

Energy consumption comparison at various insulation scenarios: Mid-rise residential buildings, Kabul city

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Abstract. An insulating substance is typically used to reduce the amount of heat that enters buildings with air conditioning from the outside. The heat conductivity of this substance is extremely low. In this scenario, having a cost-effective air conditioning system requires using an appropriate insulation material with the right thickness. Up until a certain point, when the material thickness is optimal and will give the maximum overall energy savings, given that the building industry accounts for roughly 40% of worldwide energy consumption and is the greatest producer of greenhouse gas emissions, it is well known that it has a substantial negative influence on the environment too. Therefore, Insulating the outer walls of the building is a recognized method to improve the energy efficiency of buildings in the current setting of ongoing global energy price increases and concern to support global efforts to recover the climate. This study was conducted on a residential building in Kabul city capital of Afghanistan, to study and analyse the insulation materials used to seal the building envelope to calculate how much energy can be saved. Version 4.9 of the HAP program was used to calculate the energy consumption and heating/cooling loads. According to the obtained results, adding insulation to the envelope's various elements (walls, roofs, windows, etc.) can improve thermal comfort indoors and cut the energy use of the structures under study by between 30 to 40 percent. Especially the amount of heat losses in winter decrease with proper insulation, but due to the low-temperature difference in the summertime, the insulation effect is negligible.

Keywords: *Energy Savings, Building Insulation, Sustainability, heating and cooling loads*

1. Introduction

The primary factor affecting energy usage is the thermal performance of the building envelope, depending on the construction of the building. As a result, thermally insulated walls, floors, and ceilings can minimize the energy consumption of the heating or cooling system [1][2][3][4]. Because of the decrease in CO₂ emissions and decrease in building operating expenses, reducing energy consumption in buildings is advantageous for society

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as a whole [5]. A structure with fiberglass insulation in the moderate zone can reduce its energy use by 50% compared to a building without insulation, according to a US Department of Energy assessment [6]. An investigation was performed on an existing structure in Algeria. Results indicate that there is a compromise between comfort and energy savings. materials for wall insulation including polystyrene, polyurethane, and glass wool can reduce energy use by up to 50%. The building envelope seems to be very essential in lowering summer energy consumptions [7]. The potential of adopting interior insulation was demonstrated by evaluations of theoretical energy-saving methods in certain historic case buildings in Denmark, Latvia, Italy, and Switzerland. The installation of internal façade insulation resulted in a reduction of 9–43% in the energy consumption for space heating in the case buildings [8]. For the four climate zones of Greece, namely the towns of Heraklion, Athens, Thessaloniki, and Florina, various insulating scenarios were studied, the results shown a maximum of 62% heating energy reduction and 23% of cooling energy reduction [9]. Applying insulation either inside or externally results in a significant decrease in the energy needed for heating. The installation of an insulating layer stops the outer walls from cooling during the night, whereas in the absence of insulation, more heat is being transferred from the inside to the outside air, resulting in a markedly lower wall temperature [10]. The city of Kabul is currently experiencing a severe energy crisis. Residents of Kabul City are currently only occasionally provided with electricity, and more than 70% of the city's energy needs are met by importing it from the nearby nations [11]. Rapid urbanization in Kabul city is another big challenge for its sustainability from the viewpoint of energy sustainability of the buildings. If rapid urbanization is not planned for, conflicts will inevitably arise. In the construction industry, defects are difficult to correct. Older buildings may need to be converted into sustainable ones, which could require time and money. Lack of regulations and practices, the technical capacity of the responsible organizations, a lack of understanding of the benefits of sustainability among builders, and a lack of financial incentives for building owners to include sustainability features in their structures have all contributed to the rising number of unsustainable structures in Kabul. [12]. In this paper, energy analysis performed based on a mid-rise residential building. The test building was selected to simulate heat gains and losses, respectively, in accordance with the climatic zone of Kabul city. Kabul is located between the latitudes of 34°31'41" and 69°10'20" north and east, respectively [13]. The climate in Kabul is semi-arid, with cold winters and hot summers. The highest recorded temperature is 36 °C, whereas It lowers to -7 °C during the winter [14]. Because of its geographical location, Kabul city experiences extremely few rainy days in the spring, summer, and fall; the rainiest months are winter and early spring. The building energy analysis tool (HAP) was utilized. To determine the building energy consumption for various R-values for the walls, roof, and windows, a number of parametric simulations were carried out. Analysis of energy consumption by heating and cooling systems and components of heat gain and loss as a function of insulation value of walls, roof, and windows.

