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FULL LENGTH ARTICLE

Modeling Sustainability Standards and Assessment Systems in High-Rise Buildings

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ABSTRACT

With the rapid growth of major cities, sustainability in construction has become a fundamental aspect of modern building development, particularly in high-rise residential buildings, which are increasingly important in urban expansion. This research aims to analyze how to model energy-efficiency improvement criteria in high-rise buildings through a case study of a residential tower using Revit software. The study begins by developing a comprehensive framework for assessing the environmental, social, and economic impacts of high-rise residential buildings, with a specific focus on energy efficiency as a key criterion in sustainability evaluation. By analyzing data obtained from Revit modeling, the research explores how modeling tools can be utilized to improve building design and enhance energy efficiency. The methodology includes a bibliometric content analysis to review relevant studies and leverage current sustainability assessment frameworks. These principles are applied to a real-life residential tower case study to illustrate the positive impact of improving energy efficiency on the tower's environmental performance. The results indicate that applying energy-efficiency criteria using Revit can lead to significant reductions in energy consumption, decreased carbon emissions, and enhanced resource management in residential buildings. Additionally, these criteria contribute to the overall environmental, social, and economic benefits of high-rise buildings. The research concludes with recommendations on how to effectively integrate sustainability criteria into the design of residential towers, emphasizing the importance of using advanced modeling tools such as Revit to achieve sustainable and effective outcomes in the construction field.

Keywords: Sustainability in Construction ▪ Energy Efficiency ▪ Revit Modelling ▪ Sustainability Assessment Systems ▪ Building Information Modelling (BIM) ▪ Sustainable Design ▪ Green Building Standards ▪ Building Performance Analysis ▪ Sustainable Development ▪ Efficiency Improvement Criteria

1. INTRODUCTION

With increasing environmental challenges and the growing need for more sustainable building solutions [1], improving energy efficiency in high-rise buildings is gaining significant importance in the field of design and construction. Residential towers, which have become an integral part of the urban fabric in major cities [2], require innovative strategies to reduce their environmental impact and enhance their energy efficiency. In this context, the use of advanced modeling tools [3], such as Revit, is crucial for optimizing building performance in this domain.

This research aims to present a practical case study of a residential tower in Basilea City, focusing on how to model and improve energy efficiency using Revit. It analyzes how sustainability criteria and energy-efficiency improvements can be applied through advanced design strategies and the benefits of specialized software for building design and analysis. The study begins with a comprehensive review of the theoretical framework for assessing the environmental, economic, and social impacts of residential towers, highlighting the vital role of energy efficiency in achieving sustainability [4]. Through this case study, the research explores how Revit can be used to analyze and develop design solutions that enhance the tower's energy performance [5] and contribute to reducing energy consumption and associated environmental impacts.

2. LITERATURE REVIEW

The literature indicates that sustainability in construction has become a central focus in the development of modern buildings [6], aiming to reduce environmental impacts and improve resource efficiency. Residential towers are an integral part of the urban fabric in major cities, requiring innovative strategies to enhance their energy efficiency [7]. In this context, Building Information Modeling (BIM) [8] and tools such as Revit play a crucial role in improving building design and energy performance.

Previous studies, such as Lundberg (2018), have shown that the application of thermal-insulation techniques, high-performance windows, and renewable energy can significantly reduce energy consumption in high-rise buildings [9]. Sustainability assessment systems such as LEED, BREEAM, and DGNB also represent important tools for guiding design towards sustainability standards [10], providing a comprehensive framework for evaluating the environmental, economic, and social impacts of buildings.

Smith and Tardif (2019) point out that using Revit can provide accurate data on energy consumption and environmental impacts, helping engineers make informed design decisions [11]. Furthermore, case studies such as One Central Park highlight notable improvements in energy efficiency when using BIM technologies [12], emphasizing the importance of integrating modern technological tools into sustainable design. However, gaps remain regarding the comprehensive and effective integration of sustainability standards in residential towers. Further research and development are needed to address challenges [13] related to compatibility between different assessment systems and the lack of precise data. Therefore, this research addresses some of these gaps through a practical case study of a residential tower in Basilea City, focusing on how Revit can be used to analyze and develop design solutions that enhance the tower's energy performance [14].

3. METHODOLOGY

An experimental applied methodology was used in this research to analyze and improve energy efficiency in residential towers [15] through a case study of a residential tower in Basilea City, using Revit as the primary analytical model. The research began by identifying the main objectives and key criteria, such as energy consumption, carbon emissions, and resource management, based on sustainability assessment systems such as LEED and BREEAM.

