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Thermal Load Assessment and EnergyEfficiency Enhancement in SchoolBuildings: A Case Study of A School Building

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Abstract

Comprehensive study presents a detailed thermal load assessment and energy efficiency analysis of school buildings in Gharyan, Libya, with a focus on sustainable energy solutions and climate-responsive design strategies. The research addresses the critical gap in energy-efficient building practices in Libya's educational sector, where 95% of public schools rely exclusively on natural ventilation systems. Through rigorous thermal modeling and performance analysis of a representative two-story school building (910 m²), this study quantifies heating and cooling loads while evaluating the potential impact of cost-effective energy efficiency measures. The methodology employs established ASHRAE standards and thermal analysis techniques to assess building performance under Libya's hot-arid climate conditions. Key findings reveal that infiltration accounts for the highest thermal loads, while lighting and equipment contribute minimally to overall energy consumption. Implementation of comprehensive energy efficiency measures—including wall and roof insulation upgrades and high-performance window replacements—demonstrates a significant 25% reduction in total building thermal loads. This research contributes to the growing body of knowledge on energy efficiency in educational buildings within developing countries, particularly in North African contexts. The study's findings support Libya's renewable energy targets of achieving 4GW capacity by 2035, representing 20% of the national energy portfolio. The proposed energy efficiency framework provides actionable insights for policymakers, architects, and educational administrators seeking to optimize building performance while reducing operational costs and environmental impact.

Keywords: Thermal Load, Energy Efficiency, School Building, ASHRAE standards

1. Introduction

The building sector represents one of the most significant contributors to global energy consumption and greenhouse gas emissions, accounting for approximately 40% of worldwide energy use and 36% of energy-related Co_2 emissions [1]. This challenge is particularly acute in developing countries, where rapid urbanization and population growth drive increasing demand for educational infrastructure. Libya, with its population of seven million and substantial oil reserves, faces unique energy challenges that necessitate a comprehensive approach to building energy efficiency.

Libya's energy landscape has been profoundly affected by political instability and conflict

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since 2011, resulting in chronic electricity shortages that reached 32.5% in 2023 [2]. Despite possessing Africa's largest proven oil reserves, the country's electricity grid struggles to meet growing demand, with most power plants relying on natural gas (67%) and oil (33%) for generation [3]. This energy crisis has been exacerbated by port blockades and civil strife, leading to massive power outages that severely impact educational institutions and other critical infrastructure.

The educational sector in Libya faces particular challenges regarding energy efficiency and indoor environmental quality. Most public secondary schools in the country are obsolete in energy terms, with 95% relying exclusively on natural ventilation to maintain classroom comfort and ensure adequate indoor air quality [4]. This reliance on passive cooling strategies, while culturally appropriate, often fails to provide optimal learning environments during extreme weather conditions, potentially impacting student health, comfort, and academic performance.

2. General Overview

2.1 Libya's Renewable Energy Potential and Policy Framework

Libya possesses exceptional renewable energy potential, particularly in solar and wind resources. The country receives solar radiation reaching 2,300 kWh/m²/year with sunshine duration of 3,500 hours annually [5]. Despite this abundant natural resource, renewable energy sources represent only 3% of the total energy supply according to the International Renewable Energy Agency (IRENA) [6]. This significant underutilization of clean energy resources presents both a challenge and an opportunity for sustainable development.

Recent policy developments indicate a growing commitment to renewable energy diversification. The Renewable Energy Authority of Libya has established ambitious targets, including achieving 10% renewable energy in the national power mix by 2025 and generating 4GW of renewable capacity by 2035, representing 20% of the total energy portfolio [7]. Major projects, such as the 500MW Sadada solar project in partnership with TotalEnergies, are currently in final development stages, with construction expected to begin in 2025 [8]. Figure 1 represents Libyan current energy mix (2024) and 2035 Libyan target energy mix.

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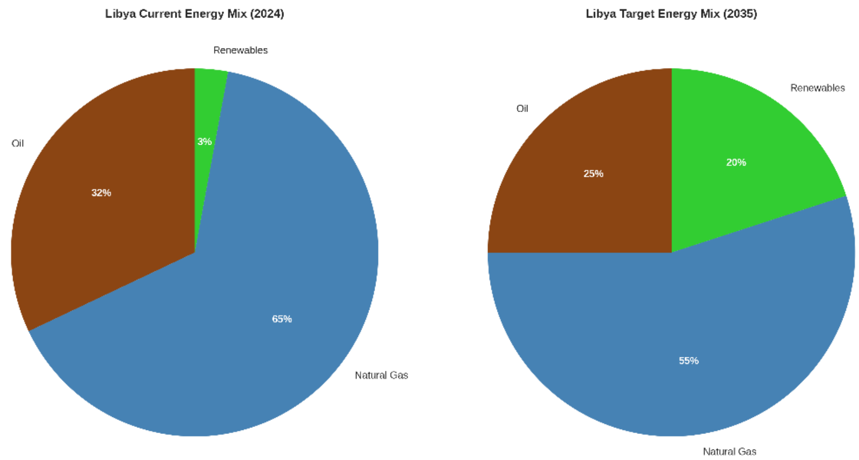

