TOWARDS ENERGY TRANSITION IN RESIDENTIAL BUILDING SECTOR: CASE STUDY OF LEBANON

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ABSTRACT

The current global context, global warming and fires, war and energy market crisis, health crisis, impose new problems for cities and risk putting the quality of life of individuals in danger.

The building sector is a priority issue for the energy and environmental transition. In developed countries, it accounts for more than 40% of energy consumption and nearly 25% of greenhouse gas (GHG) emissions. Thus, it will be important to opt for sustainable strategies that promote energy and environmental transition in the building sector. To reduce GHG emissions, both residential and tertiary building parks must therefore reduce their energy consumption needs. Hence the challenge is to provide strategies for existing buildings to reach energy targets and comply with energy transition regulations. Considering the three fundamental axes of sustainable development (economic, environmental, and social) will make it possible to cover all aspects of the energy performance for residential and tertiary parks. This study focuses on Lebanon's residential building sector, aiming to reduce GHG emissions by decreasing energy consumption. The objective of the present work is threefold. First, identify the possible sustainable strategies and solutions that aim to provide residential buildings characterized with less energy consumption thus less production of GHG gas emissions. Second, propose a short-term roadmap with a target of implementing sustainable strategies and systems relying on renewable energy with a recommended timeframe of five years. The purpose is to capture immediate opportunities of improving sustainability in the building sector, while focusing on the reduction of energy consumption as well as GHG emissions. This plan will also allow to compare different types of building envelopes, to provide optimal envelopes based on multiple criteria such as sustainability indicators, energy efficiency, GHG emissions, construction materials and other parameters to be considered. And third, examine the impact of building energy transition management on its surrounding environment.

The study will analyze a conventional building in Beirut as a reference case and propose improvements in terms of insulation, glazing, HVAC systems, and integration of renewable energy methods. The findings will then be extrapolated to 2% of Beirut's residential buildings annually over five years.

The main results indicate that implementing energy-efficient measures can significantly reduce energy consumption for both cooling and heating by approximately 46-50% and lighting by 65%. Moreover, improvements in HVAC systems and the use of photovoltaic (PV) solar panels further contribute to energy savings. CO_2 emissions were reduced by approximately 71% in the improved building scenarios. The financial analysis shows a favorable payback period of around 7 years and a return on investment (ROI) of over 110%. To achieve these objectives, the study employs a comprehensive methodology involving a detailed case study analysis, energy simulations using DesignBuilder software integrated with EnergyPlus, and an assessment of the environmental and financial impacts of the proposed strategies.

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Keywords
Energy transition; GHG emissions reduction; Sustainable Buildings; Building Envelope; Sustainability Indicators; Renewable Energy; Phase Change Material; DesignBuilder.

1. INTRODUCTION

As cities expand and populations burgeon, the demand for energy to power our homes, offices, and infrastructure has surged, accompanied by a proportional increase in GHG emissions. In recent years, policymakers, industry leaders, and researchers are acting urgently with the rapidly evolving global landscape to address energy sustainability within the built environment against the backdrop of escalating global concerns related to climate change and depleting conventional energy resources. The building sector, as both a symbol of human progress and a significant contributor to environmental degradation, stands at the epicenter of the quest for a sustainable future. This sector plays a pivotal role in the broader context of mitigating climate change and fostering environmental stewardship. Since the end of 2019, the country of Lebanon has faced an unprecedented economic crisis, marked by severe financial instability, soaring inflation, and a significant decline in the country's economic prospects. The shortfall in government-provided electricity (EDL) has driven many Lebanese to explore sustainable and self-reliant methods to meet their energy needs. About 40% of the total national final energy consumption in Lebanon is consumed in the building sector. Emissions in the housing sector account for about 34.9 % of total emissions, the largest share of which (34.8 %) is consumed for energy use [1]. Total GHG emissions in the building sector reached 12 $GtCO_2$-eq in 2019, equivalent to 21% of global GHG emissions that year, of which 57% were indirect CO_2 emissions from offsite generation of electricity and heat, followed by 24% of direct CO_2 emissions produced on-site and 18% from the production of cement and steel used for construction and/or refurbishment of buildings. If only CO_2 emissions would be considered, the share of buildings CO_2 emissions increases to 31% out of global CO_2 emissions [2]. In the face of this pressing issue, the Lebanese population has found alternative energy solutions to cope with this energy deficit. Among these, the adoption of photovoltaic solar panels has emerged as a promising avenue. Harnessing the abundant sunlight that bathes the Lebanese landscape, individuals and businesses alike have turned to solar energy as a means of generating electricity and reducing their dependence on the struggling national grid. Additionally, to compensate for the erratic electricity supply, the use of generators powered by diesel has become widespread. These generators offer a temporary solution, providing essential power during the frequent blackouts that have become a daily reality for the Lebanese people. However, the reliance on diesel generators comes with its own set of challenges, including environmental concerns and financial burden associated with the rising costs of fuel. This paper aims to explore the different strategies of managing the energy transition in the building sector in the Lebanese context, with a specific focus on implementing sustainable solutions and integrating renewable energy systems in compliance with evolving energy and environmental regulations.

