Energy-Efficient Envelope Design for High-Rise Apartments in Erbil City

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ABSTRACT

The building envelope functions as the primary interface between indoor and outdoor environments, which has long attracted the attention of building physicists and designers due to its dual role in performance and architectural expression. As the external layer of a building, the envelope conveys the design concept and visual identity of a project. Close collaboration with architects is essential to guide design decisions that enhance the thermal performance of the envelope, particularly by identifying and mitigating the dominant pathways of heat gain and heat loss through the building skin. Energy efficiency has become a central objective in the design and construction of numerous buildings. Some projects, such as those certified under the USGBC LEED framework, are formally classified as sustainable based on multiple criteria, including energy performance. However, a considerable number of these buildings fail to achieve optimal operational efficiency, often soon after completion. In this study, a proposed residential building in Erbil city was modelled, using the Park View project as a comparable case study for preliminary envelope design, to illustrate key considerations. Simulation outcomes demonstrated that optimising building orientation, together with an appropriate combination of glazing configuration, window-to-wall ratio, shading strategies, glazing specifications, and wall and roof insulation, led to a 53.6% reduction in annual energy demand. This investigation contributes to the growing body of research showing how simulation-based design can support sustainable building development and long-term energy efficiency. Furthermore, implementing such a high-performance envelope in conventional buildings, particularly high-rise structures, could yield greater energy savings and improved economic returns over the building lifecycle.

Keywords: Energy-Efficient, Envelope Design, High-Rise Apartments, Erbil City, Park View, Buildings

INTRODUCTION

Economic growth, urban expansion, and planning activities constitute the principal catalysts for technological progress through the adoption of advanced materials and innovative construction technologies (Farouk, 2011). Although many Southeast Asian countries are characterised by high population densities, Erbil has experienced a relatively limited number of large-scale developments, which are predominantly high-rise residential projects. Park View represents one of the most prominent developments of this type. It has been reported that nearly 90% of residents live in high-rise buildings, with approximately half residing in high-density public housing estates (Lam, 1996). The growing reliance on air conditioning systems to maintain indoor thermal comfort has significantly increased electricity consumption in the residential sector, particularly during the summer period.

This trend indicates a potential opportunity to reduce energy demand and associated greenhouse gas emissions by minimising dependence on mechanical cooling in high-rise buildings. In Erbil City, local developers have largely neglected passive design strategies that can moderate indoor temperatures and reduce building energy use while promoting environmental sustainability. Since the façade of high-rise buildings constitutes the largest portion of the building perimeter exposed to direct heat exchange between indoor and outdoor environments, it plays a critical role in the development of environmentally responsive structures. The building envelope comprises exterior walls, windows and glazed elements, roofs, skylights, below-grade foundation walls, and basement slabs on grade. Envelope design requires consideration of multiple factors, including architectural appearance, structural resistance to wind and gravitational loads, heat and daylight transmission for occupant comfort, safety and security requirements, acoustic performance, fire resistance, and economic feasibility (Syed, 2012).

The envelope controls solar heat gain, air infiltration and exfiltration, and conductive heat transfer across the building boundary. An energy-efficient envelope can be achieved by minimising energy-loss surfaces while enhancing solar control and heat dissipation capabilities (Al-Tamimi, 2022). Beyond improving energy performance, next-generation high-performance façades are expected to contribute to addressing broader anthropogenic environmental challenges. To develop a high-performing envelope, it is essential to apply construction codes and performance metrics, alongside a comprehensive understanding of envelope science, compliance pathways, and climatic conditions, which collectively provide designers with critical tools for effective envelope design. Overall, a central objective of this tall building design research is to enhance the overall energy efficiency of the structure. Refer to Figures 1, 2 and Table 1.

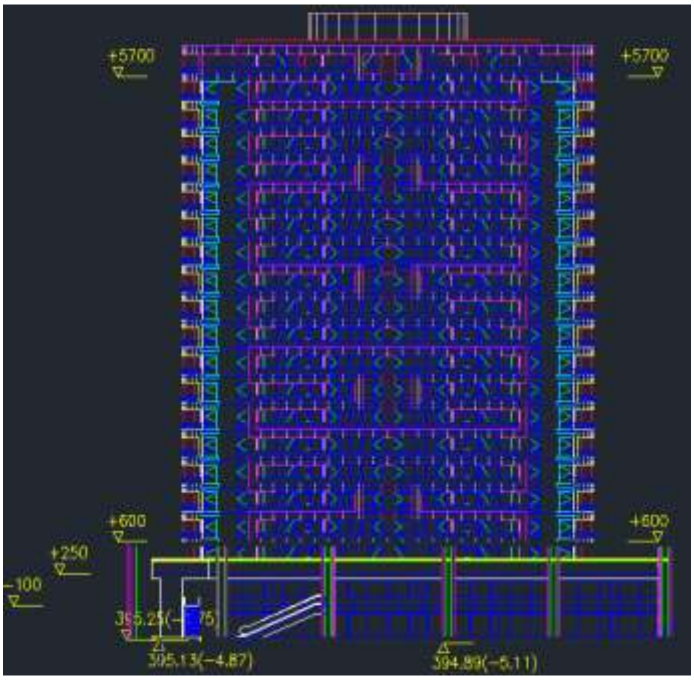

Figure 1: Section Views of the Building

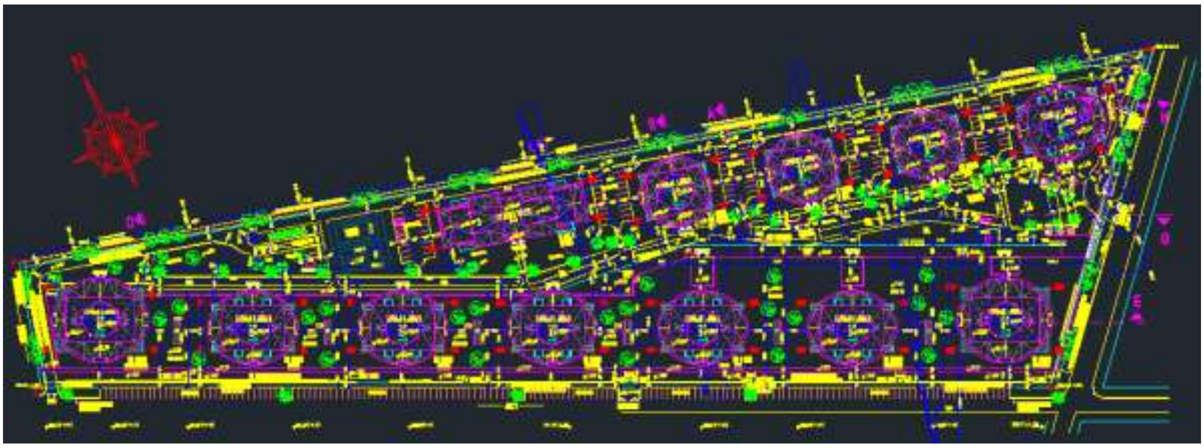

Figure 2: The Site of Park View

Table 1: Parameters of Selected Building

S. No.	Parameter	Description
1.	Usage	High Rise Residential Building
2.	Location	Park View in Erbil city
3.	N. of floor	19
4.	Wall	Compact Laminate Cladding
5.	Roof	150 mm Concrete
6.	Glazing	Double Glazed with Aluminium Frame
7.	Built-Up Area	3538.363 m2

THE STUDY'S GOAL AND METHODOLOGY

This research seeks to demonstrate the energy performance of the building envelope through the application of advanced and innovative technologies. The methodological framework adopted in this study comprises the following stages:

1. A comprehensive literature review was undertaken to establish the conceptual and theoretical foundation of the research.
2. Simulation analysis was conducted using Building Information Modelling (BIM).

