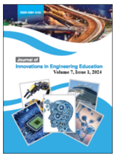

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A study on reducing energy consumption of residential building using shading devices in Pokhara, Nepal

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Abstract

Overall, around 40% of the world's energy is consumed by the building sector. Energy consumption can be reduced by passive design strategies in the buildings. Among them, shading devices are one of the effective passive design strategies that can significantly reduce solar radiation and heat gain in buildings. This study explored the effects of different types of external shading devices for the reduction of energy consumption on a residential building located in Pokhara, Nepal, and proposed the optimal shading device based on computer simulations. This study uses Autodesk Ecotect Analysis 2011 as a simulation tool. The results of the simulations demonstrate that the horizontal double inclined shading device is most effective in case of saving heating load which is 31.39 % lower than base case. And egg crate shading device is the effective one in case of cooling load annually which is 16.23% lower than the base case. For overall consideration of heating and cooling load annually, the most effective shading device is horizontal double inclined which is 12.37 % less than the base case. Even without shading devices, a west-facing orientation is the most efficient, indicating the significance of orientation in energy load management.

1. Introduction

Globally, around 40% of energy is consumed by the building sectors [1]. The importance of energy efficiency in reducing energy-related emissions, air pollution, global warming, and climate change is widely recognized. Achieving energy-efficient buildings is a priority for many nations, and this can be accomplished through the implementation of active and passive design strategies. In hot-humid climates, the largest portion of energy consumption in buildings is typically attributed to air conditioning, followed by artificial lighting [2]. In places like Pokhara characterized by subtropical highlands, or other similar subtropical climates and higher elevations where the average temperature is comfortable with few months of extreme temperature, people are resilient to the extremities and adapt to the existing built environment. However, due to the shift in construction technologies, building materials, and architectural typologies compared to that of vernacular houses, it has become important to analyze the local thermal environment to suggest appropriate adaptive design strategies.

Solar radiation entering the building has dual impacts, with both positive and negative consequences. The radiation aids in heating the spaces during the winter season while causing an increase in cooling load during the summer. Thus, effective strategies should be adopted considering both scenarios. Properly designed external shading devices on buildings can control solar radiation entering the building, influencing the building's energy use. These devices also enhance the physiological and psychological well-being of building users by providing natural illumination and a visual connection to the outside which can reduce primary energy up to 29.1 % [3].

Shading devices on building facades not only enhance the aesthetic appearance of buildings but also play a crucial role in reducing energy consumption. Researchers have conducted numerous studies focusing on the im-

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provement and impact of shading devices on buildings [4] including window opening adaptive behavior that controls thermal environment [5]. The major factor for achieving energy-efficient building is the selection of appropriate solar shading devices, which must balance two opposing objectives: maximizing winter solar gain to reduce heating energy consumption while simultaneously minimizing summer solar gain to prevent overheating and the associated increase in cooling energy demand [6]. United Arab Emirates, and south Asian countries with serious energy consumption have already taken steps into the building codes and regulations [7][8][9][10]. Without extreme heat and cold thermal conditions, residences tend to adapt to the vernacular style of construction [11], however, the incorporation of shading devices makes a huge difference in thermal control, lighting as well as protection against rain.

Moreover, shading devices on the external side of the windows include shutters, awnings, canopies, blinds, and projecting horizontal and vertical fins. These are very crucial devices in optimizing energy efficiency and creating comfortable indoor environments in buildings. Even for hot and humid weather conditions where the building energy consumption is high, the overhangs can save a significant amount of energy for cooling [12] Shading devices, such as fixed overhangs, help to manage direct beam solar radiation, reducing heat gain and preventing overheating in the building.

Research conducted by Tobias Rosencrantz concluded that external shadings are more efficient than internal ones. The study shows that while using external shading devices, both the cooling load and annual cooling demand were reduced by a factor of two, whereas the reduction with internal shadings was only by one-third [13]. Likewise, Ahmed conducted a study to compare the effectiveness of external and internal shading devices in enhancing energy efficiency and thermal comfort in a south-oriented heritage building in Alexandria, Egypt. The findings suggest that external horizontal blinds and micro louvers are more efficient than internal shading. The external devices resulted in savings of up to 46% and 35% in HVAC annual electrical energy consumption, providing thermal comfort for 228 and 261 days, respectively. Additionally, it also achieved 365 thermally comfortable days and 35% savings on HVAC annual electrical energy while applying the optimal annual operating schedule approach [14].

Ahmed A.Y. Freeman studied the effects of shading devices on a south-facing office building at Jordan University of Science and Technology (JUST). Southern orientation is crucial for controlling solar gain, improving the visual environment, and reducing glare. The study found that temperatures in offices were reduced to acceptable levels with shading devices compared to not having them. Diagonal fins and egg crate shading were found to be more efficient than vertical fins and the base case [15].