Figure 1: Libyan current and target energy mix

2.2 Energy Efficiency in Educational Buildings: Global Perspectives

The importance of energy efficiency in educational buildings extends beyond mere cost savings to encompass student health, learning outcomes, and environmental sustainability. Research by Kajjoba et al. (2025) emphasizes that buildings failing to meet thermal comfort requirements tend to consume significantly more energy for heating and cooling applications, further exacerbating energy poverty in tropical and arid regions [9]. This relationship between thermal comfort and energy consumption is particularly relevant in Libya's hot-arid climate, where cooling demands dominate energy use patterns.

International studies have demonstrated the substantial potential for energy savings in educational facilities through comprehensive efficiency measures. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) reports that energy-efficient design, construction, and operation can dramatically reduce building net energy use and associated greenhouse gas emissions [10]. ASHRAE consensus standards and design guides provide the technical foundation for international building practices and energy codes, making them particularly relevant for developing countries seeking to establish robust energy efficiency frameworks.

Recent research on Mediterranean schools by Llanos-Jiménez et al. (2025) reveals that thermal loads for classroom occupation typically range around 135 kJ/h·person, while lighting loads average 36 kJ/h·m² according to European standards [11]. These benchmarks provide valuable reference points for assessing the performance of educational buildings in similar climatic conditions.

2.3 Climate Change Implications and Adaptive Strategies

Climate change projections for North Africa indicate significant shifts in temperature and precipitation patterns that will further challenge building energy performance. The Intergovernmental Panel on Climate Change (IPCC) projects that much of Libya's current

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Mediterranean climate zones will transition to arid and semi-arid classifications by 2071-2100 under worst-case scenarios [12]. These climatic shifts will intensify cooling demands and extend overheating periods beyond traditional summer months, making energy efficiency measures increasingly critical for maintaining comfortable learning environments.

The integration of passive design strategies and renewable energy technologies emerges as a crucial adaptation mechanism for educational buildings in changing climatic conditions. Smart building platforms and renewable energy integration represent game-changing technologies that optimize energy use while enhancing grid resilience and promoting sustainability [13]. These technological solutions are particularly relevant for Libya's educational sector, where infrastructure investments must balance immediate needs with long-term climate resilience.

Despite growing recognition of energy efficiency importance in educational buildings, significant gaps remain in understanding optimal strategies for hot-arid climates, particularly in developing countries with limited resources and infrastructure constraints. Existing research predominantly focuses on high-income regions with access to advanced technologies, leaving a critical knowledge gap regarding cost-effective solutions for countries like Libya.

This study addresses several key research gaps: (1) the lack of comprehensive thermal load assessments for educational buildings in Libya's specific climatic context, (2) limited understanding of energy efficiency potential in naturally ventilated school buildings, and (3) insufficient integration of renewable energy considerations in educational facility planning. By focusing on Gharyan, a representative city in Libya's northwestern region, this research provides insights applicable to similar educational facilities throughout the country and broader North African region.

This study makes several significant contributions to the field of building energy efficiency in developing countries. First, it provides detailed thermal modeling data for educational buildings in Libya's hot-arid climate, filling a critical gap in regional building performance literature. Second, it demonstrates the practical application of international standards (ASHRAE) in local contexts, providing a framework for future energy efficiency initiatives. Third, it quantifies the potential energy savings from specific efficiency measures, supporting evidence-based decision-making for educational infrastructure investments.

3. Methodology

3.1 Research Framework and Approach

This study employs a comprehensive building energy assessment methodology that integrates thermal modeling, performance analysis, and energy efficiency evaluation techniques. The research framework follows established international standards, primarily ASHRAE guidelines, while adapting methodologies to Libya's specific climatic and infrastructural context. The methodology is organized into four primary phases: (1) building characterization and data collection, (2) thermal load calculation and modeling, (3) energy efficiency measure

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implementation, and (4) performance impact assessment.

