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Enhancing Energy Efficiency of Existing High-Rise Buildings: A Comprehensive Review

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Abstract **–** The energy crisis stemming from insufficient infrastructure, reliance on non-renewable sources, inefficient policies, population growth and urbanization has led to a persistent shortage of electricity. Buildings, particularly high-rise structures consume nearly half of the total energy largely due to air-conditioning, lighting and elevators. Improving the energy efficiency of existing high-rise buildings is crucial for combating climate change, reducing harmful emissions and promoting sustainability. Energy efficient buildings also enhance indoor comfort and health. With the increasing reliance on energy resources and the depletion of deposits finding better ways to make buildings more energy efficient is imperative. Challenges in achieving energy efficiency in high-rise buildings include their complexity, diverse uses and limited space for renewable energy systems. Basic building methods such as orientation and natural ventilation along with advanced heating, cooling and lighting systems are essential for smart energy use. Retrofitting of existing buildings with energy saving technology is crucial for reducing energy consumption, greenhouse gas emissions and ensuring long-term sustainability while adhering to regulations and environmental standards. The use of tools like building information modelling (BIM) can aid in designing energy efficient buildings. Architects and engineers are focusing on various methods to save energy in tall buildings such as optimizing cooling and heating systems. The building envelope, particularly windows plays a significant role in regulating temperature and energy usage. Upgrading buildings with improved window systems can substantially reduce energy consumption and CO_2 emissions. As energy resources dwindle and the desire for comfortable living persists, it is essential to prioritize energy efficiency in high-rise buildings.

Keywords – Existing High-Rise Buildings, Energy Efficiency, Renewable Energy, Sustainability, Building Information Modelling (BIM) and Building Envelope