Also, the design of shading devices depends upon the orientation of the openings and glazing in the windows. South-facing glass requires fixed overhangs, while east and west glass should be minimized due to the challenges in shading. Understanding sun angles is essential in various design aspects, including building orientation, selection of shading devices, and placement of solar panels or collectors. Landscaping can be utilized to provide additional shading for east and west exposures. By carefully designing shading systems, taking into account orientation, daylighting, and site-specific factors, buildings can achieve optimal energy efficiency, thermal comfort, and visual well-being for occupants. On the contrary most of the research primarily focused on the energy saving by reduction of the cooling load. Some climatic zone such as Kathmandu Nepal, Pokhara Nepal, Darjeeling India, Thimpu Bhutan, Lhasa Tibet of the same climatic zone experiences cold winters. Therefore, the effectiveness of shading devices for special types of geographical region should be analyzed considering the building orientation, summer and winter conditions as well as precipitation during the monsoon.

Building orientation is one of the major passive strategies for overall sustainability and thermal performance of the building. This design approach takes consideration of the local climate, sun angles, and prevailing winds for minimizing energy consumption. Oumarou conducted a study to evaluate the impact of change in orientation on building energy performance in the hot arid zone climate of Ouagadougou, Burkina Faso. The findings indicate that the north orientation of the building leads to reduced energy consumption due to lower heating load. On the contrary, the western facade results in the highest annual energy consumption, exceeding that of the northern orientation by 22%. Among all simulations, the least favorable orientations were "west and east", as they recorded maximum average internal temperatures (39°C) compared to North-South orientation (35°C) [16] . Similarly, Samira researched to assess the internal thermal quality of contemporary buildings on the site of the new Ali Mendjeli city of Constantine following different orientations and to determine the optimal orientation. Through a combination of on-site investigations and computer simulations, the research revealed that incorporating the orientation criterion is instrumental in thermal efficiency and energy-efficient building design [17]. Similar results were found in the study carried out by Al-Obaidi. The study analyzed the effect of orientation change on the existing case of a typical terrace house in Malaysia by finding the dynamic indoor air temperature. Research indicates that the impact of orientation stands out as a critical design variable affecting indoor temperature, showing a partial correlation value of 58% [18].

Considering the importance of orientation for energy efficiency, Ashmay conducted a study to find out the effect of building orientation on energy consumption within the building in Cairo, Egypt. With the "Energy-Plus" simulator various orientation tested, an air-conditioned building with a southern façade consumes less energy, whereas a western façade consumes 26% more energy than a southern façade. For two-façade buildings, the most energy-efficient orientation found is between the northern and southern orientations [19].

Despite extensive research on shading devices and building orientation for energy efficiency, significant gaps remain that require further exploration, particularly in the context of specific climatic conditions. These conditions demand a careful balance between minimizing cooling loads during summer, retaining heat in winter, and addressing the performance of shading devices under heavy rainfall .

Hence, this research aimed to analyze the different types of shading devices for the reduction of energy consumption in residential buildings with unique climatic and cultural conditions like Pokhara, Nepal. Also, shading devices considering the orientation of the building is done through the energy modeling software Autodesk Ecotect 2011.

2. Climate context and built form

Pokhara city falls under the subtropical highland climate characterizing warm to hot summers and mild to cool winters. Cities such as Addis Ababa-Ethiopia, Quito-Equador, Nairobi-Kenya, Mexico City-Mexico shares similar temperatures as subtropical highland due to its elevation. Pokhara is located in the Annapurna region of Nepal at coordinates 28.201° N latitude and 83.981° E longitude, situated at an elevation of 826.6 meters above sea level. It is the largest metropolitan city in terms of area and second largest in term of population. It is at a distance of 200 kilometers west from the capital city of Nepal: Kathmandu [20]. In context of Nepal, residential sector consumes maximum amount of energy in the urbanizing cities like Kathmandu and Pokhara as compared to other sectors [21].

For accurate data analysis, the climatic data collected from the DHM (Department of Hydrology and Metrology) and the analysis is done using CBE Clima Tool. As per CBE Clima tool, the climate is characterized as a temperate highland tropical climate with dry winters. As per the collected weather data from 2007 to 2021, an average yearly temperature is 18.1°C. There is the diversity of climate in this area with the hottest yearly temperature, reaching 30.2°C, while the coldest yearly temperature, descends to 1.6°C. Solar radiation is a significant climatic factor, and in Pokhara, the annual cumulative horizontal solar radiation is measured at 1601.51 Wh/m^2. Furthermore, the distribution of solar radiation includes a notable percentage of diffuse horizontal solar radiation, accounting for 33.7%. This characteristic emphasizes the region's unique atmospheric conditions, contributing to its distinctive climate profile. As per the CBE Clima tool, the heating and cooling degree days are shown in Figure 1. It shows that maximum cooling is needed in July and August whereas maximum heating is needed in January. Additionally, Pokhara experiences substantial rainfall annually, covering a catchment area of 464.94 km^2. This area constitutes 23.01% of Pokhara and 0.31% of the entire country [22]. With an annual rainfall measurement of 3901mm, the implementation of shading devices in Pokhara's buildings has been adopted as a practical solution to manage and accommodate this considerable amount of precipitation. Also, during the period from June to September, when 80 percent of the annual precipitation occurs due to the influence of the summer monsoon. This emphasizes the significance of considering monsoon rainfall when evaluating the effectiveness of shading solution [23].

