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Evaluating the Impact of Horizontal Shading on Indoor Thermal Comfort and Energy Efficiency in Tripoli

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***Abstract* -In hot climates, where the control of solar exposure is vital for building performance and occupant comfort, the selection of appropriate shading devices is a key sustainable architectural strategy. This paper conducts a comparative analysis of the efficacy and cost-effectiveness of vertical and horizontal shading devices across various building elevations. Our research demonstrates that vertical shading devices significantly outperform horizontal fins, reducing cooling loads by up to 8% when optimized for angle and length. Horizontal devices are less effective, particularly on east and west elevations, due to their inability to adequately manage sunlight. The paper outlines a set of design guidelines for optimal shading in hot climates: fixed horizontal shading devices with a depth between 0.3 meters to 0.8 meters for south-facing windows, vertical shading devices with a depth of 0.3 meters for east, west, and north elevations, and the strategic use of vegetation for additional cooling. These recommendations aim to enhance thermal comfort, reduce energy consumption, and promote economic efficiency in sustainable building design.**

Keywords -Shading, Horizontal Shading, Solar radiation, Solar gain, Direct solar radiation, Indirect solar radiation, Tripoli, Libya

1. INTRODUCTION

Horizontal shading devices are architectural features that serve to protect buildings from excessive sunlight and heat. Journal of Building Performance investigated the effectiveness of horizontal shading devices in blocking solar radiation transmitted through windows. The study highlighted that such devices could substantially reduce cooling loads in buildings by preventing excessive solar heat gain, thus contributing to energy savings and improved indoor comfort [1]. They are typically installed above windows and glass facades, and their primary function is to block the direct rays of the sun, reducing heat gain and glare inside the building. These devices are especially beneficial in hot and sunny climates, where they can significantly improve indoor comfort and reduce the need for air conditioning. The design of horizontal shading devices can vary greatly, ranging from simple fixed overhangs to complex adjustable systems. They can be made from a variety of materials, including wood, metal, and fabric, and concrete and can also be an integral part of the building's aesthetic, contributing to its overall design and appearance. In addition to their practical benefits, horizontal shading devices can also contribute to a building's sustainability by reducing energy consumption. By limiting the amount of heat entering a building, they help to maintain a more stable and comfortable indoor environment, which can lead to lower energy costs and a smaller carbon footprint. Overall, horizontal shading devices are a smart and effective way to enhance the performance and comfort of a building while also providing an opportunity for architectural expression.

Horizontal shading devices are a key feature in the design of energy-efficient buildings, serving to minimize solar heat gain and enhance indoor environmental quality. These devices, which include overhangs, louvers, and awnings, are particularly effective in climates with significant sun exposure, where they can substantially reduce the need for artificial cooling [2]. Research has shown that the strategic use of horizontal shading can lead to significant energy savings. For example, a study published in the MDPI Buildings journal demonstrated that horizontal shading devices could alleviate overheating in residential buildings in China's severe cold regions, leading to a reduction in energy consumption when compared with air-conditioned buildings[2]. Another study in the MDPI Sustainability journal investigated the impact of shading devices on the cooling load of buildings in Darwin, Australia. The findings indicated that horizontal fins could reduce the cooling load by 5%, with variations in device angles and lengths increasing the savings to 8%[3]. The field of sustainable architecture, the strategic use of shading devices plays a critical role in mitigating heat gain and optimizing natural light, particularly in hot climates. This

