ENERGY EFFICIENCY STRATEGIES FOR RETROFITTING EXISTING BUILDINGS TOWARDS NET ZERO ENERGY: EVIDENCE FROM THE SRI LANKAN CONSTRUCTION INDUSTRY

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Abstract. By 2050, a significant proportion of the buildings expected to be in use will have already been constructed. Given the substantial energy consumption associated with the construction industry, the adoption of energy efficiency strategies is essential. Net Zero Energy Buildings (NZEB) play a critical role in reducing energy use and carbon emissions. Despite the growing emphasis on NZEB, limited studies have focused on prioritizing the most effective energy efficiency strategies for retrofitting existing buildings in the Sri Lankan context. This study aimed to identify and prioritize energy efficiency strategies suitable for retrofitting existing buildings towards NZEB in Sri Lanka. A mixed method approach was adopted. Initially, a literature review was conducted to identify energy efficiency strategies, followed by preliminary interviews to validate their applicability in the Sri Lankan context. Subsequently, a questionnaire survey was administered to assess the criticality of each strategy, and the data were analyzed using one sample t-test. The findings revealed that eleven out of twelve strategies were critical, with natural ventilation, energy audits, and energy-efficient windows identified as the most impactful. The study provides actionable insights for practitioners and policymakers to guide effective retrofitting interventions and support sustainable, low-carbon building practices in Sri Lanka.

Keywords. *Energy efficiency, Existing building, Net Zero Energy Buildings, Retrofitting*

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1. Introduction

The construction industry is one of the major contributors to energy consumption, accounting for approximately 40% of the total energy consumption worldwide (Thiruchelvam & Uduwage, 2025). As a result of rapid urbanization and the increased demand for built infrastructure, energy consumption through the construction industry is considerably higher than in other industries, which has increased attention towards improving building energy efficiency (Andújar & Sergio, 2020). According to Sokolovska & Krytskyi (2022), the term energy efficiency refers to the integration of architectural and engineering solutions to reduce energy consumption while preserving a comfortable indoor environment. In recent years, the concept of Net Zero Energy Buildings (NZEB) has gained significant attention due to their self-sustaining and improved energy efficiency characteristics (Jaysawal et al., 2022). NZEB are defined as buildings that are designed in a way that balances the energy consumption of the buildings with the energy production of the building through renewable sources over a specific period of time (Noh et al., 2024). According to Langevin et al. (2024), the majority of the buildings that will be utilized by 2050 are already built, which highlights the need for greater consideration toward retrofitting existing buildings to improve energy efficiency.

Retrofitting refers to adding additional features to existing building structures to increase their durability, strength and safety against environmental forces (Mohankar, 2024). Retrofitting existing buildings towards NZEB requires the incorporation of energy

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efficiency strategies in order to improve energy efficiency within the building. For instance, incorporating passive design strategies and solar photovoltaic (PV) systems within buildings located in tropical climates has the potential to reduce energy demand by 48-50% (Ohene et al., 2022). Aksamija (2015) highlighted that the integration of passive design strategies within commercial buildings in Holyoke has the potential to improve energy efficiency. A case study conducted in an office building in Portland proved that energy efficiency strategies can reduce energy consumption intensity by 60% (Alajmi et al., 2020). Biloria & Abdollahzadeh (2022) noted that the preparation of daylight-based zoning, solar radiation-based zoning, insulation improvements, and efficient lighting systems has significant potential to serve as energy efficiency strategies for retrofitting existing buildings.

When considering the Sri Lankan context, the country experiences a tropical climate characterized by high temperatures and high humidity levels (Punyawardena, 2020). Therefore, the energy efficiency strategies applicable to the Sri Lankan context differ from those used in countries that experience polar climates with extremely low temperatures or freezing conditions (Gajaba & Dissanayake, 2025). Fasna & Gunatilake (2019) conducted a case study on Sri Lankan hotel buildings and identified barriers and strategies for overcoming barriers to implementing energy efficiency strategies. Toga et al. (2023) highlighted that energy efficiency strategies such as space cooling improvements, lighting and passive measures are applicable to Sri Lankan commercial, public and industrial buildings. Razzaq et al. (2023) suggested that building envelope retrofits, upgrades of electrical appliances, and the integration of solar systems can help to retrofit existing buildings in Sri Lanka in an energy efficient manner.

