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The Energy Saving Potential in an Office Building Using Louvers in Mid-Latitude Climate Conditions

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Abstract: Daylighting has emerged as a prominent strategy for elevating indoor environments by harmonizing visual comfort and energy efficiency. This paper introduces a louver system crafted for energy simulations, specifically tailored to address lighting and cooling requirements in office spaces. Louvers, acknowledged for their exceptional efficiency in providing daylight, are integrated as a pivotal energy-saving technique. Adopting a quantitative research approach facilitated by building information simulation tools, DIALUX evo and Rhino were employed for modeling and simulating the building's daylighting performances. The simulation outcomes reveal substantial energy savings, particularly in the realms of lighting and cooling. Notably, a 50% louver opening in office spaces results in an impressive 27.0% reduction in energy consumption. The study explores various louver configurations, providing insights into both lighting and cooling energy savings. The overall system performance excels in sustaining consistent daylight, significantly contributing to enhanced energy efficiency.

Keywords: louvers; visual comfort; energy-saving; energy-simulation

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1. Introduction

According to the International Energy Agency (IEA) 2022 report, developing economies have increased CO_2 emissions in buildings using fossil fuel gasses, leading to a rise of approximately 4% in buildings' energy demand which has been identified as the largest surge to have taken place in the last 10 years [1]. Consequently, it has been recorded that buildings are generating an all-time high of approximately 10 Gt CO_2 emissions, which is approximately 5% higher than in 2020 [1]. In 2021, buildings accounted for around 37% of global CO_2 emissions, as stated in [1]. A building is classified as energy-efficient when its construction and energy-consuming systems, such as heating, cooling, lighting, and ventilation, are designed to achieve a high level of efficiency. The performance of a building envelope is considered as a crucial factor for an energy-efficient building. As building design evolves, the façade and shading systems are now recognized as major features that serve important functions in passive design strategies and contribute significantly to improving energy efficiency and occupant comfort. The use of highly glassed facades and large windows in modern buildings is becoming increasingly popular as it allows for abundant natural light, maximizes solar energy utilization, and provides an exterior view.

For natural light illumination, various techniques have been used including louvers, light shelves, lighting redirecting, and daylighting systems [2–6].

Daylighting provides natural light in the interior spaces to save electric lighting energy consumption. Various studies have been conducted to design sunlight-redirecting systems for indoor illumination [7]. According to a study, a daylighting redirecting system can save up to 50–80% electric light energy in buildings. Likewise, researchers have developed efficient light sources that consume less power compared to conventional light sources [7]. A daylighting system redirects sunlight to indoor spaces using reflectors, lenses, light pipes, and optical fiber. Likewise, other techniques are also used for daylighting and shading, such as louvers, awnings, blinds, and light shelves [2–6]. Windows have been considered the most effective component in buildings at providing daylight in the interior space because of their high performance. Therefore, it is preferred to install the light redirecting system on windows, considering the elevation angles of the sun.

Louvers can reduce the need for artificial lighting by allowing natural light to enter the building. They are used to control the amount of light which is needed to be delivered indoors in a building. Various designs of louvers have been developed to control the amount of daylight. To provide daylight in the interior space through louvers, three types of designs are used: fixed, adjustable, and operable louvers. Fixed ones provide a consistent level of light and ventilation, while adjustable louvers allow for greater control over light levels and ventilation by varying the tilt angle of the slats. Operable louvers are motorized to provide even greater flexibility in controlling light levels [8]. In the literature, various types of louvers have been designed, including vertical, horizontal, and eggcrate louvers, and their performances have also been measured [9]. Louvers are selected based on the direction of a building and applied in different environments. Vertical ones are installed in the east–west direction of the building, while horizontal ones are generally installed in the south-facing direction [10].

To design a louver, building orientation, location, and the light level are considered important parameters [11]. The orientation of the building determines the angle of incident light, which affects the amount of direct sunlight entering the space. For high illuminance areas, louvers need to be installed with more adjustable options to control the amount of light entering the space. For buildings in urban areas, louvers are designed more efficiently to redirect maximum light inside buildings. For such cases, the design of a louver should be optimized based on the building's orientation to achieve the desired amount of daylight. The design of a louver includes the shape of the slats, the size of the slat, and the spacing between the slats. Designing the slat angle of a louver is essential to effectively redirect low-angle winter daylight and high-angle summer daylight into the deeper parts of the interior space.

Additionally, louvers can also play a critical role in energy saving by reducing the need for artificial lighting and providing ventilation systems. According to the US Department of Energy (DOE), louvers can help to reduce energy costs by improving ventilation and air circulation in buildings. Louvers can control the airflow through horizontal or vertical slats while blocking out unwanted elements such as rain and wind. They are commonly used in commercial, industrial, and residential buildings for ventilation and climate control.

Louvers are made from different materials (e.g., wood, aluminum, or glass). Material selection is another crucial factor in louver design for daylighting [12]. The material should allow for maximum light transmission while minimizing heat gain. Glass and acrylic are common materials used in louvers for daylighting, with clear or translucent options to control light transmission levels. If the illuminance level in an interior space is below the required standard value, it is recommended to incorporate additional lighting fixtures, such as light shelves and skylights. In the contemporary context, to augment the light reflection capability of louver slats, advanced coating technologies have been harnessed, yielding an impressive light reflection efficiency of up to 92% on aluminum surfaces [13]. This innovative integration of coatings marks a substantial advancement in refining the light manipulation attributes of louver systems, promising substantial enhancements in energy efficiency and precise illumination management across diverse environments.

A study is presented to optimize daylight and energy consumption using an optimization technique for louvers shading devices [14]. The design parameters of the building, including overhang, blade size, spacing, and rotation, were meticulously optimized to maximize useful daylight illuminance and shading aperture. Louvers can optimize daylight performance by providing daylight in the interior and saving energy utilization. In [15], researchers unveiled an automated prismatic louver system comprising reflective and prismatic louvers that worked together to achieve the dual objectives of shading and redirecting daylight. The results indicated that the automated louver performed better than traditional louvers. For producing electric energy and saving electric lighting energy consumption, a photovoltaic (PV)-based louver system was proposed in [16]. The PV-based louver was able to produce 22.46 kWh energy while delivering an illuminance of 2000 lx.

Louvers are considered crucial for sustainable building design to save energy, enhance visual comfort, and minimizing glare and heat gain. To assess the impact of louvers on energy consumption in buildings and indoor thermal environment, there are typically two categories of evaluation methods: (i) transmission and absorption of solar radiation; (ii) heat exchange between the building envelope and its surroundings. In [17], researchers conducted a study to explore the heat exchange that occurs between the blinds and the facade located behind them. The study found that the temperature of the air, blinds, and facade varied in response to changes in the weather. A case study was conducted to test the performance of shuttle louvers [18], and a model was presented to calculate the heat transfer through building envelopes. Further, exterior louvers have also been used to stop the solar radiation transmitting inside the interior space through windows [19].