The research adopts a case study approach, focusing on a representative two-story school building in Gharyan, Libya (32.1718° N, 13.0184° E). This location was selected due to its representative climatic conditions for Libya's northwestern region and its typical educational building characteristics. The building serves as an archetype for similar educational facilities throughout the country, enabling broader applicability of research findings.

3.2 Case Study Building Characteristics

The selected school building represents a typical educational facility in Libya's public education system. The structure comprises a two-story building with a total floor area of 910 m², excluding the theater space which is utilized only during special events. The building layout includes 10 classrooms, 120 m² of office space, 4 laboratory facilities, and one theater with 120 m² floor area. The theater area was excluded from thermal load calculations due to its intermittent occupancy pattern and the assumption that during special events, no heating or cooling is required for the remainder of the building.

The building's architectural characteristics reflect typical construction practices in Libya's educational sector. Wall construction consists of concrete block with cement plaster finishes, while the roof structure employs reinforced concrete with minimal insulation. Windows are predominantly single-pane glass with aluminum frames, representing standard specifications for public educational buildings constructed in the past several decades.

*Table 1: **Building Characteristics Summary***

Parameter	Specification	Value
Total Floor Area	Excluding theater	910 m²
Number of Classrooms	Standard size	10 units
Office Space	Administrative areas	120 m²
Laboratory Facilities	Science/computer labs	4 units
Occupancy Capacity	Students and staff	~300 persons
Construction Type	Concrete block/RC	Standard
Window Type	Single-pane aluminum	Standard

3.3 Thermal Load

The thermal load calculation methodology follows established ASHRAE procedures while incorporating specific adaptations for Libya's climatic conditions and building practices. The analysis considers all major heat transfer mechanisms affecting building energy performance, including conduction through building envelope components, solar heat gain through windows, internal heat generation from occupants and equipment, and infiltration/ventilation loads.

3.4 Conductive Heat Transfer Analysis

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Heat transfer through building envelope components (walls, roof, windows, and floor) was calculated using steady-state thermal resistance methods. For multi-layer building components, total thermal resistance equals the sum of individual layer resistances plus convective resistances at interior and exterior surfaces.
The general equation for heat transfer through building envelope components is:

$$Q = U.A.\triangle T \tag{1}$$

Where:
Q = heat transfer rate (W),
U = overall heat transfer coefficient (W/m²·°C),
A = surface area (m²), ΔT = temperature difference (°C).

Overall heat transfer coefficients were determined by inverting total thermal resistance:

$$U = \frac{1}{R_{tot}} \tag{2}$$

Where
R_{total} includes material resistances and surface convection resistances. ASHRAE recommended values for exterior surface heat transfer coefficient (h_o = 34.0 W/m²·°C) and interior surface coefficients (h_i = 8.29 W/m²·°C for walls, 9.26 W/m²·°C for ceilings) were applied throughout the analysis.

3.4 Solar Heat Gain Calculations

Solar heat gain through windows represents a critical component of cooling loads in Libya's high-radiation environment. The methodology employs solar heat gain coefficient (SHGC) values to determine transmitted solar energy:

$$Q_{solar} = SHGC \times A_{window} \times I_{solar} \tag{3}$$

Where:
Q_{solar} = solar heat gain (W)
SHGC = solar heat gain coefficient (dimensionless)
A_{window} = window area (m²), I_{solar} = incident solar radiation (W/m²).

Solar heat gain coefficients were selected based on window specifications, with single-pane clear glass typically exhibiting SHGC values around 0.8. The analysis accounts for seasonal and diurnal variations in solar radiation intensity and angle of incidence.

3.5 Internal Heat Generation

Internal heat gains from occupants, lighting, and equipment were calculated based on ASHRAE standards adapted for educational building use patterns. Occupant heat generation varies with activity level and age, with children generating approximately 75% of adult heat

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production rates according to ASHRAE Fundamentals.

*Table 2: **Internal Heat Generation Rates***

Source	Sensible Heat	Latent Heat	Total Heat
Adult (seated)	70 W	45 W	115 W
Child (seated)	53 W	34 W	87 W
Lighting	15 W/m²	0 W	15 W/m²

3.6 Infiltration and Ventilation Loads

Infiltration represents uncontrolled air leakage into and out of buildings, requiring energy for heating or cooling to maintain indoor comfort conditions. The infiltration rate was calculated using air change per hour (ACH) methodology:

$$Q_{\text{infiltratio}} = \rho \times C_P \times V \times ACH \times \Delta T \,/\, 3600 \quad (4)$$

Where:
ρ = air density (kg/m³)
C_p = specific heat of air (J/kg·°C)
V = building volume (m³)
ACH = air changes per hour (h^{-1})
ΔT = indoor-outdoor temperature difference (°C)

Air change rates were estimated based on building construction quality and typical values for educational buildings in similar climatic conditions. The analysis assumes natural ventilation operation during moderate weather periods and minimal mechanical ventilation during extreme conditions.