2. Materials and methods

This research focuses on energy savings as a result of insulation on Mid-rise residential building in Kabul city located in the central part of Afghanistan. Energy analysis performed based on the metrological data, literature review of the existing Mid-rise residential buildings, heat loss and gain, energy consumption, electricity charges, and insulation material availability and price in the current market. To evaluate the performance of insulation effectiveness for the buildings' energy saving, a series of the dynamic simulation was performed in HAP (Hourly Analysis Program). the energy required for heating and cooling this structure using a vapor-compression heater/cooler system that is readily available on the market was determined in the cases of totally insulated and uninsulated conditions. The

annual electrical energy consumption for both cases was calculated and energy saving comparison is performed at different thick insulated and uninsulated conditions. The base for this case study is a 6-story uninsulated mid-rise building constructed in 2015, having 12 apartments with 317 m² effective area for heating and cooling at each floor, oriented north to south, windows are single glazing with wood frame. Currently, heating and cooling are done by conventional air conditioners.

2.1. Specifications of the building for the case study

A 6-story mid-rise residential building with four vertical walls, 84 windows, and an uninsulated foundation case was used for simulations. The walls are constructed of two layers of common brick 101mm and 202mm thick, that have been plastered inside and finished with a mortar outside 2 cm thick each, (the whole wall's effective R-value was 0.49 m² K/W). The roof was made of four layers, 2 cm cement plaster inside, 15 cm concrete, asphalt roll, and 10 cm RCC. that had an overall R-value of 1.69 m² K/W and was waterproofed with asphalt roll. Figure 1 represents a 2D architectural plan of the building.

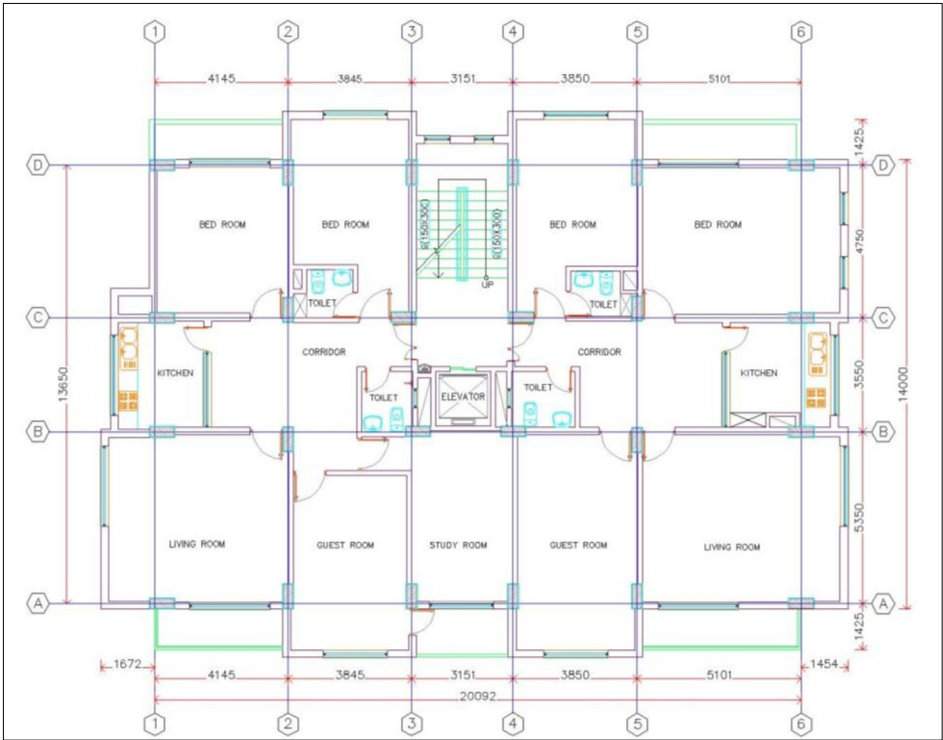


Figure 1. Architectural 2D plan of the building for case study

Table 1 shows the characteristics of building materials and optimized insulation material properties. Table 2 lists the specifications and thermal characteristics of the materials utilized. The thermal resistivity of the insulation layer, which is 1.93 m² K/W and has a significant impact on thermal transmittance, is the most crucial factor in table 2.