2. METHODOLGY

This study employs a comprehensive methodology to investigate the management of the energy transition within the residential building sector, with a focus on implementing sustainable strategies and renewable energy systems. Divided into three interconnected parts:
In this study, the dynamic simulations were conducted using EnergyPlus Version 8.9.0.001 (DLL) integrated within DesignBuilder software Version 6.1.0.6. EnergyPlus employs the heat balance method to calculate thermal loads, accounting for convective, radiative, and conductive heat transfers within building zones. The software models the zone air heat balance, surface heat balance, and HVAC system performance using detailed physical and empirical models. Radiative heat exchanges between surfaces are computed using the radiosity method. DesignBuilder define building geometry, materials, occupancy schedules, and HVAC systems, translating these inputs into EnergyPlus input files and

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processing simulation outputs to generate comprehensive energy performance and GHG emissions reports. EnergyPlus uses a combination of heat balance, mass balance, and other thermodynamic equations to simulate building performance. [3]

- The study starts with a case study examining a conventional building situated in Beirut, Lebanon, which serves as a reference point for subsequent analyses. These analyses entail improvements in various aspects such as insulation materials for the building's envelope, glazing types, HVAC systems, and the integration of renewable energy methods. Detailed assessments of cooling and heating designs, along with energy consumption, are conducted for each case to facilitate comparisons of the implemented enhancements. Furthermore, calculations are performed to establish GHG emissions and the associated cost implications.
- Following this, the projected enhancements are extrapolated to encompass 2% of the total number of buildings in Beirut annually. This gradual implementation strategy spans over a 5-year period and aims to promote the adoption of sustainable practices within the built environment. This staged approach will help display more manageable stages in which the effectiveness of energy-saving interventions can be tested on a smaller scale before implementing them widely. It also offers a practical and achievable starting point for stakeholders to become engaged. This first targeted intervention, showcasing early successes, can in the long run be a significant contribution toward the long-term goal of GHG emissions reduction by 2030 according to the Paris Agreement.
- Subsequently, the study shifts its focus towards evaluating the environmental impact of GHG emissions originating from both conventional buildings and improved scenarios.