In [20], a simulation study was conducted to assess the impact of louver shading devices on achieving comfortable indoor thermal conditions and reducing energy consumption. A movable louver with sun-tracking was designed to reduce energy consumption and improve the indoor illumination uniformity [21]. Four different types of louvers were compared: horizontal, vertical, eggcrate, and hybrid. It was concluded that the movable louver with sun-tracking could reduce lighting, heating, and colling energy up to 49.7%. Likewise, to reduce energy consumption, four different control strategies were applied on curved fixed louvers for four cities with different climate conditions [22].

A summary of different louver systems is shown in Table 1. Most of the louvers were used for visual comfort by providing daylighting in the interior space. Horizontal louvers are most widely used to redirect daylight towards the ceiling of the interior space.

Table 1. Comparison of recent work on louver systems.

Article	Type	Louver Slat Angle	Comments
Muna Alsukkar et al. (2022) [2]	Horizontal	0° to 60° and −40° to −10°	Free-glare indoor illumination
Jiaeng Fang et al. (2022) [11]	Horizontal	7°	Better daylighting luminous environment
M. Alsukkar et al. (2022) [23]	Horizontal	0° to 38°	Improve the daylighting performance of the split louver
J.-H. Kim et al. (2022) [22]	Horizontal	0° to 90°	Uniform indoor illuminance
D. Uribe et al. (2019) [20]	Horizontal	30°, 40°, 60°	Visual comfort
Fujian Jiang (2019) [17]	Horizontal	0°, 45°, 60°	Airflow for heat exchange
F.F. Hernández et al. (2017) [21]	Horizontal and vertical	Vertical 0°, 30°, 60° −30°, −60° Horizontal 0°	Visual comfort and energy saving

The proposed study investigates both the lighting and thermal energy-saving through simulations and experimental data. A test room was designed for the simulation and experiments located at Seoul, South Korea, under mid-latitude climate conditions.

2. Methodology

In this study, we conducted an assessment of the effectiveness of using louvers with energy-saving capabilities through simulation methods. The following were simulated:

- Using DIALux software 11.0, lighting conditions within a room using louvers and the amount of energy saved using the louver system [24].
- Using Rhino software 7, calculation of the energy required for heating and cooling in an office with and without the use of louvers [25]. The results were then analyzed to determine the energy-saving potential of the louver system. The research was carried out using a virtual model and a parametric approach on a simulation platform. The research workflow is depicted in Figure 1.

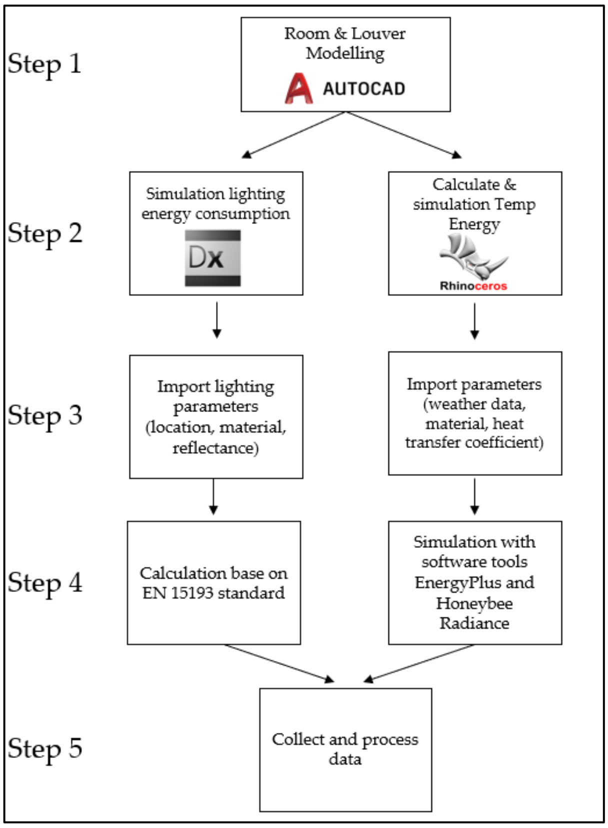


Figure 1. Research workflow [26].

The results were used to compare and validate the accuracy of the simulation method. Based on this, we made recommendations for the use of louvers to save energy and increase energy efficiency in office buildings. The findings of our study demonstrate the potential benefits of incorporating louvers into building designs as a means of reducing energy consumption and improving indoor environmental quality.

2.1. Model Specifications

2.1.1. Test Room Specifications

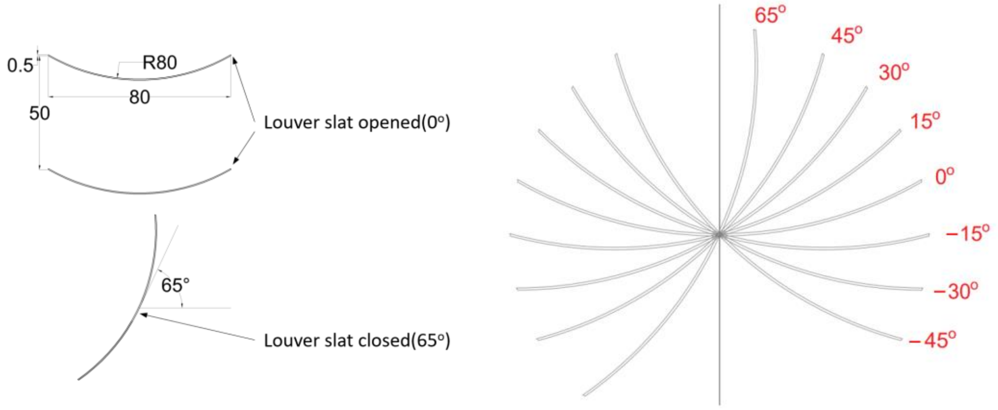
In this study, simulations were conducted on a model office with dimensions of l × w × h, 6.0 m × 4.0 m × 2.5 m, respectively, and a window size of 3.0 m × 2.0 m on the south-facing wall. Some specifications provide a framework for the simulations conducted in this study, which focused on evaluating the effectiveness of louvers with energy-saving capabilities. As shown in Table 2, the thermal transmission parameters and lighting parameters of the test room are mentioned.

Table 2. Thermal transmission and lighting specifications.

Component	Construction	Reflectance	Transmittance	Heat Transfer Coefficient (W/m^{2}K)
Interior Walls	General Interior Wall	0.5	-	2.58
Exterior Walls	General Exterior Wall	-	-	0.46
Interior Ceiling	General Ceiling	0.8	-	1.45
Interior Floor	General Floor	0.2	-	1.45
Window	Clear Glass	0.05	0.9	0.5
Louver slats	Coating Aluminum	0.9	-	10

2.1.2. Louver

In this study, curved louvers were used with a radius with a curvature of 8.0 cm, a length of 3.0 m, and a width and thickness of 0.5 mm. They were made of aluminum with a reflective coating of 90% reflectance, which was used in the simulations. The louver slats were placed 5.5 cm apart from each other. A total of 36 louver slats were applied to the window in the model. The curved louvers were able to reflect most of the direct sunlight onto the ceiling, thereby reducing the phenomenon of direct sunlight shining on the floor or occupants in the room. The specifications of the louvers are provided in Figure 2.



(**a**) (**b**)

Figure 2. (**a**) Structure of louver and (**b**) definition of louver angles used in this study.

