluctuations (Park et al., 2024; Reynolds & Kumar, 2023). This resilience becomes increasingly important as climate change intensifies.

5. Conclusion

The retrofitting project for the selected schools in Mira Bhayandar showcases the potential of green interventions in reducing energy and water consumption, while simultaneously enhancing the comfort and resilience of the built environment. By incorporating passive cooling strategies, energy-efficient technologies, and water-saving measures, the project achieves a significant improvement in sustainability and resource efficiency.

The implementation of BLDC fans, LED lighting, and dual-flush cisterns demonstrates how simple yet impactful solutions can provide long-term environmental and financial benefits. The application of SRI paint on roofs further highlights the importance of targeted interventions for reducing cooling loads in warm and humid climatic zones. Additionally, the use of advanced lighting controls and water-saving technologies underlines the effectiveness of resource optimization strategies. Schools can also adopt green roofs and vertical gardens to improve insulation and air quality while reducing urban heat island effects. Regular maintenance and monitoring of energy and water systems, along with awareness programs for students and staff, can further enhance the long-term sustainability of these interventions. Overall, these findings highlight the importance of prioritizing energy-efficient cooling solutions, roof-based SRI applications, water efficiency measures, and building design considerations in the retrofitting strategies of educational buildings in warm and humid climates.

6. Future Enhancement

The proposed changes in this study shown considerable potential for enhancing energy and water efficiency in schools. However, it is imperative to acknowlEDGE the inherent limitations. These changes may not be equally effective in other regions. The implementation of these changes in other regions may be hindered by financial and resource constraints. Although EDGE certification provides valuable insights, further data collection over time is necessary to substantiate the efficacy of these modifications. Also, we did not consider the other capital intensive measures due to the fund limitation. In the future, it will be critical to assess the performance of these interventions across a range of climates, building typologies, and communities.

Acknowledgment

We would like to express our gratitude to Sana Dharani, as well as the entire Aga Khan Agency for Habitat, for their invaluable and constructive feedback.

References

Ferrer-Balas, D., Buckland, H., & De Mingo, M. (2008). Explorations on the University's role in society for sustainable development through a systems transition approach. Case-study of the Technical University of Catalonia (UPC). Journal of Cleaner Production, 17(12), 1075–1085. https://doi.org/10.1016/j.jclepro.2008.11.006

Wan, S., Ding, G., Runeson, G., & Liu, Y. (2022). Sustainable Buildings' Energy-Efficient Retrofitting: A study of large office buildings in Beijing. Sustainability, 14(2), 1021. https://doi.org/10.3390/su14021021

Javid, A. S., Aramoun, F., Bararzadeh, M., & Avami, A. (2019). Multi objective planning for sustainable retrofit of educational buildings. Journal of Building Engineering, 24, 100759. https://doi.org/10.1016/j.jobe.2019.100759

Agdas, D., Srinivasan, R. S., Frost, K., & Masters, F. J. (2015). Energy use assessment of educational buildings: Toward a campus-wide sustainable energy policy. Sustainable Cities and Society, 17, 15–21. https://doi.org/10.1016/j.scs.2015.03.001

Stazi, F., Naspi, F., Ulpiani, G., & Di Perna, C. (2017). Indoor air quality and thermal comfort optimization in classrooms developing an automatic system for windows opening and closing. Energy and Buildings, 139, 732–746. https://doi.org/10.1016/j.enbuild.2017.01.017

Ishak, N., & Azizan, M. A. (2021). Sustainable building retrofits potential indicators. AIP Conference Proceedings, 2339, 020154. https://doi.org/10.1063/5.0044248

Abidin, N. I. A., Zakaria, R., Aminuddin, E., Shamsuddin, S. M., Mustafa, M., & Khan, J. S. (2019). Decision making tool for retrofitting of existing building for energy reduction in higher learning institution. IOP Conference Series Materials Science and Engineering, 615, 012069. https://doi.org/10.1088/1757-899x/615/1/012069

Ma, Z., Cooper, P., Daly, D., & Ledo, L. (2012). Existing building retrofits: Methodology and state-of-the-art. Energy and Buildings, 55, 889–902. https://doi.org/10.1016/j.enbuild.2012.08.018

Hong, Y., Deng, W., Ezeh, C. I., & Peng, Z. (2019). Attaining sustainability in built environment: Review of green retrofit measures for existing buildings. IOP Conference Series Earth and Environmental Science, 227, 042051. https://doi.org/10.1088/1755-1315/227/4/042051

Gondal, I. A., Athar, M. S., & Khurram, M. (2019). Role of passive design and alternative energy in building energy optimization. Indoor and Built Environment, 30(2), 278–289. https://doi.org/10.1177/1420326x19887486

Abdullah, H., & Alibaba, H. (2017). Retrofits for energy efficient office buildings: Integration of optimized photovoltaics in the form of responsive shading devices. Sustainability, 9(11), 2096. https://doi.org/10.3390/su9112096

Liu, Y., Zhang, M., & Shen, Z. (2021). Comprehensive benefits Evaluation of solar water heating system application in energy efficiency retrofit of existing residential buildings in cold climate zone. IOP Conference Series Earth and Environmental Science, 647(1), 012132. https://doi.org/10.1088/1755-1315/647/1/012132

Madushika, U. G. D., Ramachandra, T., Karunasena, G., & Udakara, P. a. D. S. (2023). Energy Retrofitting Technologies of Buildings: A Review-Based Assessment. Energies, 16(13), 4924. https://doi.org/10.3390/en16134924

Shaikh, P., Shaikh, F., Sahito, A., Uqaili, M., & Umrani, Z. (2017). An overview of the challenges for Cost-Effective and Energy-Efficient retrofits of the existing building stock. In Elsevier eBooks (pp. 257–278). https://doi.org/10.1016/b978-0-08-101128-7.00009-5

Isimbi, D., & Park, J. (2022). The analysis of the EDGE Certification System on Residential Complexes to improve Sustainability and Affordability. Buildings, 12(10), 1729. https://doi.org/10.3390/buildings12101729