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Insulation's Impact on Cutting Commercial Energy Use: A Case Study in Kabul City

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Abstract. Buildings have an impact, on the environment as they consume an amount of energy and contribute to greenhouse gas emissions. This directly affects air quality and contributes to global warming. It is essential to shift from building designs to ones in order to reduce energy usage, lower emissions improve air quality and fight against climate change. While many countries have already embraced design practices, underdeveloped regions like Kabul in Afghanistan face challenges due to population growth and unregulated construction. This has resulted in sustainability issues. Compromised air quality. The building sector is responsible for 40% of energy consumption and is a major contributor to greenhouse gas emissions making its impact on the environment significant. To address these challenges caused by buildings there are keys needed. This study specifically focuses on one solution; insulating buildings. Insulation is recognized as a method for enhancing energy efficiency especially considering the increasing costs of energy and the necessity of supporting climate improvement initiatives worldwide. The research dives into the analysis of a 6-story building with no insulation having single glazed windows with aluminium frames that are oriented north to south. The building relies on air conditioning, for heating and cooling purposes. By comparing the energy consumption under insulated and uninsulated conditions this study conducts an extensive analysis of different thickness levels of polystyrene insulation. In the end the research emphasizes the advantages of installing insulation in building walls. It highlights that this action greatly improves the comfort of temperature while significantly lowering energy usage by 30 to 50 percent in the building that was studied, and also decreases CO_2 emissions.

Keywords. Energy Savings, Building Insulation, Sustainability, Energy Consumptions

1. Introduction

The reduction of energy consumption and the promotion of sustainable practices in buildings have become critical considerations in the construction industry. Buildings are responsible for a significant amount of energy consumption and greenhouse gas emissions, which makes them a target for energy-saving initiatives [1]. The energy needs of buildings, which have an influence on both the economy and the environment, are among the biggest energy demands. Statistics from the International Energy Agency (IEA) show that the residential sector utilizes about 23 percent of the total world energy demand [2].

The major problem in the energy sectors of backward countries is energy shortage. Kabul city is also one the capital cities suffering from lack of energy. A case study shows; in commercial buildings, the majority of occupants utilize gas or electric heaters, however, some also use air conditioning. AC and fans are frequently utilized for cooling. Because all the stores and markets are exposed to open areas and hallways on the lower floors of these buildings, natural air ventilation is adequate; however, the halls and corridors on the higher floors of some of these buildings have poor indoor air quality. This is due to the absence of an HVAC system in commercial structures. On the other hand, because of the excessively large hallways, the upper floors of these structures are in poor shape [3].

Meanwhile, still, there are some technics exist to reduce energy consumption, as example; Insulation is a critical component of energy efficiency in buildings, and its impact on energy savings in buildings is well-established.

The use of insulation in buildings has been proven to be an effective way to reduce energy consumption by minimizing heat transfer through building walls, ceilings, and floors [4]-[5]. Due to their size, residents, and system complexity, mid-rise commercial buildings have particular energy requirements. It has been demonstrated that good insulation can cut a considerable amount of energy use in commercial. Building owners will save a lot of money thanks to this drop-in energy use, which also results in fewer greenhouse gas emissions [6] - [9].

According to Long et al., the thermal properties of insulation materials play a crucial role in determining the energy efficiency of buildings. The authors discovered that the heat capacity and thermal conductivity of insulation materials have contrasting impacts on the energy performance of buildings. Additionally, we observed that insulation materials perform better when applied to the external walls of buildings compared to their internal walls [10]. The researchers Densley Tingley et al. conducted a study on the emissions resulting from different types of insulation materials used in buildings, and they concluded that polystyrene is the most suitable option [11].

The aim of this research paper is to investigate the potential energy savings that can be achieved by adding polystyrene insulation to the envelope walls of mid-rise commercial buildings, using a case study in Kabul, Afghanistan. However, the potential for energy savings owing to insulation in mid-rise commercial buildings is less explored. This research comprised an assessment of energy usage in a mid-rise commercial structure by analyzing meteorological data, conducting a review of existing literature, and gathering details on heat loss, energy consumption, electricity costs, and the accessibility of insulation materials in the market. To evaluate the efficiency of insulation and its capacity for reducing energy consumption, and CO_2 emissions, the study conducted dynamic simulations using HAP software version 4.9.