Table 1. characteristics of building materials

Material	Thickness (mm)	Thermal resistance R (m ² . K /W)	Density (kg/m ³)	Weight (kg/m ²)
Common brick	200	0.27514	1922	384.4
Plaster	20	0.02771	1860	37.2
Concrete	150	0.86668	640	96.1
Wall insulation	40	1.92596	32	1.3
Roof insulation	150	3.38673	8	1.2

Table 2. Building specifications

Parameters	Value
Total floor area	343 m ²
Effective area for heating and cooling	317 m ²
Number of the floors	6
Length	23.22m
Width	16.85m
Height	18m
Wall U-value	2.039 W /m ² K
Window U-value	4.307 W /m ² K
Door U-value	1.73 W /m ² K
Roof U-value	0.592 W /m ² K
Polystyrene insulation R-value (SI/cm)	0.48149 m ² K/W
Lighting load	5 W/m ²
Occupants density	5 people per each apartment
Infiltration rate	0.25 ACH
Electrical equipment loads	1200 Watts

3. Simulation Results

3.1. Heating and cooling loads analysis

The simulation results were assessed in terms of insulation's effects on heat gain and loss aspects, and insulation's effects on energy usage by heating and cooling systems. Identification of the main targets for energy conservation techniques can be done by analyzing the components of heat gain and loss. Figures 2 and 3 show heat gain and loss of the whole building. Solar radiation, which accounts for 51.06% of heat gain, is followed by infiltration (6.43%) and conduction through windows (17.99%). A negligible amount of heat is gained through walls (1.83%), doors (0.8%), and roofs (2.51%). This implies that while insulation of the envelope is less advantageous in the summer, shading is necessary to reduce the consumption of cooling energy. about 19% of the total heat gain is attributed to internal heat gain from people (8.87%), lights (4.54%), and appliances (5.42%). (See Figure 2). This suggests that reducing the amount of heat generated by lighting and home appliances will have a significant positive impact on cooling energy usage. Utilizing energy-efficient appliances is a great way to save energy in the house.

The test residential building loses 42% of its heat through the walls and 41% of its heat through the windows, 1% through the floor slab, 2% through the doors, and 4% through the roof. 10% of the heat loss is attributed to infiltration. One might conclude that window and

wall insulation is a top-priority technique for domestic energy conservation in cold areas.

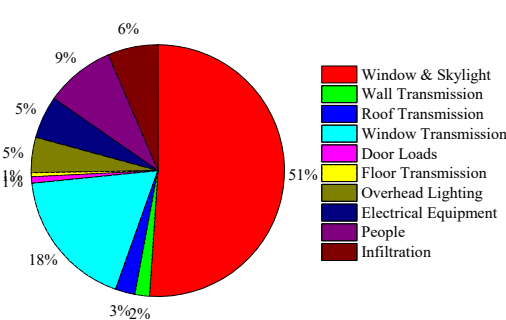


Figure 2. Heat gain components of the building

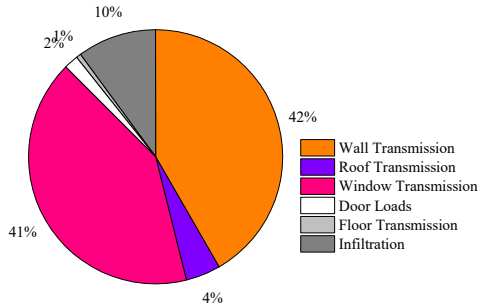


Figure 3. Heat loss components of the building

The reason for this study is to analyze energy consumption versus various insulation circumstances, such as insulation thickness of the walls, roof insulation, and windows glazing. Figure 4 displays the case's heating and cooling loads.