Primary data were collected through field surveys, interviews, and analysis of the building's architectural drawings, with a focus on heating, ventilation, air conditioning, and lighting systems. Revit was then used to model the building [16] and analyze its energy performance by creating a three-dimensional model and simulating various design scenarios to improve energy efficiency, including enhancing thermal insulation, installing high-efficiency windows, and utilizing natural lighting.

After identifying potential improvements, the impact of these modifications on the building's energy performance was assessed by testing different scenarios and comparing them with the current performance. The study concludes with a discussion of the results obtained from the analysis, highlighting the environmental and economic benefits of the proposed design improvements and providing recommendations for implementing similar strategies in future projects, thereby offering a practical framework for achieving sustainability in the design of residential towers.

3.1 Data Analysis

The key analytical steps were to model the building in Revit, describe the types of spaces in the building, export the model to Autodesk Insight, and extract the building's energy values and efficiency.

Figure 1. The modeled tower in the Revit environment.

The energy efficiency of the tower was then studied. The first step was to define rooms for all spaces in the tower, as shown in Figure 2.

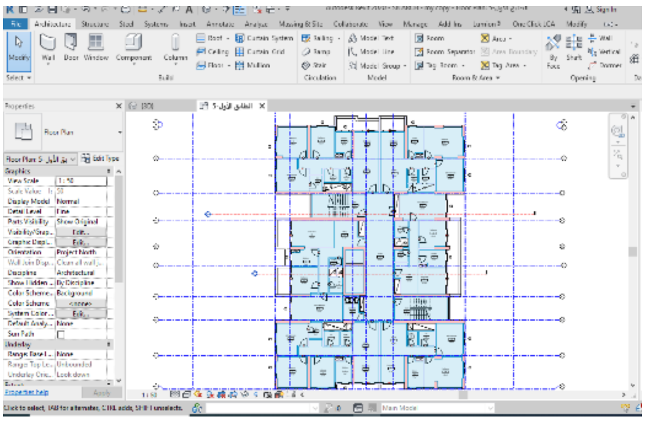


Figure 2. The first floor after defining and naming the room for each space according to the original plans.

After defining the rooms, the spaces and their properties were described for building analysis and the information was included in the model. From the Analyze window, the "Space" command was selected.

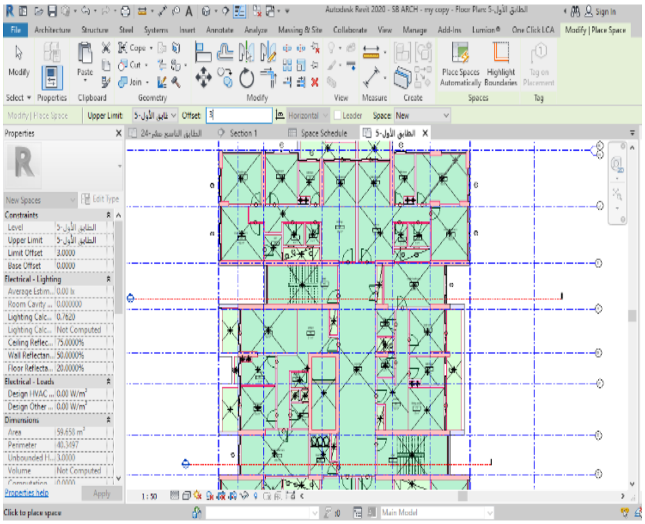


Figure 3. Describing the spaces and their properties for building analysis.

The settings required for the thermal study were then specified. An energy model was created and uploaded to Autodesk Insight.

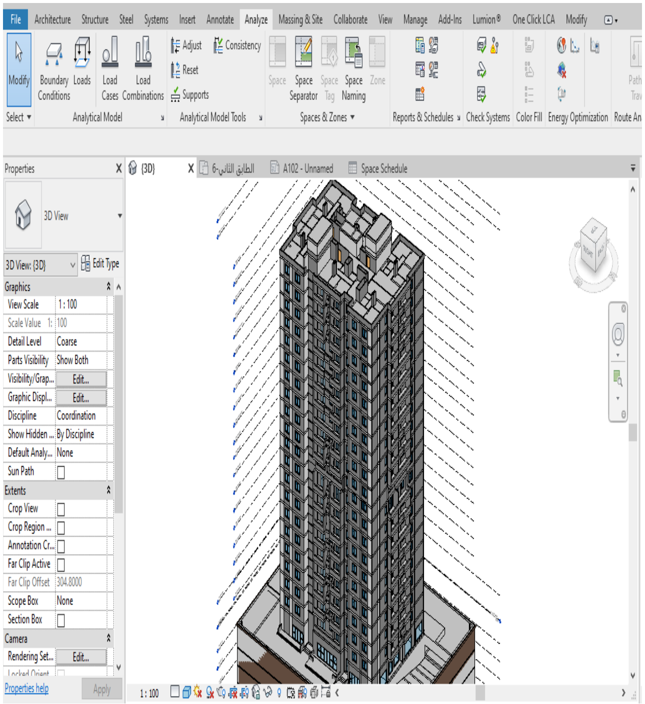
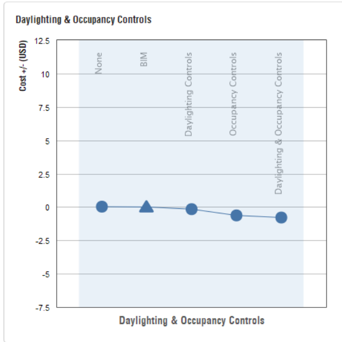