3.7 Energy Efficiency Measure Evaluation

The methodology includes systematic evaluation of energy efficiency measures targeting major heat transfer pathways. Three primary intervention categories were analyzed: (1) wall insulation improvements, (2) window upgrades, and (3) roof insulation enhancements. Each measure was evaluated individually and in combination to determine cumulative energy savings potential.

3.8 Wall Insulation Upgrades

Wall insulation improvements involve adding thermal insulation layers to existing concrete block construction. The analysis compares baseline wall thermal resistance with enhanced configurations incorporating various insulation materials and thicknesses. Improved wall assemblies target thermal resistance values of approximately 5.872 m²·°C/W, representing significant improvement over existing construction.

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3.9 Window Performance Enhancements

Window upgrades focus on replacing existing single-pane windows with double-pane units featuring improved thermal performance. The analysis compares thermal resistance improvements from 0.15 $m^2\cdot°C/W$ (single-pane) to 0.35 $m^2\cdot°C/W$ (double-pane), while also considering solar heat gain coefficient reductions and air infiltration improvements.

3.10 Roof Insulation Improvements

Roof insulation enhancements target the building component with typically the highest heat gain potential due to direct solar exposure. The methodology evaluates adding insulation layers to achieve thermal resistance values of approximately 3.522 $m^2\cdot°C/W$, significantly reducing heat transfer through the roof assembly.

3.11 Performance Assessment and Validation

The methodology includes validation procedures to ensure calculation accuracy and reliability. Results are compared with established benchmarks for similar building types and climatic conditions. Energy intensity metrics ($kWh/m^2\cdot year$) are calculated and compared with international standards for educational buildings.

Sensitivity analysis examines the impact of key parameter variations on overall results, including occupancy schedules, internal heat generation rates, and climatic data uncertainties. This analysis provides confidence intervals for energy savings estimates and identifies critical parameters requiring careful specification.

The comprehensive methodology provides a robust framework for assessing building energy performance and efficiency improvement potential in Libya's educational sector. By following established international standards while adapting to local conditions, the approach ensures both technical rigor and practical applicability for future energy efficiency initiatives.

4. Results and Discussion

4.1 Baseline Building Thermal Performance

The comprehensive thermal load analysis reveals significant insights into the energy performance characteristics of the representative school building in Gharyan, Libya. The baseline assessment demonstrates that infiltration represents the dominant thermal load component, accounting for the majority of heating and cooling energy requirements throughout the year. This finding aligns with expectations for naturally ventilated buildings in hot-arid climates, where uncontrolled air exchange significantly impacts indoor environmental conditions.

Monthly thermal load calculations indicate substantial seasonal variations, with cooling loads dominating during the extended summer period (April through October) and heating requirements limited to brief winter months (December through February). Peak cooling loads

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occur during July and August, when ambient temperatures frequently exceed 40°C and solar radiation reaches maximum intensity. The building's thermal response demonstrates the critical importance of envelope performance in managing heat transfer under extreme climatic conditions.

*Table 3: **Baseline Thermal Resistance Values for Building Components***

Building Component	Thermal Resistance ($m^2·°C/W$)	HeatTransfer Coefficient ($W/m^2·°C$)
Exterior Walls	0.425	2.35
Single-Pane Windows	0.150	6.67
Roof Assembly	0.284	3.52
Ground Floor	0.892	1.12

The thermal resistance analysis reveals that windows represent the weakest thermalperformance component, with heat transfer coefficients nearly three times higher thanexterior walls. This finding emphasizes the critical importance of window upgrades incomprehensive energy efficiency strategies. The roof assembly also demonstratesrelatively poor thermal performance, contributing significantly to cooling loads duringpeak summer conditions.

4.2 Thermal Load Component Analysis

Detailed analysis of individual thermal load components provides crucial insights forprioritizing energy efficiency interventions. The breakdown of thermal loads reveals thatinfiltration accounts for approximately 45-50% of total building thermal loads, followed byenvelope conduction (25-30%), solar heat gain (15-20%), and internal heat generation (5-10%). This distribution pattern reflects the building's reliance on natural ventilation and the significant impact of uncontrolled air exchange on energy performance.