2. Methodology

2.1. Site selection

We selected a mid-rise commercial building for this study located in Kabul city capital of Afghanistan. To ensure a diverse set of data, we took into consideration factors such as building type, age, location, and climate zone. Figure 1. shows 2D floor plan for the case building constructed in 2019, this 6-story building is faced north to south and has a total area of 2070m^2. It is consisting of 54 shops, corridors, stairs, an elevator, and toilet area.

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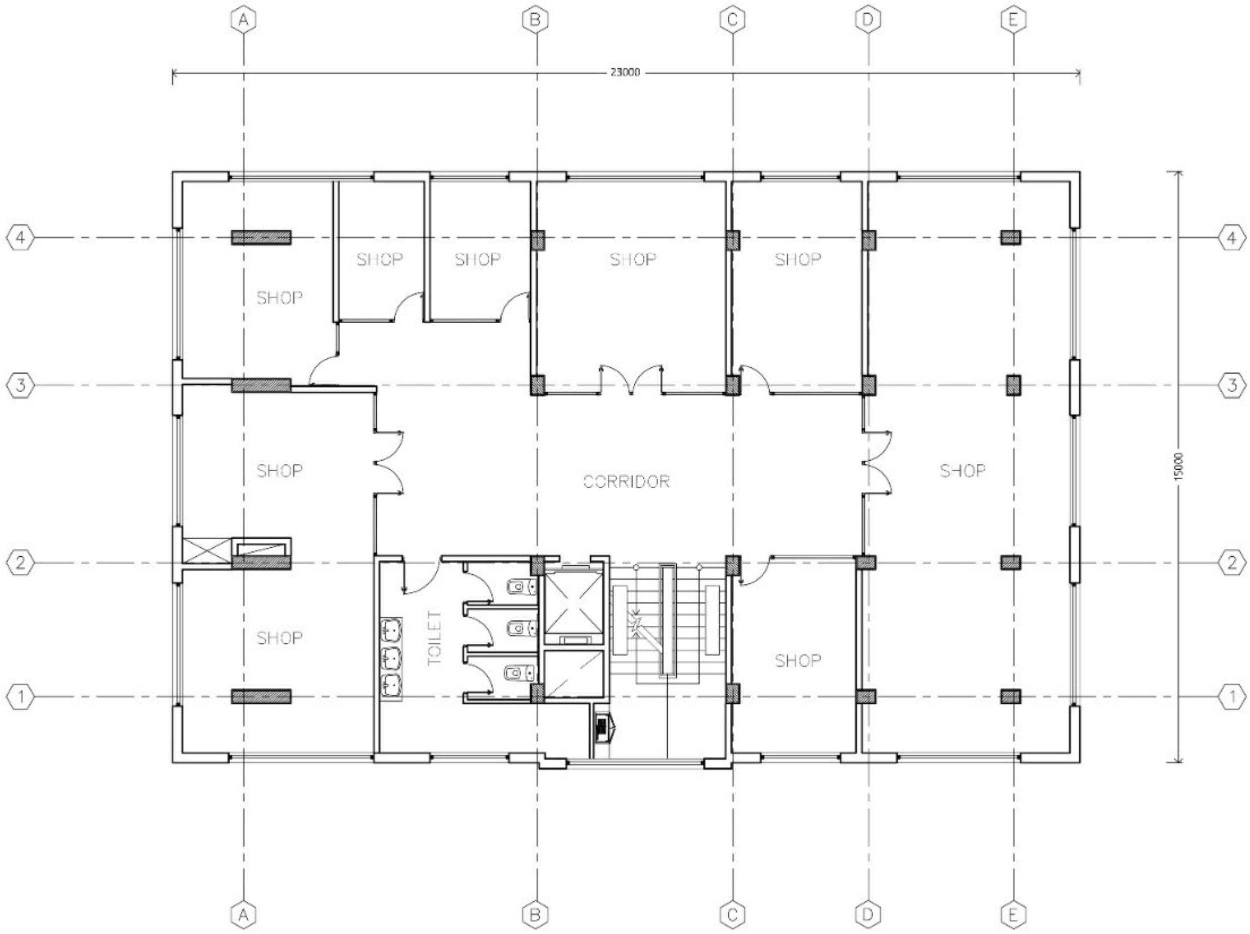

Figure 1. 2D plan for the building under the study

2.2. Energy consumption data collection

Energy consumption data for this building over a period of one year was calculated and analyzed. Hourly Analysis Program (HAP) software used to analyze the amount of annual energy consumption by using the collected data for the whole building, including HVAC systems, lighting, and plug loads. Electricity charges per kilowatt hour is a fixed amount of 0.17$ for commercial spaces [12].