For calculating the amount of light and energy, four different conditions were considered in the model: the louvers are fully open at 100%, 60%, 50%, and 30%. In the condition where the louvers were fully open at 100%, all 36 louver slats were positioned at a 0-degree angle. In the condition where the louvers were fully open at 60%, 21 louver slats (60%) were positioned at 0 degrees, while the remaining 14 slats (40%) were positioned at a 65-degree angle. Similarly, in the condition where the louvers were fully open at 50%, 18 slats (50%) were positioned at 0 degrees, and the other 18 slats (50%) were positioned at a 65-degree angle. In the condition where the louvers were fully open at 30%, only 11 slats (30%) were positioned at 0 degrees, while the remaining 25 slats (70%) were positioned at a 65-degree angle.

The louver slats placed at a 0-degree angle can bring light into the room, increasing natural light in the room and reducing energy consumption for lighting. The louver slats placed at a 65-degree angle could reflect light, reduce discomfort from sunlight in the room, and reduce the issue of increased room temperature due to sunlight radiation. The principle of this approach is described in Figure 3.

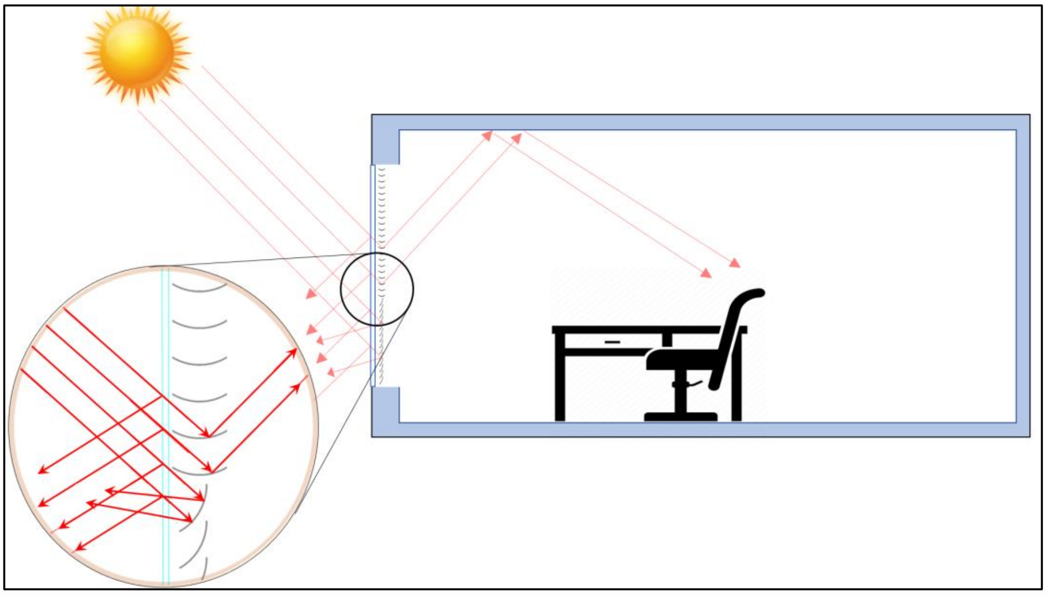


Figure 3. Louver's principle model.

2.2. Measurement and Comparison Analysis

Owing to inherent limitations, this study regrettably faced constraints that precluded the execution of experimental tests for all simulated scenarios. To address this, we constructed a dedicated testing chamber to meticulously examine both light intensity and distribution within the physical space, allowing for a nuanced comparison with the simulated light distribution outcomes. The dimensions, orientation, and types of louvers in the testing chamber were meticulously calibrated to mirror those integrated into the simulation model. The tangible manifestation of this real-world testing setup in South Korea is visually presented in Figure 4.

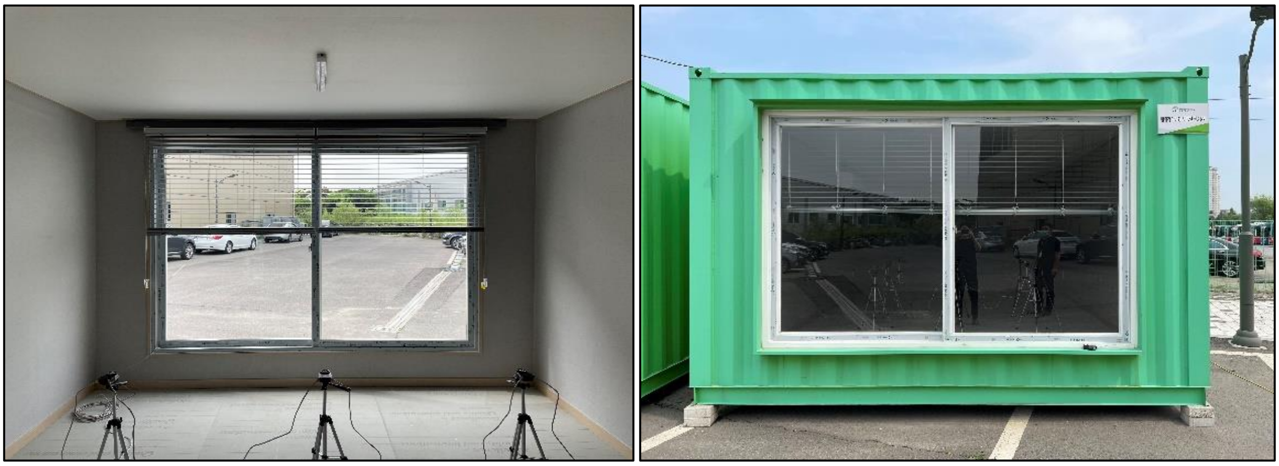


Figure 4. The test room was built for reference measurements.

Within this testing environment, we strategically positioned 09 sensors (numbers 1 to 9) to comprehensively capture and evaluate the light distribution dynamics within the confined space. Additionally, an additional sensor (number 10) was strategically placed to measure the intensity of external light. The precise locations of these sensors are meticulously illustrated in Figure 5, providing a detailed insight into our methodological approach.

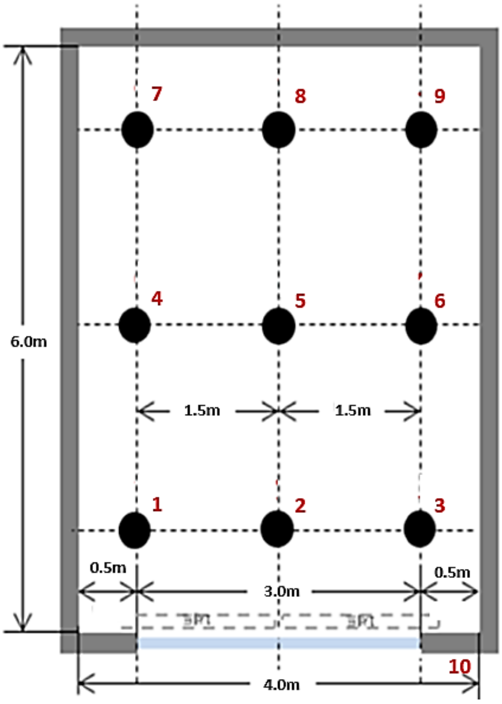


Figure 5. Distribution of sensor positions in the test room.