I. Introduction

Energy is essential for the growth of any economy, serving as its backbone and playing a crucial role in the socio-economic development of a country [1]. The energy crisis is caused by outdated infrastructure, dependence on non-renewable energy, poor energy policies, population growth and urbanization leading to ongoing electricity shortages [2]. Buildings consume nearly half of total energy largely because of air-conditioning. In offices, air-conditioning takes up 42% of electricity and in homes it uses 30% [3]. Buildings are a big source of CO_2 emissions worldwide using 40% of the energy and making up about one-third of all greenhouse gas emissions. It shows that buildings emit more CO_2 than any other sector [4]. High-rise buildings are important in cities providing space for many people and businesses [5]. They consume a lot of energy because they are large and need lots of lighting, air conditioning and elevators [6]. Making high-rise buildings more energy efficient not only saves money on bills and energy use but also helps protect the environment and promote sustainability [7]. Improving the energy efficiency of high-rise buildings is important for fighting climate change and cutting down on harmful emissions. Furthermore, Energy-efficient high-rise buildings can make indoor spaces more comfortable and healthier for people [8]. As people increasingly rely on energy resources especially with deposits running low, there is a need to find better ways to make buildings more energy efficient [9]. With climate change and fewer resources, it is clear that making buildings more energy efficient is crucial [10]. Tall buildings use energy for lighting, heating, cooling and ventilation so it is important to find ways to save energy there [11]. Saving energy in high-rise buildings is really important because they use a lot of energy and have a big impact on the environment [12]. Using energy saving technology, materials and designs can help tall buildings use less energy and produce fewer greenhouse gases [13]. As people need more energy and worry about the environment, fixing the energy problems in tall buildings is super important [14]. High-rise buildings use a lot of energy, so it is important to find ways to make them more eco-friendly. There are many challenges in making them energy efficient like improving heating, cooling, lighting and ventilation systems [15]. It is crucial to make buildings more energy efficient by improving existing buildings, the contribution to global carbon emissions can cut down help the environment and save money on running costs. Constructing eco-friendly buildings and upgrading old ones are important steps to reduce these emissions. With energy prices going up, it is a priority to reduce energy use of buildings both in new designs and in fixing up old ones. Making buildings more energy efficient not only saves money for owners but also makes buildings better and more valuable [16]. Addressing global climate change and energy security is crucial especially considering the significant energy consumption and environmental impact of buildings [17]. Making tall buildings more energy efficient comes with its own set of problems. Firstly, these buildings are complex which makes it tough to add energy-saving technology. In Addition, they have different uses and energy needs, so it is tricky to manage energy well. Moreover, there is not much space for things like solar panels and the tall height can make it hard to keep heat inside leading to more energy use. So, smart solutions are need to tackle these challenges and make high-rise buildings more energy efficient [18]. Basic building methods like the direction of buildings and allowing fresh air inside can save energy. Furthermore, using advanced systems for heating, cooling and lighting is important for smart energy use in buildings [19]. Making buildings more energy efficient and switching to renewable energy can help solve these problems. Updating existing buildings with energy saving technology is important to use less energy, produce fewer greenhouse gases and make sure buildings last a long time while following rules and being good for the environment [20]. Creating energy-efficient buildings is important because of the worldwide concern about climate change and the gases that cause it. Buildings around the world used huge amount of energy. They used 55% of the electricity and produced 19% of the gases that cause climate change. One solution is to make green buildings which are built and run in ways that are good for the environment. Using tools like BIM can help design buildings that use less energy. Fixing up existing buildings is also important because there are not many new green buildings being made [21]. Recently, people have been looking into different ways to get energy like solar power, wind power and biomass. It is crucial to pay attention to the use of energy aiming to make processes more efficient and use resources wisely. Energy management involves monitoring energy usage, planning to use it more efficiently and taking steps to reduce overall consumption [22]. Architects and engineers are focusing more on saving energy in tall buildings because the world needs more energy. They use different methods like using less energy for cooling or heating to help the environment [23]. The outside of a building especially its windows plays a significant role in regulating its temperature and energy usage. Updating buildings with better window systems is really important for saving energy because heating and cooling use about 60% energy of the building. Improving windows can reduce energy use of the building and lower its CO_2 emissions [24]. Researchers are paying a lot of attention to saving energy at home because it affects the environment. As energy resources are very less and people want to live comfortably, it is really important to use less energy in our homes [25]. Saving energy should be a top concern from the start of building planning all the way through to upkeep. Saving energy and being efficient are important in today. Energy efficiency should be a focus during every phase of life of building from design and construction to maintenance [26]. The research focuses on improving energy efficiency through thermal upgrades. Key findings include inspecting the heating system, identifying thermal issues with thermal imaging and assessing the energy efficiency of building before and after renovation [27]. Nowadays, there are more skyscrapers going up and the upper floors need special windows. Saving energy is important because windows can lose a lot of heat compared to walls. Installing new window frames instead of old wooden ones can help save energy which is especially important as energy costs rises [28]. Using passive design strategies is a smart and affordable way to make high-rise buildings more energy efficient. These strategies rely on natural elements like sunlight and airflow to cut down on the need for things like heaters and lights. By adding features like well-placed windows and good insulation, the energy use of building can be lower down [29]. Using active design strategies helps make high-rise buildings even more energy efficient. These strategies include using solar panels or wind turbines to generate renewable energy. These are important for cutting down on energy use and costs as these are a big part of making high-rise buildings more environmentally friendly [30]. Apart from making physical improvements, building can make more efficient by using smart systems to manage energy better. It includes smart meters and automated controls to track and adjust energy use. It makes building work better overall by saving money and cut down on environmental harm [31]. Making tall buildings more energy efficient is crucial even though it can be challenging. It is a worthwhile investment because it saves money, improves comfort and helps the environment. Upgrading heating, lighting and insulation is essential for reaching these benefits [32]. The importance of making the existing high-rise buildings more energy efficient shows that improving energy efficiency can cut down on greenhouse gas emissions, fight climate change and make energy more secure. Additionally, it saves money on energy bills, increase property value and make indoor spaces more comfortable and healthier [33]. In the past, constructing tall buildings focused more on looks and safety rather than saving energy. Because of this, many tall buildings have old-fashioned heating, lighting, insulation and windows. To tackle this problem, it is need to look at energy conservation measures that makes these buildings more energy efficient by saving energy, cut costs and help the environment [34]. This comprehensive overview aims to explain different measures to enhance energy efficiency in existing high-rise buildings. Improving old buildings with green techniques like fixing the outer shell, upgrading windows and using better lights. It includes adding insulation, changing single-pane windows to double or triple glazing and fitting energy-saving lights and sensors. Furthermore, making buildings greener involves adding solar panels, wind turbines and saving water with low-flow taps and collecting rainwater.