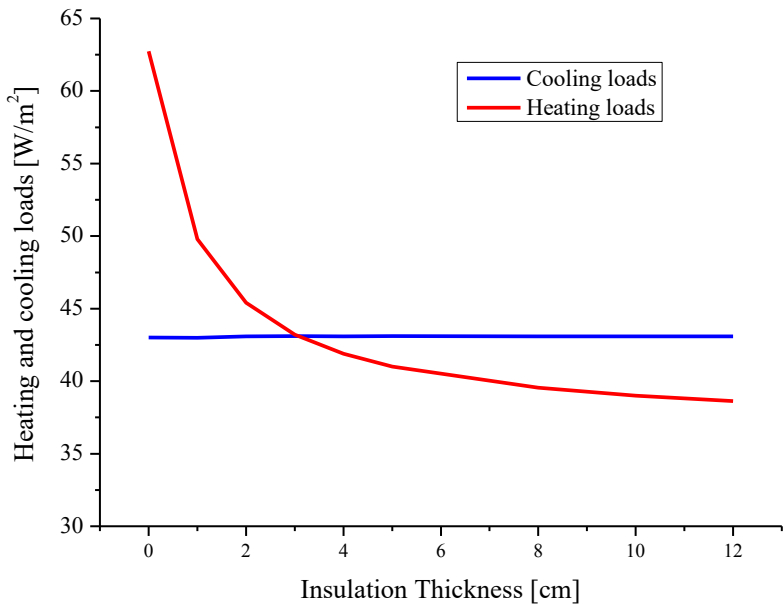


Figure 4. Heating and cooling loads versus various insulation thicknesses

It is clear that increasing insulation thickness results in reduced heating loads but slightly increase cooling loads since zero insulation denotes an uninsulated building. The difference between insulated and uninsulated buildings is significant, and this fact demonstrates how a thin layer of insulation may significantly reduce the heating loads. Figure 4's findings show that the heating load is higher than the cooling load, while the temperature difference between the inside and outside of the building in summer is less than in the winter.

3.2. Wall insulation influences

The analysed cases' actual primary energy consumption is depicted in Figure 5 for comparison. Lower primary energy consumption is a result of thicker insulation. In general, energy consumption for heating loads is higher than for cooling loads. In this case, only wall insulation is the variable parameter, roof and windows are considered to be uninsulated. The heating energy consumption reduces sharply from zero to 4 cm insulation thickness and after that, the effect of insulation thickness is not considerable and increases the initial investment cost. Considering different factors of sustainability for the buildings in Kabul city, a 4cm thick polystyrene insulation R-1.93 (SI) is selected as an optimum thickness. On the other hand, cooling load, and energy consumption slightly increases in various insulation scenarios.

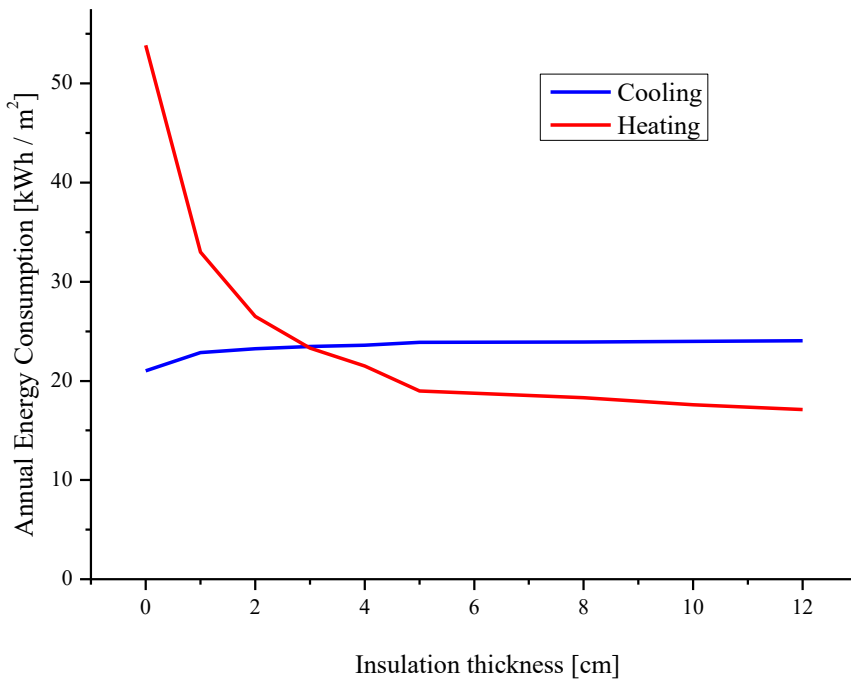


Figure 5. Energy consumption for heating and cooling loads at various insulation thicknesses