3. Simulation

In this section, we present a methodology for calculating and simulating lighting and cooling energy in the room. This holds significant implications for assessing the practical application of the louver usage plan.

3.1. Calculation and Simulation of Room Lighting

The DIALux software 11.0 is a powerful and widely used tool for lighting design in architecture and engineering [24]. This software allows users to simulate and analyze various lighting scenarios for indoor and outdoor environments, such as offices, schools, stadiums, and streets. With a user-friendly interface and an extensive database of luminaires and lighting controls, the DIALux software provides a flexible and efficient solution for lighting design projects of different scales and complexities. The software can generate detailed reports on lighting calculations, energy consumption, and light distribution, which can assist designers and engineers in making informed decisions on lighting design and optimization. Furthermore, the DIALux software has been continuously updated and improved with new features and functionalities, including the integration of sustainable lighting design concepts and support for advanced visualization and rendering techniques. As such, the DIALux software represents a valuable tool for researchers and practitioners in the field of lighting design and engineering [24].

We utilized the DIALux software to calculate the required energy for illuminating an office, as well as the illuminance and light distribution within the test room. The illuminance within the room was measured at a height of 0.8 m above the floor. The average illuminance, E_{av}, within a space is calculated using the formula [27]:

$$E_{av} = \frac{\Phi}{S}, \tag{1}$$

where Φ is the total luminous flux measured in lumens and S is the area of the room.

The uniformity of lighting in the room was calculated using the formula:

$$U = \frac{E_{min}}{E_{av}}, \tag{2}$$

where E_{min} is the minimum illuminance on the measurement plane (lux), and E_{av} is the average measured illuminance (lux).

These are the fundamental parameters for assessing whether an office meets the standards for its intended use. The parameters and standards conform to EN 12464-1:2021 [28]. EN 12464-1:2021 is a standard of the European Union (EU) and serves as a guiding tool for ensuring the level of lighting quality in working environments. This standard applies to lighting design in industrial, commercial, and residential constructions, including offices, schools, hospitals, and residential areas. The standard for reading and writing offices was used in this simulation. Analysis time is from 9:00 to 18:00 according to working hours in Korea.

The calculation of energy consumption is based on the EN 15193 standard for energy efficiency in residential lighting systems [26]. The geographical location and model are used to calculate the energy consumption when using daylight and not using daylight. For more convenience and specificity in calculating the energy consumption for lighting, we assigned two 30 Watt LED-panels with a luminous flux of 3600 lumens each to the model. The sensor is located 5 m away from the south-facing wall and between the two walls facing east and west. Figure 6 describes the test room model used in the simulation.

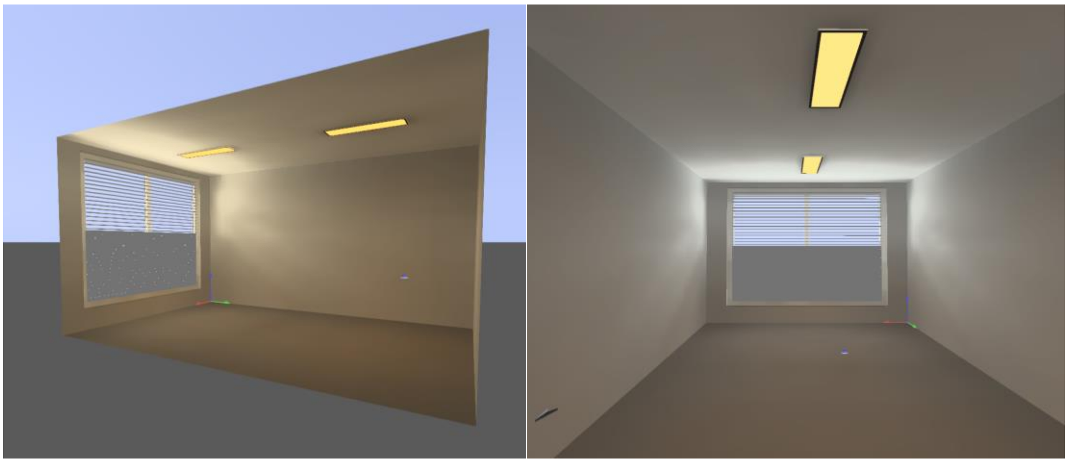


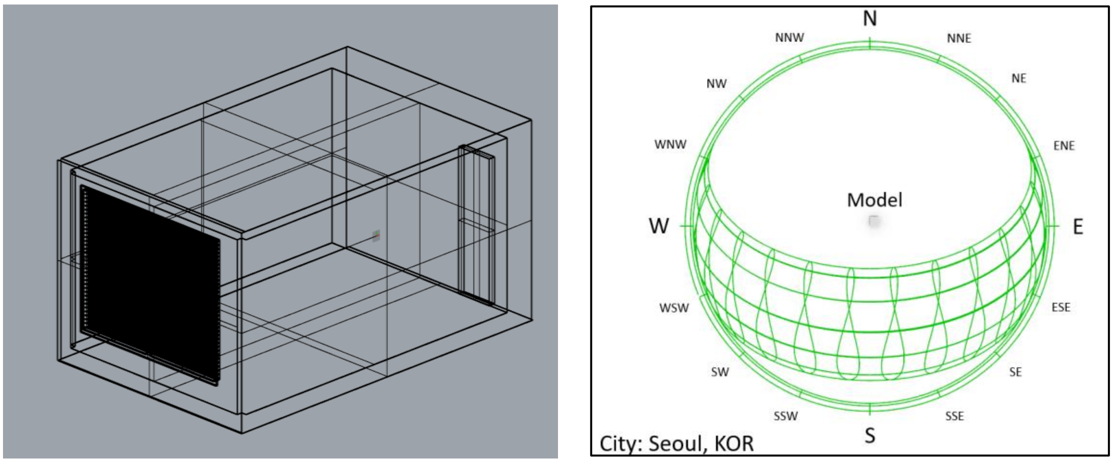
Figure 6. The test room model is used for simulation in the DIALux software [24].

The lighting standard for an average office necessitates an illuminance level between 300 and 500 lux. In this simulation, we adopted a target illuminance of 500 lux in accordance with the EN 12464-1:2021 standard on lighting requirements.

3.2. Thermal Energy Calculation and Simulation Using Rhino Software

Rhino 7 and Grasshopper are powerful software tools widely used in architecture, engineering, and construction fields. They are particularly useful for designing and simulating building systems and analyzing their energy performance. Rhino 7 is a 3D modeling software that allows users to create detailed building models, while Grasshopper is a visual programming language that enables users to automate complex tasks and create parametric models [13]. Together, they provide a powerful and flexible platform for energy calculations, enabling users to evaluate different design options and optimize building performance [25].

Typical meteorological year (TMY) provides hourly weather data for a specific location, including solar radiation and meteorological elements. It is widely used in energy simulations and renewable energy design to estimate consumption, evaluate building performance, and optimize system sizing. The data are generated by selecting a subset of weather data from a longer period, typically at least 12 years, to represent typical conditions for the location [29]. Different versions may exist for the same location based on different data sources and selection criteria. Other weather datasets are also available for different purposes. The weather data used in this study comprise the climate data of the site located at Seoul, Korea (37°33′36″ N 126°59′24″ E); regional climate data are provided by Ladybug EPWmap. Given that the operation of HVAC systems is influenced by the thermal needs of indoor environments, which vary across seasons, we did not assume the installation of an HVAC system on the site. This decision was made to ensure that our energy calculations accurately reflected the site's actual energy use patterns. Figure 7 depicts the model's image during the design phase in Rhino software, along with the sun path of the designated simulation site.