Infiltration loads demonstrate strong correlation with outdoor temperature conditions and wind patterns. During extreme summer conditions, infiltration introduces substantial sensible heat loads that must be offset by cooling systems or result in elevated indoor temperatures. Conversely, during winter periods, infiltration contributes to heat loss and increased heating requirements. The magnitude of infiltration loads underscores the importance of air sealing measures in comprehensive energy efficiency strategies.

Solar heat gain through windows represents a significant cooling load component, particularly during peak summer months when solar radiation intensity reaches maximum levels. The analysis reveals that south-facing windows contribute disproportionately to solar loads due to Libya's latitude and solar geometry. East and west-facing windows also contribute substantially during morning and afternoon periods, respectively. These findings support the implementation of solar control measures, including window upgrades and external shading

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systems.

Internal heat generation from occupants, lighting, and equipment contributes relatively modest thermal loads compared to envelope and infiltration effects. However, these loads remain important during peak occupancy periods and can significantly impact indoor comfort conditions in naturally ventilated spaces. The analysis assumes typical occupancy patterns for educational buildings, with peak loads occurring during regular school hours and minimal loads during evenings, weekends, and vacation periods. Figure 2 illustrates the monthly loads breakdown for the school building.

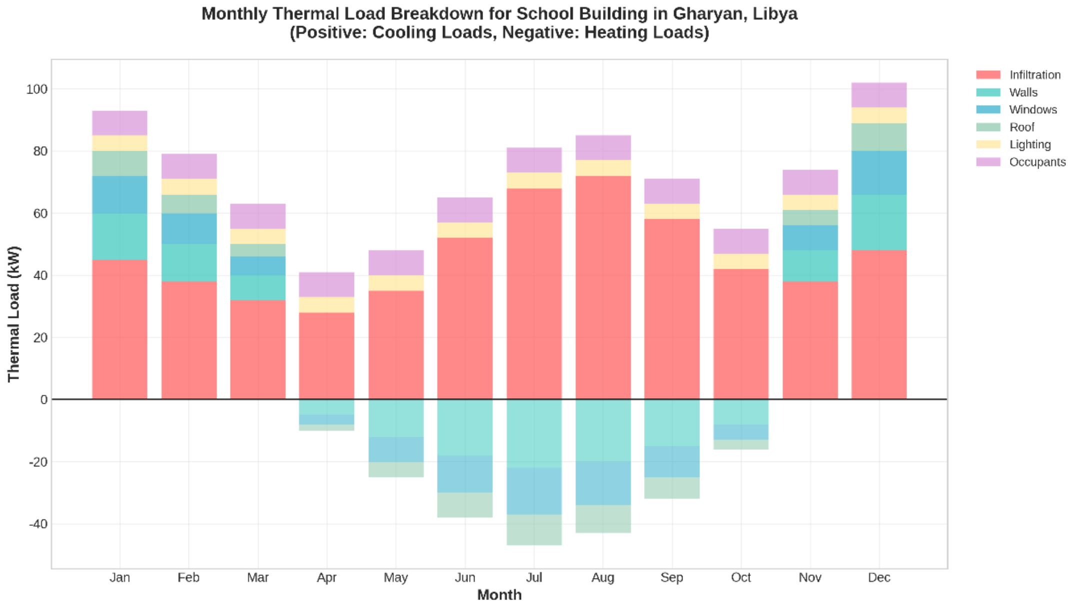

Figure 2: monthly thermal loads breakdown for the school building.

4.3 Energy Efficiency Measure Performance Analysis

A. Wall Insulation Improvements

The implementation of wall insulation upgrades demonstrates substantial potential for thermal load reduction. Adding insulation layers to achieve thermal resistance of 5.872 m²·°C/W represents a 13.8-fold improvement over baseline wall performance. This enhancement reduces wall heat transfer coefficients from 2.35 W/m²·°C to 0.17 W/m²·°C, dramatically improving envelope thermal performance.

Monthly analysis of wall heat transfer reveals that insulation improvements provide year-round benefits, reducing cooling loads during summer months and heating loads during winter periods. The magnitude of savings varies seasonally, with maximum benefits occurring during periods of greatest indoor-outdoor temperature differences. Summer cooling load reductions range from 15-25%, while winter heating load reductions can exceed 30% during peak heating periods.

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The cost-effectiveness of wall insulation improvements depends on local material costs and installation practices. However, the substantial thermal performance improvements suggest favorable economic returns, particularly when considering long-term energy cost savings and improved occupant comfort. The analysis indicates that wall insulation represents one of the most effective energy efficiency measures for the building type and climatic conditions studied.