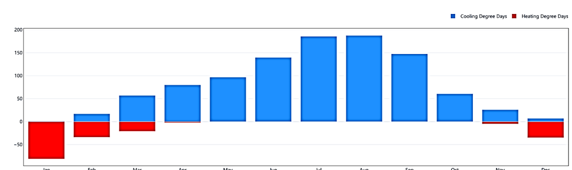

Figure 1: Heating cooling degree days (from CBE Clima tool)

In Pokhara, the residential architecture reflects a diverse range of housing types, with semi-detached houses emerging as a common and distinctive feature. The city's housing landscape often involves the careful plotting of land, where homeowners design their dwellings with space allocated on three sides and attachment on one side, creating a semi-detached configuration. This unique approach to land use highlights the importance of effective window placement and ventilation strategies [24]. Residents strategically plan their homes to optimize natural lighting and sunlight exposure, recognizing the significance of these elements in enhancing the overall livability of their semi-detached houses. This design philosophy not only accommodates the spatial constraints but also emphasizes the harmonious integration of the built environment with the natural surroundings, contributing to a unique and functional residential aesthetic in Pokhara.

Figure 3 shows that, direct solar radiation is maximum in winter (January, February, December) whereas minimum in summer (August and September). But, diffused solar radiation is maximum in summer and minimum in winter. The relative humidity maximum in summer months (June, July, August and September) and minimum in winter months (January and December) as shown in the Figure 4. It is around 80% in case of Pokhara as per CBE Clima Tool.

Additionally, Pokhara experiences substantial rainfall annually, covering a catchment area of 464.94 km^2. This area constitutes 23.01% of Kaski District and 0.31% of the entire country [22]. With an annual rainfall measurement of 3901mm, the implementation of shading devices in Pokhara's buildings has been adopted as a practical solution to manage and accommodate this considerable amount of precipitation.

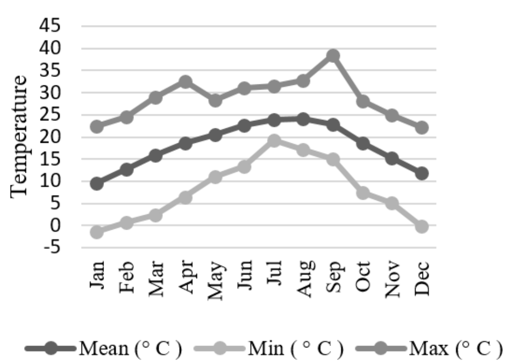

Figure 2: Temperature data(Source: Data from CBE Climatool)

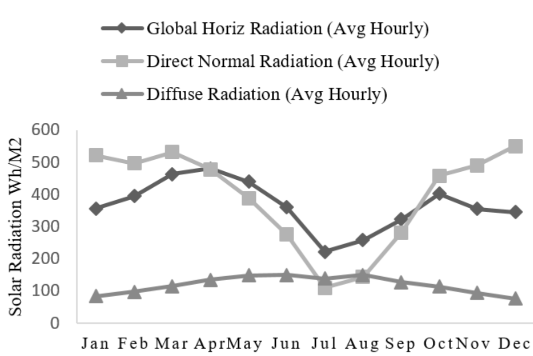

Figure 3: Solar radiation data

3. Material and methods

In the initial phase of this study, research was conducted to identify energy-efficient techniques involving the use of shading devices in buildings. The objective was to

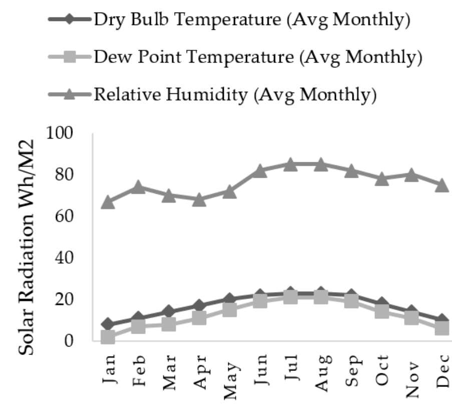

Figure 4: Temperature and Relative humidity (Source: Data from CBE Climatool)

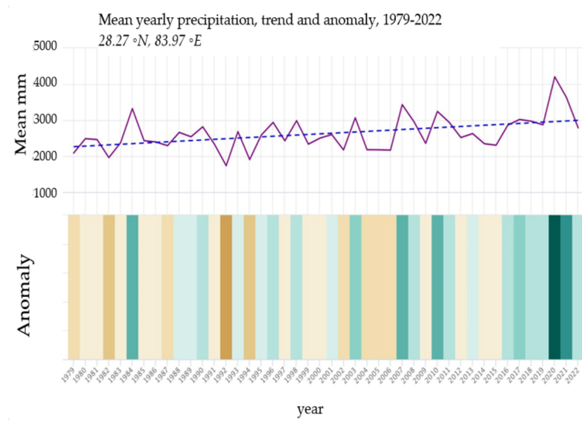

Figure 5: Mean yearly precipitation, trend and anomaly, 1979-2022

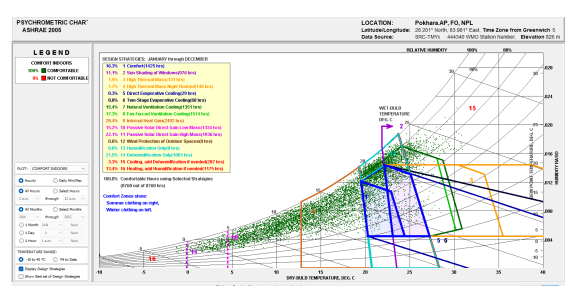

Figure 6: Psychometric chart showing the different comfort band of Pokhara (Source: Data from DHM , graph :Ecotect)

gather information on how shading devices can contribute to energy savings. Additionally, a residential building that was currently under construction was selected as a case study.