II. Retrofitting Strategies for Energy Efficiency

To enhance energy efficiency in existing buildings upgrades includes better insulation, new windows and doors, roof renovations and modernizing heating and water systems. These improvements can cut down energy use a lot. For more active solutions, concentrate on updating HVAC systems, using energy saving lights with sensors and adding window shading to lower heat buildup. Adding solar panels and wind turbines can also help reduce greenhouse gas emissions compared to regular energy sources. Retrofitting of residential buildings for energy efficiency using the overall thermal transfer value (OTTV). The retrofitting measures includes changes in wall colour, glazing system properties and external shading types. The OTTV measures average heat transfer into the building through walls and windows accounting for heat conduction and solar radiation. To improve energy efficiency in existing high-rise buildings, consider using modern thermal insulation materials and green building technologies like smart energy glass windows. These methods aim to minimize environmental impact throughout a life cycle of building from design to elimination including the use of technologies such as recuperators and solar panels. Implementing these measures can significantly save energy and resources while upgrading the energy efficiency class of buildings. A systematic approach for retrofitting and transitioning existing housing to energy-efficient near-zero energy buildings. The framework involves auditing the context of building, proposing solutions, retrofitting, transitioning to hybrid energy systems and feasibility analysis. The building modelled in DesignBuilder and simulated with EnergyPlus, underwent an energy audit and proposed upgrades to improve energy performance, integrate renewable energy and manage energy use efficiently. Building information modelling (BIM) and artificial neural network (ANN) technologies aid energy conservation in building design and retrofitting by considering factors like weather and occupancy. Retrofitting parts of a building can save as much energy as constructing a new one, though cost remains a challenge. Virtual simulations post-audit help identify key factors for effective retrofitting. HVAC systems consume a significant portion of energy in buildings especially in warm climates emphasizing the need to prioritize reducing cooling loads. Window design plays a crucial role, and BIM software like ArchiCAD facilitates detailed energy performance analysis offering insights for future retrofitting projects. The methodology involves setting detailed building parameters, creating thermal blocks and conducting simulations to analyse impact of the window design on energy consumption, cost and CO_2 emissions. An energy management system (EMS) is a systematic method for enhancing energy efficiency and savings through various solutions, employing descriptive methods and Greenship Rating Tools to assess existing buildings. Repairing and retrofitting involve enhancing physical infrastructure, such as improving the energy efficiency index (EEI), water consumption index (WCI) and air circulation systems. The retrofitting measures such as upgrading chiller systems, recycling wastewater, and replacing conventional lamps with energy efficient LED lights. Non-renewable energy such as coal and oil are running out and harms the environment. Renewable sources like solar and wind are abundant and clean but need better tech and affordability. Energy saving mechanisms in tall buildings encompass both passive and active designs. Passive strategies include optimizing facade design for daylighting and electric lighting efficiency, utilizing natural ventilation through thorough site analysis and considering wind effects on building structures. On the other hand, active designs involve implementing energy efficient HVAC systems like underfloor air distribution (UFAD) and combined heat and power (CHP) systems, as well as optimizing vertical transportation systems to minimize energy consumption and enhance efficiency. These approaches aim to reduce energy usage and promote sustainability in tall building designs. The energy efficiency of buildings depends heavily on the thermal properties of their windows which can impact energy consumption significantly. Different climates require different window glazing types for optimal energy savings. It is crucial to determine the most efficient window glazing upgrades for high-rise residential buildings in various climates. A DesignBuilder energy model and a Revit BIM model analysed 20 glazing options for energy savings in different Chinese climates. Using computer simulations, it evaluates the impact of different glazing types on total energy usage in regions with hot and cold climates like Hong Kong, Shanghai and Beijing. Wooden windows with ordinary glazing are a thing of the past. Nowadays, window designs have become more functional and durable due to advanced technologies and materials like wood, aluminium and PVC. In Russia, PVC windows are the most common making up 60-80% of the market while aluminium windows are used less frequently in residential buildings due to the cold climate. Energy-saving PVC windows are gaining popularity due to advancements in nanotechnology. These windows use k-glass or the more efficient i-glass which improves energy conservation and comfort. In contrast, i-glass is less abrasion-resistant, its inner placement in window units mitigates this issue. Benefits include better performance and lighter weight compared to traditional triple-pane windows with comparable costs due to mass production. The environmentally friendly renewable energy sources which includes the use of hybrid wind and solar power plants and vortex wind-driven power plants (aerogenerators) with a vertical axis to utilize both the energy of horizontal wind flows at height level and ascending airflows. The reduction in energy consumption can be achieved by the use of enclosing structures with optimal thermal characteristics for the climate zone of the construction site. The maximum use of reserves of natural lighting of premises with the use of larger windows. Energy efficiency strategies vary globally with developed regions like the EU focusing on mandatory standards for new buildings while emerging economies like India emphasize voluntary green certifications. Retrofitting existing buildings is crucial in developed areas while new construction challenges are prominent in rapidly growing regions like Asia and Africa. The path to energy efficiency involves gradually stricter standards from low-energy buildings to nearly zero-energy structures driven by integrated design processes and renewable energy adoption. This shift towards efficiency is economically feasible and essential for sustainable development. Implement advanced efficiency approach for up to 90% energy savings. Utilize ultra-low-energy buildings (ULEB) for maximum efficiency potential. The building envelope separates habitable areas from the external environment and includes walls, doors, windows, roofs and floors. Thermal insulation reduces heat transfer between objects of different temperatures measured by R-value (thermal resistance) and U-value (thermal conduction). Heat transfer is influenced by the temperature difference across a surface and materials with high thermal mass can absorb and slowly release heat aiding in temperature regulation. This study models various retrofitting techniques for older buildings in Sydney to improve energy efficiency focusing on adding insulation to ceilings, walls and floors. The primary objective of this study is to identify the most effective and efficient retrofitting techniques to enhance the energy efficiency of buildings specifically focusing on three types of dwellings: weatherboard, cavity brick and brick veneer. To achieve this, the study employs different software to simulate annual heating and cooling energy consumption across various retrofitting scenarios including different levels of ceiling, wall and floor insulation. The simulation results are then compared to a reference case to ascertain the percentage reduction in energy usage thereby determining the most beneficial retrofitting strategies for each dwelling type. This study investigates ventilation strategies for tall buildings focusing on single-sided ventilation and impact of balcony design on airflow. Using computational fluid dynamics (CFD), it analyses various building configurations and wind angles to predict indoor ventilation performance. The study validates its results using wind tunnel data and employs CFD simulations with standard k-epsilon turbulence model. Building models with openings and balconies are tested to understand their effects on airflow in different scenarios aiming to optimize indoor ventilation in tall buildings. Key retrofit technologies include replacing heating, cooling and water heating systems, upgrading lighting and electrical systems, improving plumbing with water recycling, and enhancing the building envelope through thermal insulation, window replacement, and roof renovation. These measures contribute significantly to energy efficiency and owner satisfaction. Installing a noise screen to allow natural ventilation using super-insulated panels and full-height glazing for a new facade and heating the entire block with a biomass boiler while incorporating solar heaters for domestic hot water. It adds public value by enhancing environmental quality, promoting mixed-use living, providing an attractive atrium space and establishing a public garden.