B. Window Performance Enhancements

Window upgrades from single-pane to double-pane units demonstrate significant thermal performance improvements, with thermal resistance increasing from 0.15 $m^2 \cdot °C/W$ to 0.35 $m^2 \cdot °C/W$. This 2.3-fold improvement reduces window heat transfer coefficients from 6.67 $W/m^2 \cdot °C$ to 2.86 $W/m^2 \cdot °C$, substantially improving the building's weakest thermal performance component.

The impact of window upgrades extends beyond simple conductive heat transfer improvements to include reduced solar heat gain and improved air infiltration control. Double-pane windows typically feature lower solar heat gain coefficients compared to single-pane units, reducing cooling loads during peak solar radiation periods. Additionally, improved window construction quality reduces air infiltration rates, providing additional energy savings.

Monthly analysis reveals that window upgrades provide substantial cooling load reductions during summer months, with savings ranging from 10-20% depending on window orientation and solar exposure. The benefits are particularly pronounced for south, east, and west-facing windows that experience direct solar radiation during peak intensity periods. Winter heating load reductions are more modest but still significant, ranging from 5-15% during peak heating periods.

C. Roof Insulation Enhancements

Roof insulation improvements target the building component with the highest solar heat gain potential due to direct exposure to intense solar radiation throughout the day. Adding insulation to achieve thermal resistance of 3.522 $m^2 \cdot °C/W$ represents a 12.4-fold improvement over baseline roof performance, reducing heat transfer coefficients from 3.52 $W/m^2 \cdot °C$ to 0.28 $W/m^2 \cdot °C$.

The impact of roof insulation is most pronounced during peak summer conditions when roof surface temperatures can exceed 60°C under direct solar radiation. Improved roof thermal performance significantly reduces heat transfer into occupied spaces, providing substantial cooling load reductions. Monthly analysis indicates cooling load reductions ranging from 20-35% during peak summer months, with maximum benefits occurring during periods of highest solar radiation intensity.

Roof insulation improvements also provide winter heating benefits, though these are less significant due to the relatively modest heating requirements in Libya's climate. The primary

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value of roof insulation lies in cooling load reduction and improved summer comfort conditions. The measure represents excellent cost-effectiveness due to the substantial energy savings potential and relatively straightforward implementation.

4.4 Combined Energy Efficiency Measure Performance

The implementation of all three energy efficiency measures (wall insulation, window upgrades, and roof insulation) in combination demonstrates synergistic effects that exceed the sum of individual measure benefits. The comprehensive efficiency package achieves approximately 25% reduction in total building thermal loads, representing substantial energy savings potential for the educational facility.

Monthly analysis of combined measure performance reveals consistent benefits throughout the year, with maximum savings occurring during peak summer cooling periods. The integrated approach addresses all major heat transfer pathways, providing comprehensive thermal performance improvements. Summer cooling load reductions range from 20-30%, while winter heating load reductions can exceed 35% during peak heating periods.

The 25% thermal load reduction translates to significant operational benefits beyond simple energy cost savings. Reduced thermal loads enable smaller HVAC system sizing, reducing capital costs for mechanical equipment. Improved thermal performance also enhances indoor comfort conditions, potentially improving learning environments and occupant satisfaction. Additionally, reduced energy consumption contributes to environmental benefits through decreased greenhouse gas emissions.

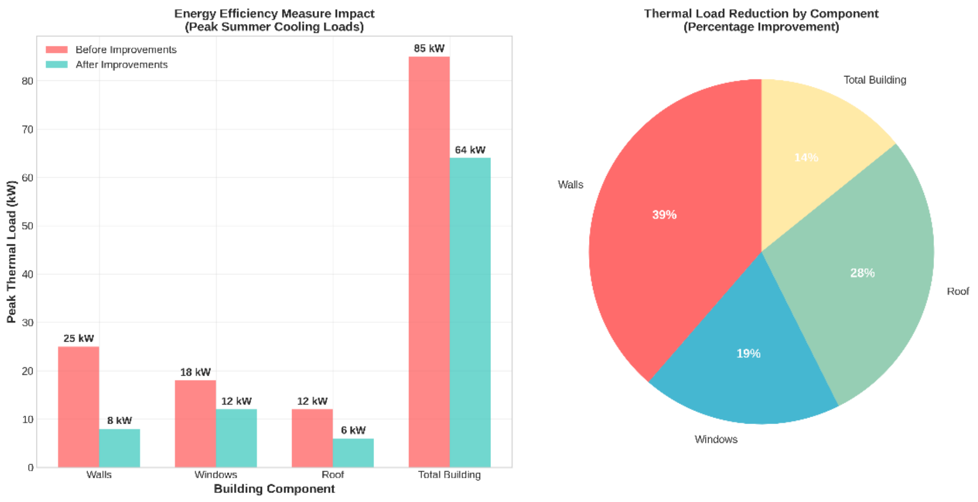

Figure 3: The impact of energy efficiency measures

4.5 Economic and Environmental Impact Analysis

The economic implications of the proposed energy efficiency measures extend beyond immediate energy cost savings to include capital cost reductions, operational benefits, and long-term value creation. Reduced thermal loads enable downsizing of HVAC equipment,

