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Building Information Modeling (BIM) for Energy Optimization in Green Buildings: A Case Study of a Residential Villa in the UAE

Adil K. Tamimi[1], Ghanim Kashwani[2], Amr Hamam[3], Ismail Abu AlHaj[4], Yousef Himeidi[5], Bilal Ramadan[6]
atamimi@aus.edu[1], ghakas90@gmail.com[2]
Department of Civil Engineering, American University of Sharjah, UAE[1]
Professor of Practice, Society of Engineers, UAE[2]
American University of Sharjah, UAE[3,4,5,6]

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ABSTRACT

This paper explores the application of Building Information Modeling (BIM) in evaluating and optimizing energy efficiency in green buildings, focusing on a residential villa in Sharjah, UAE. The study assesses thermal bridges, energy consumption, and the potential energy savings from applying insulation. The villa's energy performance was modeled using Revit and IES-VE software, and actual energy consumption was measured for comparison. The results show that applying insulation could reduce the villa's energy consumption by up to 17.91 MWh annually, confirming the accuracy of BIM in simulating energy performance. Additionally, this paper discusses how improvements in insulation and thermal management can significantly reduce the energy demands of residential buildings in hot climates.

1. INTRODUCTION

The rise in urbanization and energy consumption, particularly in rapidly growing regions like the UAE, has brought energy efficiency to the forefront of building design. The need to reduce greenhouse gas emissions and reliance on fossil fuels has led to the proliferation of green building practices. One of the tools that has transformed the construction industry is Building Information Modeling (BIM), which allows architects and engineers to assess energy efficiency and sustainability from the design phase through to the building's operation.

Building Information Modeling (BIM) plays a crucial role in achieving energy efficiency by integrating energy simulation tools, thereby enabling designers to optimize energy performance during the design process (Azhar, 2011). This study applies BIM to evaluate the energy efficiency of a residential villa in Sharjah, UAE, with a focus on the impact of thermal bridges and insulation on energy consumption. The simulation results are compared with in-situ measurements to ensure the accuracy of the findings.

2. Literature Review

Numerous studies have shown that BIM can be used to model and improve building energy performance. BIM, when integrated with energy analysis tools like Revit and IES-VE, provides detailed insights into energy consumption and potential savings (Azhar et al., 2011; Kamel & Memari, 2019). By simulating different building elements, BIM can predict the thermal performance and energy demands of buildings, allowing for the optimization of materials, insulation, and mechanical systems. In hot climates like the UAE, buildings are exposed to extreme temperatures, leading to higher energy demands, especially for cooling (Alyami & Rezgui, 2012). This makes the identification and mitigation of thermal bridges critical for reducing energy consumption. A study by Ficco et al. (2015) highlighted that buildings with insufficient insulation or improper detailing at thermal bridges experience significant heat transfer, which increases the overall energy load. Thermal bridges are weak points in a building's envelope where heat transfer occurs more easily than in surrounding areas. They are often found around windows, doors, or at structural junctions. Measuring the U-value (thermal transmittance) of building components is critical for assessing their energy performance (Jiménez et al., 2009). This paper focuses on the identification of thermal bridges in the villa and their effect on overall energy consumption.

3. Methodology

3.1 Thermal Bridge Detection

The study uses a Flir E75 thermal camera to detect thermal bridges in the villa. The camera, with a sensitivity of 0.03 °C, provides high-resolution images of the building's thermal performance. The villa was surveyed both inside and outside to detect areas with higher heat transfer.

Figure 1: Thermal Image of the Villa from the Entrance

The images revealed significant thermal bridges at the **window frames**, **door frames**, and **wall junctions**.

3.2 U-Value Calculation

Theoretical U-values were calculated for the villa's walls using the known thermal properties of the materials. These values were compared with in-situ measurements conducted using the TRSY01 apparatus, which measures heat flux over a period of 48 hours

Table 1: Theoretical U-Value Calculation

Layer	Thickness (mm)	Thermal Conductivity (W/mK)	R-value (m^2K/W)
Concrete Block	175	0.51	0.3431
Plaster	25	0.50	0.0500
Total	-	-	**0.5631**

The actual U-value was calculated as **1.7789 W/m²K**, closely matching the theoretical value of 1.7759 W/m²K, confirming the accuracy of the model.

4. Energy Modeling and Simulation

4.1 Energy Simulation with Revit and IES-VE

The villa was modeled using Autodesk Revit, and the model was exported to IES-VE for energy simulation. The model incorporated shading, wall materials, and internal loads to estimate the villa's annual energy consumption. The simulation was run twice: once with shading from nearby trees and once without shading.