Figure 4. Three-dimensional model of the building.

After the model was uploaded, the platform analyzed the building, its energy efficiency, and its energy consumption, providing values for the various building elements. Each card presents specific information about a building element and its effectiveness in reducing or increasing energy consumption. Figures 5–10 reproduce all cards used in the baseline analysis in the same sequence as the source document.



Daylighting control and the occupancy-sensor system, with the entire range specified.

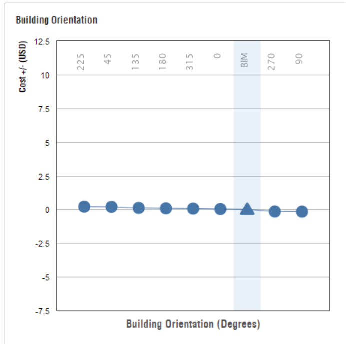
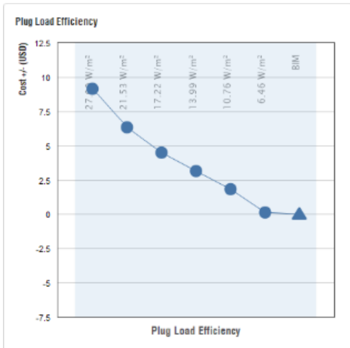
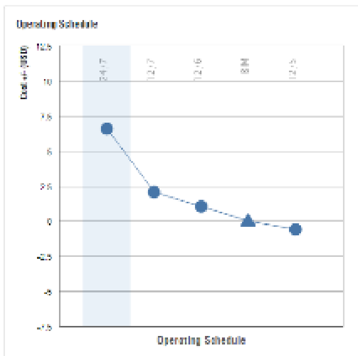


Diagram of the optimal building orientation that can reduce energy consumption. The range is defined at the triangle marker because the required values are known.

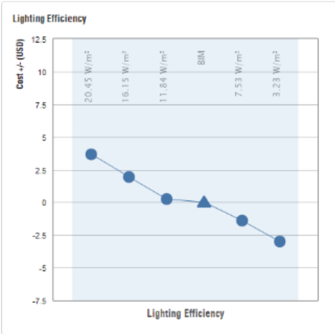


Energy used by electronic devices, excluding lighting. It includes occupants' usage hours and the range for heating and cooling systems. These are electrical inputs, so the full range was assumed.

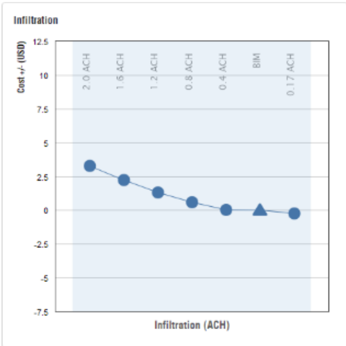


Number of hours per day throughout the entire week used for reference.

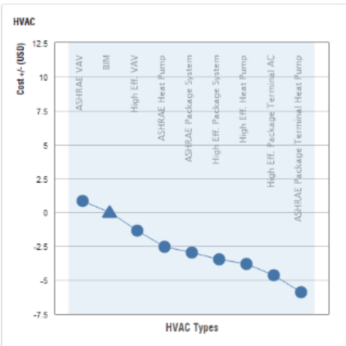
Figure 5. Baseline analysis cards: occupancy, orientation, plug loads, and operating schedule.



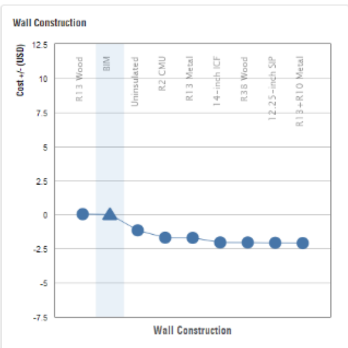
Heat emitted by lighting fixtures and energy consumed per square meter. These are electrical inputs, so the full range was assumed.