According to Krygiel and Nies (2008), BIM facilitates multiple aspects of sustainable design, including the following elements:

- Building Orientation: Selecting an optimal orientation contributes to lowering energy demand and associated operational costs.
- Building Massing: Building form and volumetric configuration are evaluated to optimise the performance of the building envelope.
- Daylighting Assessment: Natural lighting performance is analysed to enhance visual comfort and reduce artificial lighting requirements.
- Energy Modelling: Simulation-based energy modelling is applied to minimise energy consumption and to evaluate the feasibility of integrating renewable energy systems.
- Sustainable Material Selection: Environmentally responsible materials are considered, including recycled content and strategies to minimise material usage.
- Site and Logistics Management: Construction planning is optimised to reduce waste generation and carbon emissions.

3. Achieving Potential LEED Credited Points

In recent years, a wide range of building energy simulation software tools has become available. Some tools utilise highly detailed, time-step-based models, whereas others provide simplified approaches for energy assessment. In this study, simulation analysis was performed using BIM, enabling a comprehensive evaluation through Ecotect software. The assessment aligns with LEEDTM Credit EA1, Enhance Energy Efficiency. To evaluate incremental improvements in energy performance beyond the baseline requirements of the prerequisite standard, three alternative compliance pathways were defined.

PREVIOUS RESEARCH

Research addressing the design of energy-efficient apartment buildings in hot and arid climates remains limited. Existing studies in Middle Eastern and Asian contexts have largely prioritised occupant thermal comfort, while façade and roof envelope optimisation has received comparatively less scholarly attention. Evidence suggests that approximately one-quarter of building heat gains are associated with inappropriate wall material selection, whereas nearly three-quarters are linked to poorly designed window systems, with façade elements contributing almost 90% of total thermal gains (Rakheja & Agarwal, 2015).

A study conducted by The Built Environment Research Group proposed an integrated passive design framework to reduce cooling energy demand in high-rise residential buildings through enhanced envelope design. The findings indicated reductions of 31.4% in annual cooling energy consumption and 36.8% in peak cooling load for a baseline apartment model, although passive measures exhibited minimal influence on latent cooling loads, typically below 1% (Hu et al., 2023). Frank Lloyd Wright's holistic design philosophy emphasised the integration of building technologies, including materials, systems, and construction techniques, with architectural form in response to contextual conditions (Geva & Morris, 2012).

Furthermore, technical investigations of envelope components have highlighted advancements in energy-efficient wall systems, such as glazed, ventilated, and Trombe walls, alongside fenestration technologies including vacuum glazing, aerogel, and advanced framing systems. Developments in roofing systems, such as green roofs, solar roofs, radiant barriers, and evaporative cooling methods, have also been documented, together with criteria for selecting thermal insulation materials. These studies concluded that energy-efficient design strategies do not necessarily require increased capital expenditure, as integrated design approaches can offset costs through reductions in mechanical system capacity (Tzempelikos et al., 2007).

Previous investigations have shown that high-performance envelope designs can reduce total and peak cooling energy demand by up to 35% and 47%, respectively (Chan & Chow, 1998). Despite this, tall buildings are frequently perceived as environmentally unsustainable due to the substantial resources and energy required for their construction. However, limited quantitative assessments have been conducted to substantiate this perception. Additional research reported that infiltration control and thermal insulation strategies in walls, roofs, and floors reduced energy consumption by 20–40% and 20%, respectively, while light-coloured roofs and façades, together with external shading devices, reduced cooling demand by 30% and 2–4%. Passive design strategies, typically initiated at the architectural design stage, represent the initial step in reducing building energy consumption (Balaras et al., 2000).

The influence of insulation thickness and its placement within the building envelope on cooling load and energy use was analysed, with external wall insulation shown to reduce cooling energy demand by approximately 7%. It has been examined passive solar heating systems such as solar chimneys, roof-based systems, unglazed perforated collectors, and Trombe walls, in addition to evaporative passive cooling techniques and their integration into building design (Gupta & Tiwari, 2016). Prior studies have typically focused on individual envelope components rather than comprehensive system-level optimisation. In regions such as Erbil, systematic research examining the maximum achievable energy efficiency of high-rise buildings in hot and arid climates remains insufficient. By analysing the energy performance of the Park View project, this study seeks to provide deeper insights into resource-efficient and energy-conscious design strategies for tall buildings in similar climatic contexts.

This research also contributes to understanding annual energy consumption through Rivet modelling, architectural programming, and Ecotect-based design analysis. In addition, the study considers LEED 2009 point-based evaluation criteria, with particular emphasis on site selection, mitigation of heat island effects, promotion of locally sourced materials to support the regional economy, and the integration of daylight and external views into occupied spaces. Although numerous factors influence envelope design, LEED-based assessment is considered a critical framework for evaluating technologies and strategies aimed at reducing energy consumption, enhancing indoor environmental quality, and minimising environmental impacts in high-rise buildings.

Contemporary building design increasingly prioritises environmental sustainability and energy efficiency (Sadineni et al., 2011). The principal objectives of sustainable construction include the development of green buildings and the enhancement of energy performance. This study provides a comprehensive evaluation of strategies to maximise the energy efficiency of high-rise buildings in hot and dry climates and offers innovative design recommendations. Sustainable buildings are increasingly recognized as essential infrastructure for addressing climate change, reducing greenhouse gas emissions, and minimizing the environmental impact of the built environment. The transition towards sustainable construction practices requires integrated approaches that balance architectural innovation, engineering excellence, and environmental stewardship.

High-rise buildings in hot and arid regions face particular design challenges due to extreme solar radiation, high ambient temperatures, and limited natural water resources, necessitating specialized envelope design strategies and passive cooling techniques. Energy performance optimization in these climates requires systematic evaluation of multiple design variables and their synergistic interactions, including building orientation, façade configuration, window-to-wall ratio, glazing properties, external shading mechanisms, thermal insulation specifications, and ventilation systems. The design approach for high-rise buildings in hot-dry climates must prioritize minimization of solar heat gain through strategic façade design while simultaneously optimizing daylighting access to reduce artificial lighting energy consumption. Additional previous studies on building envelopes and energy-saving approaches are presented in Table 2.

Table 2: The Summary of Previous Research According to the Source (Stevanović, 2013)

Objective Function	Design Variables	Optimization Method	Simulation Method	Case Study Location	Major Findings/Limitations	Ref.
Solar Irradiation of the Equatorial-Facing Facade	Seven Building Shapes, Shape Aspect Ratio	Parametric Study	Energy Plus	Canada	To enhance solar potential, reduce the ratio of shading to shaded facade lengths and increase the angle enclosed between shading and shaded facades.	(Hachem et al., 2011)
Energy Demand, Lifecycle Cost	Window dimensions (all orientations); Building orientation; 8+ design parameters	Genetic alg.	DOE-2	USA including Chicago	Demonstrated effective GA-DOE-2 coupling; Addressed local minima challenges; Foundation for building design optimization using GA; 527+ citations	(Caldas & Norford, 2002)
Lifecycle Cost, Lifecycle Environmental Impact	Polygonal Shape of Building Footprint, Structural System, Insulation Levels, Glazing Type, Windows-to-Wall Ratio, Overhangs Presence, Depth and Height	Genetic alg.	Unknown	Canada	Solutions with reduced lifespan costs have geometries near to the regular polygon, whereas solutions with lower lifecycle environmental effect have longer edge lengths on the south facade.	(Wang et al., 2006)
Lifecycle Cost and Environment Impact	Roof/wall insulation thickness, insulation material type, thermal conductivity, annual energy costs, capital costs	Parametric Study	LCC assessment	China	Optimal insulation configuration at building-scale does NOT correlate to optimal component-level U-values. Non-linear cost-thickness relationship identified.	(Jie et al., 2018)

