A Comparative Study on Improving Energy-Efficiency in Multi-Apartment Residential Buildings

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Abstract
This comparative study explores strategies to enhance energy efficiency in multi-apartment residential buildings, aiming to improve occupants' comfort and productivity while promoting sustainability. It analyzes efficient building design strategies, construction modalities, and the need to upgrade these buildings in the 21st century. The research emphasizes the importance of reducing greenhouse gas emissions and providing indoor air quality, visual, and thermal comfort. Passive design strategies are highlighted as essential for achieving energy efficiency in this context. Through comparative analysis, sources of data were from two specific databases, namely ResearchGate and Google Scholar. This study finds out that renovation efforts in multi-apartment residential building have significant potential to improve safety, comfort and energy efficiency and concludes that collaboration across a range of stakeholders, including governments, housing corporations, building owners, architects, energy specialists, and inhabitants be encouraged. This study therefore recommend that multi-apartment residential buildings can be made more energy-efficient, occupant-friendly, and sustainable through encouraging renovations, integrating building energy management systems (BEMS), employing passive design, enhancing data collecting, and coordinating policies with energy efficiency targets.

Keywords: Comfortable living, Energy Efficiency, Multi-Apartment Residential Building, Passive design, Sustainable construction.

1.0 Introduction

The pursuit of sustainable and energy-efficient practices has become increasingly crucial in all sectors especially in the building sector where energy consumption rate contributes significantly to over 40 percent in many cities (Adewumi et al., 2023). The construction of energy efficient multi-apartment residential building is an important pathway of sustainable development to meet the sustainable development goals (SDG) agenda in reducing greenhouse gas emission, building carbon footprint and produce structures that enhances the quality of life and protects the environment efficiently, as the rate at which energy is consumed to meet inhabitants' energy needs and maintain their physical comfort and the rate at which energy is lost via the building's physical structure (the building envelope) determine a building's energy efficiency (*ENERGY EFFICIENCY FOR BUILDINGS*, n.d.; Isang, 2023). The three main factors that determine how comfortable inhabitants are in a building are air quality, thermal comfort and visual comfort(Mariano-Hernández *et al.*, 2021; Asaju et al., 2022).Thus, the merit of designing energy-efficient buildings is for a high level of comfort, creating a favorable microclimate in a residential building, reducing the negative impact on the environment, reducing harmful emissions into the atmosphere, and saving energy resources(Onamade et al., 2022; VILINSKA, BURLAK and GURSKA, 2023). This is because building and construction sector must decarbonize by 2050 to meet the goals of Paris agreement (Marinakis, 2020). When it comes to lowering energy consumption and enhancing thermal comfort, passive design elements like efficient spatial planning, building orientation, natural ventilation techniques, and efficient use of thermal mass, as well as passive solar systems for heating and cooling, are crucial(Economidou et al., 2020).The aim of this study is a comparative study to improve energy efficiency in multi-apartment residential building to enhance productive and comfortable living of occupants and the environment. The objectives of this study are to analyze efficient building design strategies that has been studied to create comfortable buildings; determine the modalities of constructing energy efficient multi-apartment residential buildings and the need to improve multi-apartment residential buildings to be energy efficient in the 21st century. The statement of research problem is that reducing greenhouse gas emission, providing quality indoor air, visual comfort and thermal comfort is an essential factor to attaining a productive and comfortable living of occupants in multi-apartment residential buildings. Therefore, the modalities of using passive design strategies to achieve energy efficiency in MARB is the basis of this study. The significance of this study is to comprehend the essence of improving energy efficiency in multi-apartment residential building as a measure of achieve productive and comfortable living for sustainable development. The scope of this study is a comparative study of improving energy efficiency in multi-apartment residential buildings (example are Russia (Rostov-on-Don), Latvia, Hebron (Palestine), Ukraine) and so on.

2.0 Literature Review

The comparative study of this article analyzes measures to improve energy efficiency in multi apartment residential building through 15 selected research papers and reviewed.