(**a**) (**b**)

Figure 7. (**a**) Test room in Rhino software and (**b**) the sun path of the designated simulation site [25].

Once we obtained the model to be simulated, the parameters of the walls, roof, floor, glass, louvers were applied, and we simulated them on the software tools EnergyPlus and Honeybee Radiance. The simulation was carried out using the Rhino software, and we focused on the energy consumption for cooling only.

The study adhered to the ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) Standard 55-2020 schedule for Thermal Environmental Conditions for Human Occupancy [30], which specifies cooling temperatures. In this simulation, temperatures of 25 °C were applied during summer.

4. Result

In this section, we present the results of comprehensive calculations and energy simulations, including an assessment of energy consumption for lighting and cooling. In addition, we performed a comparative analysis of the light distribution in the room, drawing out the differences between the results obtained from simulation and those obtained through real measurements.

4.1. Compare the Results of Measuring Light Distribution in the Test Room and the Simulated Values

In the realm of lighting simulation using Dialux Evo software 11.0, the utilization of typical meteorological year (TMY) data limits the available daylighting options to three categories: clear sky, average sky, and overcast sky. This constraint poses a challenge to accurate modeling as real-time weather conditions exhibit constant variations influenced by factors such as clouds, wind, and other atmospheric elements. Consequently, a substantial disparity arises in the intensity of interior lighting values between simulated scenarios and real-world measurements.

To bridge this gap, a practical measurement was conducted on 30 November 2022, spanning from 11:00 to 14:00, with a sampling interval of 30 s per observation. Table 3 presents a segment of the dataset acquired through these real-time measurements. Due to the voluminous nature of the dataset, our comparative analysis focuses on specific time points: 11:15, 12:00, 13:00, and 14:00.

Table 3. Segment of the dataset acquired through these real-time measurements.

Data No.	Date and Time	Ev [lx] (10)	Ev [lx] (1)	Ev [lx] (2)	Ev [lx] (3)	Ev [lx] (4)	Ev [lx] (5)	Ev [lx] (6)	Ev [lx] (7)	Ev [lx] (8)	Ev [lx] (9)
1	30 November 2022 11:05:57	1.35	0.28	0.26	1.38	0.2	0.68	0.36	0.13	0.44	0.19
2	30 November 2022 11:06:27	5830	0.27	0.26	1.37	0.2	0.68	0.36	0.14	0.44	0.19
3	30 November 2022 11:06:57	12,530	0.28	0.26	1.4	0.2	0.68	0.37	0.12	0.45	0.19
4	30 November 2022 11:07:29	12,860	4710	8330	5840	2287	3200	2641	711	0.44	0.19
5	30 November 2022 11:07:58	14,240	4770	8370	5860	2321	3230	2659	944	1278	1134
6	30 November 2022 11:08:31	24,790	4830	8380	5860	2336	3240	2662	951	1286	1137
7	30 November 2022 11:09:01	39,700	4890	8430	5880	2354	3260	2673	959	1296	1143
8	30 November 2022 11:09:32	54,400	4960	8430	5880	2365	3270	2672	964	1302	1143
9	30 November 2022 11:10:02	65,700	5050	8440	5880	2377	3280	2676	970	1309	1147
10	30 November 2022 11:10:31	68,700	5090	8420	5850	2378	3270	2663	970	1309	1142
11	30 November 2022 11:11:01	68,700	5150	8420	5840	2388	3280	2663	974	1314	1143
12	30 November 2022 11:11:31	68,700	5170	8430	5840	2398	3280	2662	979	1321	1145
13	30 November 2022 11:12:01	69,600	5260	8520	5890	2432	3320	2686	992	1336	1156
14	30 November 2022 11:12:31	69,600	5280	8530	5900	2440	3330	2693	998	1344	1160
15	30 November 2022 11:13:01	69,700	5290	8530	5880	2448	3330	2682	997	1342	1155
16	30 November 2022 11:13:31	69,500	5280	8490	5850	2448	3320	2669	997	1342	1151
17	30 November 2022 11:14:01	69,300	5270	8460	5810	2449	3310	2654	996	1338	1145
18	30 November 2022 11:14:31	69,200	5270	8440	5800	2452	3310	2650	998	1340	1144

Table 3. *Cont.*

Data No.	Date and Time	Ev [lx] (10)	Ev [lx] (1)	Ev [lx] (2)	Ev [lx] (3)	Ev [lx] (4)	Ev [lx] (5)	Ev [lx] (6)	Ev [lx] (7)	Ev [lx] (8)	Ev [lx] (9)
19	30 November 2022 11:15:01	69,500	5290	8530	5880	2448	3330	2682	997	1242	1355
20	30 November 2022 11:15:31	69,800	5290	8470	5800	2478	3330	2651	1007	1349	1145
21	30 November 2022 11:16:01	69,800	5290	8490	5800	2489	3340	2651	1012	1353	1147
22	30 November 2022 11:16:31	70,100	5310	8520	5820	2505	3350	2659	1019	1361	1150
23	30 November 2022 11:17:01	70,200	5300	8500	5800	2511	3350	2650	1020	1361	1148
24	30 November 2022 11:17:31	70,200	5310	8510	5800	2520	3360	2650	1024	1364	1148
25	30 November 2022 11:18:01	70,100	5310	8500	5790	2525	3360	2645	1026	1366	1145
26	30 November 2022 11:18:31	70,000	5320	8490	5770	2530	3350	2638	1029	1367	1144
27	30 November 2022 11:19:01	70,200	5350	8510	5770	2542	3360	2640	1035	1372	1145
28	30 November 2022 11:19:31	70,100	5360	8490	5760	2547	3360	2631	1035	1372	1141
29	30 November 2022 11:20:01	70,100	5380	8490	5750	2555	3370	2628	1039	1374	1141
30	30 November 2022 11:20:31	70,400	5410	8530	5760	2571	3380	2634	1045	1382	1144
31	30 November 2022 11:21:01	70,800	5420	8560	5780	2586	3390	2641	1051	1389	1148
32	30 November 2022 11:21:31	71,400	5460	8630	5820	2615	3420	2659	1062	1402	1156
33	30 November 2022 11:22:01	71,700	5460	8650	5820	2629	3440	2662	1069	1408	1158
34	30 November 2022 11:22:31	72,000	5470	8680	5830	2647	3450	2665	1075	1414	1160
35	30 November 2022 11:23:01	72,100	5470	8680	5820	2658	3450	2660	1079	1416	1159
36	30 November 2022 11:23:31	72,200	5460	8670	5800	2666	3450	2653	1082	1417	1156

Table 3. *Cont.*

Data No.	Date and Time	Ev [lx] (10)	Ev [lx] (1)	Ev [lx] (2)	Ev [lx] (3)	Ev [lx] (4)	Ev [lx] (5)	Ev [lx] (6)	Ev [lx] (7)	Ev [lx] (8)	Ev [lx] (9)
37	30 November 2022 11:24:01	72,400	5470	8690	5800	2682	3460	2653	1089	1422	1157
38	30 November 2022 11:24:31	70,900	5350	8500	5660	2639	3390	2590	1073	1394	1132
39	30 November 2022 11:25:01	68,400	5140	8180	5440	2556	3260	2481	1036	1341	1083
40	30 November 2022 11:25:31	60,300	4520	7170	4750	2264	2860	2173	922	1184	953
41	30 November 2022 11:26:01	59,700	4480	7150	4730	2258	2840	2174	924	1188	957

Figure 8 juxtaposes the results of the simulation against the actual measurements. The color-coded distribution in the image represents the simulated lighting distribution within the room through the software. Notably, the discrepancy between simulated and actual conditions becomes apparent, emphasizing the need for improved methodologies in lighting simulation to enhance accuracy and reliability in architectural and environmental design practices.