Table 2 (continued): The Summary of Previous Research According to the Source (Stevanović, 2013)

Objective Function	Design Variables	Optimization Method	Simulation Method	Case Study Location	Major Findings/Limitations	Ref.
Heating Load, Cooling Load	Leaf Area Index of the Green Roof, Roof Insulation	Parametric Study	TRNSYS	Greece, France, Sweden	Green roofs are better suited to retrofitting non- or weakly insulated existing structures than for use in well-insulated new buildings.	(Jaffal et al., 2012)
Heating Load, Cooling Load	Building Aspect Ratio, South Windows Size	Parametric Study	SUNCODE-PC	Five Cities in Turkey	The building aspect ratio has minor influence on energy performance compared to the south windows size in both cool and warm climates.	(Inanici & Demirbilek, 2000)
Heating Load, Cooling Load	Complex origami-based dynamic shading, Shading device, Façade orientation, solar radiation threshold, indoor illuminance threshold, outdoor temperature threshold	Parametric Study	IES-VE	China	Dynamic shading improved daylighting performance by 91.5% compared to conventional static overhang shading, Energy performance improved by 19.9% with dynamic shading strategy, and dynamic behaviors with proper control algorithms can significantly exceed static shading effectiveness	(Wu & Zhang, 2022)
Thermal Comfort	Window Facing Orientation, Window-to-Wall Ratio, Openable Window Area Ratio, Shading Device Type, Number of Shading Devices	Parametric Study	Ladybug VP	Hainan Island, China	EUI reduction 18.60–25.62% (HSD superior to VSD), TCP improved 11.21–23.18%, UDI improved 35.66–37.96%, South-facing optimal for energy/comfort, East/West optimal for daylighting.	(Wu et al., 2025)

WEATHER AND CLIMATE ANALYSIS

Iraq is largely a landlocked country, bordered by Saudi Arabia to the south, the Arabian Gulf and Kuwait to the south-east, Jordan and Syria to the west, Turkey to the north, and Iran to the east. The city of Erbil is located at approximately 44°04′ longitude and 36°12′ latitude, with an elevation of about 470 metres above sea level. Iraq is characterised by some of the highest recorded ambient temperatures globally. During mid-May, April, and March, Erbil experiences lush landscapes with green plains and rolling hills, and these months are typically marked by warm daytime conditions and cooler evenings. The period from May to September constitutes the hottest and driest season, with air temperatures frequently approaching 50 °C. In contrast, the winter season is relatively cold and often accompanied by rainfall, while heavy snowfall in mountainous regions can occasionally lead to icy conditions. The prolonged hot and arid summer season in Erbil significantly increases the demand for air conditioning to maintain indoor thermal comfort. Long-term climatic and meteorological data for Erbil are presented in Table 3, which summarises the monthly average weather conditions.

Table 3: The Average for Erbil Weather in Various Months

Month	Avg Max Temp	Avg Min Temp	Avg Hrs of Sunshine Per Day	Avg Days W/ Rain Per Mo.	Avg Mm Of Rain Per Month
January	12	2	5	14	61-100 mm
February	15	3	6	11	61-100 mm
March	19	7	7	10	61-100 mm
April	25	11	8	10	61-100 mm
May	32	16	10	5	31-60 mm
June	39	21	14	1	0-5 mm
July	43	25	14	1	0-5 mm
August	42	24	13	1	0-5 mm
September	38	19	11	1	0-5 mm
October	29	14	8	5	6-30 mm
November	21	8	6	7	31-60 mm
December	14	4	5	10	61-100 mm

CLIMATE DATA FOR ERBIL

Based on the Köppen climate classification, Erbil is characterised by a hot-summer Based on the Köppen climate classification, Erbil is characterised by a hot-summer Mediterranean climate, featuring hot, dry summers and mild, moderately rainy winters. January is typically the month with the highest precipitation. Traditional Erbil architecture, including thick earthen walls (stone and adobe), courtyard-centered building forms, deep window overhangs, and white-painted exterior surfaces, evolved specifically to address these dual challenges by utilizing high thermal mass for temperature moderation and low solar absorptance for heat rejection. Modern residential construction in Erbil has largely abandoned these climate-responsive principles, with contemporary buildings achieving only 50% of traditional houses' thermal performance and consuming substantially higher mechanical cooling energy loads, prompting architectural research initiatives to reintegrate passive design strategies proven effective in historical building stock. See Table 4 for detailed climatic data on monthly precipitation, temperature ranges, and humidity variation, to support parametric building simulation and envelope optimization studies for Erbil and comparable hot-summer Mediterranean climate zones

Table 4: The Climate Data for Erbil City

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record High °C (°F)	20.1 (68.2)	27.9 (82.2)	31.3 (88.3)	34.5 (94.1)	41.9 (107.4)	43.3 (109.9)	48 (118)	49.3 (120.7)	44.8 (112.6)	38.2 (100.8)	30.6 (87.1)	24.2 (75.6)	49.3 (120.7)
Average High °C (°F)	12.4 (54.3)	14.2 (57.6)	18.1 (64.6)	24 (75)	31.5 (88.7)	38.1 (100.6)	42 (108)	41.9 (107.4)	37.9 (100.2)	30.7 (87.3)	21.2 (70.2)	14.4 (57.9)	27.2 (80.98)
Daily Mean °C (°F)	7.4 (45.3)	8.9 (48)	12.4 (54.3)	17.5 (63.5)	24.1 (75.4)	29.7 (85.5)	33.4 (92.1)	33.1 (91.6)	29 (84)	22.6 (72.7)	15 (59)	9.1 (48.4)	20.18 (68.32)
Average Low °C (°F)	2.4 (36.3)	3.6 (38.5)	6.7 (44.1)	11.1 (52)	16.7 (62.1)	21.4 (70.5)	24.9 (76.8)	24.4 (75.9)	20.1 (68.2)	14.5 (58.1)	8.9 (48)	3.9 (39)	13.22 (55.79)
Record Low °C (°F)	−16.2 (2.8)	−14 (7)	−9.3 (15.3)	−2.1 (28.2)	2.6 (36.7)	9.1 (48.4)	11.7 (53.1)	10.3 (50.5)	9.5 (49.1)	1.6 (34.9)	−5.6 (21.9)	−12.3 (9.9)	−16.2 (2.8)
Average Precipitation mm (Inches)	111 (4.37)	97 (3.82)	89 (3.5)	69 (2.72)	26 (1.02)	0 (0)	0 (0)	0 (0)	0 (0)	12 (0.47)	56 (2.2)	80 (3.15)	540 (21.25)
Avg. Precipitation Days	9	9	10	9	4	1	—	—	1	3	6	10	—
Avg. Snowy Days	1	0	—	0	0	0	0	0	0	0	0	—	—
Average Relative Humidity (%)	74.5	70	65	58.5	41.5	28.5	25	27.5	30.5	43.5	60.5	75.5	50.04

Source: Climate-Data.org, My Forecast for records, humidity, snow and precipitation days.
Source: (Norton, 2014): What's the Weather Like.org, and Erbilia.