In the following sections, calculations' results will be presented, and discussed. Energy simulations were conducted using DesignBuilder as mentioned. A conduction finite difference (CTF) solution algorithm should be employed to discretize the building envelope into nodes as well as numerically solving the heat transfer equation using a finite difference scheme [6]. Furthermore, the software can simulate advanced construction materials such as PCM with changeable thermo-physical properties. The simulation runs throughout the year, starting from January 1st till December 31st with a time step of 12 per hour. Through the detailed analysis of data, important factors such as energy usage, GHG emissions, and their environmental impact will be explored. These sections aim to provide a comprehensive evaluation of how effectively sustainability must be promoted in the residential building sector through the implemented strategies. Concerning CO_2 emissions, DesignBuilder utilizes energy simulation models to estimate the energy consumption of buildings. Once the energy consumption is estimated, the software uses emission factors to translate energy consumption into CO_2 emissions. These factors are typically based on regional or national average values for the carbon intensity of electricity generation and fuel sources used for heating, cooling, and other energy needs. By combining the energy consumption data with emission factors, DesignBuilder can provide estimates of CO_2 emissions associated with the operation of buildings under different scenarios. The cost analysis presented in this report will focus primarily on two critical indicators: the payback period (PP) and return on investment (ROI). The payback period refers to the length of time required for an investment to recoup its initial cost through net cash inflows generated by the investment. It is a measure of the time it takes for the investment to break even. On the other hand, the return on investment (ROI) is a financial metric used to evaluate the profitability of an investment relative to its cost. It is calculated by dividing the net profit generated by the investment by the initial cost of the investment and expressing the result as a percentage. Both PP and ROI are essential metrics in assessing the financial viability and attractiveness of investment opportunities, providing valuable insights into the efficiency and profitability of projects. It will be noted that only half of the improvement cost will be considered in HVAC system, as factors such as ducting, FCU units, sensors, and dampers will remain unchanged. Additionally, it is worth mentioning that the old systems such as in lighting can be sold for half their original price, further offsetting the total improvement expenditure. In this scenario, the PP is a basic evaluation method that disregards discount rates. Here, the initial investment refers to improvement costs, while annual cash inflows represent energy savings. In our analysis, we have considered the broader economic landscape in Lebanon, where instability and regulatory fluctuations often influence the practical cost of electricity. In conjunction with the prevalent generator rate, we have arrived at an average cost of 0.60$ per kWh. This approach aims to provide a more comprehensive understanding of

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the actual expenses incurred by consumers, factoring in both official benchmarks and real-world conditions within Lebanon's energy sector.

$$Payback\ Period\ = \frac{Initial\ Investment}{Annual\ Cash\ Inflows} \quad (1)$$

$$Net\ Profit = Total\ Net\ Profit - Total\ Investment \quad (2)$$

$$ROI = (Net\ Profit\ Total\ Investment) \times 100\%\ ROI = (Total\ Investment\ Net\ Profit) \times 100\% \quad (3)$$

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2.1. Building Energy Modeling

Three cases of buildings are considered: a conventional building, an improved building, and an improved building with integration of PCM. As mentioned earlier, these cases will be implemented in Beirut, Lebanon which is located in Zone 1 (coastal region) [4]. The conventional building will be composed of eight floors with an occupied area of 120 m^2 per floor. Each apartment will be divided as the plan shown below. Figure 1 depicts the typical floor map, showcasing detailed dimensions of the layout. Meanwhile, Figure 1 delineates the domestic zones of the floor, comprising 2 bathrooms, 2 bedrooms, a kitchen, a salon, and 2 circulation areas. In DesignBuilder, rooms are classified into zones to facilitate energy analysis, HVAC system design and airflow modeling. Zoning allows for a more accurate assessment of energy consumption by considering different occupancy patterns, internal gains, and thermal characteristics within each zone. It also enables efficient HVAC system design by tailoring heating and cooling requirements to the specific needs of different zones. Additionally, zoning facilitates the analysis of airflow patterns, which is crucial for maintaining indoor air quality. By implementing customized control strategies at the zone level, such as setpoints and schedules based on occupancy and thermal properties, buildings can achieve better comfort conditions while minimizing energy usage. In this case study, RAFIC HARIRI INTL location template is considered, and site characteristics are taken by default.