III. Impacts of Improved Energy Efficiency

The results showed that combining retrofitting measures decreased OTTV by up to 75.6% improving building energy efficiency and indoor comfort. Light colours like white reduced OTTV by 21.05 W/m² compared to dark brown paint. Upgrading glazing to low-E types lowered OTTV by up to 26.94 W/m². Horizontal shading devices were more effective, reducing OTTV by 17.41 W/m², while Egg-crate shading achieved 27.68 W/m² reduction. These measures individually reduced OTTV by 21.05 W/m² to 27.68 W/m². Combining them further reduced OTTV to 20.19 W/m², enhancing energy efficiency by up to 75.6%. The planned energy efficiency class for the residential compound was upgraded from high to very high, meeting green building criteria. Implementing energy efficient measures in construction significantly saves energy and resources. As a result, the building has become more efficient than before whereas the payback time was 10 years. The economic and environmental analysis highlighted that it is possible to save energy demand by up to 51–75% for heating and up to 5–32% for cooling; electricity and hot water consumption was covered at 98% and 80% respectively, whereas associated gas emissions are reduced by up to 252 tons per building reduction of 91%. The Wisma R&D model in ArchiCAD was carefully crafted to match real world conditions revealing that window design plays a crucial role in cutting cooling loads. Optimal window selection guided by thermal resistance can significantly reduce energy use and CO_2 emissions emphasizing the importance of detailed modeling for sustainability. By optimizing window parameters, cooling loads were reduced by 3% to 6% leading to substantial energy and carbon dioxide savings. This study underscores value of ArchiCAD for retrofitting decisions and highlights the need for a comprehensive approach to energy conservation in high-rise buildings. Future research assess the cost and investment impact of these initiatives and explore LED lighting to further decrease cooling load demand. The average energy efficiency index (EEI) of 134.04 kWh/m^2/year and water consumption index (WCI) of 27.18