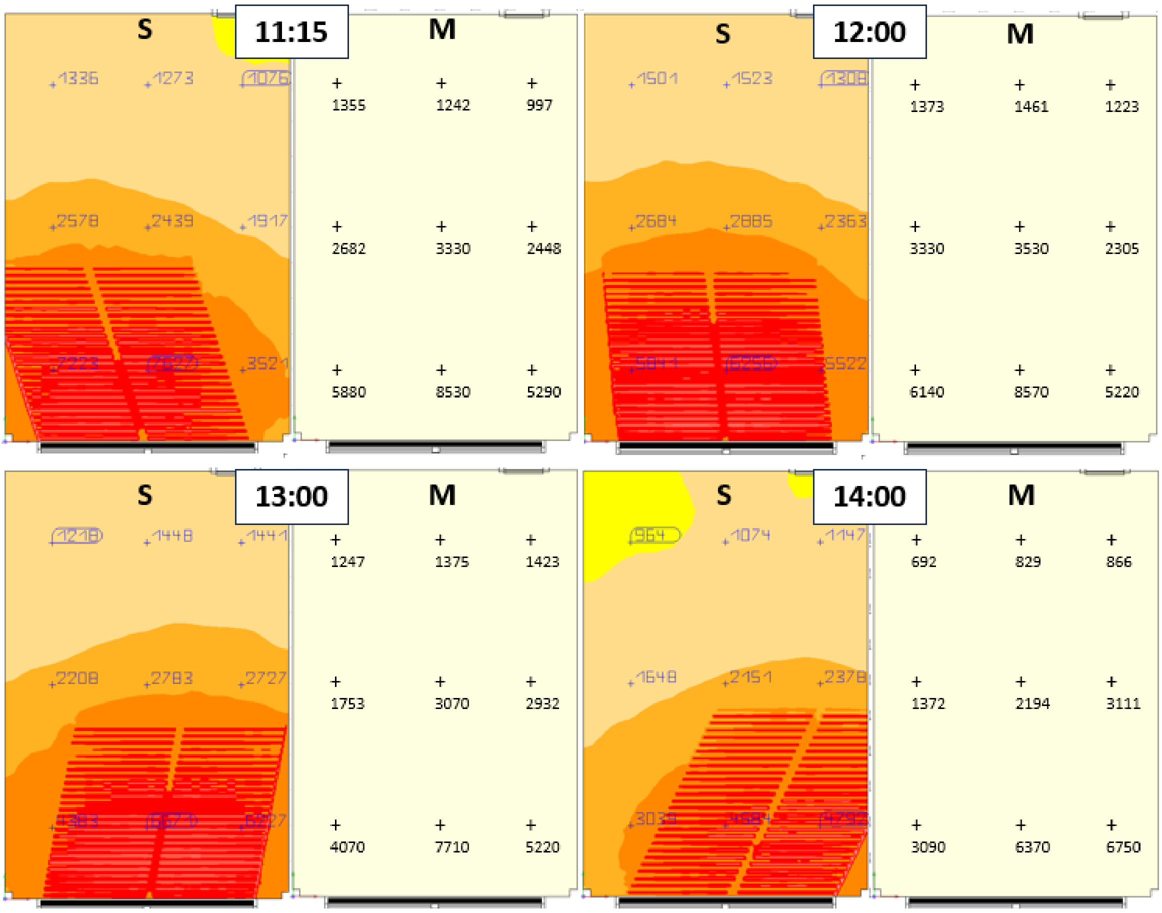


Figure 8. The results of the simulation against the measurements (S: simulation result; M: measurements result).

Fundamentally, the values at six measurement points situated away from the window in the simulation closely mirror the actual results; however, a noticeable deviation emerges in the immediate vicinity of the window. This peculiarity can be expounded by considering the sun's position in November, marked by a notably low altitude (altitude: 30.64°; azimuth: 174.44° at noon). The direct sunlight, endowed with a high reflectance (>90%), undergoes two reflections off the slat louvers before impinging directly onto the floor. This process gives rise to regions characterized by alternating high and low light intensities, with minimal separation between these contrasting zones. Consequently, the placement of sensors in these two regions yields markedly distinct readings, underscoring the intricate interplay of sunlight reflections and surface interactions.

4.2. Calculation and Simulation Results of Lighting Energy

In this section, we present an analysis of the lighting energy consumption and potential savings achieved through various scenarios. The following data in Table 4 illustrate the lighting energy requirements and the corresponding energy savings for each case.

Table 4. Energy required for lighting through the case.

	Energy Requirement	Louver Opened 100%	Louver Opened 70%	Louver Opened 60%	Louver Opened 50%	Louver Opened 30%
Lighting energy during a Year (kWh)	95	15.8	19.3	23.6	24.4	36.3
Energy saving (kWh)	0	79.2	75.7	71.4	70.6	58.7
Savings rate (%)	0	83.3%	79.7%	75.2%	74.3%	61.8%

The lighting energy requirement for the office in this study is 95 kWh. In the case of a 100% louver opening, the annual lighting energy consumption is 15.8 kWh, resulting in energy savings of 79.2 kWh, with a savings rate of 83.3%. For a 70% louver opening, the annual lighting energy consumption is 19.3 kWh, leading to energy savings of 75.7 kWh, with a savings rate of 79.7%. With a 60% louver opening, the annual lighting energy consumption is 23.6 kWh, resulting in energy savings of 71.4 kWh, with a savings rate of 75.2%. When the louvers are opened 50%, the annual lighting energy consumption is 24.4 kWh, leading to energy savings of 70.6 kWh, with a savings rate of 74.3%. Finally, for a 30% louver opening, the annual lighting energy consumption is 36.3 kWh, resulting in energy savings of 58.7 kWh, with a savings rate of 61.8%. The trend description indicates an inverse relationship between the percentage of louver opening and energy consumption, as well as lighting energy savings rates. In other words, as the louver opening percentage decreases (from 100% to 30%), there is an increase in overall energy consumption (from 15.8 kWh to 36.3 kWh) and a decrease in lighting energy savings rates (from 83.3% to 61.8%). With a reduction in the louver opening percentage, less natural light is allowed into the space. This can lead to an increasing reliance on artificial lighting, contributing to higher energy consumption. The decrease in natural light can also impact the overall energy efficiency of a building.