2.3. Building envelope inspection

We conducted a detailed inspection of the building envelope, including walls, roofs, and floors, to determine the level of insulation installed. It was found that there was no insulation used for this building, we noted the type, thickness, and R-value of the materials used in the walls, floors, ceiling, and windows. All materials' characteristics and properties are shown in table 1.

Table 1. Building material properties and characteristics

Material	Thickness (mm)	Thermal resistance R (m^2. K /W)	Density (kg/m^3)	Weight (kg/m^2)
Common brick	250	0.34392	1922.2	480.6
Plaster	20	0.02771	1860	37.2
Concrete	150	0.86668	640	96.1
Wall insulation (Polystyrene)	40	1.92596	32	1.3

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2.4. Energy modelling

Using the energy consumption data and the building envelope inspection results, we developed a baseline energy model. We used energy modeling software (Hourly Analysis Program) to simulate energy consumption for this building without insulation. Hourly Analysis Program (HAP) software is primarily a tool for HVAC systems design and load estimation. It may be used to simulate energy usage and estimate energy costs. HAP leverages energy simulation approaches for energy analysis in addition to the ASHRAE-recommended transfer function method.

2.5. Insulation upgrades

We then implemented only wall insulation upgrades for the case building, the most available and cheapest insulation material in Kabul market is polystyrene boards. In order to compare the annual energy consumption, and find the optimized insulation thickness, energy consumption and cost analysis performed for 10mm thick polystyrene board insulation to 100mm thick.

2.6. Data analysis

We compared the energy consumption data and energy models for the case building before and after insulation upgrades to the walls. We calculated the energy savings achieved by insulation upgrades and analyzed the results to determine the impact of wall insulation on energy consumption and cost savings in mid-rise commercial buildings that are still using conventional energy resources for air conditioning systems.

3. Results

3.1. Annual energy consumption

Figure 2 displays the annual energy consumption of the HVAC system for the building with no insulation. The data is presented in terms of kilowatt-hours (kWh) of energy used per month. This is expected since these are typically the coldest months of the year and the HVAC system has to work harder to maintain a comfortable temperature indoors. The energy consumption for the HVAC system was generally lower in the months with milder temperatures, such as April, May, and October.

The lowest energy consumption for the HVAC system occurred in October, with only 2,451 kWh used. Overall, the annual energy consumption of the HVAC system for the building with no insulation was estimated 203,830 kWh.