Building airtightness and air leakage into the spaces. These are mechanical inputs, so the full range was assumed.

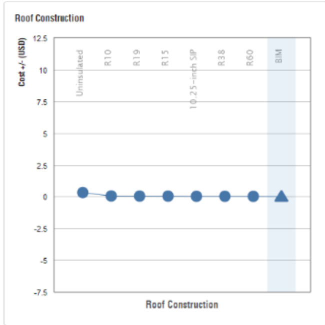


Heating and cooling system.

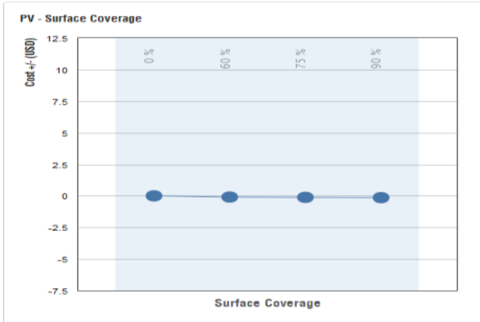


Details of the walls and their construction materials.

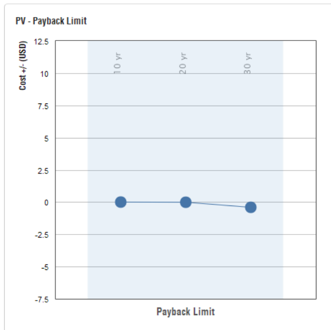
Figure 6. Baseline analysis cards: lighting, infiltration, HVAC, and wall construction.



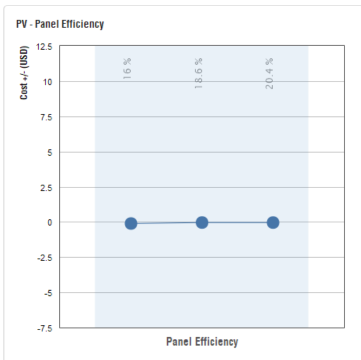
Details of the roof and its construction materials.



Area covered by solar panels.

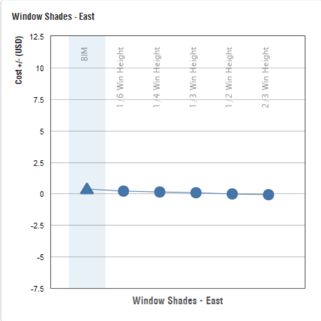


Payback limit for the photovoltaic system.

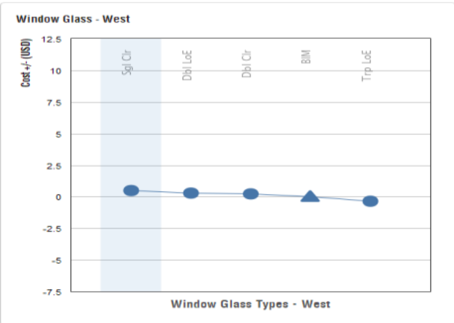


Efficiency of solar panels in converting solar energy.

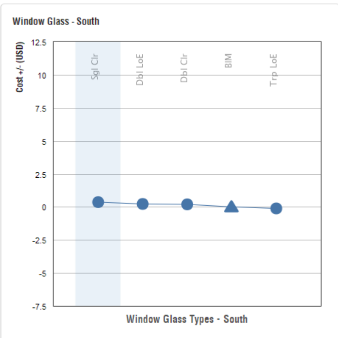
Figure 7. Baseline analysis cards: roof and photovoltaic-system parameters.



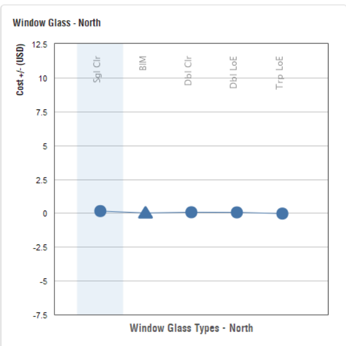
Extension of shading devices relative to the height of the windows on the eastern facade.



Type of glass used on the western facade.

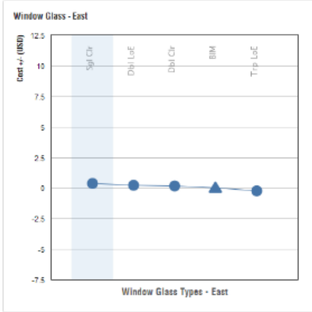


Type of glass used on the southern facade.