To perform energy modeling, measurements were taken at the construction site of a typical residential building.

The consumption patterns of the building were analyzed to understand how energy was being used. These patterns were then utilized to define specific zones within the building for simulation purposes, aiming to replicate the existing setting accurately.

A quantitative approach was employed to collect data for this study. Autodesk Ecotect 2011 simulation tool was chosen as the primary method for conducting simulations. The simulations were carried out to accurately measure the energy consumption of the selected typical residential building in Pokhara. Different configurations of external shading devices were implemented during the simulations to observe their impact on energy consumption. The constant variables throughout the simulations included building glazing types, and internal loads, thermal configurations. On the other hand, the main manipulated variable was the use of various types of shading devices in the building. In addition to that orientation of the building is changed in all the four directions to calculate the difference in heating and cooling loads. For accurate data analysis, the climate study of the selected area is also an important factor which is collected for the DHM (Department of Hydrology and Metrology). The analysis is done using CBE Clima Tool.

3.1. Types of shading devices

impact on the indoor environment. These devices not only enhance energy efficiency by reducing the need for artificial cooling but also contribute to the overall comfort and aesthetics of a space. For this research, the constant variables for the modeling typically include the orientation, the types of glazing, and the internal loads of the building, and the manipulated variable is the various type of shading devices used in the building. The options for external shading devices are shown in Figure 7.

The depth of the size and the material of these shading devices were fixed for the simulation as different types of material and sizes of the shading could cause inconsistencies in the result. By strategically designing and incorporating shading devices, buildings can significantly reduce their energy consumption and reliance on air conditioning. These devices help to block direct sunlight, prevent heat buildup, and create a more comfortable indoor environment. Furthermore, shading devices can contribute to daylighting strategies, optimizing natural lighting and reducing the demand for artificial lighting [12].

3.2. Study area

The case study selected for the simulation is a typical two-story residential building located in Chhorepatan, Pokhara, Nepal. (28°11’41"N 83°56’35" E) This is a

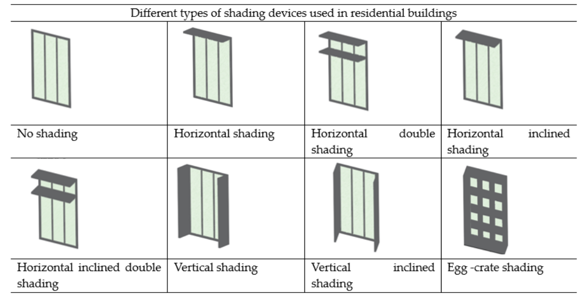

Figure 7: Different types of shading devices used in the residential buildings

prototype building designed in a housing plot. The base case of building entrance is facing south and windows are placed in the three sides (north, west, south) of the elevation whereas there are no windows in east direction. The orientation of building is changed as per the scenario during the simulation process.

The ground floor has one bedroom, living and kitchen dining area with an area of 83.6 square meter. And first floor consists of a three-bedrooms with area 72 square meter. The total built up area for the simulation is 155.7 square meter. There is a central staircase that serves both units. For this simulation, seven shading device models are considered variants, which include the basic forms of shading devices that are typically used in buildings. The behaviors of the shading provided by these models demonstrate the influence of each configuration of the shading device on the cooling loads of the building, which would lead to the understanding of the device’s efficiency.

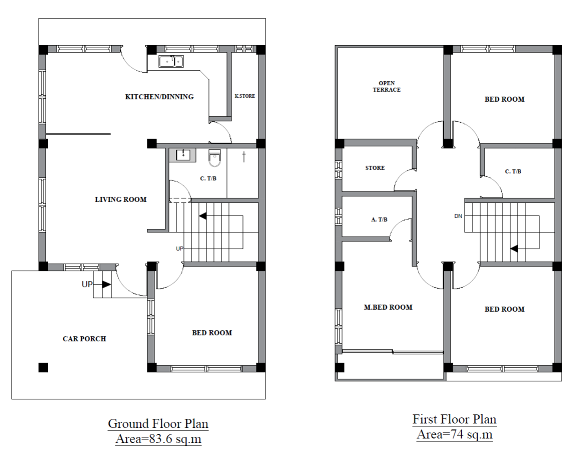

Figure 8: Plan view of case study building

3.3. Simulation process

Ecotect is a building analysis software program that helps architects and engineers simulate and evaluate the