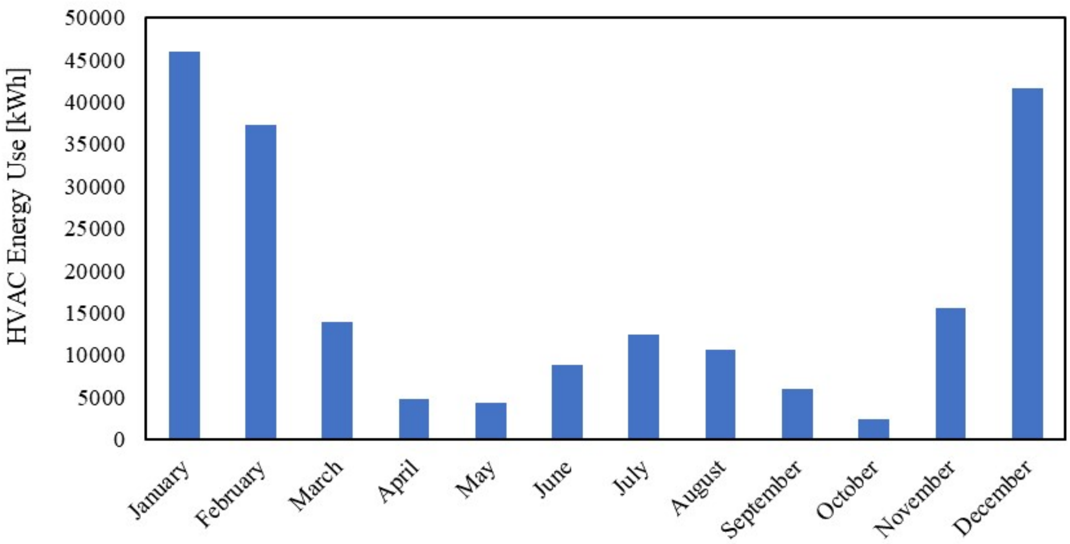

Figure 2. Monthly energy consumption for the heating and cooling systems

The data presented in figure 2 highlights the significant energy consumption of HVAC systems in buildings without insulation, particularly during the colder months of the year. This has important implications for reducing the carbon footprint of buildings and improving energy efficiency. The data also underscores the potential benefits of adding insulation to the walls, which can help to reduce energy consumption and lower costs. In order to save the energy and prevent environmental pollutions, the wall insulation effects are analyzed in details. The highest energy consumption for the HVAC system occurred in January and December, with 46,027 kWh and 41,619 kWh respectively.

3.2. Effect of Insulation on energy consumption

Figure 3 illustrates the annual energy consumption per square meter (kWh/m^2) for different insulation thicknesses. The horizontal axis of the graph represents the thickness of polystyrene insulation used in the walls in millimeters, ranging from 0mm to 100mm, and the vertical axis represents the annual energy consumption in kWh/m^2. As the wall insulation thickness increases from 0mm to 100mm, the graph shows a continuous decrease in annual energy consumption for both cooling and heating. But due to climate zone effects, the amount of energy reduction is very less for the cooling system. The graph indicates that the building's annual energy consumption decreases significantly with an increase in the wall insulation thickness.

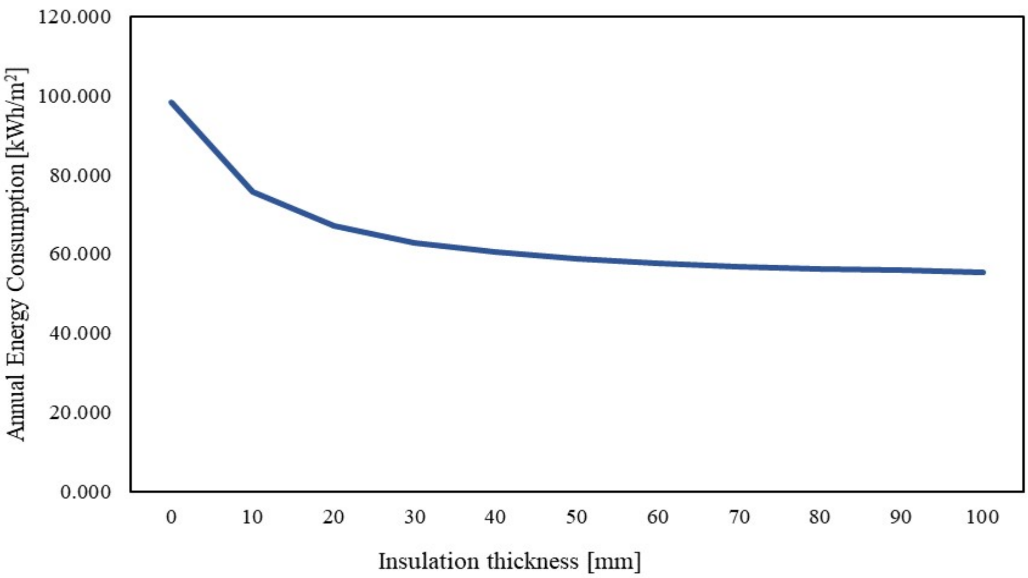

Figure 3. Annual energy consumption for different insulation thicknesses

At uninsulated existence condition, the building consumes the highest amount of energy for both cooling and heating, with an annual energy consumption of 98.465 kWh/m^2. As the wall insulation thickness increases, the annual energy consumption decreases, reaching at a lowest point at 100mm insulation thickness, with an annual energy consumption of 55.395 kWh/m^2.

Adding insulation to the walls can improve indoor thermal comfort and cut energy use by 30% to 50%. There is a gradual reduction in energy consumption as the insulation thickness increases up to 100mm. However, the reduction in energy consumption is not as significant for thicker insulation. This suggests that there is a point of diminishing returns, beyond which additional insulation may not yield significant energy savings. Insulating the wall beyond 50mm thickness does not result in a significant reduction in energy consumption. Therefore, the 50mm thickness is selected an optimized thickness for this study. At 50mm insulation thickness, the total cooling energy consumed per year is 45,392 kWh and the total heating energy consumed per year is 76,352 kWh, resulting in a total energy consumption of 58.814 kWh/m^2/year. This is significantly lower than the energy consumption without

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insulation, which was 98.465 kWh/m^2/year. At this point, there is an approximately 40% energy usage reduction comparing to no insulation condition.