Moreover, although the concept of NZEB is widely recognized as a way to improve energy efficiency and reduce energy consumption, scholarly attention towards retrofitting existing buildings into NZEB remains limited, particularly within the Sri Lankan construction industry. Several studies have been conducted in different countries. For instance, Razzaq et al. (2023) focused on retrofitting existing buildings into NZEB in Pakistan, while Patel et al. (2019) examined energy retrofitting of commercial buildings in India. Ohene et al. (2022) developed retrofit guidelines in the Ghanaian context, and Ananwattanaporn et al. (2021) investigated NZEB retrofitting in Thailand. However, the findings of these studies are context specific and cannot be directly transferred to the Sri Lankan construction industry due to differences in climatic conditions, economic constraints, policy frameworks, and technological availability across countries (Thiruchelvam & Uduwage, 2025). In particular, Sri Lanka's tropical climate, characterized by high temperature and humidity, requires energy efficiency strategies that focus more on cooling demand reduction rather than heating, which is commonly emphasized in many global studies (Punyawardena, 2020). Although some studies conducted in Sri Lanka have listed suitable energy efficiency strategies for retrofitting existing buildings towards NZEB, scholarly attention on identifying the most effective energy efficiency strategies for retrofitting existing buildings towards NZEB remains limited. Identifying the most effective energy efficiency strategies is essential to accelerate the implementation of energy efficiency measures for retrofitting existing buildings towards NZEB. To fill this gap, this study aims to identify and prioritize energy efficiency strategies for retrofitting existing buildings towards NZEB in the Sri Lankan construction industry. To achieve this aim, the following objectives were formulated.

1. To identify energy efficiency strategies applicable for retrofitting existing buildings towards NZEB in the Sri Lankan construction industry.
2. To evaluate and prioritize the identified energy efficiency strategies based on their impact on improving building energy efficiency in the Sri Lankan construction industry.

2. Literature review

2.1. NET ZERO ENERGY BUILDINGS AND THEIR IMPORTANCE

Net Zero Energy Buildings (NZEB) refer to buildings that produce as much renewable energy as they consume over a specific period of time through energy efficiency improvements and renewable energy integration (Rosen, 2015). In other words, NZEB balance the energy consumption of the building with its energy production (Noh et al., 2024). NZEB provide several benefits across environmental, economic, and social dimensions. For instance, reducing greenhouse gas emissions and mitigating climate change are core environmental benefits associated with NZEB (Ohene et al., 2022). In terms of economic benefits, NZEB result in lower lifecycle energy costs, which attracts building owners towards adopting NZEB (Biloria & Abdollahzadeh, 2022). Furthermore, NZEB prioritize occupant comfort and indoor environmental quality, which helps improve occupant wellbeing and contributes to social benefits (Aksamija, 2015). NZEB focus on the combination of energy efficiency strategies and the integration of renewable energy technologies (Rosen, 2015). Once the energy demand is reduced through energy efficiency strategies, renewable energy technologies such as solar photovoltaic (PV) systems can be used to meet the remaining energy requirements of the building (Sokolovska & Krytskyi, 2022). Therefore, energy efficiency strategies play a crucial role in achieving NZEB.

2.2. RETROFITTING EXISTING BUILDINGS TOWARDS NZEB

Although the concept of NZEB is often associated with new building construction, according to Langevin et al. (2024), approximately 80–90% of the buildings that will be in use by 2050 have already been constructed. Therefore, greater attention is required for converting existing buildings to NZEB rather than solely focusing on new building construction. Building retrofitting refers to the process of altering existing buildings to improve their performance by incorporating new technologies or upgrading existing building components (Mohankar, 2024). Existing studies have shown that the incorporation of energy efficiency strategies within existing buildings through retrofitting significantly supports the transition towards NZEB (Biloria & Abdollahzadeh, 2022).

2.2.1. Energy efficiency strategies for retrofitting existing buildings towards NZEB

Energy efficiency strategies are often acknowledged as one of the most effective methods for reducing energy consumption while preserving a comfortable indoor environment (Sokolovska & Krytskyi, 2022). According to Alajmi et al. (2020), the implementation of energy efficiency measures can reduce energy consumption intensity by up to 60%. Existing studies have identified several energy efficiency strategies for retrofitting existing buildings towards NZEB, as outlined in Table 1.