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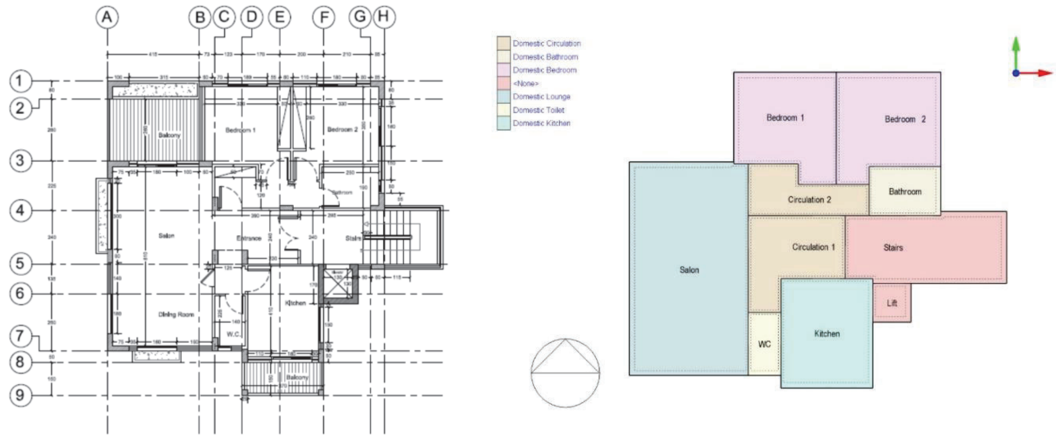
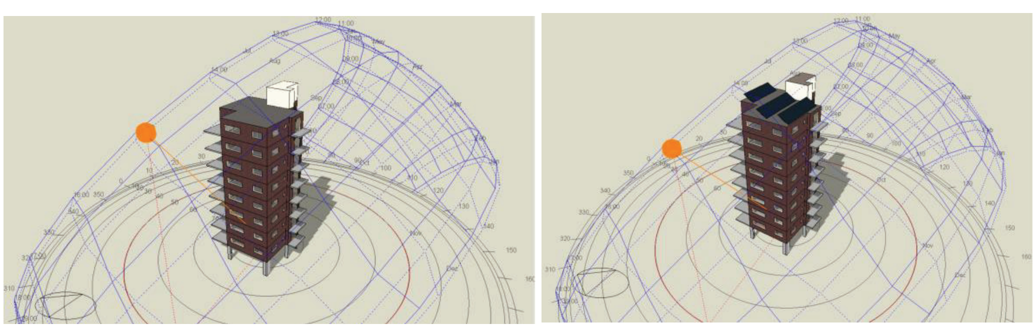


(a) **(b)**

Figure 1: Apartment Architectural Plan

2.1.1. Conventional Building

The baseline situation reflects the current state of construction in a respective country, as no building code is enforced in Lebanon [5]. As a result, no thermal insulation has been planned, heating and cooling supply is a reversible split unit with a COP of 1.8 for heating and 1.5 for cooling, and hot water is supplied by an electric appliance with an efficiency of 90%. The ventilation is natural, and the lighting system is based on CFL technology. Concerning the windows, the glazing is simple, composed of 6 mm of air. All the structural elements of the building envelope are composed of 20 cm concrete blocks (heavyweight).



(a) **(b)**

Figure 2: (a) Conventional and (b) Improved Building Modeling using DesignBuilder

2.1.2. Improved Building with XPS Extruded Polystyrene

The improved scenario is characterized by adding insulation materials to the building envelope, enhancing the HVAC system COP up to 3 for heating and 2.5 for cooling system. Moreover, a heat pump has been used instead of an electric resistance to provide DHW. Regarding Case 2 and Case 3, the change of the HVAC system from a constant refrigerant flow (DX) to a VRF system (inverter) can reduce energy consumption while providing a better level of comfort. The electricity from the grid serves as the energy source. The ventilation remains natural, and the lighting system is based on LED technology. The windows glazing is double clear 6 mm/13 mm air.

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2.1.3. Improved Building with PCM

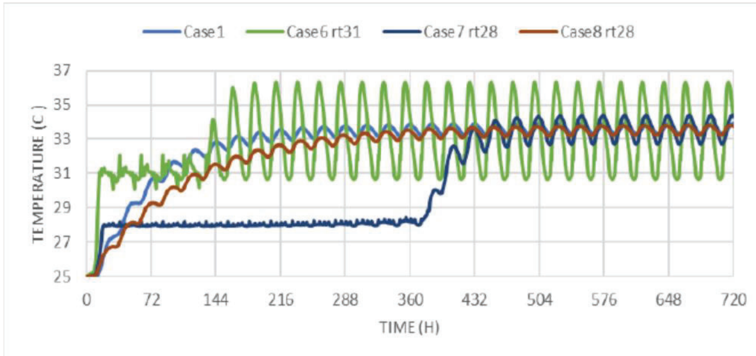

Figure 3: Internal temperature variations of Beirut cases in August with internal PCM [6]

According to Figure 3 [6], the integration of PCM into the building envelope in cases 6, 7 and 8 where PCM RT31, RT28 and RT28 are employed respectively helps the internal temperature to decrease the peak temperature and remain constant for a longer period compared to case 1 considered as conventional building without PCM. This result demonstrates the importance of the integration of PCM on reducing thermal fluctuations and lowering peak temperatures, thereby enhancing thermal comfort.