ENVELOPE OPTIMIZATION THROUGH PASSIVE STRATEGIES

Ecotect software was employed to develop a simulation model for calculating the building's annual energy consumption and evaluating the effects of various proposed design modifications. Building modelling software allows for the assessment of trade-offs associated with different solar heat gain coefficient values, particularly in climates where both heating and cooling demands are significant. As the energy performance of floors 2, 3, and 4—the middle levels—is largely similar, the building's BIM model extracts relevant data from the floor schedule for five floors, with the first and top floors representing the only deviations. To determine the optimal envelope configuration, the building's annual energy consumption under multiple design scenarios was calculated and compared against the baseline model. In passive solar building design, windows, walls, and floors are intended to minimise solar heat gain during summer while absorbing, storing, and distributing solar energy as heat during winter. Effective passive solar design requires careful analysis of the site and climate, with consideration of factors such as window orientation and dimensions, glazing type, thermal insulation, thermal mass, and shading devices (Norton, 2014).

Building Orientation Optimization

The building's expansive façades capture substantial solar radiation and daylight throughout the year, particularly across exterior surfaces. Therefore, tightening the envelope is essential to maximise solar heat storage during winter and minimise unwanted solar gains in summer. The azimuth angle significantly affects both direct solar radiation and other forms of solar heat gain. For instance, the roof receives the greatest solar exposure from sunrise to sunset, whereas exterior walls require shading according to the sun's position and angle. Charron (2008) found that in cost-effective net-zero energy projects, climatic conditions primarily influence the selection of external wall types and the area of southern glazing, while building orientation substantially affects overall window area and active solar system parameters.

Given that the sun's azimuth varies seasonally, simulations were conducted for multiple building orientations independently. During summer, external walls are most exposed to solar radiation as the sun shifts from south to east and west. The baseline energy performance was determined by averaging the outcomes of four annual simulations: one reflecting the building's current site orientation and three others rotating the structure by 90°, 180°, and 270°, allowing for evaluation of optimal siting, a process facilitated by BIM. Results indicated that total energy consumption across the four principal orientations—north, east, south, and west—was broadly similar. Minor differences were observed between the baseline and proposed models, with the south-east orientation proving advantageous. Consequently, a southern orientation is optimal for both summer and winter, as it maximises beneficial solar heat gain. The building's design positions the largest wall surfaces facing south, while eastern façades receive minimal exposure. Implementing the south-east orientation reduced annual energy use by approximately 1.6%, from 229,684 m^2Wh to 225,969 m^2Wh (see Figures 3 and Figure 4).

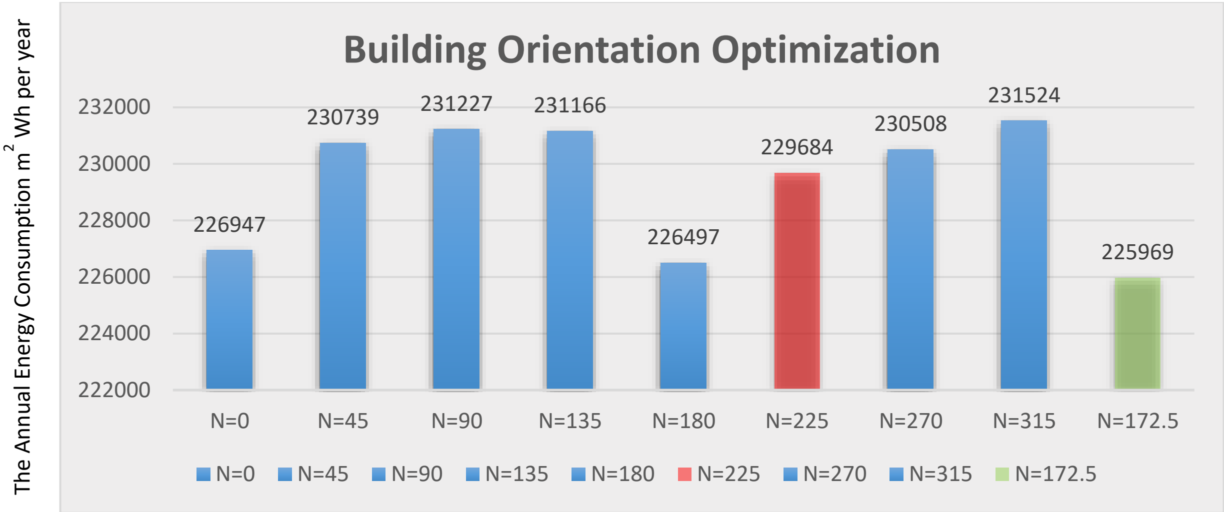

Figure 3: Graph Highlighting Impact of Building Orientation on Energy Consumption

It is important to note that reorienting a building may not always be practicable; therefore, alternative strategies must be employed to protect the structure from direct solar heat gains.

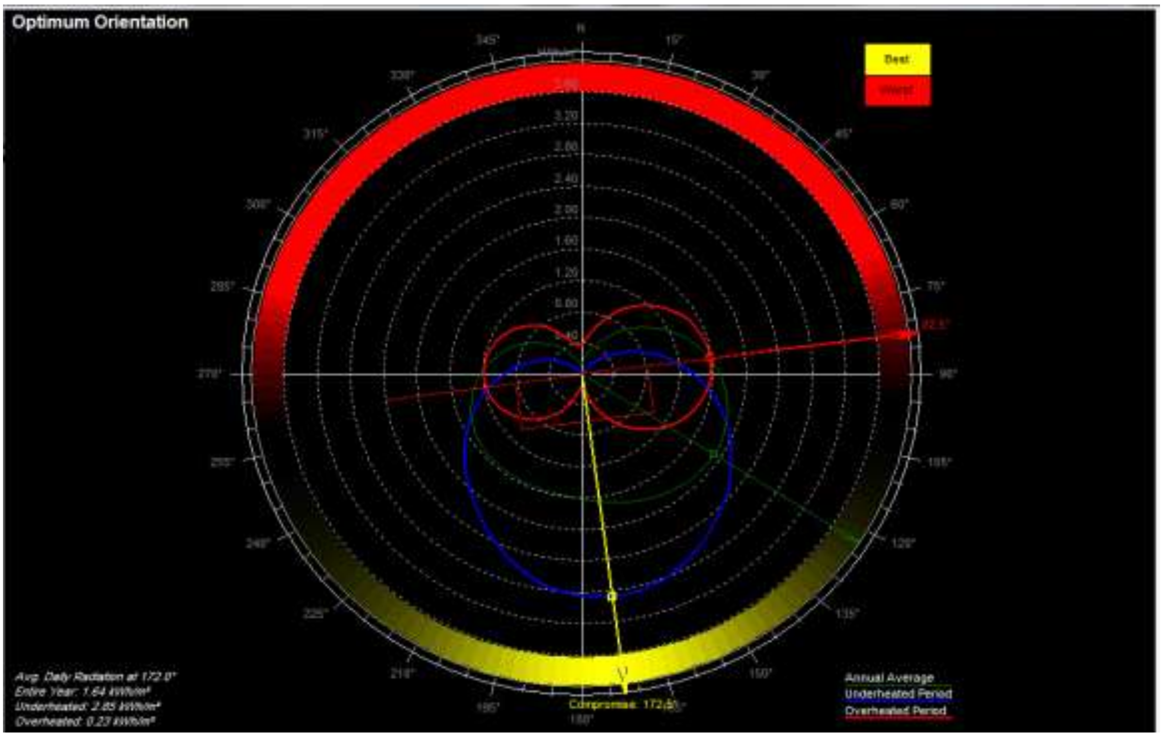

Figure 4: BIM Model of the Building (Made in Revit Architecture) Shows the Best Orientation of the Building

Glazing Type Window-to-Wall Ratio Optimization

Fenestration is a critical factor in controlling a building's energy performance, as it must reduce unwanted heat gain while maintaining adequate daylighting in occupied spaces. Heat conduction through the building envelope also contributes significantly to overall energy loads. Reducing the window-to-wall ratio where possible is important, as insulated walls generally provide superior thermal performance compared to even the most efficient glazing systems.