Table 1, Energy efficiency strategies

Energy efficiency strategies	Sources
Building envelope improvements	
Upgrade insulation	[2], [3], [4], [7], [8], [10], [11]
Install energy efficient windows	[3], [4], [5], [7], [8], [10], [11]
Use reflective roofing materials and solar photovoltaic (PV) system	[2], [4], [6], [8], [9], [10], [11]
Energy-Efficient HVAC Systems	
Implement inverter-based air conditioning	[3], [4], [7], [11]
Demand-controlled ventilation	[2], [11]
High efficiency ceiling fans	[4], [7], [8], [10], [11]
LED Lighting and Smart Controls	
Replace incandescent bulbs with LED lighting	[2], [3], [6], [7], [8], [9], [10], [11]
Install motion sensors and timers to reduce unnecessary energy consumption.	[3], [4], [6], [7], [8], [10], [11]
Energy Audits	
Conduct an energy audit before renovation to identify inefficiencies and optimize improvements	[3], [7], [11]
Passive Cooling Techniques	
Utilize natural ventilation	[1], [3], [4], [5], [7], [8], [10], [9], [11]
Shaded areas	[3], [5], [7], [9], [11]
Green roofs to reduce cooling demand	[1], [3], [4], [5], [7], [8], [10], [11]
[1] Aksamija (2015); [2] Biloria & Abdollahzadeh (2022); [3] Lan et al. (2019); [4] Lu et al. (2015); [5] Ohene et al. (2022); [6] Razzaq et al. (2023); [7] Rodriguez-Ubinas et al. (2014); [8] Shayan (2020); [9] Toga et al. (2023); [10] Tumminia et al. (2019); [11] Wu & Skye (2021)	

A total of 12 energy efficiency strategies were extracted from the existing literature for retrofitting existing buildings towards NZEB. These strategies were categorized into five major aspects, namely building envelope improvements, energy-efficient HVAC systems, LED lighting and smart controls, energy audits, and passive cooling techniques. Under building envelope improvements, three key strategies were identified. Upgrading building insulation, particularly for key elements such as roofs, walls, and windows, helps to minimize heat transfer and reduce the required heating and cooling loads in buildings (Lu et al., 2015). The installation of energy-efficient windows limits unwanted heat gain and heat loss between indoor and outdoor environments (Ohene et al., 2022). The use of reflective roofing materials can reduce solar heat absorption, while the integration of solar photovoltaic (PV) systems supports on-site renewable energy generation. These uses of reflective roofing materials and solar photovoltaic (PV) systems are particularly more suitable for tropical climate countries (Wu & Skye, 2021).

The second category discusses energy-efficient HVAC systems. Inverter-based air conditioning systems enhance efficiency by adjusting compressor speeds to match cooling demand precisely, thereby avoiding unnecessary energy waste (Lan et al., 2019). Demand-controlled ventilation optimizes indoor air quality while minimizing energy use by regulating airflow based on occupancy (Biloria & Abdollahzadeh, 2022). High-efficiency ceiling fans increase thermal comfort with low power consumption (Shayan, 2020).

The third category focuses on LED lighting and smart controls. LED lighting consumes significantly lower energy compared with conventional incandescent bulbs (Biloria & Abdollahzadeh, 2022). Therefore, replacing incandescent bulbs with LED bulbs can significantly reduce the energy demand of a building. Motion sensors and timers help reduce unnecessary energy consumption by automatically switching off electrical systems when spaces are unoccupied (Tumminia et al., 2019).

Before initiating proper retrofitting, it is recommended to conduct an energy audit to identify inefficiencies in building energy use and provide suitable recommendations for improvements (Rodriguez-Ubinas et al., 2014). Therefore, energy audits were identified as another subcategory of energy efficiency strategies. Finally, passive cooling techniques were identified as another subcategory, which includes utilizing natural ventilation, creating shaded areas, and implementing green roofs. Moreover, these energy efficiency strategies collectively contribute to reducing building energy consumption and improving the energy performance of existing buildings.