These findings provide valuable insights into the influence of louver opening on lighting energy consumption. The results demonstrate that changing the louver opening leads to significant energy savings, indicating the potential for enhanced energy efficiency and cost reduction. Optimal louver settings are crucial for achieving efficient lighting performance and maximizing energy savings in various lighting design applications.

4.3. Calculation and Simulation Results of Cooling Energy

The cooling energy consumption analysis includes different scenarios: without louver, 100% louver opening, 70% louver opening, 60% louver opening, 50% louver opening, and 30% louver opening. The results are shown in Table 5.

Table 5. Energy required for cooling through the case.

	Without Louver	Louver Opened 100%	Louver Opened 70%	Louver Opened 60%	Louver Opened 50%	Louver Opened 30%
Cooling energy during a year (kWh)	788	692	661	643	620	610
Energy saving (kWh)	0	96	127	145	168	178
Savings rate (%)	0	12.2%	16.1%	18.4%	21.3%	22.5%

In the base case without louvers, the cooling energy consumption during a year is 788 kWh. When the louvers are fully opened (100% louver opening), the cooling energy consumption reduces to 692 kWh, resulting in energy savings of 96 kWh (savings rate: 12.2%). For a 70% louver opening, the cooling energy consumption decreases to 661 kWh, achieving savings of 127 kWh (savings rate: 16.1%). With a 60% louver opening, the cooling energy consumption further decreases to 643 kWh, resulting in energy savings of 145 kWh (savings rate: 18.4%). When the louvers are opened 50%, the cooling energy consumption reduces to 620 kWh, leading to energy savings of 168 kWh (savings rate: 21.3%). Finally, with a 30% louver opening, the cooling energy consumption decreases to 610 kWh, resulting in energy savings of 178 kWh (savings rate: 22.5%).

The efficiency of louvers in conserving cooling energy stems from their capability to regulate the influx of natural light and solar heat into space. Well-adjusted louvers can effectively modulate the amount of sunlight entering a room. Sunlight, accompanied by solar heat, is managed by controlling this entry, aiding in the regulation of internal temperature. When the louvers are fully or partially closed, less solar heat permeates the space, thereby diminishing the overall cooling load.

The results highlight the impact of louver opening on cooling energy consumption. As the louver opening decreases, it leads to a reduction in the demand for cooling energy, leading to substantial energy savings. The highest savings rate of 22.5% is achieved with a 30% louver opening, leading to a cooling energy savings of 178 kWh.

These findings emphasize the effectiveness of louver systems in optimizing cooling energy performance and enhancing energy efficiency. By selecting the appropriate louver opening percentage, substantial energy savings can be realized, leading to cost reductions and improved sustainability in cooling operations. Further research can explore additional louver configurations to advance energy-efficient building design and sustainable cooling strategies.

4.4. Total Energy Saved

The analysis reveals that incorporating louver openings can result in significant energy savings in lighting and cooling (Figure 9).

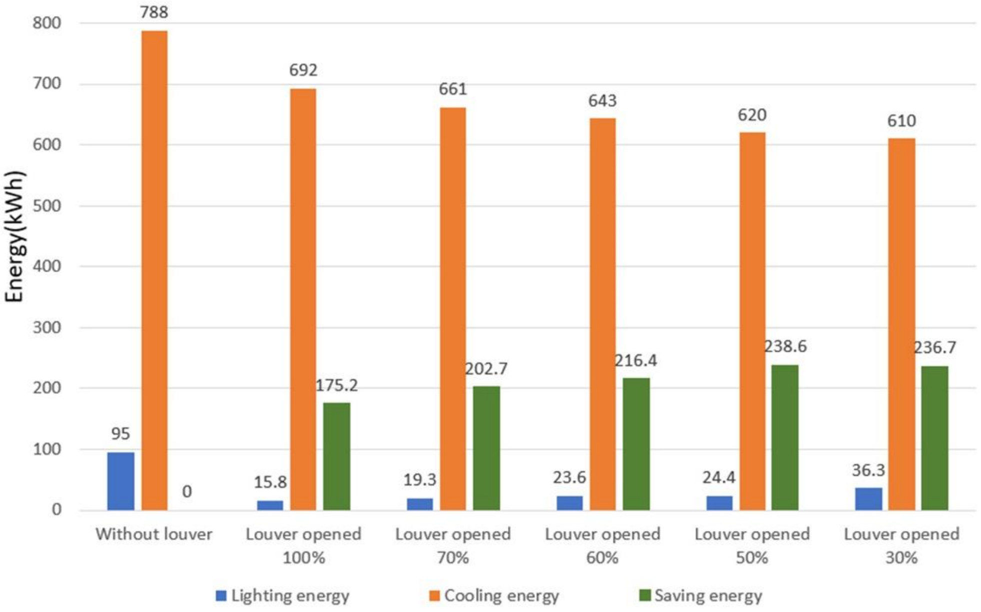


Figure 9. Total energy that can be saved through the use cases of louver.

In the scenario where the louvers are opened 100%, the greatest energy savings are observed in lighting compared to the baseline case. However, the overall total energy savings achieved are relatively modest, amounting to 175.2 kWh (19.84%). With a 70% louver opening, the total energy savings increase to 202.7 kWh (22.96%). Further, opening the louvers to 60% results in a higher total energy savings of 216.4 kWh (24.50%).

The most significant total energy savings among the cases considered in this study are attained with a 50% louver opening, reaching 238.6 kWh (27.02%). On the other hand, when the louvers are opened by 30%, although the cooling energy savings are the greatest, the savings in lighting lead to a total energy savings of only 236.7 kWh (26.80%).

Louvers have an impact on heating energy. They block the sun's radiant energy through windows, leading to energy loss, especially in winter. However, when we assess the energy expended for heating during winter in comparison to the energy lost due to louvers on windows, the impact of louvers on heating becomes negligible. In other words, given the substantial energy requirements for heating in winter, the energy loss attributed to louvers becomes inconsequential. Additionally, when we contrast this minimal heating energy loss with the cooling energy savings achieved by louvers in summer, the impact is so minor that it does not significantly affect the overall energy savings. This rationale underlies our decision not to include heating energy in the calculation of total energy savings.

5. Conclusions

In this study, we conducted energy simulations for lighting, cooling, and heating requirements in an office located in Seoul, South Korea. The results of the study indicate that the use of louvers in different opening configurations can lead to energy savings, particularly in the lighting aspect. The obtained results demonstrate that the utilization of a louver system in office spaces can achieve energy savings of over 80% for lighting requirements and up to 22% for cooling energy consumption.

Opening the louvers in different configurations results in varying levels of energy savings. The highest energy savings are achieved with a 50% louver opening, reaching 27.02%. However, the overall energy savings observed in the study are relatively modest. Opening the louvers 100% leads to a 19.84% energy savings, while a 70% opening yields 22.96% savings. The study also found that a 30% louver opening has the highest cooling energy savings but lower savings in lighting and heating, resulting in a total energy savings of 26.80%.

These findings suggest the potential for energy reduction through louver adjustments, although additional measures may be needed to achieve more significant energy efficiency improvements.