3.3. Cost analysis

Insulation is an important factor in reducing heating and cooling costs for buildings. However, choosing the right insulation thickness can be tricky, as it involves balancing the cost of insulation against the energy savings it provides.

Figure 4 depicts the monthly energy cost for the HVAC system of the whole building. The energy source as a baseline for cost calculations is considered to be city electricity. The electric cost of the building varies significantly from month to month, with the highest costs occurring during the winter months when heating is required. For example, in January, the electric cost for heating the building was $6,444, while in February, it was $5,218. On the other hand, during the summer months, the electric cost was relatively lower, with the cost in August being $1,482.

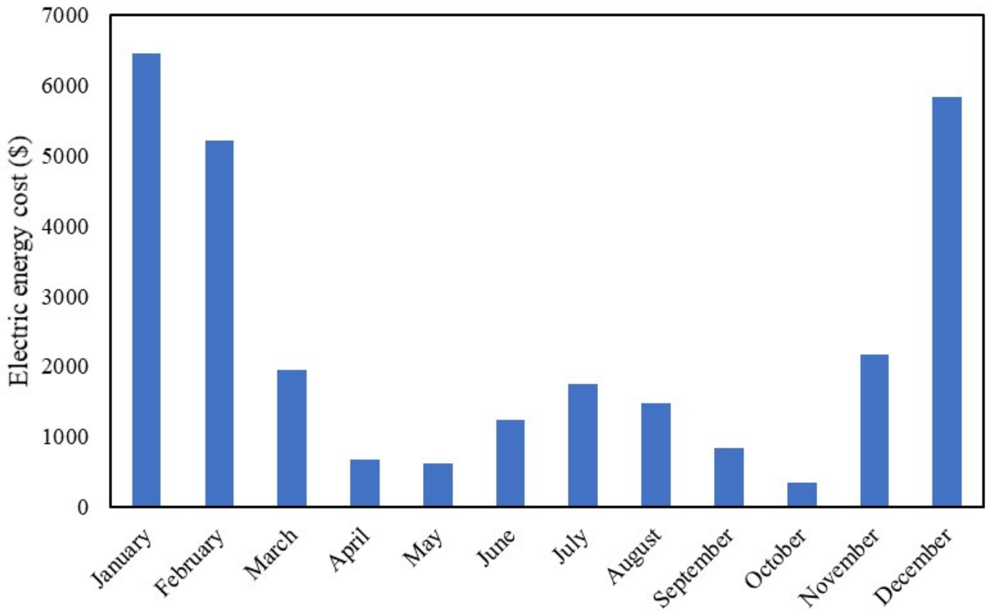

Figure 4. Monthly energy cost for the heating and cooling in the case of no insulation

The lack of insulation in the building is likely the main cause of the high electric costs during the winter months. Without insulation, the building loses heat through its walls and roof, making it more difficult to maintain a comfortable indoor temperature. As a result, the heating system has to work harder, which increases electricity usage and costs. The data suggests that insulation upgrades or other energy efficiency measures could significantly reduce the electric costs associated with heating and cooling the building. We analyzed the cost of cooling and heating for different insulation thicknesses to determine the optimal thickness. Figure 5 shows the annual cooling and heating costs per square meter for different insulation thicknesses. Based on our analysis, we selected the 50mm insulation thick as an optimal insulation thickness for this study, with a cost per square meter of $13.786. As the thickness of the insulation increases, the cost per square meter decreases. However, the savings in energy costs are not significant enough to offset the increased cost of insulation.

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Therefore, 50mm is the most cost-effective insulation thickness, and switching from 0mm insulation thickness to 50mm insulation thickness would result in a savings of approximately 40.22% in annual energy cost per square meter. It is important to note that these results may vary depending on the specific circumstances of the building, such as its location, size, and energy usage. Additionally, other factors such as the type and quality of insulation used may also impact the results. Therefore, it is important to conduct a thorough analysis of the costs and benefits of insulation before making decision on the optimal thickness.

