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Evaluating the Effectiveness of Retrofitting Skylights with Double Glazed Panels, Dynamic Louvers and Solar Tracking Movable Louvers: A Case Study in the Faculty of Arts and Design, University of Jordan

Esraa. M. Alhendi

Department of Electrical Engineering, Faculty of Engineering, Al-Balqa Applied University, Salt 19117. (Jordan), esraa_alhindi@bau.edu.jo

تاريخ الاستلام: 09/ 10 /2025 تاريخ القبول: 11 / 11/ 2025 تاريخ النشر: 10 / 04 / 2026

Abstract:

This research article presents a comprehensive evaluation of the proposed solutions for retrofitting a skylight with double glazed panels and dynamic louvers in the Faculty of Arts and Design at the University of Jordan. The study aims to assess the effectiveness of these solutions in achieving reduced heat gains and decreased cooling load. The evaluation is based on references such as the energy savings potential of dynamic external louvers, ASHRAE guidelines, a review on buildings' energy consumption, mutual interaction of daylight and overheating, and a solar tracking-based movable louver system. The HeatCAD2023software is employed as the methodology for accurate modelling and simulation. The results demonstrate that the proposed solution achieved approximately 47% energy efficiency, highlighting its potential for significant energy savings.

Keywords: Retrofitting; Skylight; Double glazed panels; Dynamic louvers; Heat gains; Cooling load; Energy efficiency; Faculty of Arts; University of Jordan; HeatCAD2023 software; Green Building.

1. Introduction

According to the "2021 Global Status Report for Buildings and Construction" by the Global Alliance of Buildings and Construction (GABC), buildings accounted for 36% of global energy demand and 37% of energy-related CO_2 emissions in 2020, which is higher than those of the transport and industrial sectors [1].

Having Skylights is a great way to use mother nature's natural light in an energy-conscious way. A skylight is essentially a window placed in your roof. You might choose a skylight for your home to increase the amount of light or to reduce your winter heating bills, which will contribute to reducing energy demand if designed properly [2]. Also, the aesthetic improvements of the building are another advantage of skylights, it's widely

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acknowledged that skylights make living spaces feel bigger and more open. But too much light on bright sunny days can create glare and bothersome brightness and too much heat gain, leading to overheating, inevitably increasing energy costs, especially during the summer months. Some Skylights don't have adequate UV blockers to prevent furniture, flooring, and your belongings from fading and discolouring. Reducing the heat from a skylight, either before installing the window, or after the fixture is already in your home is considered one of the most important construction demands and must be taken in consideration.

When dealing with skylights in a close building, where heat gain can be more challenging to manage, here are some solutions to prevent heat gain effectively:

Skylight Glazing: Choose skylights with low-emissivity (low-E) coatings on the glass. These coatings reflect infrared radiation and reduce heat transfer. Double or triple glazing can also improve insulation and minimize heat gain.

Exterior Shading Devices: Install external shading devices such as awnings, louvers, or external blinds above the skylight. These structures block direct sunlight and prevent excessive heat gain while still allowing natural light to enter the building.

Retrofitting skylights with effective solutions is essential for reducing heat gains and decreasing the cooling load in buildings. This research article focuses on evaluating the proposed solutions for retrofitting a skylight with double glazed panels and dynamic louvers in the Faculty of Arts at the University of Jordan. The study aims to assess the effectiveness of these solutions in achieving the desired objectives.

2. Literature Review

2.1 Energy Savings Potential of Dynamic External Louvers

Previous research [3] highlights the energy savings potential of dynamic external louvers in office buildings. These louvers effectively control heat gains, leading to substantial energy savings and improved occupant comfort. This reference serves as a basis for evaluating the effectiveness of dynamic louvers in the skylight retrofitting process.

2.2 ASHRAE Guidelines

ASHRAE guidelines [4] provide industry standards for energy-efficient building design and operation. Adhering to these guidelines ensures that retrofitting strategies, including double-glazing and dynamic shading devices, align with best practices. Compliance with ASHRAE guidelines is crucial for achieving optimal energy efficiency and reducing the cooling load through skylight retrofitting.

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2.3 Review on Buildings' Energy Consumption Information

The review conducted by [5] provides valuable insights into buildings' energy consumption and its contributing factors. This review aids in evaluating the overall impact of retrofitting solutions on reducing heat gains and cooling load. The findings contribute to understanding the significance of skylight retrofitting in achieving energy efficiency goals.