liters/person/day. Retrofitting efforts included chiller replacement, resulting in a 25% improvement in efficiency. The comparison of electricity bills before and after retrofitting showed a significant decrease with an estimated Return on Investment (ROI) of 46.33 months or 3.86 years. The case studies highlight innovative engineering and architectural solutions such as double-skin facades (DSFs) and dynamic shading systems tailored to extreme climates like scorching weather of the Abu Dhabi. They emphasize using high performance glass and renewable energy sources like geothermal systems, PV panels and wind turbines to reduce energy consumption. Integration of building systems from physical to visual and performance aspects is crucial for sustainable tall building design, ensuring energy efficiency and long-term cost savings. The study explores energy efficient window solutions for high-rise residential buildings in three different climate zones in China. It suggests that low-e glass works best for hot climates like Hong Kong, tinted double low-e glazing is more effective in places like Shanghai and clear double low-e glazing is ideal for colder regions like Beijing. However, factors like cost and practicality also need consideration. Future research should delve into other aspects such as window frames, monthly energy consumption, payback periods and the impact of shading systems to further enhance energy efficiency in buildings across various climatic conditions. Using BIM software and energy simulation tools, it suggests that 6 mm low-e double-glazing with 13 mm air fill is the most effective option offering significant energy savings. Tinted glass is recommended for hot climates while clear glass is better for cold climates. Retrofitting existing buildings with these solutions could help meet energy reduction targets and inform future design decisions. A number of studies show that the use of solar and wind energy in buildings makes it possible to save up from 11% to 15% in energy consumption per year. The energy from renewable energy sources is converted into heat, and hot water has proved to be the most popular and economically viable one. The analysis of opportunities of renewable energy sources has shown that to ensure energy conservation in high-rise buildings, it is feasible to use hybrid wind and solar power plants. The solar panels generate up to 180 megawatt-hours of electricity annually and uses wind turbines to produce 10% of its energy needs. Green technologies enable efficient use of energy, water and materials in buildings, promoting healthier environments and reducing costs. These technologies minimize harmful impacts on health and the environment throughout the life cycle of building by optimizing construction, design, operation and waste management. Sustainable architecture enhances creativity allowing architects to pursue universal values and energy efficiency without compromising aesthetics or functionality. Low-energy and ultra-low-energy buildings across various climates allowing for targeted energy efficiency efforts. Starting with low-energy buildings and progressing to ultra-low-energy structures is advisable for countries aiming to enhance building efficiency with potential for rise to higher efficiency levels. Continued research and practical examples are essential for refining standards particularly in hot climates to ensure cost effectiveness and widespread adoption. Easy efficiency approach reduces primary energy consumption by 40% to 60%. Advanced efficiency approach achieves savings up to 90% compared to standards. Retrofitting dwellings with insulation significantly reduces energy usage. For weatherboard houses, adding R2-6 ceiling insulation cuts energy use by 47%-52%, R2.25 Rockwool wall insulation reduces it by 69% and R1 floor insulation reduces it by 71%, though the improvement from the second stage is only 2%. In cavity brick houses, adding R2-6 ceiling insulation reduces energy use by 62%-66%, R1.25 Rockwool wall insulation by 77% and R1 floor insulation by 83%. For brick veneer houses, R2-6 ceiling insulation cuts energy use by 44%-49% and R2.25 Rockwool wall insulation by 69%. Across all types, ceiling insulation offers the most significant initial energy savings followed by wall insulation. Floor insulation provides minimal additional benefits and is generally not cost effective. The validation study indicated inaccuracies in wind pressure predictions by CFD especially at lower levels of buildings affecting indoor ventilation rate predictions. Cross ventilation outperformed single sided ventilation with balconies reducing ventilation effectiveness in single sided setups but enhancing it when split into two openings. Balconies improved ventilation especially when openings were reconfigured. Balconies can improve ventilation performance in high-rise buildings. Incorrect combination of balcony configurations can reduce ventilation performance. Heat recovery, daylighting, natural ventilation and large UV-coated swing windows employed. Retrofitting saved MYR 14 million and shortened construction time by 29 months compared to new building. Effective integration of green technology equipment and fittings along with enhancing the building envelope using passive systems, installing energy-saving lighting systems and maximizing the use of daylight. Improving heating, cooling and ventilation systems along with implementing renewable energy sources resulted in a remarkable 30% reduction in energy consumption. Additionally, carbon emission reduction exceeded 50% after four years of implementing retrofitting measures. Improvements in envelope materials, energy consumption, domestic hot water and heating and cooling systems were achieved through the use of solar collectors and PV cells. Heating reductions ranged from 51% to 75% while cooling reductions ranged from 32% to 5%. Nearly all electricity needs met (97%), along with 80% of thermal needs for heating and domestic hot water. Excess energy generated by renewable energy sources was estimated at 27% for electricity and 12% for thermal production. The investment cost for the retrofitting transition system resulted in a 10-year payback period. Greenhouse gas emissions for the entire building could be reduced by up to 91%. Optimizing the building envelope through improvements to the external walls and roof along with installing a PV system led to a retrofit package that reduced the payback time. These actions saved 72% of the energy used for heating and cooling. Improving the building envelope, HVAC and artificial lighting systems along with integrating passive heating and cooling components significantly reduced energy use. In enclosed and cellular office buildings, these retrofits lowered total energy consumption by 48% in the North Coastal region and 56% in the North European region. Implementing heat recovery, daylighting, boiler efficiency economizer, preheat upgrades and lighting load reduction can significantly cut energy consumption. These five retrofit options could reduce electricity use by 20% and decrease natural gas consumption by 30%. Upgrading windows, adding insulated reflective barriers, implementing tenant daylighting and energy efficient lighting and plugs, retrofitting the chiller plant, using a new air handling layout and demand control ventilation can reduce energy use by 38%. These measures can save 105,000 metric tons of CO_2 over 15 years. Wall insulation, window upgrades, shading devices, energy efficient heating and cooling systems and renewable energy systems are key retrofits. In warm zones achieving a 40% reduction in energy consumption requires higher investment and more complex measures due to the cooling demands. Improving wall insulation is the most effective way to enhance the thermal performance of building evaluated by the U-value which measures the heat transfer coefficient of external walls. Insulating exterior walls and roofs, replacing outer windows, retrofitting the central air conditioning system and using energy-efficient appliances can significantly reduce energy consumption. Lighting and air conditioning systems when upgraded together can reduce total energy use by 8% to 13%. Installing LED lighting and a frequency conversion device for the water chiller not only cuts energy use but also saves costs. These improvements can lower total energy consumption by about 13% with a payback period of 7 to 8 years. The proposed strategies include mixed-mode ventilation, solar and thermal control, replacing lighting and air conditioning units and using Building integrated photovoltaic (BIPV) systems. These passive measures significantly improved electricity use cutting consumption from 84 to 43.5 kWh/m²/year compared to the base case. External wall insulation, low-E double glazing and simulation conducted along with the application of a green roof. The majority of savings came from the green roof accounting for approximately 29%. In terms of electricity consumption, the maximum saving was about 890 kWh, roughly 15% reduction. Improvements like external wall and roof insulation, external shading and changing glazing systems. The analysis showed that all retrofit solutions paid back in less than 20 years. LED lights, internal blinds, double glazing and existing external shading commonly found in optimal retrofit solutions. These measures could lead to energy use reductions of up to 50%. Options for reducing building energy usage include improving the building envelope, adding shading elements, designing a natural ventilation system and installing energy-efficient lighting. Implementing these strategies can lead to significant energy savings, insulating the building envelope saves up to 5.75%, adding shading can save 8.87% and combining energy reduction techniques can achieve a 28.52% reduction. The remaining energy needs can be met by integrating solar panels and wind turbines generating 44% and 56.7% of the required energy respectively. Upgrading external walls and roofs, altering glazing and adding overhangs on the west and south sides. LED lighting will replace existing fixtures and a mixed-mode HVAC system will be installed allowing for natural and mechanical ventilation. This retrofit strategy reduced annual energy consumption by 46%–65% and CO_2 emissions by 59%–72% across all retrofitted cases. Enhance natural airflow, establish a rooftop garden with vertical plants, implement runoff management, employ a flexible building covering, install a rainwater harvesting system, integrate a wastewater treatment setup and utilize smart building management. Additionally, install solar water heating and a PV system. This resulted in significant annual CO_2 emission savings of 5716.3 kg, reduced dust by 140.2 kg, lowered runoff coefficient and maintained indoor environmental quality within acceptable standards. Improve insulation for walls, roofs, floors, upgrade windows and shading, enhance chiller units, HVAC systems, lighting, utilize gas-fired boilers and centrifugal chillers for heating and cooling. Achieve accurate simulations of real world scenarios using physics based modeling supported by sensitivity analysis, optimization algorithms and non-linear regression tools. Improve HVAC and lighting systems, switch from oil to natural gas boilers, install sub-metering and control systems, enhance roof and wall insulation, upgrade windows with shading, films, double-layer glass and add solar power. Upgrade the building envelope by insulating walls, roofs, windows and replace single glass windows with low-E ones. Upgrade lighting systems to LEDs, implement a domestic hot water system with heat recovery and card-operated efficient cookers, and upgrade HVAC systems by replacing heat pumps, motors and exhaust fans. Install water saving cooling towers and a solar water heater. Achieve energy savings of 26% and 38% respectively with energy use intensity (EUI) savings of 66.68 and 54.06 kWh/m^2. Actual measurements showed a 10.4% increase compared to simulated benefits. Different options for a green envelope including wall insulation, double-glazed windows, green roof and sun shading devices. The green roofs significantly reduced energy consumption by 62.6%, dropping from 207,693 kWh to 77,738 kWh. Following this, the installation of double-glazed windows resulted in higher energy consumption compared to the green roof reaching 163,368 kWh.