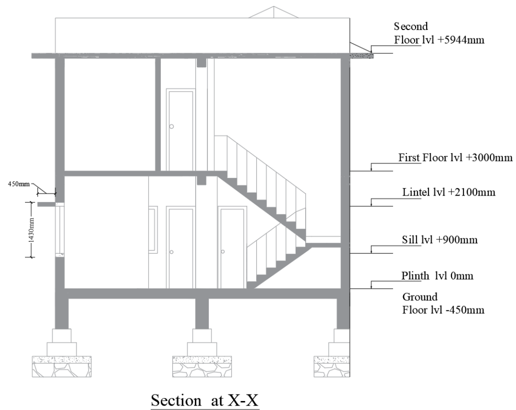

Figure 9: Sectional view of case study building

energy performance of buildings. While Ecotect itself does not provide a direct method for calculating heating and cooling loads, it can be used to analyze and visualize the energy performance of a building, which can indirectly inform load calculations. It integrates various simulation tools to analyze aspects like solar exposure, thermal performance, lighting, acoustics, and shading. Ecotect remains a useful tool for early-stage sustainable design assessments. Additionally, it focuses on interior environments and building materials but does not incorporate surrounding environmental conditions comprehensively. Typically, one side of the building aligns with the site boundary, with road access on one side. Based on this primary scenario, all other orientations have been analyzed, as detailed in Figure 10. The orientation and surrounding environment, which may influence shading effects on the case study building, have been carefully considered. To address the limitation of Ecotect, which does not account for the impact of external surroundings, we have calculated the average energy performance of the building across all potential orientations and conditions. This approach ensures that the results exhibit minimal variation across scenarios .

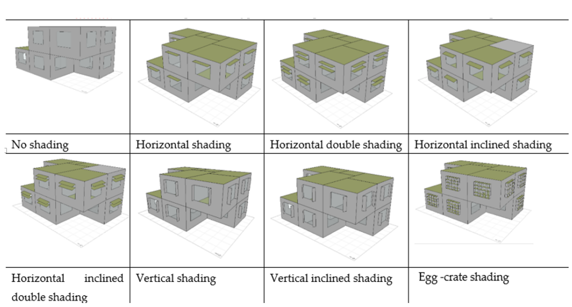

Figure 10: Ecotect Model for simulation

The above Figure 10 shows the different types of windows shading devices used in the residential buildings. The size of the windows is 1800mm width and 1350mm length in all the models. The vertical and horizontal shading length is as per the size of the windows whereas the width of shading device is 450 mm in all the windows. The orientation for the base case is as shown in Figure 8. The general process of simulation and parameters used in the buildings are shown in Table 1 and Table 2 respectively.

Table 1: General Approach for Simulation process

Steps	Components for Simulation	Resources
I	Building Geometry	Detailed 3D model including walls, windows, doors, roofs, and any other relevant elements with accurate dimension in Ecotect software.
II	Climate Data	Weather data from Department of Metrology and Hydrology using CBE Clima Tool.
III	Building properties	U-value, Solar heat Gain coefficient, material properties, types of Shading devices.
IV	Thermal Zones	As per the rooms in the layout of the buildings.
V	Energy Simulation	Simulation of the building's energy performance.
VI	Load Calculations	Calculation of heating and cooling loads for each thermal zone, using various types of shading devices.
VII	Results and analysis	Discussion of results and tabulation in bar chart.

As per the Table 4, the base case scenario involves a building oriented towards the south. This serves as the reference point. In Scenario 1, the building's orientation is shifted so that it faces west. In Scenario 2, the building's orientation is altered to face north. In Scenario 3, the building is adjusted to face east. Each scenario represents a different orientation of the building relative to the original south-facing direction.

4. Results and discussion

The total heating and cooling loads using different types of shading devices are collected and interpreted into table and bar charts. The results are calculated from the simulation software: Ecotect. The maximum

Table 2: Parameters and conditions used in the simulation

Parameter	Details
Type of Building	Residential
Total Floor Area	140.0 m^2
Story	Two stories
Shading Configurations	Eight types of shading configuration
Shading Width	450mm (Same in all windows of 1800mm x 1350mm)
Simulation For	Annual heating and cooling load calculation
Location	Pokhara, Kaski, Nepal

Table 3: Thermal performance of the building materials

Components	Materials	Thickness (mm)	U-Value (W/m^2K)
Wall	Brick Plaster	110	2.8
Wall	Brick Plaster	230	1.9
Ceiling	RCC with plaster	125	3.25
Ground Floor	Stone soiling PCC, cement punning	260	2.78
Windows	Timber frame windows	30	3.11
Windows	Single glazed	6	5.44

Table 4: Different Scenario for orientation

Different Scenarios	Orientation	Direction	Building Parameters	Thermal Performance
Base Case	South Facing	0° N	Same as base case	Same as base case
Scenario 1	West Facing	90° N		
Scenario 2	North Facing	180° N		
Scenario 3	East Facing	270° N		

monthly heating and cooling loads for different types of shading devices are shown in the Figure 11 below. It is known that, maximum cooling load is needed in the September and maximum heating load in needed in the months of February which is also shown in Table 5.