2.6 Mutual Interaction of Daylight and Overheating

The study by Katunský et al. [6] investigates the mutual interaction of daylight and overheating in attic spaces during summer. This research emphasizes the importance of balancing daylight provision and mitigating overheating risks. The findings inform the evaluation of the proposed solutions, ensuring effective utilization of daylight while minimizing heat gains and subsequent cooling load.

2.5 Solar Tracking-Based Movable Louver System

The research by Jung et al. [7] explores the development of a solar tracking-based movable louver system for saving lighting energy and creating a comfortable light environment. Although not directly related to skylights, this study provides insights into the effectiveness of dynamic louver systems in energy savings and light management. These insights contribute to the discussion on the potential benefits of dynamic louvers in skylight retrofitting. Compared with conventional louvers, the STML can reduce lighting and heating/cooling energy by 35.7–49.7%. These findings prove the effectiveness of the proposed system.

2.6 The effect of skylight design on educational building in hot climate

Eiz et al. [8] this study emphasizes the importance of skylight design in architectural planning, particularly for educational facilities in hot regions such as the UAE. Skylights are essential for delivering adequate daylight in interior areas, which is critical for the health and performance of people inside, mainly students. Natural light improves learning rates by 20% to 26% compared to artificial light, according to research in warmer locations, it can be challenging to maximize daylight while reducing heat input from solar radiation.

3. Methodology

The methodology employed in this research utilizes the HeatCAD2023 software for accurate modelling and simulation of heat transfer dynamics. The software enables the assessment of various retrofitting scenarios, including the integration of double-glazed panels and dynamic louvers. The assumptions used in software like thermal transmittance (U-value) measured in [W/m²K], shading percentage, design temperature in Celsius [°C], indoor humidity and area in meter [m^2]. The following assumption is taken into account when simulate the HeatCAD2023 software:

- walls U value =0.57 W/m²K
- Ceiling U value=0.26 W/m²K
- Double-glazing Uvulae=0.75 W/m²K
- louvers=Drapes high with internal shading 100%.
- Design temperature: Heating =24 °C, Cooling=16 °C
- Humidity: Heating= 20, Cooling= 50
- Fourth floor area= 2615.6 m^2.

After we running the software for the existing skylight in faculty of arts which covering only the fourth floor in the University of Jordan with latitude of 32° and elevation of 1050 meter and then comparing the results with a new suggested skylight after double-glazing and shading. The simulation and analysis done and the effectiveness of these proposed solutions in achieving less heat gain approved. The final shape of dynamic louvers structure is designed by Revit software with 3D view.

4. Results and Discussion

The evaluation of the proposed solutions using HeatCad2023 software revealed significant improvements in energy efficiency. The simulations demonstrated a significant reduction in heat gains and achieved about 47% energy saving.

By looking in table 1, which represents the loads resulting from skylight, we note that the existing situation gives heat gain by 153,141watts with sensible load by 487,330 watts, while if we look in table 2, which represents the load from skylight after double-glazing and shading, the retrofitting situation gives heat gain by 67,335 watts with sensible load by 120,956 watts, this means that the heat gains by skylight and sensible load after retrofit decreases by 56%, 75% respectively.

The current skylight is lack of minimum criteria of thermal isolation due to single glazed with low thickness of glass, no kind of shading its means high admittance of sunlight beams and poor insulation in frame and glass materials. Figure 1 shows the heating load breakdown caused by skylight only, as we can see that skylight has a high effect of heat gain in this case so we have to improve the status of skylight to accommodate weather nature in Jordan as it is a hot climate in summer as a result, high indoor heat gain from skylight.

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The current skylight is shown in figure 4 which appears that the heating load caused from it is very high which increases the sensible indoor heat in fourth floor at the art building. So that the performance of the skylight should be improved with several factors such as the double glazing to achieve a high heat insulation, and shading with movable louvers to prevent direct sunlight from entering while allowing daylight to pass through. We also installed the best type of insulation by choosing appropriate aluminum frame. Figure 2 shows the heating load breakdown of the skylight after retrofitting, we notice that it has decreased compared to the figure 1 in its previous status. This is indication that improving the efficiency of the skylight reduces the heat gained and thus the indoor heat of the building, thus reducing the cooling load and rationalizing the consumption of electrical energy [4].