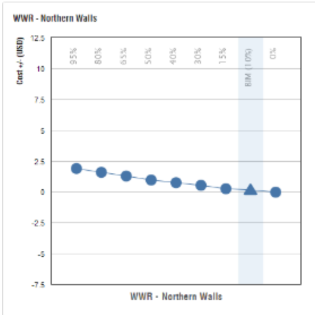


Type of glass used on the northern facade.

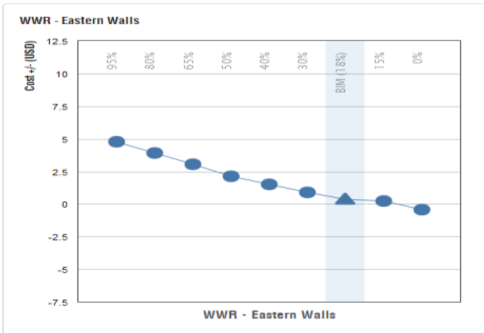
Figure 8. Baseline analysis cards: eastern shading and facade glazing types.



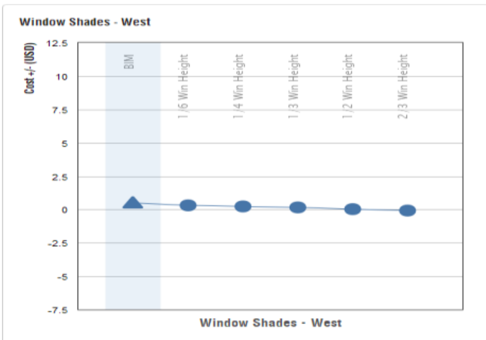
Type of glass used on the eastern facade.



Percentage of glazing on the northern facade.

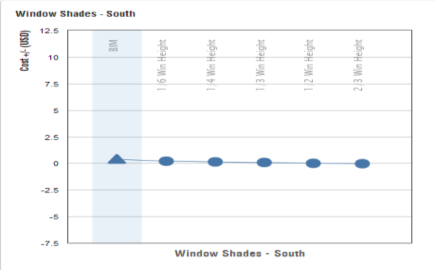


Percentage of glazing on the eastern facade.

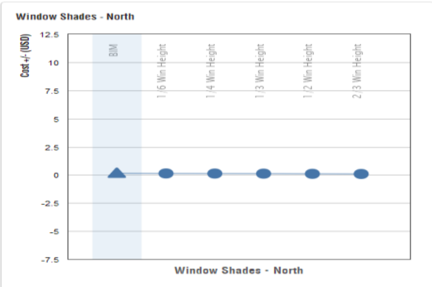


Extension of shading devices relative to the height of the windows on the western facade.

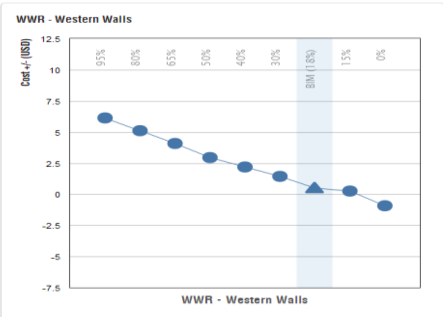
Figure 9. Baseline analysis cards: eastern glass, glazing ratios, and western shading.



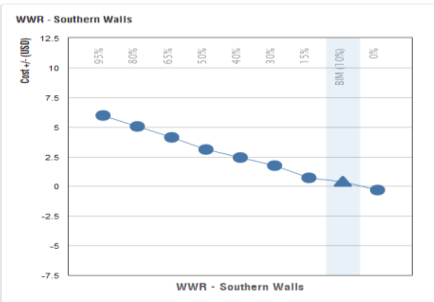
Extension of shading devices relative to the height of the windows on the southern facade.



Extension of shading devices relative to the height of the windows on the northern facade.



Percentage of glazing on the western facade.



Percentage of glazing on the southern facade.

Figure 10. Baseline analysis cards: southern and northern shading and facade glazing ratios.

The ranges were defined for specified and known elements, while all options were considered for undefined elements. The analyses produced an annual energy-use intensity of $357\,\mathrm{kWh/m^2/yr}$, as shown in Figure 11. The model was then re-evaluated by changing selected ranges and elements to determine the impact of those changes.