In Case 3, an innovative approach is undertaken with the integration of a layer of BioPCM M91/Q23 within both the walls and the roof of the building envelope. This strategic inclusion of phase change material (PCM) aims to enhance thermal comfort, where melting temperature is selected to be close to the temperature set point. The temperature at which BioPCM M91/Q23 changes phase is typically around 23°C. This is the temperature at which it absorbs heat to melt and releases heat to solidify.

The latent heat of fusion for BioPCM M91/Q23 is approximately 220 kJ/kg. This is the amount of energy absorbed or released during the phase change from solid to liquid or vice versa, without changing its temperature. The decision to utilize BioPCM M91/Q23 was informed by careful consideration and research of this PCM variant over alternatives [7]. BioPCM M91/Q23 offers significant advantages in maintaining thermal comfort inside buildings for extended periods compared to using only insulation materials. While XPS provides effective insulation by reducing heat transfer, BioPCM enhances thermal comfort by absorbing, storing, and releasing thermal energy as it changes phase. This ability to stabilize indoor temperatures helps in smoothing out temperature fluctuations, thereby maintaining a more consistent and comfortable indoor environment. The enhancements made for HVAC system, DHW, type of glazing remain the same as for case 2.

Table 1: U-Value of materials used in Case 2 & Case 3

Material	U-Value ($W/m^2.K$)
External Walls with 3 cm of XPS Extruded Polystyrene CO_2 Blowing	0.730
Flat Roof with 5 cm of XPS Polystyrene CO_2 Blowing	0.444
External Walls with 3.71 cm of BioPCM M91/Q23	1.487
Flat Roof with 3.71 cm of BioPCM M91/Q23	1.150

For both cases 2 and 3, PV solar panels were installed on the roof. This renewable energy system is the most suitable for Beirut situation for several reasons, including:

- Abundant sunlight: Beirut experiences long hours of sunlight throughout the year, making it an ideal location for solar energy generation.
- Potential for decentralization: Solar panels allow for distributed energy generation, enabling individual homes and businesses in Beirut to produce their own electricity and lessen strain on centralized power grids.

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- Photovoltaic efficiency: PV technology efficiency rates have been steadily improving, allowing solar panels in Beirut to convert a higher percentage of sunlight into electricity, optimizing energy output.

2.2. Improved Scenario Projection

According to Beirut Built Environment Database Base-map, the total count of fully constructed residential buildings in Beirut stood at 1649 as of 2022, comprising approximately 57.46% of the city's overall building stock [8]. A gradual enhancement of 2% of the residential buildings annually is proposed to ensure a seamless transition. This section utilizes statistical analysis to forecast the impact of the implemented scenario proposed in section 2.1.2.