3.3. Window insulation influences

Solar radiation and conduction heat transfer through the window has a significant effect on heating and cooling energy consumption. The existing windows are consisting of wood frames and single glazing 3mm thick glass. In the current condition, 41.2% of heat loss and 69.1% of heat gain are through windows. To reduce the solar radiation and heat conduction through to the windows, the existing condition was compared with a double-glazing window each layer 3mm thick with a 6mm air gap and vinyl frame. Figure 6 shows the comparison between single-glazing and double-glazing windows' energy consumption for heating and cooling on an Annual basis. The is about an 11% energy consumption reduction while the windows are insulated. In this case, the walls and roof are considered to be uninsulated. The impact of window insulation is greater on heat loss than on heat gain. Heat loss reduces from 62.01W/m² to 36W/m² and heat gain decreases from 62.74W/m² to 52.5W/m². A

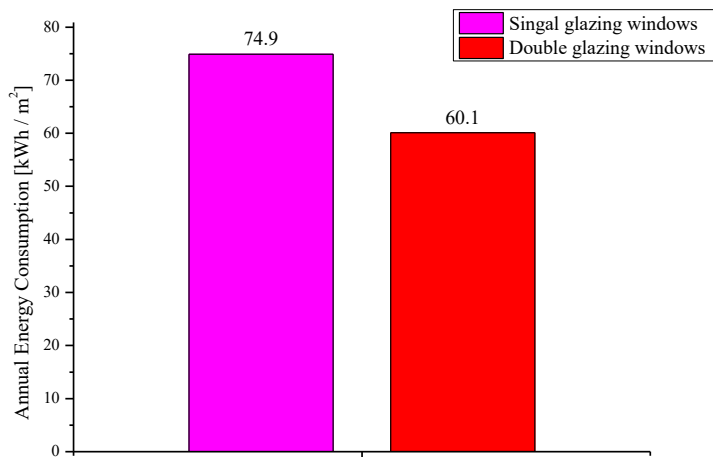


Figure 6. Energy consumption for heating and cooling in the cases of single- and double-glazing windows

3.4. Roof insulation influences

Similarly, with wall and window insulation, roof insulation also reduces heat transfer rate and Annual energy consumption. With increasing R-value of the roof, heat loss and gain are significantly reduced. As in this study, the roof area is quite smaller compared with the walls and windows, but the impact of roof insulation on the last floor of the building is always significant, Annual energy analysis for the whole building shows a 3% of energy consumption reduction for the whole building in the case of roof insulation, all other parameters assumed to be constant and uninsulated. Energy consumption decreases from 74.9kWh/m² to 72.65kWh/m² figure 7. Heat loss and gain analysis show a 23.3% reduction in heat loss and 31.5% in heat gain through to the roof at the last floor of the building. Considering the climate conditions in Kabul city, heat loss is significantly higher than heat gain through to the roof.