Advanced fenestration technologies, despite their extremely low thermal transmittance, can inadvertently increase cooling loads in hot climates by restricting the dissipation of internal heat to the external environment (Ming et al., 2024). Inanici and Demirbilek (2000) observed that, in both cold and warm regions, the size of south-facing windows has a greater effect on energy performance than the building's aspect ratio. Similarly, A. Nsaif et al. (2025) demonstrated that the dimensions of triple-glazed low-e windows in passive buildings significantly influence cooling demand, while having minimal effect on heating loads.

When selecting envelope components, both annual energy consumption and daylighting performance should be considered. In hot climates such as Iraq, where cooling is the dominant seasonal requirement, reducing direct solar radiation is essential for energy conservation. Yıldız and Arsan (2011) indicated that building aspect ratio, solar heat gain coefficient, glazing U-value, and total window area are the most influential parameters for energy performance in hot and humid regions. Choosing glass with a low U-factor helps minimise heat gains and losses, but designers must also account for the complete window assembly, including frames and spacers, since the absence of thermally broken frames can substantially reduce the effectiveness of high-performance glazing. Achieving optimal energy efficiency requires carefully balancing glass type, window area, aesthetics, and both capital and operational costs.

In this study, various glazing types were installed on the building model's external windows, and the resulting annual energy consumption was calculated and compared to the baseline scenario. The results indicate that high-performance glazing significantly enhances energy efficiency. Specifically, triple-glass aluminium frames with double 16 mm argon-filled cavities achieved energy savings of up to 98% relative to single-glass windows. Compared with the base case construction, this configuration reduces energy consumption by approximately 37.5%, corresponding to LEED-achievable points (see Figure 5).

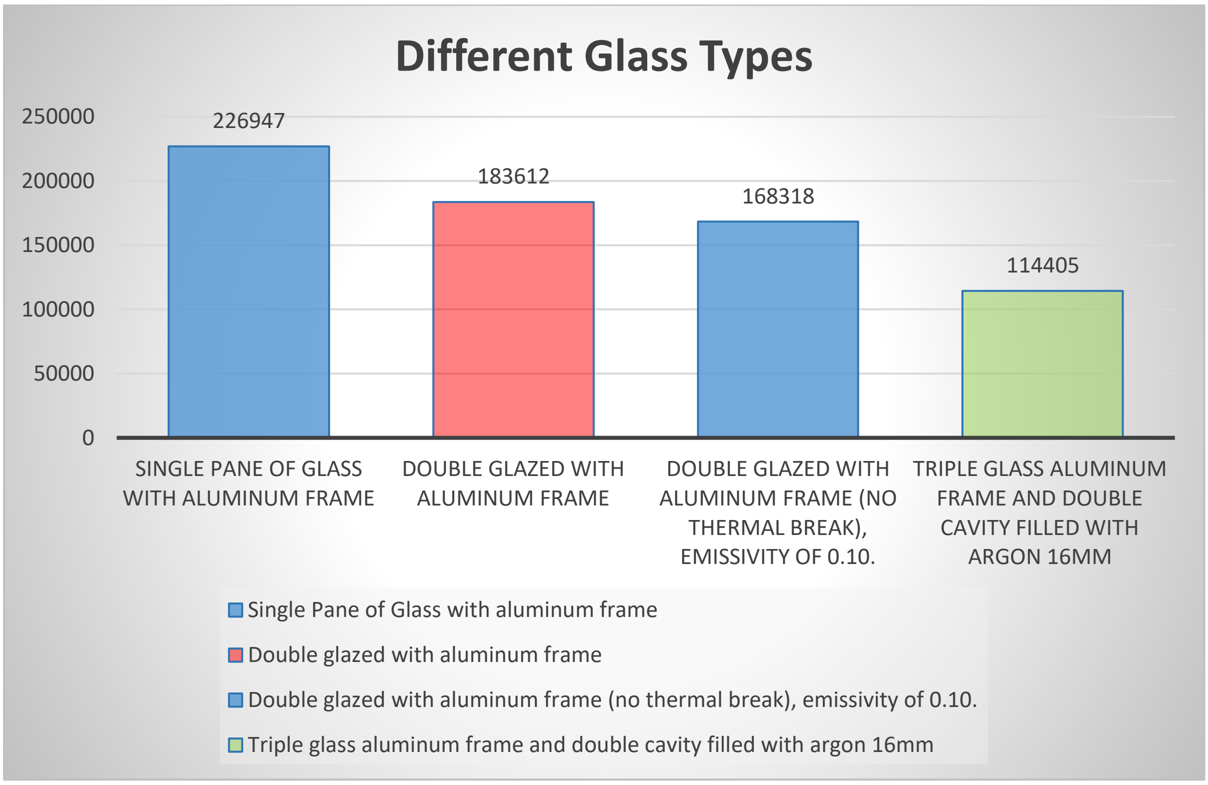

Figure 5: Graph Highlighting Impact of Different Glass Types on Energy Consumption

Consequently, glazing should be carefully positioned and oriented to optimise daylight penetration and external views while minimising unwanted heat gain. Since opaque elements generally provide superior resistance to heat transfer compared with glass, adjusting the building envelope's window-to-wall ratio (WWR) in the case study influenced the amount of heat entering the interior. An optimised WWR of 20% was found to reduce the building's annual energy consumption by approximately 9%, decreasing it from 152,739 m²Wh to 140,006 m²Wh (see Figure 6).

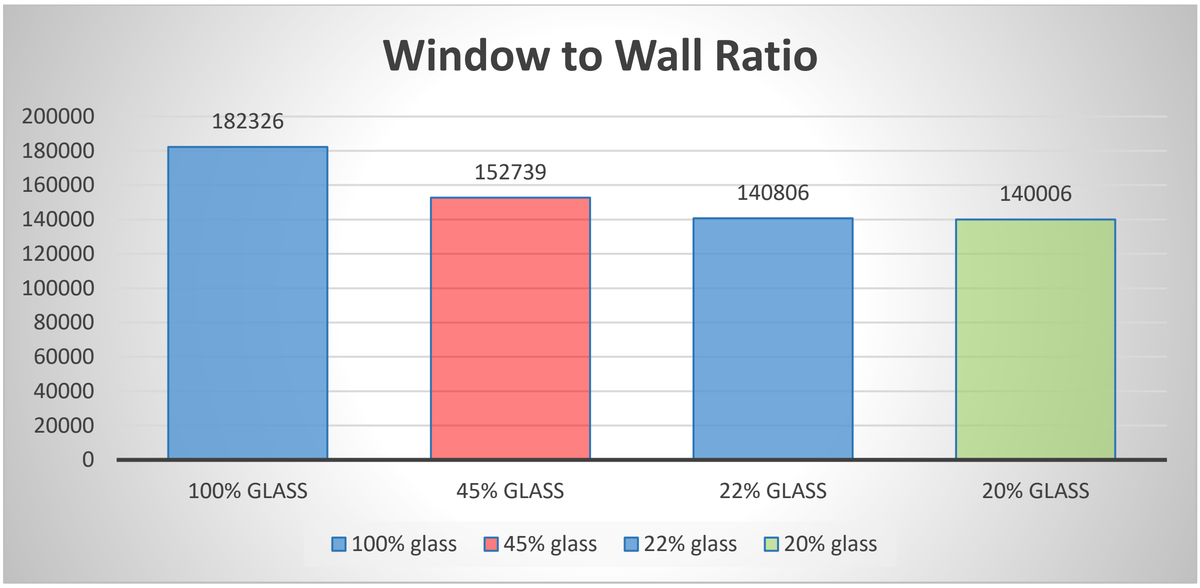

Figure 6: Graph Highlighting Impact of WWR on Energy Consumption

Energy Simulation Based on Different Types of Roof and Wall Assembly Optimization

Walls are designed to provide both thermal and acoustic comfort within interior spaces without compromising architectural aesthetics. They often constitute a substantial portion of a building's façade and significantly influence overall energy consumption. In high-rise structures with a large wall-to-envelope ratio, the thermal resistance (R-value) and thermal conductivity (K) of walls and roofs play a critical role in determining energy performance. Incorporating insulation with high R-values reduces the U-factor of walls and roofs by providing a continuous internal layer that mitigates thermal bridging caused by structural elements. The study indicated that, in optimal designs, window cells are predominantly located in the top-west quadrant of façades (Wright & Mourshed, 2009).