2.3. Environmental Impact Assessment

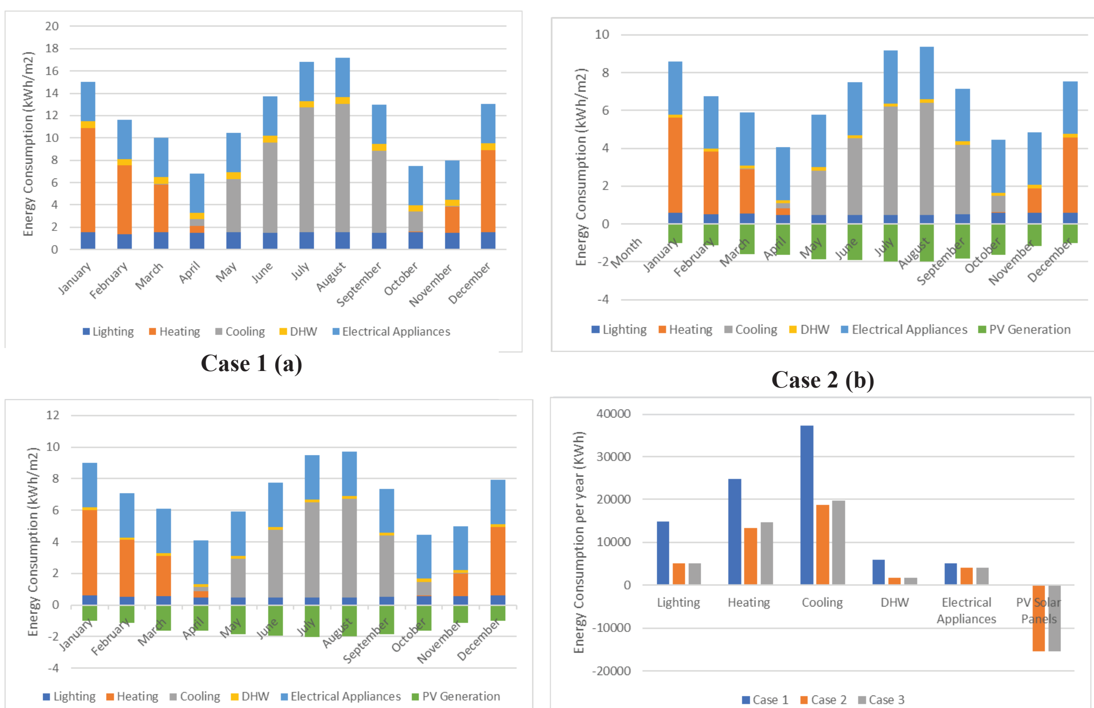
The study evaluates how GHG emissions affect the environment, with a specific focus on their contribution to global warming. This section aims to understand the wider environmental consequences of the proposed energy transition strategies.

3. RESULTS AND DISCUSSIONS

3.1. Energy Consumption, GHG Emissions and Cost

Energy Consumption

In this section, monthly energy consumption is calculated per occupied area for each of the 3 cases. Multiple simulations were launched calculating the energy consumption for lighting, heating, cooling, DHW, electrical appliances and PV solar panels generation installed on the roof of the building in case 2 and case 3 as shown in Figure 4 (a), (b), (c). Figure 4 (d) presents an annual comparison of the energy consumption of the 3 scenarios mentioned earlier.



Case 1 (a)

Case 2 (b)

Case 3 (c)

Cases 1, 2 & 3 (d)

Figure 4: Monthly (a), (b), (c) and Annual (d) Energy Consumption per m^2 for cases 1,2 & 3

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Notable results emerged regarding the seasonal energy demand within buildings. Specifically, a considerable demand for cooling was observed during the month of August, while elevated energy consumption for heating was evident in January. Remarkably, the implementation of energy-efficient measures resulted in significant reductions in energy consumption for both cooling and heating, with reductions of 45.88% and 49.57% respectively in case 2 and 41.09% and 46.91% in case 3. Moreover, advancements in lighting technology led to a noteworthy 65.38% reduction in electricity consumption for lighting between case 1 and both cases 2 and 3. Additionally, the adoption of a high-efficiency heat pump for DHW generation contributed to a substantial 70.56% decrease in energy consumption. Furthermore, the replacement of electrical appliances with higher efficiency models in Case 2 yielded a notable reduction of 20.80% in energy consumption. On the other hand, it becomes apparent that case 2 exhibit lower levels of energy usage regarding heating by 11.68% and cooling by 5.67% compared to case 3. As a result, using XPS Extruded Polystyrene for the building envelope reduces more the energy consumption than the integration of BioPCM M91/Q23.