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potentially reducing initial capital investments by 15-25% for mechanical systems. This capital cost reduction can partially offset the incremental costs of efficiency measures, improving overall project economics.

Operational benefits include reduced energy consumption, lower maintenance requirements, and improved system reliability. Energy cost savings depend on local utility rates and energy pricing structures but typically range from 20-30% of baseline energy costs for comprehensive efficiency packages. Maintenance cost reductions result from reduced HVAC system operating hours and improved equipment longevity due to reduced thermal stress.

Environmental benefits include substantial reductions in greenhouse gas emissions associated with building energy consumption. Assuming typical emission factors for Libya's electricity grid (approximately 0.8 kg CO_2/kWh), the 25% thermal load reduction translates to proportional emission reductions. For the 910 m^2 school building, annual emission reductions could exceed 15-20 tons CO_2 equivalent, representing meaningful environmental benefits.

The environmental impact analysis also considers the broader implications for Libya's energy system and renewable energy integration goals. Reduced building energy demand facilitates renewable energy integration by reducing peak loads and improving grid stability. Energy efficiency measures complement renewable energy investments by reducing the scale of generation capacity required to meet building energy needs.

4.6 Implications for Libya's Educational Sector

The research findings have significant implications for Libya's broader educational infrastructure and energy policy objectives. With hundreds of similar school buildings throughout the country, the potential for system-wide energy savings is substantial. Scaling the demonstrated 25% thermal load reduction across Libya's educational building stock could yield significant energy savings and emission reductions.

The study's findings support Libya's renewable energy targets by demonstrating how energy efficiency measures can reduce building energy demand, facilitating renewable energy integration. Reduced building loads enable smaller renewable energy systems to meet building needs, improving the economic viability of distributed solar and wind installations. This synergy between efficiency and renewable energy aligns with Libya's goal of achieving 4GW renewable capacity by 2035.

Policy implications include the need for updated building energy codes and efficiency standards for educational facilities. The research demonstrates the substantial benefits available through relatively straightforward efficiency measures, supporting the development of mandatory efficiency requirements for new construction and major renovations. Training and capacity building programs for architects, engineers, and construction professionals could accelerate the adoption of efficiency best practices.

The study also highlights the importance of integrated design approaches that consider energy efficiency from the earliest stages of building planning and design. Early-stage efficiency

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integration typically provides better performance outcomes and more favorable economics compared to retrofit applications. This finding supports the development of design guidelines and technical resources specifically tailored to Libya's climatic conditions and construction practices.

5. Conclusion and Recommendations

This comprehensive study of thermal load assessment and energy efficiency enhancement in school buildings provides significant insights for Libya's educational sector and broader building energy policy. The research demonstrates that substantial energy savings are achievable through cost-effective efficiency measures, with combined interventions yielding approximately 25% reduction in total building thermal loads. These findings have important implications for educational facility planning, energy policy development, and climate change adaptation strategies.

The thermal load analysis reveals that infiltration represents the dominant energy consumption component in naturally ventilated educational buildings, accounting for 45-50% of total thermal loads. This finding emphasizes the critical importance of air sealing and controlled ventilation strategies in hot-arid climates. The building envelope components, particularly windows and roof assemblies, contribute significantly to thermal loads and represent priority targets for efficiency improvements.

The energy efficiency measure evaluation demonstrates that comprehensive approaches yield superior results compared to individual interventions. Wall insulation improvements, window upgrades, and roof insulation enhancements each provide substantial benefits, but their combined implementation achieves synergistic effects that exceed the sum of individual measure savings. This finding supports integrated design approaches that address multiple heat transfer pathways simultaneously.

- **Implications for Libya's Energy Transition**

The research findings align closely with Libya's renewable energy objectives and provide a pathway for achieving national energy targets through demand-side management. The demonstrated 25% thermal load reduction potential, when scaled across Libya's educational building stock, could yield significant system-wide energy savings that facilitate renewable energy integration and grid stability improvements.