Thermal insulation, combined with high thermal mass construction materials, is a key component of wall and roof assemblies that substantially contributes to energy savings. However, when the relative humidity of ambient air exceeds 80%, insulated walls are more prone to surface condensation, particularly if the external wall's convective and radiative heat transfer coefficients are low. This phenomenon is most pronounced in colder, humid climates and during winter months (Aelenei & Henriques, 2008). Furthermore, in hot climates, the study found that the most cost-effective energy-saving measures are high-performance window glazing and roof insulation (Florides et al., 2002).

Rather than relying solely on the baseline case, the energy performance formula was applied to the roof and four distinct wall types. The results demonstrate that façades can significantly influence energy performance, particularly in tall buildings where the wall-to-envelope ratio is high. In contrast, the roof contributes minimally, saving only around 0.5% of total energy, whereas external wall insulation can achieve approximately 4% energy savings. The limited impact of roof systems is attributable to the relatively smaller proportion of roof area compared with other envelope components. Consequently, optimising the façade system is essential for enhancing energy efficiency in high-rise buildings (see Figure 7).

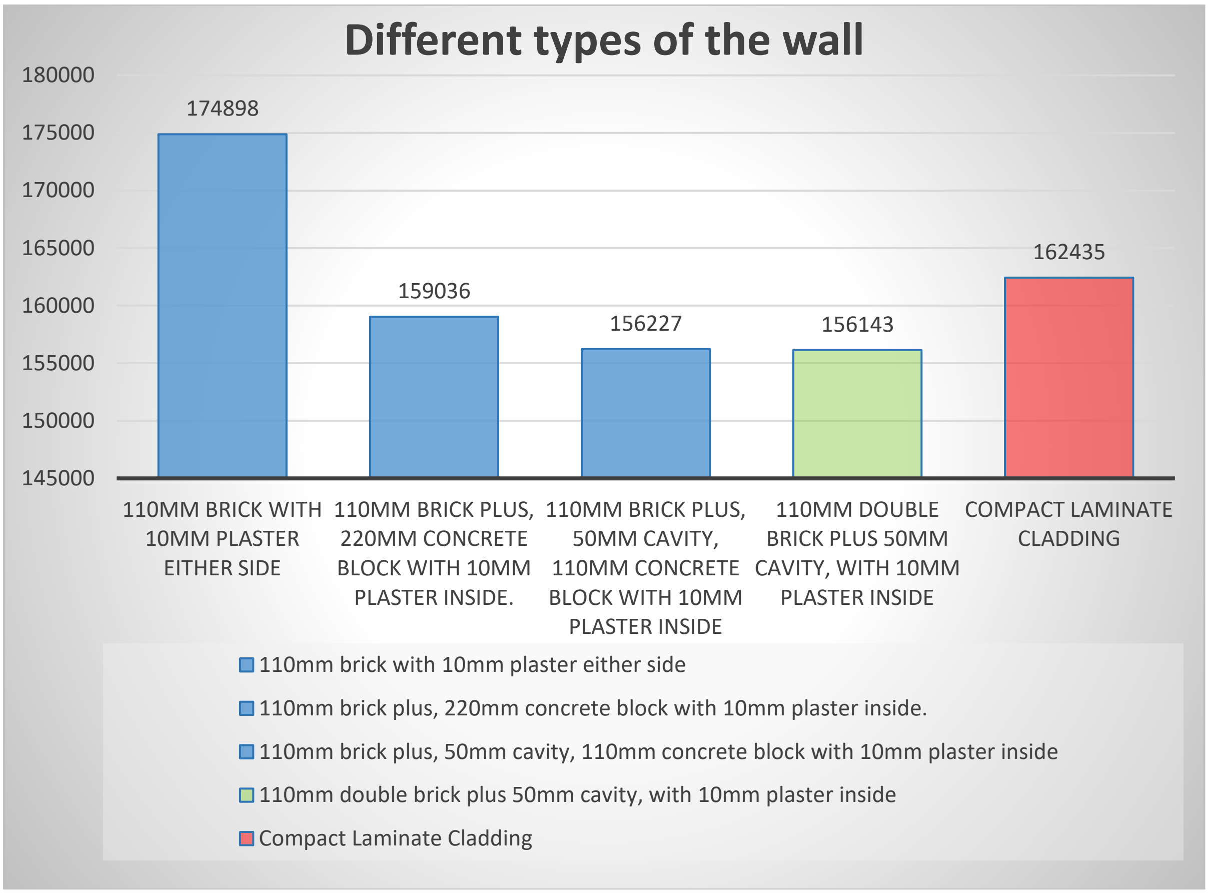

Figure 7: Graph Highlighting Impact of Wall Assembly on Energy Consumption

Shading Devices Optimization

External sunshades are an effective design strategy for reducing solar heat gains. In addition to mitigating heat, they also limit solar glare, restrict views into and out of the building, protect operable windows from rainfall, and serve as part of a broader protective design approach. For sunshade designs to function effectively, it is essential to consider solar geometry and sun-path analysis. One study reported that a fully glazed building, when combined with appropriate shading, control set points, and glass selection, may increase energy consumption by only 15% relative to a reference building with a 30% window-to-wall ratio (Li & Wu, 2024). Another study indicated that horizontal projections with a 30° downward tilt are most effective for eastern and western façades, while half egg-crate louvers are best suited for southern and northern façades (Chua & Chou, 2010). According to ASHRAE, solar radiation entering through windows can provide substantial advantages during the summer cooling season, which can be effectively controlled through the use of external shading. Vertical shading on east and west façades can reduce these benefits during sunrise and sunset, whereas horizontal overhangs on the south façade block intense sunlight throughout the day for most of the year.

Various shading widths were simulated to assess their effectiveness in reducing direct solar radiation entering occupied spaces. The results demonstrated reduced direct solar exposure, lower solar infiltration, and increased penetration of diffuse daylight. Implementing optimised 2-foot external shades decreased annual energy consumption slightly, from 152,743 m²Wh to 152,690 m²Wh (see Figure 8). Overall, combining six key design strategies—optimal building orientation, window-to-wall ratio, shading devices, glazing type, and wall/roof insulation—resulted in a 53.6% reduction in yearly energy demand. This analysis underscores the importance of well-considered core design decisions, showing that early design interventions not only optimise initial costs but also significantly reduce annual energy consumption (see Figure 9).