CO_2 Emissions

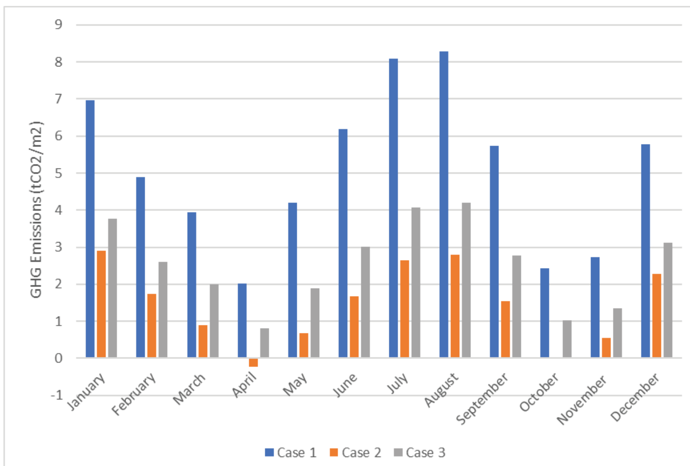

Figure 5: Monthly CO_2 Emissions for Cases 1, 2 & 3

According to the data analysis made for CO_2 production, the total calculated indirect CO_2 emissions amounted to 61.26 tCO_2/m^2 in case 1. Subsequently, upon implementing improvements in cases 2 and 3, the indirect CO_2 emissions were significantly reduced by 71.41% for an amount of 17.52 tCO_2/m^2 for case 2 and by 50.03% for an amount of 30.61 tCO_2/m^2 for case 3. These findings highlight the significant environmental benefits achievable through strategic energy efficiency interventions in building design and construction.

Total Cost

Table 2: Economic Calculations

Ref. Building Energy Consumption per year (kWh)	104,207.49
Improved Building Energy Consumption per year (kWh)	33,183.42
Energy Savings per year (kWh)	71,024.07
Average Energy Price ($/kWh)	0.60
Project Lifetime (years)	15
PP (years)	6.91
IRR (%)	12%
ROI (%)	117%

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Based on calculations made and according to the Lebanese Center for Energy Conservation (LCEC), the duration of the project span is 15 years, during which the payback period has been calculated to be 6.91 years for case 2 and 7.08 years for case 3. Additionally, the return on investment stands at 117%, for case 2 and 112% for case 3 indicating a favorable financial outcome, with an internal rate of return of 12% for case 2 and 11% for case 3. These numbers underscore the viability and potential profitability of the project over its intended lifespan. Considering the relatively short payback period, high return on investment, and favorable internal rate of return, the project appears to be more successful in case 2 compared to case 3.

3.2. Model Projection

By applying the scenario outlined in Case 2 to 2% of the residential sector over a time span of 5 years, it is projected that a total of 158 buildings will undergo renovation. The data presented in Figure 5 illustrates indirect CO_2 emissions amounting to 101 Gt/m^2 for the existing scenario. The constant emission level suggests that without any intervention, the CO_2 emissions remain stable at 101 Gt/m². This scenario acts as a control to compare the effects of the improvement measures. Conversely, the projection of the case 2 scenario on 2% of the total Beirut buildings indicates a decrease to 98.13 Gt/m^2 after a 5-year roadmap. The decrease in CO_2 emissions in the improved scenario (approximately 2.87 Gt/m² over five years) demonstrates the potential impact of targeted renovation efforts. This suggests a significant cumulative reduction in emissions when applied to the larger residential sector.

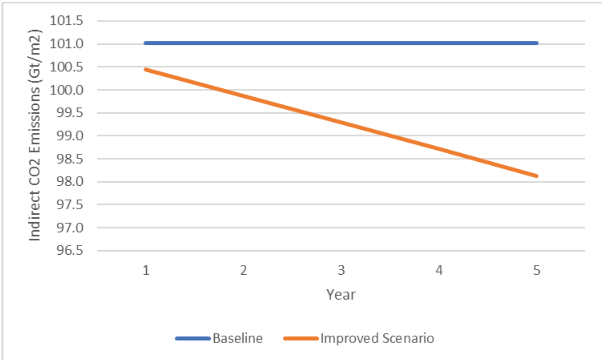

Figure 6: Annual Indirect CO_2 Emissions per m^2 for existing and improved scenarios

3.3. Impact of GHG Emissions from Buildings on Climate Change and Mitigation Strategies

The CO_2 equivalent emissions for each of the three cases were determined through comprehensive analysis and calculations. According to the Ministry of Environment, 1 kWh of electric energy produced by EDL is responsible for 0.65 kgCO_2-eq emissions.