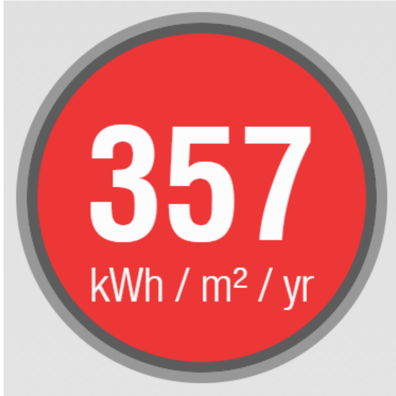
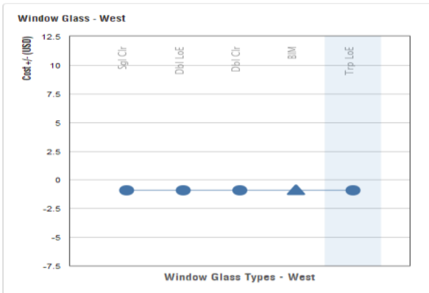
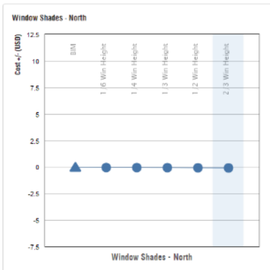


Figure 11. Annual energy-use intensity of the baseline building model.

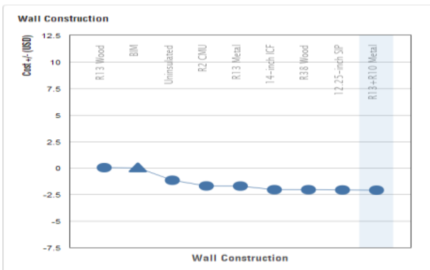
According to the analysis, the lower range that reduces energy consumption was selected. The best window type was double glazing. The optimal shading ratio on the northern, eastern, western, and southern facades was two-thirds of the window height. The selected wall type achieves a thermal transmittance of $U = 0.3316\,\mathrm{W/(m^2{\cdot}K)}$, and the selected HVAC system is the ACASHRAE Package Terminal Heat Pump. All corresponding selection cards are reproduced in Figures 12–14.



Selected double-glazed windows for the western facade.

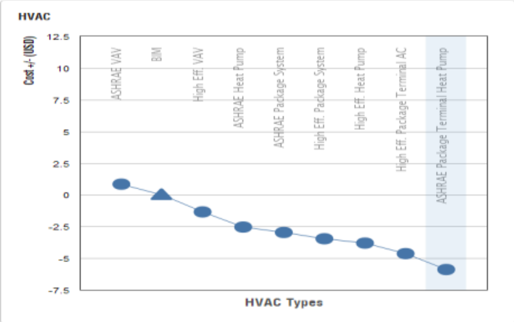


Selected northern-facade shading ratio of two-thirds of the window height.

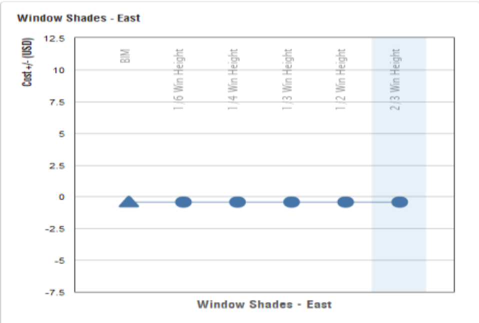


Selected wall construction with a thermal transmittance of $U = 0.3316\,\mathrm{W/(m^2{\cdot}K)}$.

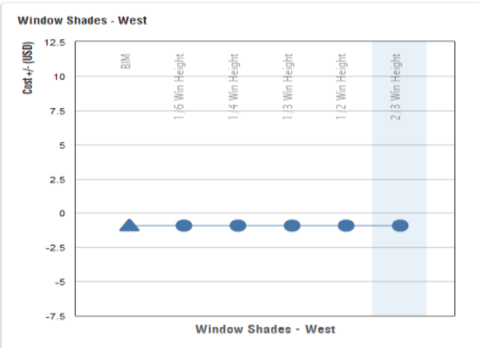
Figure 12. Selected western glazing, northern shading, and wall-construction parameters.



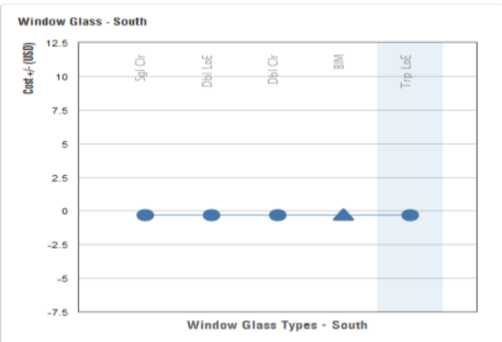
Selected ACASHRAE Package Terminal Heat Pump HVAC system.