However, the selection of energy efficiency strategies for retrofitting existing buildings towards NZEB varies depending on several factors, including climate zone, building type, occupant safety, and economic feasibility (Bruck, 2023). For instance, countries with polar climates mainly focus on insulation and airtightness, whereas countries with tropical climates focus more on solar shading and cooling efficiency (Gajaba & Dissanayake, 2025). Furthermore, the decision on selecting retrofitting strategies heavily depends on the total cost over the building lifespan as well as occupant behaviour in terms of energy usage patterns and willingness to adopt newly incorporated technologies (Aksamija, 2015). Even though several studies have been conducted to identify energy efficiency strategies for retrofitting existing buildings towards NZEB, their contextualization within the Sri Lankan context remains limited. Existing literature in the Sri Lankan context has mainly focused on identifying available energy efficiency strategies. However, limited attention has been given to identifying the most critical strategies. Identifying the most effective energy efficiency strategies can support the retrofitting of existing buildings towards NZEB more efficiently and cost-effectively.

3. Research methodology

The study adopted a mixed research method to prioritize energy efficiency strategies for retrofitting existing buildings towards NZEB in the Sri Lankan construction industry. The target population of the study consists of construction industry professionals in Sri Lanka who are involved in building design, construction, and building services, as they are primarily engaged in decision making during the retrofit planning and implementation stages (Kulasekara et al., 2023; Periyannan et al., 2023). The sample frame includes professionals with a minimum of three years of experience in building design, construction, building services engineering, or energy management. The purposive sampling method was used to select professionals who possess relevant knowledge and experience in energy efficiency and retrofitting practices. Figure 1 presents the research design of the study.