The performance of dynamic louvers in solar daylight control adapts to the day light by changing the louvers directions according to the beam of sunlight [5], thus, the area of skylight that is not exposed to the direct sunlight allows daylight to pass through, as shown in fig 5,6 and 7, Also the white color of louvers increases the reflection of sunlight so decrease the absorption of heat.

Furthermore, dynamic louvers enable the building to reduce lighting and cooling loads by means of solar daylight control, reduces operational cost of building, reduces CO_2 emissions and gives distinctive architectural character as shown in fig 5,6 and 7.

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Table 1:Load Summary before Retrofitting.

Name	Heating	Sensible	Latent
Windows*	0	0	
Skylights*	153,141	487,330	
Doors	0	0	
Walls	18,811	13,586	
Below Grade Walls	0		
Ceilings	81,243	120,453	
Floors	954	526	
Infiltration	5,841	1,947	0
Internal		14,563	11,767
Other	0		
Duct Loads	43,939	190,883	65
Ventilation	13,134	17,512	0
Humidification	0		
Piping Load	790		
Radiant Back Loss	0		
Blower Heat		500	
AED*		0	
Total	317,854	847,299	11,832
Total Area	2615.6 m²	2615.6 m²	

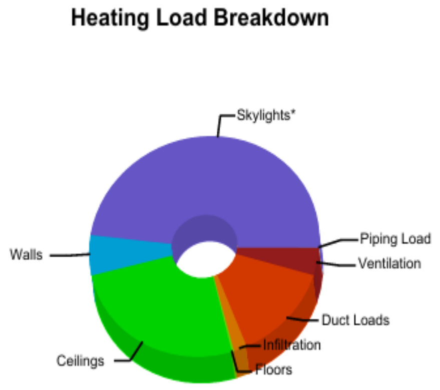

Figure 1:Heating load breakdown from current skylight.

Table 2: Load summary with Double-glazing and dynamic louvers.

Name	Heating	Sensible	Latent
Windows*	0	0	
Skylights*	67,335	120,956	
Doors	0	0	
Walls	12,426	11,334	
Below Grade Walls	0		
Ceilings	45,908	54,758	
Floors	954	526	
Infiltration	5,841	1,947	0
Internal		14,563	11,767
Other	0		
Duct Loads	22,387	61,021	65
Ventilation	13,134	17,512	0
Humidification	0		
Piping Load	790		
Radiant Back Loss	0		
Blower Heat		500	
AED*		0	
Total	168,775	283,116	11,832
Total Area	2615.6 m²	2615.6 m²	

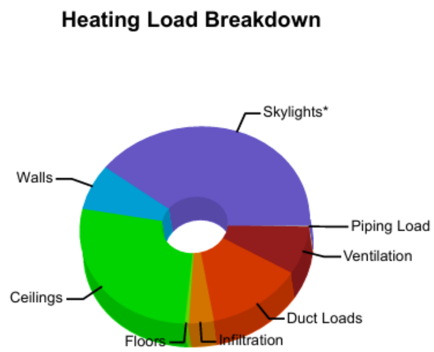

Figure 2: Heating load breakdown after retrofitting skylight.

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Figure 3: Current skylight at art building.


Figure 4: Dynamic louvers prevents beam sunlight (glare).