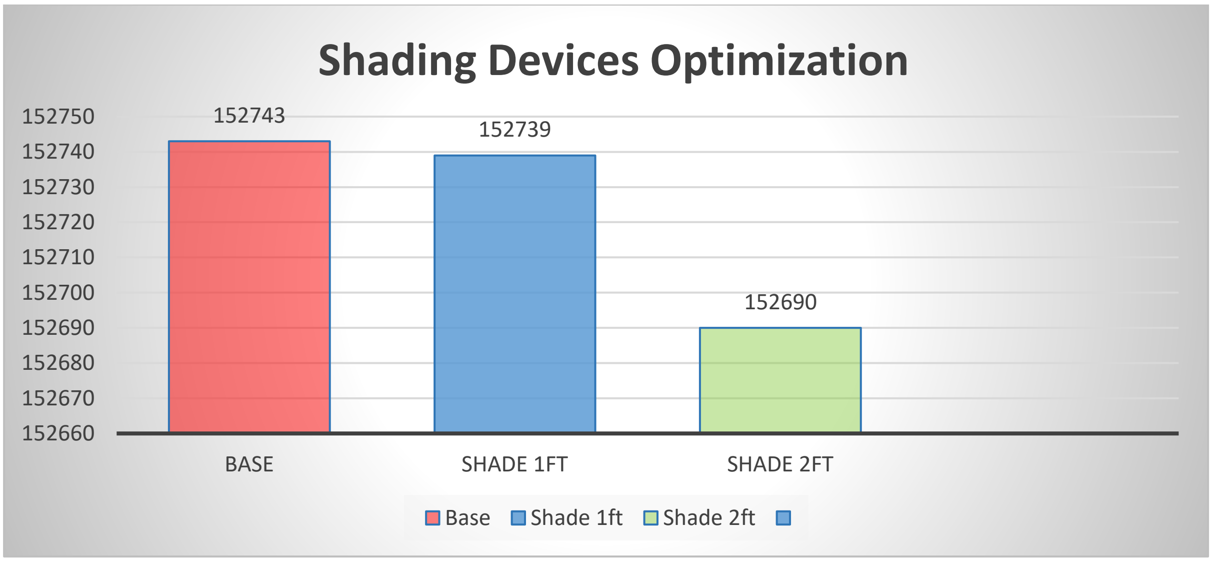

Figure 8: Graph Highlighting Impact of Shading Devices Width on Energy Consumption

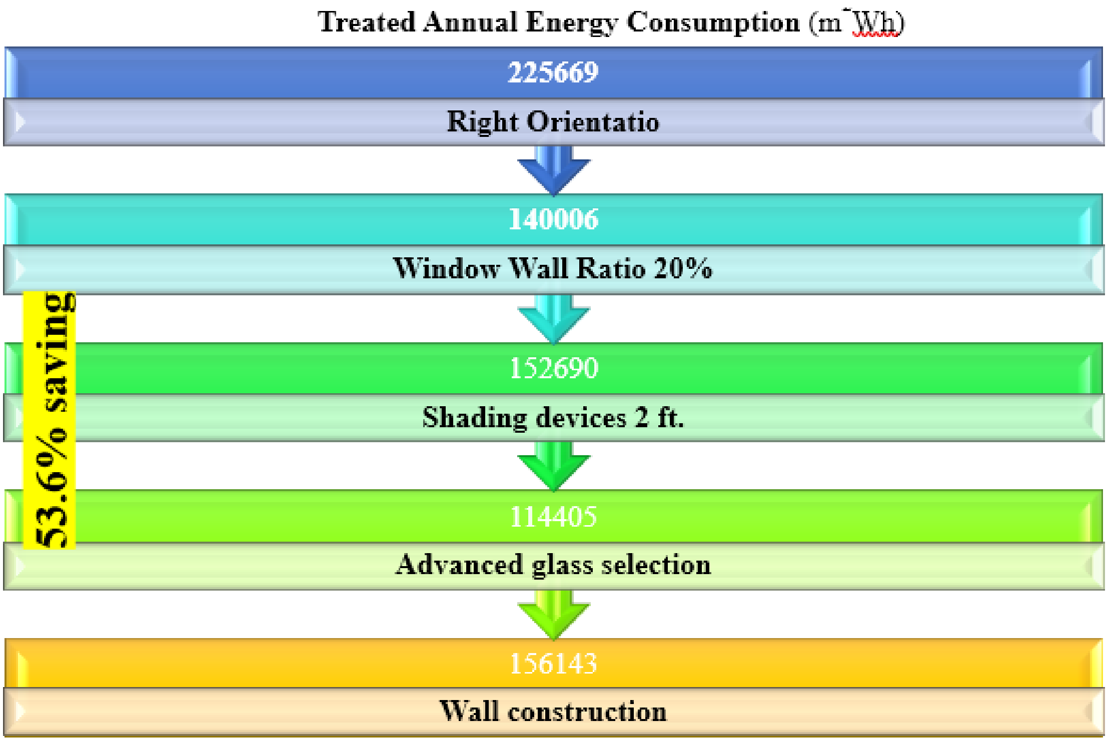

Figure 9: Cumulative Reduction in Energy Consumption by Applying Basic Passive Strategies

LEED ACHIEVABLE POINTS CALCULATION

Eco-Friendly Website

The Sustainable Sites (SS) category addresses aspects of the building's exterior, the surrounding land, and the local community, rather than the building itself. The proposed project consists of a moderately dense residential development situated on a brownfield site adjacent to a main street within an urban neighbourhood, with convenient access to public transportation, including buses. The external design incorporates a substantial amount of open space for landscaping, along with adequate bicycle storage and changing facilities. However, a considerable portion of the building's roofs has not yet been specifically designed. To mitigate the urban heat island effect and reduce its impact on the local microclimate, the following strategies are recommended: for low-sloped roofs (slope ≤ 2V:12H), roofing materials should have a Solar Reflectance Index (SRI) of at least 78, while for steep-sloped roofs (slope > 2V:12H), the SRI should be at least 29, or at least half of the roof area should be covered with vegetation. Additionally, vegetated roof surfaces with high albedo may be installed, provided they meet the following criterion:

Total Roof Area = (Area of SRI Roof/0.75) + (Area of Vegetated Roof/0.5). Refer to Table 5.

Table 5: Sustainable Site Analysis

LEED 2009 for New Construction and Major Renovation			
Leed Points: 21		**Sustainable Sites**	**Possible Points: 26**
	Prereq 1	Construction Activity Pollution Prevention	
1	Credit 1	Site Selection	1
5	Credit 2	Development Density and Community Connectivity	5
1	Credit 3	Brownfield Redevelopment	1
6	Credit 4.1	Alternative Transportation – Public Transportation Access	6
1	Credit 4.2	Alternative Transportation – Bicycle Storage & Changing Rooms	1
	Credit 4.3	Alternative Transportation – Low-Emitting & Fuel-Efficient Vehicles	3
2	Credit 4.4	Alternative Transportation – Parking Capacity	2
1	Credit 5.1	Site Development – Protect or Restore Habitat	1
1	Credit 5.2	Site Development – Maximize Open Space	1
1	Credit 6.1	Stormwater Design – Quantity Control	1
1	Credit 6.2	Stormwater Design – Quality Control	1
	Credit 7.1	Heat Island Effect – Non-Roof	1
	Credit 7.2	Heat Island Effect – Roof	1
1	Credit 8	Light Pollution Reduction	1

Water Efficiency

Rainwater harvesting systems, water treatment and recycling installations, and high-efficiency plumbing fixtures should be employed to optimise water use. Potable water consumption for irrigation should be reduced by 50% relative to a baseline midsummer scenario. Refer to Table 6.

Table 6: Water Efficiency Analysis

LEED 2009 for New Construction and Major Renovation			
Leed Points: 10		**Water Efficiency**	**Possible Points:10**
	Prerequisite 1	Water use reduction – 20% reduction	
4	Credit 1	Water efficient landscaping	2 to 4
		Reduce by 50%	2
		No potable water use or irrigation	4
2	Credit 2	Innovative wastewater technologies	2
4	Credit 3	Water use reduction	2 to 4
		Reduce by 30%	2
		Reduce by 35%	3
		Reduce by 40%	4

Energy and Atmosphere

Energy-efficient HVAC systems, high-performance façade assemblies, and advanced lighting control technologies should be integrated into the building design. The objective of this credit is to establish a minimum standard of energy efficiency for the building and its associated systems. Throughout the project development phase, comprehensive energy-saving strategies should be applied alongside detailed energy simulations. Enhancing energy performance in this manner helps mitigate the environmental and economic impacts associated with excessive energy consumption (see Table 7).