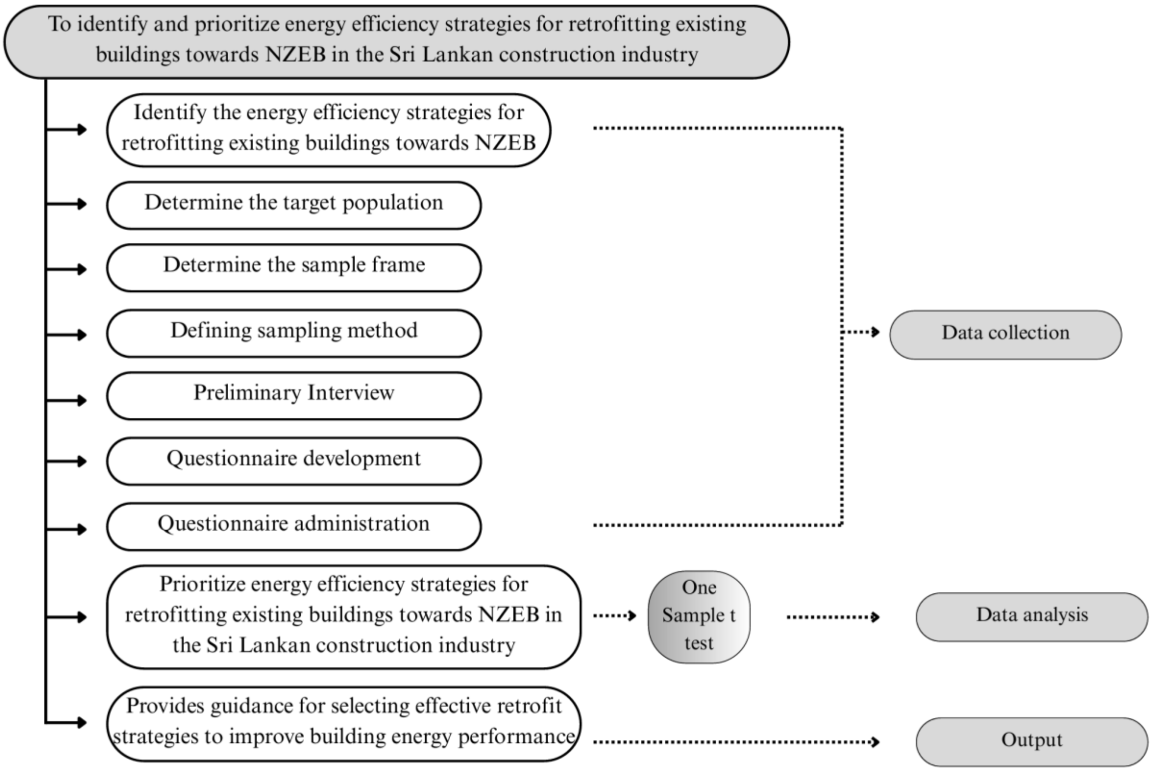

Figure 1, Research design

Initially, a comprehensive literature review was conducted to identify energy efficiency strategies for retrofitting existing buildings towards NZEB. Then, preliminary interviews were conducted with five experts in order to validate the identified energy efficiency strategies within the Sri Lankan context. After that, a questionnaire survey was conducted. The questionnaire was distributed to 100 construction industry professionals through online platforms such as email, LinkedIn, and WhatsApp. The collected data were then analyzed using one sample t-test in SPSS software. One sample t-test allows the comparison of the mean score of each energy efficiency strategy against a predetermined threshold value in order to identify the critical energy efficiency strategies. The study used 3.5 as the threshold value to determine the critical energy efficiency strategies, as Ahadzie et al. (2007) used 3.5 as a threshold value to extract critical factors in a similar study.

The following hypotheses were formulated for the analysis.

- Null Hypothesis (H_0): The energy efficiency strategy is considered critical.
- Alternative Hypothesis (H_1): The energy efficiency strategy is not considered critical.

If the mean value is greater than 3.5, the null hypothesis is accepted. Otherwise, the null hypothesis is rejected.

4. Research findings

Twelve energy efficiency strategies for retrofitting existing buildings towards NZEB were identified through a comprehensive literature review. Then, preliminary interviews were conducted with five experts who had more than 15 years of experience in the construction industry and had direct involvement in projects incorporating sustainable or energy-efficient practices to validate the identified energy efficiency strategies in the Sri Lankan context. Table 2 presents the profile of the experts consulted during the preliminary interview. The experts confirmed that all twelve identified strategies are relevant to the Sri Lankan context, and no additional strategies were suggested or removed.

Table 2, Preliminary interview experts' profile

Experts code	Years of experience	Key area related to research objectives
E1	30	Construction management, sustainable building design
E2	27	Sustainable construction, resource management
E3	18	Building services, sustainable construction
E4	16	Energy management, Energy auditing
E5	22	Green building practices, project management

Based on the preliminary interview responses, a questionnaire survey was developed and distributed among 100 construction professionals. A total of 63 valid responses were received, resulting in a 63% response rate. Respondents were asked to rate the energy efficiency strategies based on their impact on retrofitting existing buildings towards NZEB using a 1–5 Likert scale (1-No impact, 2-Low impact, 3-Moderate Impact, 4-High impact, 5-Very high impact). The responses were then analyzed using one sample t-test, and the results are presented in Table 3.

Table 3, One sample t-test result for energy efficiency strategies impact

Code	Energy efficiency strategies	N	Mean	Standard deviation
ES1	Utilize natural ventilation	63	4.10	0.875
ES2	Conduct an energy audit before renovation to identify inefficiencies and optimize improvements	63	3.87	1.055
ES3	Install energy efficient windows	63	3.83	0.871
ES4	Replace incandescent bulbs with LED lighting	63	3.78	0.832
ES5	Upgrade insulation	63	3.78	0.906
ES6	Use reflective roofing materials and solar photovoltaic (PV) system	63	3.75	0.915
ES7	Green roofs to reduce cooling demand	63	3.71	1.007
ES8	Install motion sensors and timers to reduce unnecessary energy consumption.	63	3.70	1.116
ES9	Demand-controlled ventilation	63	3.65	0.806
ES10	Implement inverter-based air conditioning	63	3.63	1.052
ES11	Shaded areas	63	3.62	1.023
ES12	High efficiency ceiling fans	63	3.19	0.913

As presented in Table 3, one sample t test employed to determine the mean score of each energy efficiency strategy, which is significantly greater than the threshold value of 3.5, which represents the level at which a strategy is considered critical. Among the 12 energy efficiency strategies, 11 strategies show mean values higher than the threshold value of 3.5. Therefore, these 11 strategies are considered critical energy efficiency strategies for retrofitting existing buildings towards NZEB. At the same time, high efficiency ceiling fans (ES12) showed a mean value lower than 3.5. Therefore, ES12 was considered a non-critical energy efficiency strategy. Prioritization of strategies was subsequently carried out based on the mean values of the statistically significant strategies.