2.1 Renovation as a Feature of Improving Energy Efficiency in Latvia

In order to enhance safety, comfort, market value, building life, and prolonged usefulness, residential buildings typically undergo renovations that involve a range of energy-saving techniques(Chandrasekaran & Dvarionienė, 2022). The elucidation of the notion of energy efficiency must take into account not only the Latvian setting, but also the European Union (EU) and worldwide arena. The majority of the multi-apartment buildings from the million programs are owned by public housing corporations and are situated in low-income areas. These businesses don't get money directly from the government to carry out the modifications, rather, they acquire funds from banks to gain access to loans(Boussaa et al., 2023). Energy efficiency is defined as "the ratio of output of performance, service, goods, or energy, to input of energy" in Article 2 of Directive 2012/27/EU of the European Parliament and of the Council. A productive and comfortable living is relative to the energy performance of the building. Thus, "Energy performance of a building means the calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water, and lighting," according to Article 2 of Directive 2010/31/EU of the European Parliament and of the Council(Upitis et al., 2020). This is thus measured in kilowatt hours per square meter annually (kWh/m2/year).

The European Parliament and Council's Directive (EU) 2018/2002, which amends Directive 2012/27/EU on energy efficiency, establishes a target of 32.5% energy efficiency to be met by 2030, with the possibility of an upward modification in 2023. The guideline further states that after 2020, the requirement to achieve yearly energy savings must still be fulfilled. Furthermore, a revised directive on the energy performance of buildings was adopted in May 2018. It contains measures to improve the energy efficiency of new buildings by utilizing smart energy management systems, as well as to expedite the renovation of existing buildings and the transition to more energy-efficient systems. After analyzing the notion of energy efficiency, the writers come to the conclusion that energy efficiency may be defined as a shift in values, which can show up as a decrease in energy usage as well as an increase in productivity(Upitis et al., 2020). Buildings, which often represent a nation's greatest asset and represent its accumulated wealth over time(A. Onamade et al., 2022), should be repaired timely by taking into account replacement of deteriorated building components. For instance, the World Bank-initiated Energy Efficiency Housing Pilot Project in Lithuania, which focused on renovating residential homes and educational institutions, has demonstrated that, as of right now, residential and public buildings constructed between 1960 and 1980 have two issues: inefficient heat consumption and deteriorating structural components and engineering systems. Consequently, this leads to interior building conditions that don't meet modern standards for safety and comfort.

Climate change sustainability and the need for increased supply stability and quality have drawn a lot of attention to the idea of smart grids in recent years. In Latvia and most other EU cities, multi-story apartment buildings make up the majority of the stock of urban housing. In many nations, increasing these structures' energy efficiency is of utmost importance. Unclassified buildings, however, offer a great deal of possibilities for the implementation of cutting-edge energy-saving techniques. Although apartment owners frequently participate in the decision-making process in a passive manner because they are unaware of the problems with energy-efficient processes and solutions as well as the administration of shared ownership of homes. This is because, a significant portion of Latvia's multi-unit residential buildings were built during the soviet period (1946 and 1990)(Lūce et al., 2022).These buildings have low energy efficiency and significant wear and tear on the engineering systems and building structures. Thus, since 2016, the nation has had access to 156 million EUR in EU structural funds (85% of which come from the EU structural funds and 15% from state financing) for the renovation of multi-apartment buildings which is anticipated to be sufficient for roughly1,030 multi-unit apartment buildings. Through this program, help is given in the form of loans, grants, guarantees, and counseling, hence fostering energy efficiency, smart energy management, and renewable energy in multi-apartment residential buildings. It is expected that the heating usage of a residential building following the completion of works must not exceed 90 kWh/m² per calendar year in order to be eligible for EU financing under this program(Upitis et al., 2020).

Nevertheless, a cost-effective refurbishment of 60% to 70%, or roughly 25,000 apartment complexes with a total area of 38 million m², is feasible. During the 2007–2013 EU funding programming period, 741 buildings, or 3% of the total number of dwellings, underwent renovations(Lūce et al., 2022; Upitis et al., 2020). In contrast, the buildings constructed after 2003, or roughly 3% of all buildings, are comparatively energy-efficient and have low energy usage. Now in Latvia, there are over 23,500 (or 94% of 25,000) potentially energy-efficient renewable buildings spread throughout an area of 30.6 million m²(Upitis et al., 2020). By this, Latvia has set ambitious goals for energy efficiency through co-financing support of European union programmes, for without this, renovation of multi-apartment residential building would have been impossible(Lūce et al., 2022). In all, it can be said that in the process of renovating multi-apartment buildings, the nature of energy efficiency and related activities should be implemented using a model that will improve a dwelling's exterior, comfort, and efficiency(Upitis et al., 2020).