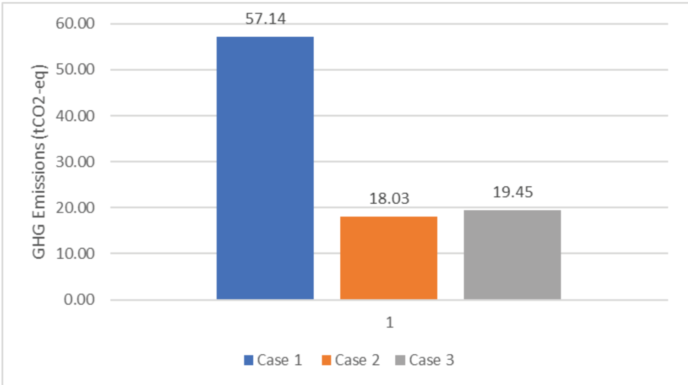

Figure 7: Annual GHG Emissions for Cases 1, 2 & 3

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The diagram depicted in Figure 7 illustrates the GHG emissions across the 3 cases. Notably, case 2 demonstrates a reduction of nearly 68% in CO_2 equivalent emissions while case 3 results of approximately 66% of GHG emissions compared to case 1. A smooth implementation of the 2 scenarios for Beirut buildings on a 5-year roadmap will result in 90.15 tCO_2-eq of GHG emissions for case 2 and 97.24 tCO_2-eq for case 3.

4. CONCLUSION AND FURTHER DEVELOPMENTS

In conclusion, the rapid increase in energy consumption within the building sector, particularly in the residential sector, poses significant challenges for environmental sustainability. This surge in energy demand inevitably leads to a corresponding rise in GHG emissions, causing atmospheric warming and contributing to global climate change. However, the case studies conducted in this paper offer promising solutions to mitigate these negative impacts. Through thermal energy renovations to building envelopes, along with improvements in HVAC and DHW systems, we can substantially reduce energy consumption by nearly 50% compared to conventional buildings. This translates to a corresponding decrease of approximately 68% in CO_2-eq emissions, showcasing the efficacy of targeted interventions in enhancing energy efficiency and reducing environmental impact. Furthermore, our analysis suggests that it will be more beneficial to use XPS Extruded Polystyrene than BioPCM M91/Q23 in terms of energy savings, cost and GHG emissions' reduction. On the other hand, the installation of PV solar panels emerges as a highly beneficial strategy. Not only does it alleviate the strain on electricity grids and reduce reliance on fossil fuel-based generators, but it also serves as a renewable energy source, free from GHG emissions. By harnessing solar energy, we can simultaneously address energy demands while advancing sustainability goals, paving the way for a cleaner and greener future. In essence, by implementing targeted energy efficiency measures, leveraging renewable energy sources, and adapting strategies to local climatic conditions, we can effectively combat the adverse effects of escalating energy consumption in the building sector.

In addition to the applied methodology and integration of PV solar panels in our case study, we can enhance renewable energy systems such as hybrid renewable systems combining PV, wind, and geothermal energy to maximize renewable energy utilization. Furthermore, we can invest in advanced energy storage technologies, such as lithium-ion batteries, or hydrogen storage, to store excess renewable energy and ensure a stable energy supply.

In parallel, we can apply Building Energy Management Systems (BEMS) for multiple advantages such as optimizing energy usage in real-time by ensuring that heating, cooling, and lighting systems operate at peak efficiency, and deploy advanced analytics and machine learning algorithms to monitor energy consumption patterns, predict maintenance needs, and identify opportunities for further efficiency improvements.

NOMENCLATURE

GHG	Greenhouse Gas
HVAC	Heating, Ventilation and Air Conditioning
DHW	Domestic Hot Water
LED	Light-Emitting Diode
CFL	Compact Fluorescent Lamps
COP	Coefficient of Performance
PV	Photovoltaic cell

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CO_2	Carbon dioxide
PCM	Phase Change Material
CO_2-eq	Equivalent Carbon Dioxide
tCO_2/m^2	Tons Carbon Dioxide per square meter
Gt/m^2	Gigatons per square meter
PP	Payback Period
ROI	Return on Investment
IRR	Internal Rate of Return
EDL	Electricité du Liban
FCU	Fan Coil Unit
LCEC	Lebanese Center for Energy Conservation

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