IV. CONCLUSION

Improving energy efficiency in high-rise buildings has challenges but offers great potential for better performance, cost savings and environmental benefits. Key obstacles include a lack of awareness among building owners, inconsistent government incentives and fragmented rebate programs. Addressing these issues through education and accessible support can lead to significant improvements. Creating net-zero energy buildings involves careful consideration of building placement and appliance types. The construction industry is increasingly focusing on net-zero energy buildings aiming for more sustainable construction methods. As environmental awareness grows, net-zero buildings will play a crucial role in urban development. Improving energy efficiency in existing high-rises requires a comprehensive approach that includes technology, financial considerations and occupant behaviour. Research highlights that costs and lack of awareness are significant hurdles. Enhancing energy efficiency in high-rise buildings involves retrofitting with better insulation, upgrading windows and doors, renovating roofs and updating heating and water systems. Active solutions include upgrading HVAC systems using energy efficient lighting with sensors and employing window shading. Renewable energy sources like solar panels and wind turbines can further reduce greenhouse gas emissions. Managing heat gain and loss in tall buildings is crucial especially with mixed concrete facades. Common strategies include shading and thermal resistance to reduce summer heat and increase winter warmth with a focus on frontal windows due to their significant heat transmission. Energy efficient buildings are essential globally to combat climate change. High-rise buildings, especially un-renovated ones can emit large amounts of carbon dioxide and other pollutants. However, employing advanced energy-efficient technologies can significantly reduce these emissions. Advances in technology enable buildings to be programmed for economical and environmentally friendly operation from the construction stage. Existing buildings often lack these advantages due to limitations in current tools and systems. Keeping up with technological developments is essential for offering innovative automation and energy systems. Upgrading HVAC systems in high-rise buildings is crucial for improving energy efficiency and reducing costs. Despite the high initial investment, benefits include lower energy bills, longer equipment lifespan and meeting sustainability goals. Upgrading lighting in high-rise buildings can cut electricity costs, improve lighting quality and reduce environmental impact. Building owners should assess their current systems and consider retrofits for better energy efficiency. New LED technology and advanced controls like occupancy sensors make these upgrades increasingly practical. Upgrading insulation in high-rise buildings helps reduce energy use, lower costs, and improve comfort by maintaining indoor temperatures, thus decreasing greenhouse gas emissions and contributing to sustainability. Implementing energy efficient measures in high-rise residential buildings can significantly save energy and resources, improving their energy efficiency class. This includes using modern thermal insulation and green building technologies. Ensuring accuracy in building energy simulations is crucial before retrofitting decisions. It emphasizes the importance of sustainable development and energy consciousness to address global challenges like energy shortages, pollution and climate change. Collaboration among engineers, architects, policymakers and other stakeholders is crucial for implementing renewable energy solutions and reducing greenhouse gas emissions ensuring a sustainable future. The development of green skyscrapers which utilize natural resources to create healthy living conditions is promising. The goal is to achieve passive buildings with low energy consumption and zero-energy buildings using bioclimatic design and renewable energy sources to enhance comfort without costly technologies.