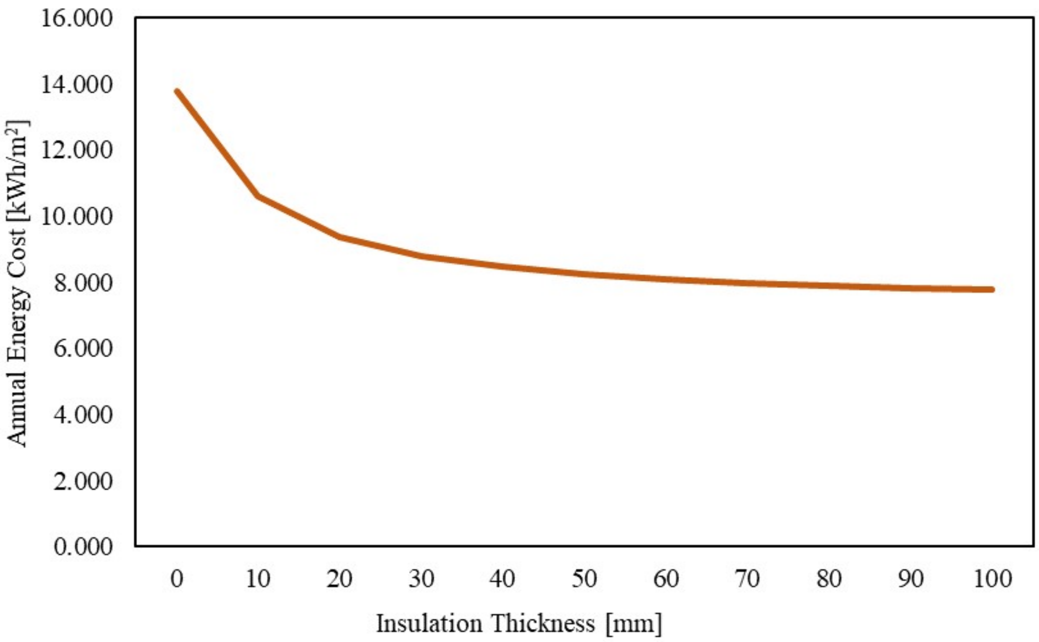

Figure 5. Yearly expenses for heating and cooling at various insulation thicknesses

3.4. CO_2 emissions

Starting at zero insulation thickness, the recorded CO_2 equivalent emissions stand at 50 kg/m². However, even a modest insulation thickness of 10mm results in a reduction to 41 kg/m², signifying a 17.7% decrease from the initial value. As the insulation thickness escalates to 20mm, 30mm, and 40mm, there's a continuous decline in emissions to 38 kg/m² (a 24% decrease), 36 kg/m² (a 28% decrease), and 35 kg/m² (a 30% decrease) respectively.

Remarkably, beyond 50mm thickness, the reduction in emissions shows a pattern of marginal improvements. While there are incremental increases in insulation thickness from 50mm to 100mm, the CO_2 equivalent emissions plateau at 35 kg/m². Therefore, the data suggests that an insulation thickness of 50mm is optimal, demonstrating that further increases in thickness do not significantly decrease CO_2 emissions.

A pivotal observation is the substantial environmental benefit achieved by implementing insulation. The data underscores the potential for mitigating CO_2 emissions through thoughtful insulation strategies in construction. Furthermore, it emphasizes the significance of balancing insulation thickness with efficiency, as the reduction in emissions gradually diminishes beyond a certain point.