2.2 Building Energy Management System as a Measure of Improving Energy Efficiency

Energy efficiency is seen in many developed and emerging nations as the best way to combat and overcome ever-increasing energy needs(Mariano-Hernández et al., 2021). However, promoting energy sustainability necessitates a multifaceted strategy that includes putting policies that support sustainable development into action, adopting energy-efficient building design practices, and promoting renewable energy sources(Adewumi et al., 2023). For the past ten years, there has been a notable increase in research interest in building comfort and energy management(Mariano-Hernández et al., 2021). The concept of Building Energy Management Systems (BEMS) is currently in use, taking into account the usage of the building which is the simultaneous realization of green building and intelligent building(Nurrahman et al., 2021). BEMS is defined as an amalgamation of measures and techniques required to enhance its functionality, efficiency, and energy usage to improve energy efficiency.(Mariano-Hernández et al., 2021). Building management systems (BEMS) are a crucial component of an intelligent grid because they allow building administrators to monitor and control the energy utilized in their structures, reducing demand and energy use such as smart meters data(Marinakis, 2020). Smart metering systems can be used to better control supplied services, educate occupants about their behavior, and promote energy-saving practices(Economidou et al., 2020). Also is the introduction of nearly zero-energy building as well as smart building concept(Nurrahman et al., 2021). A nearly zero energy building (NZEB) is one in which energy from renewable sources generated nearby or on-site should account for a large portion of the practically zero or extremely low amount of energy needed(Boussaa et al., 2023).

2.3 Passive Design Strategies

Day lighting is a naturally occurring, renewable, and non-depleting energy source that is crucial to building design from an aesthetic and environmental perspective(Alatawneh et al., n.d.). Population growth, temperature changes, and losses are driving up energy demand, which accounts for the building envelope's high energy use(Bataineh & Ali, 2021). Passive or natural ventilation is a popular technology for buildings since it improves the indoor conditions for inhabitants and has minimal operating costs(Belussi et al., 2019). OH can already be effectively mitigated by using passive strategies like solar shading and natural ventilation(Péan et al., n.d.). The most popular method of ventilating apartments and residential structures is natural air exchange, which happens through windows and doors(Strenk & Strakova, 2023). Its effectiveness is, however, dependent on a number of variables, including human behavior, building design, and weather. Building orientation, external wall construction, roof construction, window design and construction, lighting, and cooling thermostat setting are some of the configurations and actions that can be taken to reduce energy consumption and improve building efficiency(Adeboyejo et al., 2022; Bataineh & Ali, 2021).

2.4 Energy Consumption Data as a Measure of Improving Energy Efficiency.

One of the main issues facing the twenty-first century is climate change, which calls for international cooperation to develop effective energy supply, resource conservation, and greenhouse gas (GHG) emission reduction plans(Lanko et al., n.d.). Prior to developing any steps aimed at reducing a building's energy consumption, it is imperative to have current, high-quality, diverse consumption data that is as detailed as possible. These figures ought to show how different human activities differ in terms of energy use. Finding the sources of rising consumption as well as the causes behind it will be made easier with more comprehensive and varied data supplied. With the use of this data, energy-saving solutions like replacing outdated insulation, streamlining heating and cooling systems, or switching to renewable energy sources can be strategically implemented. Furthermore, tracking energy use over time makes it possible to assess how well efficiency measures are working and aids in the establishment of attainable targets for energy reduction(Lanko et al., 2020).