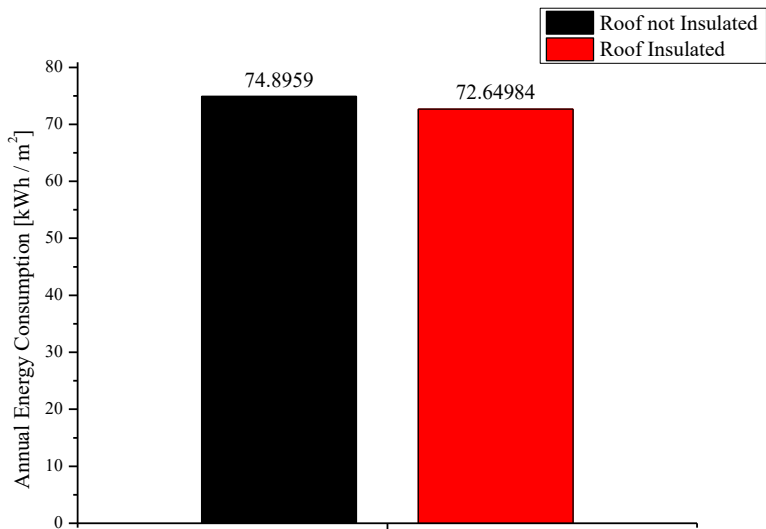


Figure 7. Energy consumption for heating and cooling in the cases of insulated and uninsulated roof

3.5. Optimized condition

An insulating material is typically used to reduce the amount of heat that it losses and gains. The heat conductivity of this substance is extremely low. In this scenario, having a cost-effective air conditioning system requires using an appropriate insulation material with the right thickness. Up until a certain point, when the material thickness is optimal and will give the maximum overall cost and energy savings. Figure 8 shows the comparison for no insulation, 4cm thick wall insulation total (R-13 SI), roof insulation (R-30 SI), and double-glazing windows made of vinyl frame. In this case, if no insulation; energy consumption is 75.9 kWh/m², it decreases to 55.84 kWh/m² (25.44%) if only 4cm polystyrene insulation is added to the walls. And finally, in the case of 4cm wall-insulated, roof-insulated, and double-glazing windows; energy analysis for the whole building is performed. A considerable reduction of about 33.59% (49.74 kWh/m²) was achieved in annual energy consumption.

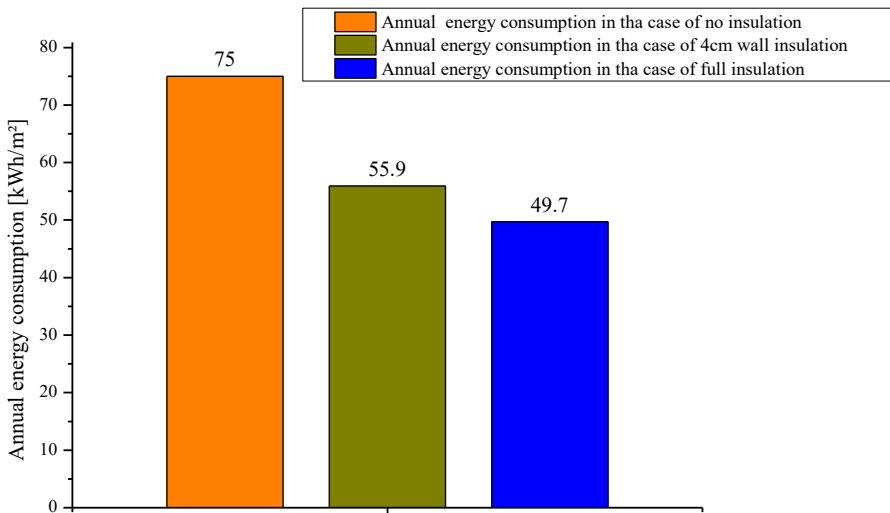


Figure 8. Annual energy consumption for three cases (no insulation, only wall insulation, and full insulation)

4. Conclusion

Building insulation is a simple and efficient technique to save energy. By increasing the thermal resistance of the building envelope, the installation of insulation material in the structure primarily seeks to reduce energy consumption for heating or cooling. The comparison of the heat gain and loss components reveals that in a cold climate, heat loss is always greater than heat gain. Internal and external heat gains in the winter will help lower the heating load, whereas heat gain in the summer will increase the cooling load. The proper shading of windows during the warm season is a significant approach for reducing a building's cooling load because solar heat gain accounts for the single largest component of heat gain (51.06%). The amount of energy saved from heating or cooling would not be greatly increased by adding more insulation. As anticipated, applying insulation significantly lowers the demand for heating energy. however, the cooling demand has not changed significantly. Another important point is that the prevention of heating loads should be the top priority in building design in cold climates. It is also crucial to note that buildings with higher insulation thickness have lower environmental impacts because their CO₂ emissions are lower. This is an additional factor that should be considered before using well-insulated structures.

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