Selected eastern-facade shading ratio of two-thirds of the window height.

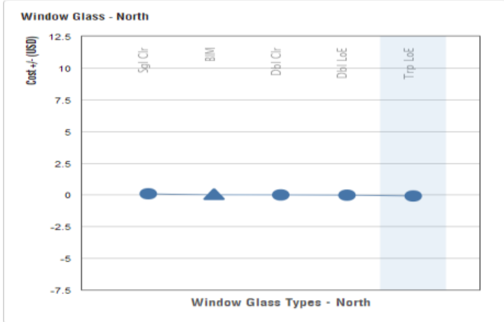


Selected western-facade shading ratio of two-thirds of the window height.

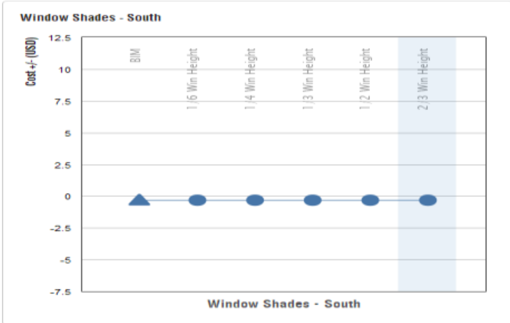


Selected double-glazed windows for the southern facade.

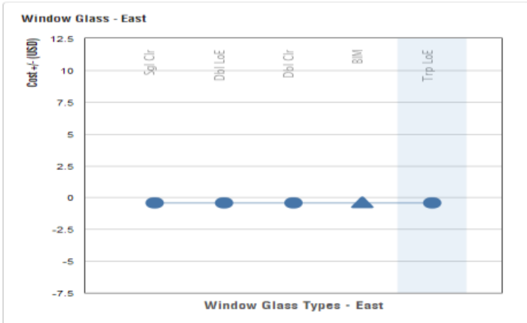
Figure 13. Selected HVAC, eastern and western shading, and southern glazing parameters.



Selected double-glazed windows for the northern facade.



Selected southern-facade shading ratio of two-thirds of the window height.



Selected glazing option for the eastern facade.

Figure 14. Selected northern glazing, southern shading, and eastern glazing parameters.

Several elements were changed to observe the difference in results: the HVAC system, the types of windows used, the shading ratios on windows, and the wall types and their thermal transmittance. The modified design produced an annual energy-use intensity of $160\,\mathrm{kWh/m^2/yr}$ (Figure 15).

Figure 15. Annual energy-use intensity after the design modifications.

Figure 16 compares the current design and the modified design in terms of energy savings.

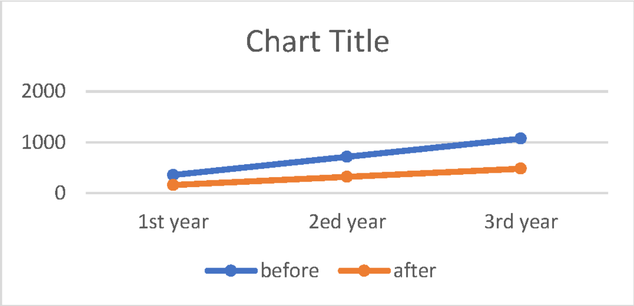


Figure 16. Comparison between the current design and the modified design regarding energy savings.

The percentage difference in energy consumption per square meter between the current and modified designs of the building is calculated as

$$\left(\frac{\text{New Value} - \text{Old Value}}{\text{Old Value}}\right) \times 100 = 55.1\%. \tag{1}$$

This indicates that the reduction in consumption between the two cases is more than half. Regulating the exchange between internal and external spaces is crucial for achieving energy efficiency in the building by ensuring the airtightness of openings and designing an external envelope with low thermal transmittance.

The heating and cooling system must be carefully studied. Protecting spaces from solar radiation is essential, and shading studies should be conducted to block or capture solar rays as needed. BIM tools make it possible to include information that simulates the local environment in the adopted design and to study the relationship between them. This integration allows designers to determine whether a design is harmonious or discordant with its local environment and what adjustments should be considered.

Further studies can include more detailed information about the design, more accurate modeling of building elements and systems, and a more thorough description of the surrounding environment, such as wind, climate, and equipment used. This creates results that more closely reflect reality. The more comprehensive the information included in the model, the more accurate the results and reports that can help reduce the cost of design modifications in the early stages.