3.0 Methodology

This study utilizes a comparative methodology by gathering data from two specific databases, namely ResearchGate and Google Scholar. This choice was made due to the search engine's sophisticated options, allowing for a precise selection of the publication year range, and the databases' wealth of innovative articles. Keywords such as energy efficiency, multi-apartment residential buildings (MARB), nearly zero energy buildings (NZEB), sustainable construction, and passive design, comfortable living among others were utilized in the search process. Mendeley, a reference manager, was employed to import the search results from both databases for in-text citation and references. 12 out of 23 articles are analyzed in the table below;

Table 1: Executive summary of Literature

S/N	Author(s)	Year of publication	Country	Title	Aim	publisher	Methodology
1	Adewumi, Bamidele J Onamade, Akintunde, O Asaju, Opeyemi,	2023	Nigeria	Impact of Architectural Education on Energy Sustainability in Selected Schools of Architecture in Lagos	to investigate the impact of architectural education on energy sustainability in selected architectural	CIJDS (Caleb International of Development Studies)	quantitative approach

	A. Adegbile, Michael B.O			Megacity	schools in the Lagos Megacity		
2	Bataineh, Asma' M. Ali, Hikmat H.	2021	Jordan	Improving energy efficiency of multi-family apartment buildings case of Jordan	To provides an overview of building design criteria that can reduce the energy demand for heating and cooling of multi-family apartment residential buildings.	IJEEP (International Journal of Energy Economics and Policy)	Quantitative and qualitative methods
3	Boussaa, Youcef Dodoo, Ambrose Nguyen, Truong Rupar-Gadd, Katarina	2023	Sweden	Comprehensive renovation of a multi-apartment building in Sweden: techno-economic analysis with respect to different economic scenarios		BRI (Building Research Information)	parametric analysis
4	Chandrasekaran, Vidhyalakshmi Dvarionienė, Jolanta	2022	Lithuania	A Conceptual Methodology for the Renovation of Multi-apartment Buildings with a Combined Performance and Lifecycle	to have a set of integrated indicators for the renovation of residential buildings and, to develop an assessment methodology aimed at a	EREM (Environmental Research, Engineering and management)	qualitative multi-method research approach

				Approach	comprehensive evaluation of the renovation process throughout its lifecycle stages.		
5	Economidou, M. Todeschi, V. Bertoldi, P. D'Agostino, D. Zangheri, P. Castellazzi, L.	2020	Italy	Review of 50 years of EU energy efficiency policies for buildings	a review of EU energy policies spanning over the last half century with a focus on policy instruments to encourage measures on energy efficiency in new and existing buildings	ELSEVIER	Web of Science and the Scopus databases
6	Isang, Inimbom Walter	2023	Nigeria	A historical review of sustainable construction in Nigeria: a decade of development and progression	to present a historical review of the development of SC in Nigeria over a 10-year period.	FEBE (Frontiers in Engineering and Built Environment)	Secondary Data Source
7	Lanko, Aleksandr De La Flor, Francisco José Sánchez Geraskin, Yuri	2020	Russia	The Analysis of Multi-Apartment Residential Buildings Energy Consumption in Russia.	to identify the main reasons for high energy consumption in multi-family residential buildings (MRB) in Russia and	EDP Science	Qualitative approach.

					suggest ways to improve the energy efficiency of buildings		
8	Lūce, Intra Amoliņa, Iveta Neibergs, Mārcis	2022	Latvia	Renovation of multi-apartment residential buildings in latvia	to study the available support and co-financing mechanisms for the renovation of multi- apartment buildings in Latvia	Vytautas Magnus University	general scientific research methods.
9	Mariano-Hernández, D. Hernández-Callejo, L. Zorita-Lamadrid, A. Duque-Pérez, O. Santos García, F.	2021	Spain	A review of strategies for building energy management system: Model predictive control, demand side management, optimization, and fault detect & diagnosis	To mitigate the impact of the growing demand of electricity	ELSEVIER	general scientific research methods
10	Marinakis, Vangelis	2020	Athens	Big data for energy management and energy-efficient buildings	to present a high-level data-driven architecture for buildings data exchange, management	Energies	Quantitative approach

					and real-time processing		
11	Nurrahman, Hafiz Permana, Asep Yudi Susanti, Indah	2021	Indonesia	Implementation of the smart building concept in parahyangan office rental space and apartment design		Journal of Architectural Research and Education	
12	Péan, Thibault Cleries Tardío, Elisenda Borghero, Luca Avanzini, Marcello Ortiz, Joana Cleries, Elisenda Salom, Jaume	2022	Barcelona	Assessing natural ventilation strategies to improve thermal resilience to extreme temperatures of the residential buildings in Barcelona	to analyze the thermal resilience of a reference building in Barcelona against extreme temperature events and assess its ability to maintain a comfortable and safe indoor environment through passive strategies	ResearchGate	Quantitative and qualitative approach

Source: The Author, T.O Oru ,2024.