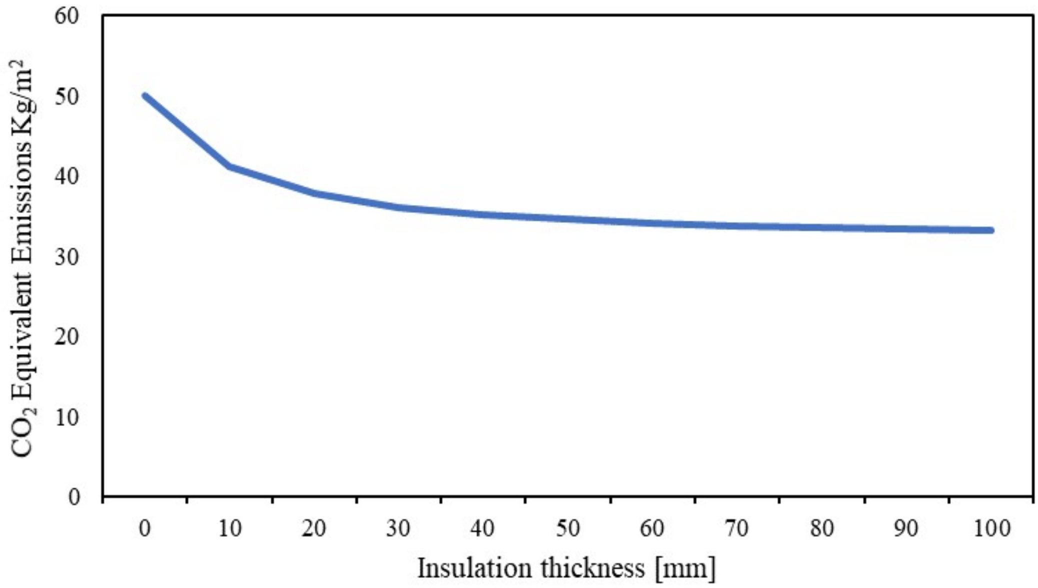

Figure 6. CO_2 equivalent emissions per square meter

4. Discussions

This paper highlights the substantial energy demand and greenhouse gas emissions associated with buildings globally, emphasizing their considerable contribution to environmental concerns. Specifically, in Kabul, energy usage patterns in commercial buildings heavily rely on conventional heating and cooling methods. Insulation emerges as a pivotal strategy to mitigate energy consumption, drawing upon existing research that establishes its efficacy in reducing heat transfer through building envelopes. The study underscores the importance of insulation in mid-rise commercial structures, projecting significant reductions in energy usage and subsequent greenhouse gas emissions, leading to cost efficiencies and environmental benefits. The methodology entails a comprehensive investigation of the uninsulated commercial building in Kabul, encompassing energy consumption data collection, thorough building envelope inspection, energy modeling, insulation upgrades, and subsequent rigorous data analysis. The results vividly illustrate the stark contrast in energy consumption between insulated and uninsulated conditions, revealing substantial reductions in annual energy usage per square meter with increased insulation thickness. Notably, a 30% to 50% decrease in energy usage was observed with insulation, with the optimal thickness identified at 50mm, beyond which marginal improvements in energy savings were noted. The findings also underscore the cost-effectiveness of 50mm insulation thickness, showcasing a 40% reduction in annual energy costs per square meter compared to uninsulated conditions. Moreover, the research delves into the environmental impact, particularly CO_2 emissions reduction attributed to insulation. The data supports the notion that while thicker insulation leads to decreased emissions, there's a diminishing return beyond the 50mm thickness, aligning with the optimal thickness identified for energy savings.

Overall, this research offers valuable insights into the potential of insulation to revolutionize energy efficiency in commercial buildings, paving the way for sustainable practices in construction and global efforts to combat climate change.

5. Conclusions

In conclusion, this research comprehensively underscores the pivotal role of insulation in transforming the energy landscape of mid-rise commercial buildings. The study, centered on an uninsulated 6-story commercial building in Kabul, illuminates insulation as a catalyst for reducing energy consumption, cutting greenhouse gas emissions, and fostering cost-effective construction practices. By spotlighting the considerable energy demands and environmental implications tied to conventional building approaches, this study advocates urgently for sustainable strategies, especially in rapidly developing urban areas. The findings consistently demonstrate the profound impact of insulation, showcasing a substantial 30% to 50% decrease in energy usage as insulation thickness increases up to an optimal 50mm.

Critical to the research's narrative is its emphasis on the economic viability of insulation. The meticulous cost analysis reveals the compelling cost-effectiveness of 50mm insulation thickness, providing a noteworthy 40% reduction in annual energy costs per square meter. This underscores insulation not just as an energy-saving measure but also as a financially prudent investment for stakeholders in commercial building ventures.

Environmental considerations form a core aspect of this study, with a clear correlation established between insulation thickness and CO_2 emissions reduction. The data indicates that while thicker insulation mitigates emissions, the optimal thickness at 50mm marks the threshold for significant energy savings and emissions reduction.

This research extends beyond academic discourse; it is a clarion call to industry stakeholders, policymakers, and urban planners to embrace insulation as a cornerstone of sustainable construction. Its immediate impact on energy reduction and cost efficiency is matched by its long-term environmental implications.

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