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References

[1] Javeria A. Rehma, Babar Hussain, Aamir Habib, and Rizwan Mughal (2021, June). Current Energy Crisis of Pakistan: Status, Impact and Potential Solutions. Volume 1, No. 1 (1-5); Pakistan Journal of Scientific Research.

[2] Usama Rehman (2023, March). Energy Crisis in Pakistan; Modern Diplomacy.

[3] Yasser Arab, Ahmad Sanusi Hassan, Zeyad Amin Al-Absi, Hussam Achour, Boonsap Witchayangkoon and Bushra Qanaa (2023, February). Retrofitting of a High-Rise Residential Building for Energy Efficiency with OTTV as an Assessment Tool. Volume 102: Semarak ilmu. https://doi.org/10.37934/arfmts.102.2.110119.

[4] Adelwyn Holder (2023, August). Design Strategies for Resilient Buildings. IKIGAI.

[5] Christina Diakaki and Evangelos Grigoroudis (2021, April). Improving Energy Efficiency in Buildings Using an Interactive Mathematical Programming Approach. Volume 13: MDPI. https://doi.org/10.3390/su13084436.

[6] Christopher Anthony Moore, Dietmar Schuwer and Stefan Thomas (2013, June). A global strategic approach to energy efficiency in the building sector.E3S Web of Conferences.

[7] Teresa Parejo-Navajas (2015, September). A Legal Approach to the Improvement of Energy Efficency Measures for the Existing Building Stock in the United States Based on the European Experience. Volume 5: MDPI.

[8] Anna Yu. Zhigulina and Alla M. Ponomarenko (2018, March). Energy efficiency of high-rise buildings. Volume 33: E3S web of conferences. https://doi.org/10.1051/e3sconf/20183302003

[9] S. G. Sheina , L. V. Girya , A. E. Shvets *and* N. S. Larin *(2022, December).* Methods of Enhancing Energy Efficiency at the Stage of Construction of High-Rise Residential Buildings. Volume 1: Modern Trends in construction, urban and Territorial Planning. https://doi.org/10.23947/2949-1835-2022-1-1-17-23.

[10] Laila M. Khodeir and Fatma Fathy (2023, May). Identifying Retrofit Technology to Improve Building Energy Performance: A Review. Volume 178: Engineering Research Journal. https://doi.org/10.21608/ERJ.2023.302133

[11] Aysenur Sumer Coskun and Semra Arslan Selçuk (2022, April). Global Research Trends on Energy Efficient Retrofitting in Existing Buildings. Volume 53: Periodica Polytechnica Architecture. https://doi.org/10.3311/PPar.18507.

[12] Inessa Lukmanova and Roman Golov (2018, March). Modern energy efficient technologies of high-rise construction. Volume 33: E3S web of conference. https://doi.org/10.1051/e3sconf/20183302047.

[13] O A Oguntona, B M Maseko, C O Aigbavboa and W D Thwala (2019, October). Barriers to retrofitting buildings for energy efficiency in South Africa. Volume 640: IOPscience. https://doi.org/10.1088/1757-899X/640/1/012015

[14] Kenneth T. Gillingham , Pei Huang, Colby Buehler, Jordan Peccia and Drew R. Gentner (2021, August). The climate and health benefits from intensive building energy efficiency improvements. Volume 7: Science Advances. https://doi.org/10.1126/sciadv.abg0947.

[15] Pavel Khavanov, Ekaterina Fomina and Natalia Kozhukhova (2018, March). The improvement of thermal characteristics of autoclave aerated concrete for energy efficient high-rise buildings application. Volume 33: E3S web of conferences. https://doi.org/10.1051/e3sconf/20183302073.