Table 5: Maximum heating and maximum cooling loads

Types of Shading Devices	February (Heating Load) KWh	September (Cooling Load) KWh
No Shading	8.65	10.43
Horizontal Shading	8.53	11.24
Horizontal Double Shading	8.8	12.47
Horizontal Inclined Shading	5.25	10.35
Horizontal Double Inclined Shading	6.82	9.51
Vertical Shading	8.29	10.57
Vertical Inclined Shading	8.13	10.63
Egg Crate	8.63	9.94

The Table 5 provides a comparative analysis of the energy consumption, measured in kilowatt-hours (KWh), associated with various shading devices during the months of February and September, corresponding to heating and cooling loads, respectively. The shading devices are categorized into different types based on their orientations and configurations. The "No Shading" condition represents the baseline energy consumption, with 8.65 KWh in February and 10.43 KWh in September for heating and cooling loads, respectively. Notably, the table reveals the impact of different shading strategies on energy efficiency. For instance, "Horizontal Inclined Shading" demonstrates a significant reduction in heating load (5.25 KWh in February) compared to other configurations and which is 39.3 % less than base case. But "Horizontal Double Shading" exhibits higher energy consumption than base case for both heating (8.8 KWh in February) and cooling (12.47 KWh in September) loads. Also, horizontal double inclined shading is most effective in case of September, consumes 9.51 KWh of cooling load, which is 8.67% less than the base case.

Figure 11: Showing heating and cooling loads in: No shading, Horizontal Shading, Horizontal Double Shading, Horizontal Inclined shading, Horizontal Double Inclined Shading, Vertical Shading, Vertical Inclined Shading, Egg Crate Shading. (The graph is the illustrative summary of the data result obtained from Ecotect)

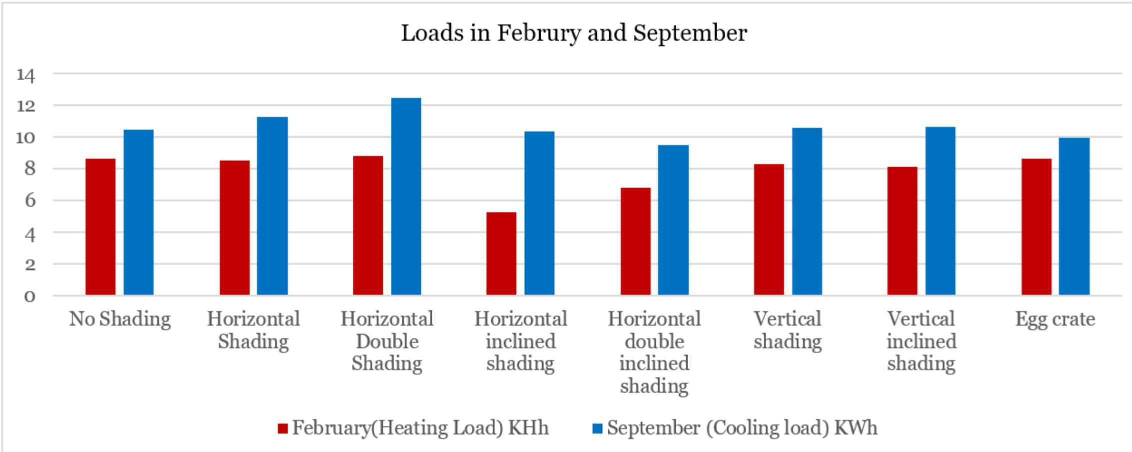

Figure 12: Heating and cooling loads in February and September respectively

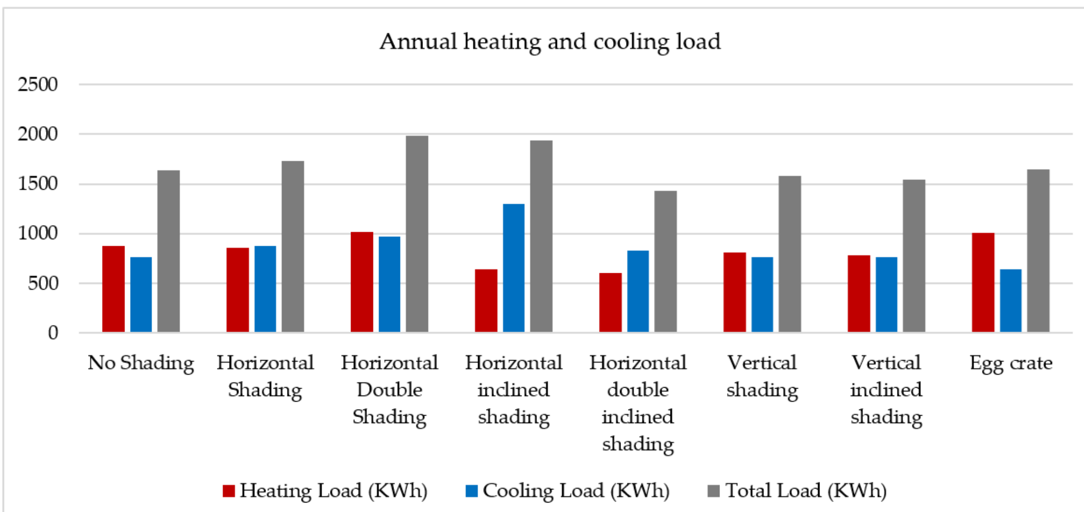

Figure 13: Annual Heating and cooling loads

As shown in the Figure 12, horizontal inclined shading is the effective shading device in winter, (February), when used in the windows of residential building. It helps in the consumption of minimum heating load in the building in comparative to the other shading devices. Similarly horizontal double inclined shading device is effective for minimum cooling load consumption in the summer, (September).