Table 7: Energy and Atmosphere Analysis

LEED 2009 for New Construction and Major Renovation			
Leed Points: 26		**Energy and Atmosphere**	**Possible Points: 35**
	Prereq 1	Fundamental Commissioning of Building Energy Systems	
	Prereq 2	Minimum Energy Performance	
	Prereq 3	Fundamental Refrigerant Management	
10	Credit 1	Optimize Energy Performance	1 to 19
		Improve by 12% for new building or 8% existing building renovation	1
		Improve by 14% for new building or 10% existing building renovation	2
		Improve by 16% for new building or 12% existing building renovation	3
		Improve by 18% for new building or 14% existing building renovation	4
		Improve by 20% for new building or 16% existing building renovation	5
		Improve by 22% for new building or 18% existing building renovation	6
		Improve by 24% for new building or 20% existing building renovation	7
		Improve by 26% for new building or 22% existing building renovation	8
		Improve by 28% for new building or 24% existing building renovation	9
		Improve by 30% for new building or 26% existing building renovation	10
		Improve by 32% for new building or 28% existing building renovation	11
		Improve by 34% for new building or 30% existing building renovation	12
		Improve by 36% for new building or 32% existing building renovation	13
		Improve by 38% for new building or 34% existing building renovation	14
		Improve by 40% for new building or 36% existing building renovation	15
		Improve by 42% for new building or 38% existing building renovation	16
		Improve by 44% for new building or 40% existing building renovation	17
		Improve by 46% for new building or 42% existing building renovation	18
		Improve by 48% for new building or 44% existing building renovation	19

Table 7 (Continued): Energy and Atmosphere Analysis

LEED 2009 for New Construction and Major Renovation			
Leed Points: 26		**Energy and Atmosphere**	**Possible Points: 35**
7	Credit 2	On-Site Renewable Energy	1 to 7
		1% Renewable energy	1
		3% Renewable energy	2
		5% Renewable energy	3
		7% Renewable energy	4
		9% Renewable energy	5
		11% Renewable energy	6
		13% Renewable energy	7
2	Credit 3	Enhanced Commissioning	2
2	Credit 4	Enhanced Refrigerant Management	2
3	Credit 5	Measurement and Verification	3
2	Credit 6	Green Power	2

Material and Resources

The reuse of building materials and products should be prioritised to reduce construction waste and the reliance on virgin resources, thereby minimising the environmental impact associated with the extraction and processing of new materials. Furthermore, the demand for locally sourced products and construction materials should be increased to support the use of regional resources and reduce the environmental consequences of transportation. The utilisation of certified wood and other environmentally certified materials from sustainable forest management practices is also encouraged (see Table 8).

Table 8: Material and Resources Analysis

LEED 2009 for New Construction and Major Renovation			
Leed Points: 8		**Materials & Resources**	**Possible Points: 14**
	Prerequisite 1	Storage and Collection of Recyclables	
	Credit 1.1	Building reuse – Maintain existing walls, floors, roof	1 to 3
		Reduce by 55%	1
		Reduce by 75%	2
		Reduce by 95%	3
	Credit 1.2	Building reuse – Maintain 50% of interior non-Structure elements	1
2	Credit 2	Construction Waste Management	1 to 2
		50% Recycled or salvaged	1
		75% Recycled or salvaged	2
1	Credit 3	Materials Reuse	1 to 2
		Reduce by 5%	1
		Reduce by 10%	2
1	Credit 4	Recycled Content	1 to 2
		10% of content	1
2		20% of content	2
	Credit 5	Regional Materials	1 to 2
		10% of Materials	1
		20% of Materials	2
1	Credit 6	Rapidly Renewable Materials	1
1	Credit 7	Certified Wood	1

Indoor Environmental Quality

Measures should be implemented to minimise or eliminate occupants' exposure to harmful pollutants. Enhancing indoor air quality through increased outdoor air ventilation improves comfort, health, and productivity (Haselbach, 2010). Consequently, interior thermal comfort can be optimised by combining effective smoke control, enhanced ventilation, well-designed daylighting, and high-performance façade systems (see Table 9).

Table 9: Indoor Environmental Quality Analysis

LEED 2009 for New Construction and Major Renovation			
Leed Points: 15		**Indoor Environmental Quality**	**Possible Points: 26**
	Prereq 1	Minimum Indoor Air Quality Performance	
	Prereq 2	Environmental Tobacco Smoke (ETS) Control	
1	Credit 1	Outdoor Air Delivery Monitoring	1
1	Credit 2	Increased Ventilation	1
1	Credit 3.1	Construction IAQ Management Plan – During Construction	1
1	Credit 3.2	Construction IAQ Management Plan – Before Occupancy	1
1	Credit 4.1	Low-Emitting Materials – Adhesives & Sealants	1
1	Credit 4.2	Low-Emitting Materials – Paints & Coatings	1
1	Credit 4.3	Low-Emitting Materials – Flooring Systems	1
1	Credit 4.4	Low-Emitting Materials – Composite Wood & Agrifiber Products	1
1	Credit 5	Indoor Chemical & Pollutant Source Control	1
1	Credit 6.1	Controllability of Systems – Lighting	1
1	Credit 6.2	Controllability of Systems – Thermal Comfort	1
1	Credit 7.1	Thermal Comfort – Design	1
1	Credit 7.2	Thermal Comfort – Verification	1
1	Credit 8.1	Daylight & Views – Daylight	1
1	Credit 8.2	Daylight & Views – Views	1

LEED Total Points and Certification Level Check

LEED-achievable points for the project (see Tables 5–9) can be summarised as follows:

1. Sustainable Sites: 26 points
2. Water Efficiency: 10 points
3. Energy and Atmosphere: 35 points
4. Materials and Resources: 14 points
5. Indoor Environmental Quality: 15 points
6. Innovative and Design Process: 1 point
7. Regional Priority Credits: 0 points

This results in a total of 80+ certified points. For contemporary high-rise buildings, LEED provides a robust and adequate framework for sustainability assessment (Del Percio, 2004).

CONCLUSION

Energy efficiency remains a critical challenge in contemporary high-rise residential developments, drawing increasing attention from architects and designers towards optimising the building envelope. This study investigated six strategies to reduce energy consumption in high-rise apartment complexes in Erbil, demonstrating that residences in hot, dry climates can achieve energy savings comparable to other regions. Simulation results indicate that advanced glazing for external windows is more effective than wall improvements in reducing energy loads. Adjusting the building envelope's WWR, however, may increase heat gains, as opaque surfaces typically offer superior resistance to heat transfer. The findings also show that while roofs contribute minimally to overall energy performance, façades play a decisive role, particularly in high-rise buildings with a high wall-to-envelope ratio. Architects can adopt low-cost measures, such as external sunshades and blinds, to limit solar heat gains while controlling glare and external views. Thermal modelling enables evaluation of these solutions, supporting the design of more energy-efficient structures. Combining these insights with life cycle cost and energy analyses provides a broader understanding of the economic and environmental benefits of low-energy apartment design. Modern high-rise buildings can further reduce their environmental footprint through adherence to the USGBC LEED standards. The use of natural and recycled materials, energy-efficient systems, and sustainable construction practices minimises resource consumption and emissions. Ultimately, following fundamental building design principles ensures optimal performance, providing a foundation for the integration of advanced technologies in an economically feasible manner.

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