[16] G. M. Calvi, Cristiana Ruggeri & Luis Sousa (2016, May). Energy Efficiency and Seismic Resilience: A Common Approach, Multi-hazard Approaches to Civil Infrastructure Engineering (pp 165–208) DOI:10.1007/978-3-319-29713-29.

[17] Montserrat Zamorano (2022, August). Recent Advances in Energy Efficiency of Buildings. PP 146: Applied Scieces. https://doi.org/10.3390/books978-3-0365-4910-1.

[18] Paola Penna, Alessandro Prada, Francesca Cappelletti and Andrea Gasparella (2014, July). Enhancing the Energy and non-Energy Performance of Existing buildings: a Multi-Objectives Approach. MDPI.

[19] N V Rudenkoa, V V Ershovb and N A Konshinac (2019, February). Energy Conservation in High-Rise Buildings Based on Environmentally-Friendly Renewable Energy Sources. IOPscience. https://doi.org/10.1088/1755-1315/224/1/012020.

[20] Khadidja Rahmani, Atef Ahriz and Nahla Bouaziz (2022, March). Development of a New Residential Energy Management Approach for Retrofit and Transition, Based on Hybrid Energy Sources. MDPI. https://doi.org/10.3390/su14074069.

[21] Siti Birkha Mohd Ali, Amirhossein Mehdipoor, Noora Samsina Johari, Md. Hasanuzzaman and Nasrudin Abd Rahim (2022, November). Modeling and Performance Analysis for High-Rise Building Using ArchiCAD: Initiatives towards Energy-Efficient Building. MDPI. https://doi.org/10.3390/su14159780.

[22] Marsul Siregar, Firma Purbantoro and Tajuddin Nur (2019, September). Implementation of Energy Management Concept and Energy Management System in High Rise Office Building. Volume 16: Jurnal Tiarise. https://doi.org/10.32816/tiarsie.v16i3.55.

[23] Mir M. Ali, Kheir Al-Kodmany and Paul J. Armstrong (2023, February). Energy Efficiency of Tall Buildings: A Global Snapshot of Innovative Design. Volume 16: PP (2063-2063): MDPI: https://doi.org/10.3390/en16042063.

[24] Qiong He, S. Thomas Ng, Md. Uzzal Hossain and Martin Skitmore (2019, November). Energy-Efficient Window Retrofit for High-Rise Residential Buildings in Different Climatic Zones of China. Volume 11: PP 6473: MDPI. https://doi.org/10.3390/su11226473.

[25] Yirong Huang (2023, July). Energy Benchmarking and Energy Saving Assessment in High-Rise Multi-Unit Residential Buildings. Toronto Metropolitan University.

[26] Sergey Korniyenko (2018, March). Complex analysis of energy efficiency in operated high-rise residential building: Case study. Volume 33: Web of Conferences. https://doi.org/10.1051/e3sconf/20183302005.

[27] L. V. Kosenko, o. O. Koval, e. L. Yurchenko and o. A. Tymoshenko (2023, january). Energy efficiency of the heating system of the high-rise building of pdaba. Volume 6: ukrainian journal of construction and architecture. https://doi.org/10.30838/j.bpsacea.2312.271222.66.912.

[28] Olga Gamayunova, Eliza Gumerova and Nadezda Miloradova (2018, March). Smart glass as the method of improving the energy efficiency of high-rise buildings. Volume 33: E3S web of conferences. https://doi.org/10.1051/e3sconf/20183302046.

[29] Claire Far and Harry Far (2019, June). Improving energy efficiency of existing residential buildings using effective thermal retrofit of building envelope. Volume 28: Sage Journals. https://doi.org/10.1177/1420326X18794010.

[30] Parejo Navajas, Teresa (2014, December). The Energy Improvement of the Urban Existing Building Stock: A Proposal for Action Arising from Best Practice Examples. MDPI. https://doi.org/10.7916/D88C9VDF.

[31] Mohamed M. F., King S., Behnia M. and Prasad D. (2011, November). A study of single-sided ventilation and provision of balconies in the context of high-rise residential buildings. LiU electronic press. http://dx.doi.org/10.3384/ecp110573216.

[32] Natalia D. Potienko, Anna A. Kuznetsova, Darya N. Solyakova and Yulia E. Klyueva (2018, February). The Global Experience of Deployment of Energy-Efficient Technologies in High-Rise Construction. Volume 33: E3S Web of Conference. https://doi.org/10.1051/e3sconf/20183301017.

[33] Oguzhan Timur, Kasım Zor, Ozgur Celik and Ahmet Teke (2018, July). Enhancement of a Low-Cost Intelligent Device for Improving Energy Efficiency in Buildings. Volume 60: Academia.edu. https://doi.org/10.1501/commua1-20000000118.

[34] Kheir Al-Kodmany (2014, September). Green Retrofitting Skyscrapers: A Review. MDPI. https://doi.org/10.3390/buildings4040683.