5. Discussion

Among the identified critical energy efficiency strategies for retrofitting existing buildings towards NZEB, natural ventilation (ES1) recorded the highest mean value among all other strategies, indicating the respondents’ priority towards ES1. This priority might be due to the tropical climatic conditions of Sri Lanka (Punyawardena, 2020). Proper placement of windows and ventilation openings can reduce reliance on mechanical cooling systems. Since the majority of existing buildings in Sri Lanka already incorporate features such as verandas and large openings, improvements to natural ventilation can be done with minimal structural changes. Energy audits allow identification of major inefficiencies and help prioritize suitable energy efficiency strategies, avoiding unnecessary investments (Rodriguez-Ubinas et al., 2014). Therefore, respondents might have viewed ES2 as the second most critical strategy. ES3’s priority is also directly linked to the tropical climate of Sri Lanka, where excessive solar radiation entering through windows increases cooling demand (Punyawardena, 2020).

Regarding ES4, since LED lighting has become widely available, energy-saving, and relatively affordable in Sri Lanka, respondents might view replacing incandescent bulbs with LED lighting as a high energy-saving option (Biloria & Abdollahzadeh, 2022). Strategies ES5, ES6, and ES7 are related to lowering indoor temperature and reducing cooling loads (Umar & Asfour, 2025). Since existing buildings in Sri Lanka were constructed without adequate consideration for insulation, strategies ES5, ES6, and ES7 might significantly impact retrofitting existing buildings towards NZEB. In Sri Lanka, electricity costs have been increasing in recent years. Automated systems with motion sensors and timers (ES8) can significantly reduce energy consumption (Gupta et al., 2025). However, ES8 is associated with high initial costs and requires proper installation and maintenance, which might have influenced respondents to assign a moderate ranking. Similarly, ES9 and ES10 are associated with advanced control systems and high initial costs, which might have caused respondents to assign a lower priority (Ozdagli et al., 2018).

Although shading is an effective passive cooling strategy, its implementation in existing buildings may require structural modifications or additional installations. This might be the reason for the lowest priority assigned to ES11. At the same time, high-efficiency ceiling fans (ES12) were identified as a non-critical energy efficiency strategy. Since ceiling fans are already widely used in Sri Lanka as a basic cooling method, respondents might not have viewed them as critical compared to other available strategies.

Overall, the findings of the study highlight several context specific insights related to the Sri Lankan construction industry. For instance, studies conducted in cold climate countries tend to give more priority to improvements in insulation and heating efficiency

(Biloria & Abdollahzadeh, 2022), whereas the findings of this study indicate a greater priority towards natural ventilation and cooling related strategies. This difference is primarily due to the tropical climate conditions in Sri Lanka, which are characterized by high temperatures and humidity (Punyawardena, 2020). Furthermore, low cost energy efficiency strategies such as natural ventilation and LED lighting have been ranked higher compared to more technically advanced and relatively high-cost strategies such as the use of motion sensors and timers, demand-controlled ventilation, and inverter-based air conditioning. This highlights the influence of economic feasibility and technological accessibility on the prioritization of energy efficiency strategies in the Sri Lankan context. Based on these findings, several practical implications emerge. Industry professionals can use this study as guidelines to select energy efficiency strategies for retrofitting existing buildings towards NZEB. Prioritization of energy efficiency strategies may help to allocate resources more effectively under constraints such as limited financial resources, technical limitations, and varying building conditions, thereby achieving maximum improvement in building energy performance. Countries with similar characteristics to Sri Lanka can adopt the findings of this study to improve energy performance in their buildings.

5. Conclusion

The study aimed to identify and prioritize energy efficiency strategies for retrofitting existing buildings towards NZEB in the Sri Lankan construction industry. Twelve energy efficiency strategies were identified through a literature review and validated for the Sri Lankan context. A one sample t-test was used to prioritize the energy efficiency strategies. Based on the results, eleven out of the twelve strategies were identified as critical. Natural ventilation (ES1), energy audits (ES2), and energy-efficient windows (ES3) were found to be the most impactful strategies, while only high-efficiency ceiling fans (ES12) were considered non-critical due to their existing prevalence and limited impact on overall energy consumption.

Moreover, the findings provide valuable insights for practitioners, policymakers, and construction professionals by highlighting the most effective strategies for retrofitting existing buildings towards NZEB. Prioritizing these interventions can support energy efficiency improvements, reduce carbon emissions, and promote sustainable building practices in Sri Lanka. Future studies can extend this research by evaluating the long-term economic and environmental feasibility of different retrofit strategies across various building types. Furthermore, the role of government policies, financial incentives, and regulatory frameworks in promoting the adoption of retrofits in the Sri Lankan construction industry can be examined by future researchers.

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