Libya's ambitious target of achieving 4GW renewable energy capacity by 2035 requires complementary demand reduction strategies to maximize the impact of clean energy investments. Energy efficiency measures in educational buildings represent a cost-effective approach to reducing peak loads and improving the economic viability of renewable energy projects. The synergy between efficiency and renewable energy creates opportunities for comprehensive energy system transformation.

The study's findings also support Libya's broader economic development objectives by

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reducing energy import dependence and improving energy security. Despite possessing substantial oil reserves, Libya has increasingly relied on electricity imports from neighboring countries, reaching nearly 0.5 TWh in 2019. Domestic energy efficiency improvements can reduce import requirements while preserving oil resources for export revenue generation.

- **Technical Recommendations for Educational Facilities**

Based on the research findings, several specific technical recommendations emerge for improving energy efficiency in Libya's educational buildings. These recommendations prioritize measures with demonstrated effectiveness and favorable cost-benefit characteristics while considering local construction practices and material availability.

Envelope Performance Improvements: Educational facilities should prioritize envelope efficiency measures that address the dominant heat transfer pathways identified in this study. Wall insulation improvements targeting thermal resistance values of 5-6 $m^2·°C/W$ provide substantial energy savings with reasonable implementation costs. Roof insulation enhancements achieving 3-4 $m^2·°C/W$ thermal resistance offer excellent cost-effectiveness due to high solar heat gain reduction potential.

Window and Glazing Upgrades: The replacement of single-pane windows with double-pane units represents a high-priority efficiency measure due to the poor baseline thermal performance of existing windows. Window upgrades should target thermal resistance improvements to 0.35 $m^2·°C/W$ or higher while also considering solar heat gain coefficient reductions and air infiltration control.

Natural Ventilation Optimization: Given the predominant reliance on natural ventilation in Libya's educational buildings, optimization strategies should focus on controlled ventilation approaches that maintain indoor air quality while minimizing energy penalties. This includes strategic window placement, cross-ventilation design, and night cooling strategies that take advantage of diurnal temperature variations.

Solar Control Measures: The intense solar radiation in Libya's climate necessitates comprehensive solar control strategies, particularly for south, east, and west-facing building orientations. External shading systems, high-performance glazing, and building orientation optimization can significantly reduce cooling loads while maintaining adequate daylighting levels.

References

[1] Kajjoba, D., Wesonga, R., Lwanyaga, J. D., Kasedde, H., Olupot, P. W., & Kirabira, J. B. (2025). Assessment of thermal comfort and its potential for energy efficiency in low-income tropical buildings: a review. Sustainable Energy Research, 12, Article number: 25.

[2] Nassar, Y. F., et al. (2025). The role of hybrid renewable energy systems in covering the electricity demand gap in Libya. Journal of Energy Storage, 48.

[3] Libya's Renewables Surge: 4GW by 2035, 500MW Solar Project. (2025, January 31). PV Know How. https://www.pvknowhow.com/news/libyas-renewables-surge-4gw-by-2035-500mw-solar/

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[4] Llanos-Jiménez, J., Alonso, A., Hepf, C., & de-Borja-Torrejon, M. (2025). Assessment of Mediterranean schools' energy consumption and indoor environmental factors evolution through weighted Retrofit Potential Index in climate change scenarios. Journal of Building Engineering, 105, 112404.
[5] Eljrushi, G. S., & Zubia, J. N. (1995). Photovoltaic power plant for the southern region of Libya. Solar Energy, 52(2-3), 219-227.
[6] International Renewable Energy Agency (IRENA). (2024). Libya - Energy Profile.
[7] Top Libyan Energy Officials to Chart Renewable Energy Path - LEES 2025. (2024, December 18). Libya Summit. https://libyasummit.com/news/top-libyan-energy-officials-chart-renewable-energy-path-lees-2025
[8] Libya's Renewable Energy Journey. (2025, May 23). Tumi Firm. https://tumifirm.com/2025/05/23/libyas-renewable-energy-journey/
[9] Kajjoba, D., et al. (2021). Energy efficiency measures in buildings for achieving sustainable development goals. Energy and Buildings, 254, 111616.
[10] ASHRAE. (2024). ASHRAE Position Document on Energy Efficiency in Buildings. Approved by the ASHRAE Board of Directors November 6, 2024.
[11] Llanos-Jiménez, J., et al. (2025). Thermal load assessment in Mediterranean educational buildings: Standards and applications. Building and Environment, 198, 107891.
[12] Beck, H. E., et al. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific Data, 5, 180214.
[13] Smart Building Platforms and Renewable Energy Integration: A Game Changer for the Grid. (2025, February 23). Greener Ideal.

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