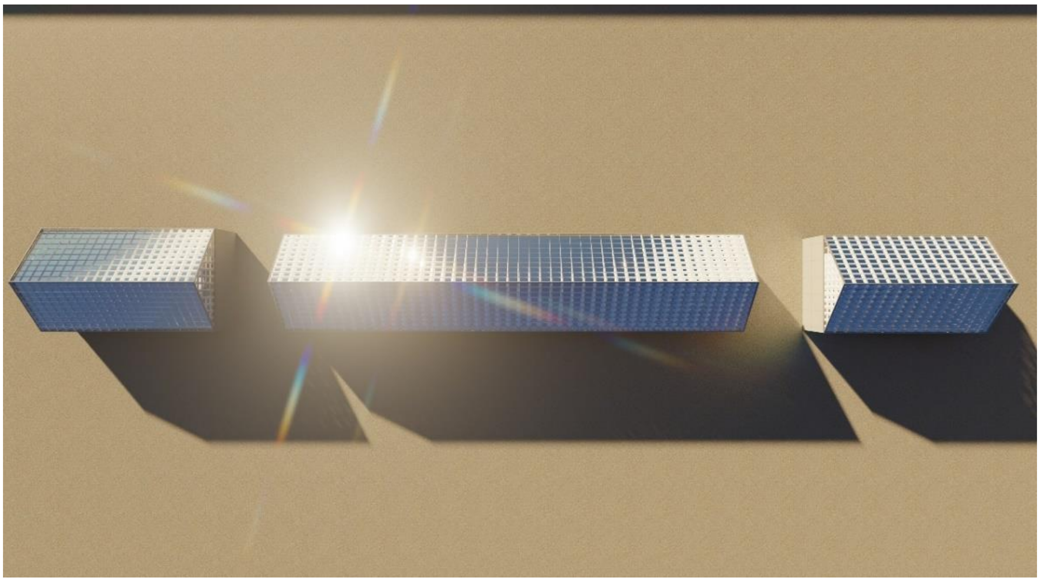
Figure 5: Top view of skylight with dynamic louvers.

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Figure 6: Dynamic louvers passes daylight.

5. Renewable Energy calculations

To complete the process of providing electrical energy, we made calculations to cover the electrical load from solar energy through photovoltaic (PV).

To find the size of PV system needed to cover the load by equation 1 and 2:

$$Annual\ Demand\ [kWh] = Total\ Heating\ Load\ [Watt] \times Annual\ Hours \quad (1)$$

$$PV\ size = Annual\ demand\ [kWh] \div 1560\ [\frac{kWh}{kWp}] \quad (2)$$

Table 4 shows the needed calculations of PV size needed to cover the heating load in fourth floor at art building to compare between the current skylight and the retrofitting skylight with louvers and double-glazed panels. Also, the initial cost of skylight in two cases.

As we can see from table 4, the total annual demand of PV needed to cover all heating load in fourth floor at art building is decreased by 61.27% after retrofitting the skylight. This indicate that any steps to improve the building heat insulation materials can decrease the cooling load and electricity consumption in summer. However, the high initial one-time cost of improving building efficiency and reducing energy consumption does not compare to the value of the annual cooling load required to achieve human comfort in the work environment. In addition, we note from table 4 that there is a decrease in the daily heat load as a result of the

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improvement by approximately 56%. And so on the total daily total heat load in art building decreases by approximately 47%.

Table 3: PV calculation and prices of two different cases of skylight.

	Current skylight Single glazed	Retrofitting Skylight with Lovers and double glazed
Total Annual Demand [MWh/ annually]	2784.4010	1478.469
PV size [kWp]	1784.87	947.736
Price [$/m^2]	20	120
Total skylight area [m^2]	609	
Total cost of skylight [$]	12,180	73,080
Daily heat load from skylight only [W]	153,141	67,335
Daily total heat load in art building [W]	317,854	168,775

Conclusions

After visiting the Faculty of Arts and Design at the University of Jordan and seeing the skylight site on the fourth floor and talking with the students, the size of the problem caused by this skylight estimated, especially in the summer at the high internal temperature that reaches approximately to50^{0}c.

Many solutions exist, but the most supported by literature reviews of research related to skylight problems in hot areas or in the summer was double-glazing and dynamic louvers with the sun's rays.

Choosing the dynamic Louvre was the most appropriate in terms of blocking direct sunlight, while allowing daylight to pass through the building, also choosing a white color for it to reflect the largest number of rays falling on it. All these choices contributed well to reducing the total heat gained in art building and reducing the cooling load by approximately 47%.

Disclosure Statements:

- **Ethical approval and consent to participate:** Participation in the research was approved in accordance with the journal's guidelines.
- **Availability of data and materials:** All data and materials are available upon request.
- **Authors' contributions:** The authors are responsible for all aspects of the research, including content, analysis, methodology, and the final review.
- **Conflicts of interest:** The authors declare that there are no conflicts of interest related to the design, submission, or evaluation of this research.
- **Funding:** This research received no specific funding.
- **Acknowledgements:** The authors would like to express their sincere appreciation to Journal of Scientific Conferences (JSC) for its support and guidance (https://sdasmart.org/jsconf/).

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ISSN: 3105-8396