In conclusion, while the use of louvers, especially at higher opening percentages, can contribute to energy savings, the impact on the overall total energy consumption is limited. Further optimizations and complementary strategies may be required to achieve more substantial energy efficiency improvements in the studied context.

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References

1. United Nations Environment Programme. 2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. 2022. Available online: https://wedocs.unep.org/20.500.11822/41133 (accessed on 8 March 2023).
2. Alsukkar, M.; Hu, M.; Eltaweel, A.; Su, Y. Daylighting performance improvements using of split louver with parametrically incremental slat angle control. *Energy Build.* **2022**, *274*, 112444. [CrossRef]
3. Bian, Y.; Chen, Y.; Sun, Y.; Ma, Y.; Yu, D.; Leng, T. Simulation of daylight availability, visual comfort and view clarity for a novel window system with switchable blinds in classrooms. *Build. Environ.* **2023**, *235*, 110243. [CrossRef]
4. Bahdad, A.A.S.; Fadzil, S.F.S.; Onubi, H.O.; BenLasod, S.A. Sensitivity analysis linked to multi-objective optimization for adjustments of light-shelves design parameters in response to visual comfort and thermal energy performance. *J. Build. Eng.* **2021**, *44*, 102996. [CrossRef]

5. Hassan, F.H.; Ali, K.A.; Ahmed, S.A. Biomimicry as an Approach to Improve Daylighting Performance in Office Buildings in Assiut City, Egypt. *J. Daylighting* **2023**, *10*, 1–16. [CrossRef]
6. Atthaillah, A.; Mangkuto, R.A.; Koerniawan, M.D.; Hensen, J.L.; Yuliarto, B. Optimization of Daylighting Design Using Self-Shading Mechanism in Tropical School Classrooms with Bilateral Openings. *J. Daylighting* **2022**, *9*, 117–136. [CrossRef]
7. Jakubowsky, M.; De Boer, J. Façade elements for room illumination with integrated microstructures for daylight redirection and LED lighting. *Energy Build.* **2022**, *266*, 112106. [CrossRef]
8. Tao, Y.; Fang, X.; Setunge, S.; Tu, J.; Liu, J.; Shi, L. Naturally ventilated double-skin façade with adjustable louvers. *Sol. Energy* **2021**, *225*, 33–43. [CrossRef]
9. Yu, G.; Yang, H.; Luo, D.; Cheng, X.; Ansah, M.K. A review on developments and researches of building integrated photovoltaic (BIPV) windows and shading blinds. *Renew. Sustain. Energy Rev.* **2021**, *149*, 111355. [CrossRef]
10. Freewan, A.A.; Shao, L.; Riffat, S. Interactions between louvers and ceiling geometry for maximum daylighting performance. *Renew. Energy* **2009**, *34*, 223–232. [CrossRef]
11. Fang, J.; Zhao, Y.; Tian, Z.; Lin, P. Analysis of dynamic louver control with prism redirecting fenestrations for office daylighting optimization. *Energy Build.* **2022**, *262*, 112019. [CrossRef]
12. Kobayashi, H.; Kawagishi, K.; Arata, K. Stationary dielectric daylighting louver based on concept of Köhler integrator. *Sol. Energy* **2022**, *241*, 361–371. [CrossRef]
13. Liu, R. An Overview of Aluminum Protective Coating Properties and Treatments. 2009. Available online: https://wp.optics.arizona.edu/optomech/wp-content/uploads/sites/53/2016/10/An-Overview-of-Aluminum-Protective-Coating-Properties-and-Treatments.pdf (accessed on 8 March 2023).
14. Khidmat, R.P.; Fukuda, H.; Paramita, B.; Koerniawan, M.D. The optimization of louvers shading devices and room orientation under three different sky conditions. *J. Daylighting* **2022**, *9*, 137–149. [CrossRef]
15. Eltaweel, A.; Mandour, M.A.; Lv, Q.; Su, Y. Daylight Distribution Improvement Using Automated Prismatic Louvre. *J. Daylighting* **2020**, *7*, 84–92. [CrossRef]
16. Chen, H.; Cai, B.; Yang, H.; Wang, Y.; Yang, J. Study on natural lighting and electrical performance of louvered photovoltaic windows in hot summer and cold winter areas. *Energy Build.* **2022**, *271*, 112313. [CrossRef]
17. Jiang, F.; Li, Z.; Zhao, Q.; Tao, Q.; Lu, S.; Zhao, K. The influence of exterior louver blinds' geometric and thermal attributes on the convective heat transfer at building facades. *Sol. Energy* **2019**, *193*, 654–665. [CrossRef]
18. Tao, Q.; Jiang, F.; Li, Z.; Zheng, J. A model of heat gain calculation for buildings with shuttle louvers: Verification and a case study. *J. Build. Eng.* **2020**, *29*, 101101. [CrossRef]
19. Jiang, F.; Yuan, Y.; Li, Z.; Zhao, Q.; Zhao, K. Correlations for the forced convective heat transfer at a windward building façade with exterior louver blinds. *Sol. Energy* **2020**, *209*, 709–723. [CrossRef]
20. Uribe, D.; Vera, S.; Bustamante, W.; McNeil, A.; Flamant, G. Impact of different control strategies of perforated curved louvers on the visual comfort and energy consumption of office buildings in different climates. *Sol. Energy* **2019**, *190*, 495–510. [CrossRef]
21. Hernández, F.F.; López, J.M.C.; Suárez, J.M.P.; Muriano, M.C.G.; Rueda, S.C. Effects of louvers shading devices on visual comfort and energy demand of an office building. A case of study. *Energy Procedia* **2017**, *140*, 207–216. [CrossRef]
22. Kim, J.H.; Han, S.H. Indoor Daylight Performances of Optimized Transmittances with Electrochromic-Applied Kinetic Louvers. *Buildings* **2022**, *12*, 263. [CrossRef]
23. Alsukkar, M.; Hu, M.; Gadi, M.; Su, Y. A Study on Daylighting Performance of Split Louver with Simplified Parametric Control. *Buildings* **2022**, *12*, 594. [CrossRef]
24. DIALux. Available online: https://www.dialux.com/en-GB/about-dial (accessed on 2 April 2023).
25. Rhino. Available online: https://blog.rhino3d.com/ (accessed on 2 April 2023).
26. *EN 15193:2017*; European Standard: Energy Performance of Buildings—Energy Requirements for Lighting. European Committee for Standardization (CEN): Brussels, Belgium; p. 2017.
27. Ullah, I.; Shin, S. Highly Concentrated Optical Fiber-Based Daylighting Systems for Multi-Floor Office Buildings. *Energy Build.* **2014**, *72*, 246–261. [CrossRef]
28. *EN 12464-1:2021*; European Standard: Light and Lighting—Lighting of Work Places—Part 1: Indoor Work Places. European Committee for Standardization (CEN): Brussels, Belgium, 2021.
29. Wu, Y.; An, J.; Gui, C.; Xiao, C.; Yan, D. A global typical meteorological year (TMY) database on ERA5 dataset. *Build. Simul.* **2023**, *16*, 1013–1026. [CrossRef]
30. Thermal Environmental Conditions for Human Occupancy (Standard 55-2020) (ashrae.org). Available online: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy (accessed on 2 April 2023).