In addition to the monthly heating and cooling loads, the annual heating, cooling and total loads are also calculated using the same eight types of shading devices. This comprehensive analysis enables the determination of the most effective shading device throughout the entire year, as well as specifically during the winter and summer months. The outcomes of this assessment are presented in Table 6.

As per the Figure 13, horizontal double inclined shading device is most effective in case of saving heating load which is 31.39 % lower than base case. And egg crate shading device is the effective one in case of cooling load annually which is 16.23% lower than the base case. For overall consideration of heating and cooling load annually, the most effective shading device is horizontal double inclined which consumes 1434.443 KWh which is 12.37 % less than the base case.

Now considering orientation as one of the important factors for the energy efficient building design. The calculation of heating and cooling loads with the change in orientation of the buildings are given the Table 7.

Table 6: Annual heating, cooling and total loads using eight types of shading devices

Types of Shading Devices	Heating Load (KWh)	Cooling Load (KWh)	Total Load (KWh)
No Shading	875.119	761.505	1636.624
Horizontal Shading	854.546	874.292	1728.837
Horizontal Double Shading	1017.736	967.831	1985.567
Horizontal Inclined Shading	639.372	1300.564	1939.936
Horizontal Double Inclined Shading	600.34	834.103	1434.443
Vertical Shading	811.532	768.497	1580.029
Vertical Inclined Shading	779.165	765.908	1545.073
Egg Crate	1011.416	637.86	1649.275

Table 7: Annual loads as per the orientation of buildings

Types of Shading Devices	Base Case (KWh)	Scenario 1 (KWh)	Scenario 2 (KWh)	Scenario 3 (KWh)
No Shading	1636.624	1238.066	1413.203	1795.446
Horizontal Shading	1728.837	1334.630	1485.045	1846.448
Horizontal Double Shading	1985.567	1541.835	1706.727	2103.179
Horizontal Inclined Shading	1939.936	1608.022	1663.004	1881.675
Horizontal Double Inclined Shading	1434.443	1225.744	1326.038	1552.908
Vertical Shading	1580.029	1213.672	1339.426	1699.096
Vertical Inclined Shading	1545.073	1193.755	1339.426	1616.210
Egg Crate	1649.275	1224.576	1289.900	1696.728

Overall, scenario 1 is the most effective one in case of all the types of shading devices. Among them, use of horizontal double inclined shading device gives the effective results which is exactly 14.54 % energy efficient than that of base case as shown in Table 7. After that vertical shading and vertical inclined shading gives the effective results as shown in Figure 14.
The analysis of total load consumption for different building orientations and shading devices reveals significant insights for optimizing energy efficiency. As per Table 8, in the base case scenario, where the building is oriented south, horizontal shading devices result in the lowest annual load consumption of 1434.44 kWh. When the building orientation is changed to the west (Scenario 1), vertical inclined shading devices prove to be the most effective, reducing the total load consumption to 1193.75 kWh annually. For a north-facing building (Scenario 2), egg crate shading devices minimize the annual load to 1289.9 kWh. Lastly, in Scenario 3, with the building facing east, horizontal double inclined shading devices achieve the lowest total load consumption of 1552.9 kWh annually.

When considering orientation without the use of shading devices, Scenario 1, with the building facing west, is the most effective, resulting in a total load of 1238.06 kWh annually. This is followed by the base case (south-facing) at 1636.62 kWh, north-facing (Scenario 2) at 1413.2 kWh, and east-facing (Scenario 3) at 1795.44 kWh. These findings suggest that both the orientation of the building and the type of shading device used significantly impact energy efficiency. The most effective configuration overall, when considering orientation alone, is the building facing west. However, when shading devices are incorporated into the design, vertical inclined shading devices on a west-facing building stand out as the most efficient, which consumes 12.35% less energy than in the base case with no shading devices demonstrating the importance of integrated design strategies for optimal energy performance.

5. Conclusion

The observed results from the simulation revealed several key findings. As per the simulation result, horizontal inclined shading is the effective shading device in winter, (February), when used in the windows of residential buildings. It helps in the consumption of minimum heating load in the building in comparison to the other shading devices. Similarly, a horizontal double-inclined shading device is effective for minimum cooling load consumption in the summer, (September). Also, the