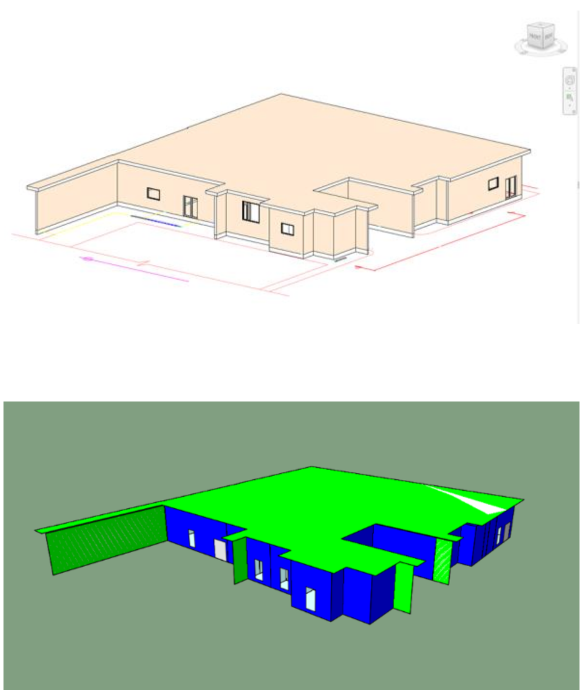

Figure 2: Villa Model in IES-VE Software

The energy consumption estimates with shading were **151.5942 MWh,** while without shading the consumption rose to **157.5294 MWh**, demonstrating a 3.84% savings due to the shading effect.

5. Results

5.1 Energy Breakdown

The energy consumption breakdown revealed that **cooling demands** represented the highest portion of energy usage, particularly during the summer months. July and August, with temperatures exceeding 45°C, had the highest energy demands.

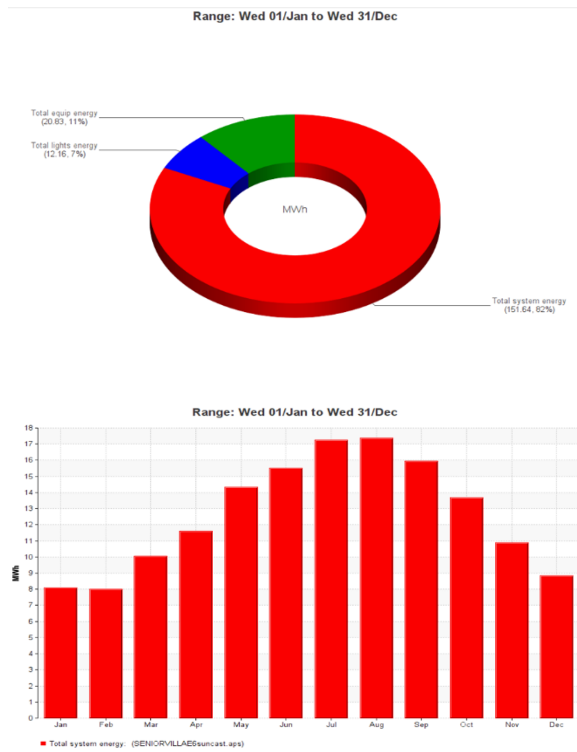

Figure 3: Energy Usage Breakdown

5.2 Impact of Insulation

Simulations were conducted to assess the impact of adding different thicknesses of Expanded **Polystyrene (EPS) insulation** to the villa's walls. The results indicated significant energy savings, with a **17.9079 MWh** annual reduction when a **100 mm layer** of insulation was applied.

Table 2: Energy Savings with Insulation

Insulation Thickness (mm)	Energy Consumption (MWh)	Energy Savings (MWh)
0	151.5942	-
100	133.6863	17.9079

6. Discussion

6.1 Thermal Bridges

The thermal images revealed significant thermal bridges at window frames and junctions, where heat transfer was more pronounced. This highlights the importance of detailed design and construction practices to minimize heat loss in buildings. A study by Jiménez et al. (2009) supports these findings, showing that even small thermal bridges can significantly impact overall energy performance.

6.2 Insulation and Energy Savings

The application of 100 mm EPS insulation resulted in a 11.82% reduction in energy consumption. This confirms the importance of insulating building envelopes in hot climates like the UAE. As Alyami & Rezgui (2012) suggest, insulation plays a critical role in reducing cooling loads, particularly in regions with extreme temperature variations.

6.3 Shading Effect

The shading provided by nearby trees reduced energy consumption by 3.84%, particularly during the summer months. This finding aligns with previous research that demonstrates the value of passive shading techniques in reducing cooling demands in hot climates (Elgendy, 2011).

7. Conclusions

This study demonstrates the value of Building Information Modeling (BIM) in assessing and optimizing the energy performance of buildings. The findings indicate that applying insulation and passive shading can significantly reduce energy consumption, particularly in hot climates like the UAE. The study's comparison of theoretical and actual U-values highlights the accuracy of BIM tools in simulating energy performance. Future research should explore the integration of smart HVAC systems and advanced materials to further reduce energy consumption in residential buildings.

8. References

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