4. DISCUSSION

The results of the data analysis using Revit demonstrate that significant improvements in energy efficiency in residential towers can be achieved through well-considered design modifications. The findings indicate that the energy efficiency of the building under study reached 160 kWh per square meter per year, reflecting improvements resulting from the implementation of various design strategies. The graph shows a substantial reduction in energy consumption following the proposed modifications, with a decrease of more than 55% compared with the original design.

Through the creation of an energy model using Autodesk Insight, it became evident that key elements contributing to enhanced energy efficiency include improved thermal insulation, the use of double-glazed windows for better thermal performance, and the application of a more efficient air-conditioning system such as the ACASHRAE Package Terminal Heat Pump. Additionally, controlling the ratio of openings and shading on facades, such as setting the optimal window shading ratio at two-thirds of the window height, effectively reduced thermal loads and energy consumption.

Moreover, integrating techniques such as Building Information Modelling (BIM) [17] provides the capability to incorporate data regarding the local environment and design elements, allowing verification of the design's compatibility with local climatic conditions. However, challenges remain concerning the alignment of precise data and the effective integration of different assessment systems. It is crucial to continue research to enhance modeling accuracy and simulate various scenarios that can offer a clearer perspective on the extent to which a design achieves actual sustainability in different environments. The results underscore that advanced modeling tools can lead to significant improvements in energy performance and cost savings over the long term.

5. CONCLUSION

5.1 Summary of Key Findings

Current research focusing on improving energy efficiency in residential towers using Building Information Modelling (BIM) [18] techniques and Revit software has highlighted several key findings that emphasize the effectiveness of sustainable design strategies in reducing energy consumption and achieving environmental goals. A significant reduction in energy consumption of more than 55% was achieved in the residential tower after design optimization, indicating the effectiveness of the measures taken to enhance energy efficiency.

The results demonstrated that using materials with low thermal conductivity and installing high-performance double-glazed windows plays a crucial role in reducing thermal loss and increasing the building's energy efficiency. The ACASHRAE Package Terminal Heat Pump HVAC system showed notable efficiency in reducing energy consumption while maintaining thermal comfort, underscoring the importance of selecting appropriate heating and cooling systems to improve energy performance.

Natural-light utilization was enhanced and reliance on artificial lighting was reduced through the design of building facades that allow effective natural-light entry, with appropriate shading ratios for windows identified as a critical factor in reducing thermal loads. The research confirmed that integrating BIM [19, 20] techniques into the design and analysis process provides a comprehensive framework for evaluating and improving building performance by simulating different scenarios and identifying design strengths and weaknesses.

Despite the positive results, the research noted challenges related to system integration and the need for accurate and comprehensive data to achieve more precise outcomes. This requires the development of more complex analytical models that consider additional environmental and technical factors. The improvement in energy efficiency positively affects the environment by reducing carbon emissions and conserving natural resources, while also contributing to lower long-term building operating costs. These results demonstrate that adopting sustainable design techniques and relying on

Building Information Modelling [16, 21, 22] can offer effective solutions to energy-consumption challenges in high-rise buildings, contributing to sustainable development and global sustainability goals.

5.2 Concluding Remarks

The current study highlights the importance of applying energy-efficiency improvement strategies in high-rise buildings by modeling sustainability criteria and evaluation systems using Revit software. Analysis of a residential-tower case study in Basel confirmed that advanced modeling techniques, such as Revit and Autodesk Insight, can significantly enhance energy efficiency in high-rise buildings.

The study demonstrated that well-considered design modifications, such as improving thermal insulation, using double glazing, and implementing a more efficient HVAC system [23], such as the ACASHRAE Package Terminal Heat Pump, resulted in a notable reduction in energy consumption of more than 55% compared with the original design. These improvements not only reduced energy consumption but also contributed to lower carbon emissions and better resource management, enhancing the environmental and social benefits of high-rise buildings.

By integrating Building Information Modelling (BIM) [24] techniques, the study provides a comprehensive framework for evaluating and improving the energy performance of buildings and enables the effective integration of local environmental data and design elements. However, challenges related to data accuracy and the integration of evaluation systems remain, necessitating further research to develop more complex analytical models.

The findings indicate that improving energy efficiency requires a holistic design approach that considers all influencing factors, such as controlling openings and shading on facades and selecting appropriate building materials. Additionally, the study shows that advanced modeling tools contribute to effective solutions for energy-consumption challenges, providing a practical framework for achieving sustainability in high-rise building design.

In conclusion, the research recommends continued research and development of modeling tools to include more details about the design and surrounding environment. This will contribute to more accurate results and reduce costs associated with design modifications in the early stages, providing a strong foundation for applying sustainability strategies in high-rise buildings, promoting sustainable development, and achieving global sustainability goals [25, 26].

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