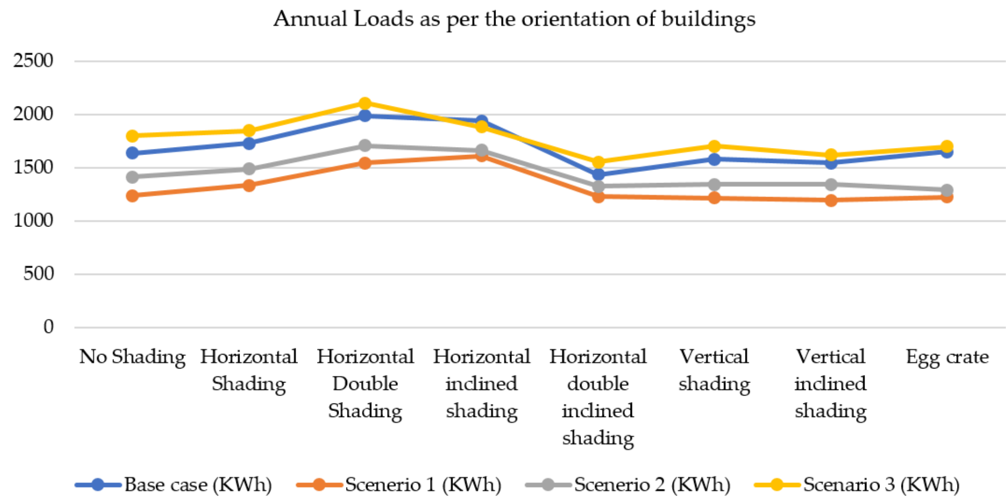

Figure 14: Annual loads as per the orientation of buildings

Table 8: Annual heating, cooling, and total loads as per the orientation of buildings

Types of Shading	**Base Case (KWh)**			**Scenario 1 (KWh)**			**Scenario 2 (KWh)**			**Scenario 3 (KWh)**		
	Heating Load	**Cooling Load**	**Total Load**	**Heating Load**	**Cooling Load**	**Total Load**	**Heating Load**	**Cooling Load**	**Total Load**	**Heating Load**	**Cooling Load**	**Total Load**
No Shading	875.1	761.5	1636.6	497.1	740.9	1238.0	716.8	696.3	1413.2	1082.1	713.2	1795.4
Horizontal Shading	854.5	874.2	1728.8	479.4	855.1	1334.6	685.5	799.4	1485.0	1033.5	812.8	1846.4
Horizontal Double Shading	1017.7	967.8	1985.5	587.0	954.7	1541.8	818.8	887.9	1706.7	1616.2	902.9	2103.1
Horizontal Inclined Shading	639.3	1300.5	1939.9	310.0	1297.6	1608.0	406.9	1256.0	1663.0	641.4	1240.2	1881.6
Horizontal Double Inclined Shading	600.3	834.1	1434.4	408.0	817.6	1225.7	517.9	808.0	1326.0	755.7	797.1	1552.9
Vertical Shading	811.5	768.4	1580.0	469.3	744.2	1213.6	646.4	692.9	1339.4	997.5	701.5	1699.0
Vertical Inclined Shading	779.1	765.9	1545.0	453.8	739.8	1193.7	646.4	692.9	1339.4	918.6	697.5	1616.2
Egg Crate	1011.4	637.8	1649.2	599.7	624.8	1224.5	705.2	584.6	1289.9	1112.0	584.6	1696.7

horizontal double-inclined shading proved effective but came at a higher cost, being twice as expensive as conventional horizontal shading.

Also, the horizontal double inclined shading device is most effective in case of saving heating load which is 31.39 % lower than base case. And egg crate shading device is the effective one in case of cooling load annually which is 16.23% lower than the base case. For overall consideration of heating and cooling load annually, the most effective shading device is horizontal double inclined which consumes 1434.443 KWh which is 12.37 % less than the base case. In addition to that, a synergistic approach involving both horizontal inclined shading and vertical shading emerged as a strategy to maximize energy savings. This involved utilizing fixed vertical shading in conjunction with dynamic horizontal shading devices equipped with small motors, responsive to climate demands sensed by sensors.

A study conducted by Al-Obaidi yielded similar findings, analyzing the impact of orientation changes on a typical terrace house in Malaysia by examining the dynamic indoor air temperature. The research highlights that orientation is a crucial design variable influencing indoor temperature, with a partial correlation value of 58% [18].

Additionally, the orientation analysis highlighted that the effectiveness of shading devices was influenced by the building's orientation, although this aspect may be challenging to fully control in already constructed buildings so the consideration should be done during the design phase. Some of the key findings while changing orientation are given below:

- Optimal Orientation Without Shading Devices: When no shading devices are used, the most energy-efficient orientation is Scenario 1, with the building facing west, resulting in a total load of 1238.06 KWh annually.
- Optimal Orientation with Shading Devices: Considering the use of shading devices, Scenario 1 remains the most effective. Specifically, a building facing west with vertical inclined shading devices consumes only 1193.75 KWh annually. This is the lowest energy consumption observed among all scenarios with shading devices.
- Energy Savings Comparison:
  - Base Case (South-facing with Horizontal Shading Devices): 1434.44 KWh
  - Scenario 1 (West-facing with Vertical Inclined Shading Devices): 1193.75 KWh

The west-facing building with vertical inclined shading devices consumes (1193.75 KWh) 12.35% less energy compared to the base case without shading devices (1636.62 KWh).

Overall, horizontal double inclined shading devices are the most effective one in the existing building orientation. Also, considering the orientation vertical inclined shading devices with a west-facing orientation are the most effective combination, yielding the lowest energy consumption. Even without shading devices, a west-facing orientation is the most efficient, indicating the significance of orientation in energy load management.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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