The results of the executive summary of literature shows that in the last five years, appreciable research efforts have been made from different researchers across the world to help reduce greenhouse gas emission and carbon footprint in the pursuit to attain energy efficiency in multi-apartment residential buildings in the 21st century. This is eminent to help have a more energy-efficient, comfortable, occupant-friendly and productive living in MARB.

4.0 Research Findings

This research findings deduced that renovation efforts in multi-apartment residential building have significant potential to improve safety, comfort and energy efficiency according to research study from 2019- 2023. This became eminent due to the intervention policy of the EU Directives to provide financial support. The research juxtaposed study reviews from different publishers and concluded that energy efficiency measures can optimally be achieved through passive design strategies, which will help reduce energy usage with application of different policies, awareness and management efforts.

5.0 Conclusion and Recommendations

5.1 Conclusion

In conclusion, collaboration across a range of stakeholders, including governments, housing corporations, building owners, architects, energy specialists, and inhabitants, will be necessary to put these proposals into practice. Multi-apartment residential buildings can be made more energy-efficient, occupant-friendly, and sustainable through encouraging renovations, integrating BEMS, employing passive design, enhancing data collecting, and coordinating policies with energy efficiency targets. In addition to lowering energy use and greenhouse gas emissions, these initiatives will improve the general standard of living in these buildings.

5.2 Recommendations

This study recommends the following as deductions to improve energy efficiency in multi-apartment residential building;

1. Promoting Renovation Efforts: Governments and housing corporations should work to support renovation efforts in multi-apartment buildings by providing direct funding or incentives. As a result, building owners and residents should be informed about the benefits of renovations, which include improved safety, comfort, and energy efficiency. Energy efficiency standards and guidelines for renovations should be provided while the above measures are being implemented to ensure that upgrades meet modern efficiency requirements.

2. Implementing Building Energy Management Systems (BEMS): Encouragement should be given to the integration of Building Energy Management Systems (BEMS) in multi-apartment complexes in order to monitor and optimize energy use. In order to do this, building administrators and residents should participate in training and educational programs about the uses and advantages of BEMS. For the of purpose of promoting adoption, financial incentives or subsidies for the setup and upkeep of BEMS should be provided.

3. Utilizing Passive Design Strategies: It is important to create and promote design rules that support the use of passive design techniques including sun shading, natural ventilation, and daylighting. In order to guarantee that energy efficiency is given priority as an architectural standard in new construction and renovations, passive design principles should be integrated into building rules and regulations. Additionally, there should be established occupant education regarding the advantages of passive design principles and how they may help save energy by performing basic tasks like opening windows for ventilation.

4. Updating The Collection and Analysis of Data: The development of tools and platforms for evaluating energy consumption data to spot trends, areas for improvement, and chances for efficiency gains should enhance investments in systems for gathering varied and comprehensive data on energy consumption in multi-apartment buildings. In order to evaluate the energy efficiency of similar buildings and encourage healthy competition for energy saving, benchmarking programs should be established.

5. Policy and Regulatory Support: Introduce financial incentives through policy alignment, such as tax relief or reimbursements for energy-efficient installations and renovations, to ensure that national and regional policies are in line with EU regulations and targets for energy efficiency in buildings. In order to do this, it is important to promote cooperation amongst stakeholders, such as governments, housing corporations, building owners, architects, and energy specialists, in order to create and carry out efficient energy efficiency policies and programs.

6. Research and Innovation: Continued research on innovative technologies and approaches to improve energy efficiency in multi-apartment buildings should be supported by implementing pilot programs to test new energy-saving technologies and strategies in real-world multi-apartment building settings. This will then facilitate knowledge sharing and best practices exchange among stakeholders through conferences, workshops, and online platforms.

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