research paper presents a comparative analysis of vertical versus horizontal shading devices, examining their effectiveness and economic viability across different building elevations. These findings indicate that vertical shading devices are markedly more effective than horizontal ones when applied to east, west, and north elevations. Moreover, they present a cost-effective solution to the challenges posed by solar radiation. The use of horizontal shading devices on east and west elevations is identified as suboptimal due to their limited capacity to control sunlight. This paper proposes a set of guidelines for the optimal design of shading devices, tailored to the unique solar exposure of each elevation:
South Elevation: Fixed shading devices with a depth between 0.3 meters to 0.8 meters are recommended for south-facing windows, offering substantial protection from the direct sunlight prevalent from April 1st to August 1st. East Elevation: Subject to solar radiation from sunrise at 06:17 until 13:15, this elevation benefits from vertical shading devices with a depth of 0.3 meters, aligning with the sun's intensity and the corresponding rise in temperature. West Elevation: Experiencing a similar duration of sunlight as the east, the west elevation encounters a significant increase in solar radiation after 13:30, necessitating additional cooling measures. The integration of trees and vegetation provides a superior cooling effect compared to shading devices alone, with a recommended vertical shading depth of 0.3 meters. North Elevation: Receiving the least solar exposure, with sunlight from 17:00 to sunset at 20:00, the north elevation allows for the construction of a vertical shading devices extending from 0.3 to 1.0 meters, enhancing outdoor comfort and usability. Through this analysis, the paper aims to contribute to the development of more efficient, comfortable, and economically viable architectural designs in regions with hot climates, while also considering the potential limitations of such shading arrangements in residential architecture.

2. Materials and Methods

This study aims to evaluate the effectiveness of horizontal shading devices in reducing solar heat gain and improving thermal comfort in buildings. A mixed-methods approach was adopted, combining simulation modeling with empirical data collection. For general model information:

- Model area: 62.570m2
- location: Latitude: 32.7, Longitude:13.1, Tripoli - Libya
- Model date/time 13:30, 20th of July
- Building consists of five 5 zones: Hall, Living room, kitchen, bedroom and restroom. The analysis will be taken in the living room as shown green in the model, see figure (1) for information.
- Total South Window (used in this study): 6.110 m2 (11.5% flr area).
- Materials used for construction is concrete 1,2,4mix and concrete plaster as finish layer, see figure (2-3-4-5-6-7-8) for information.

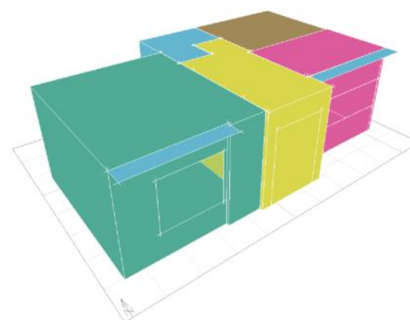

Figure 1. 3D Model, shows building zones

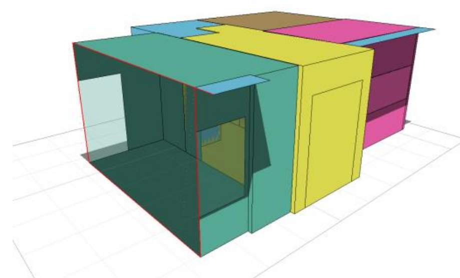

Figure 2. 3D Model, shows zone section

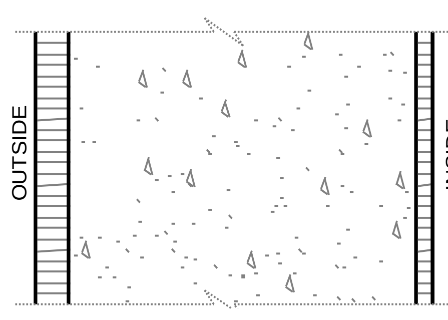

Figure 3. Wall section, Concrete cinder

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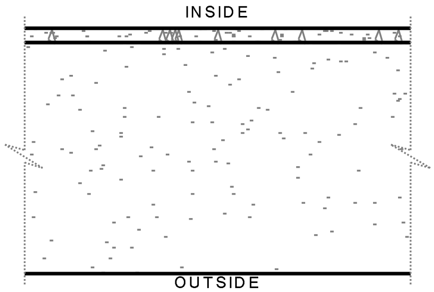

Figure 4. Floor Section, 10cm Concrete

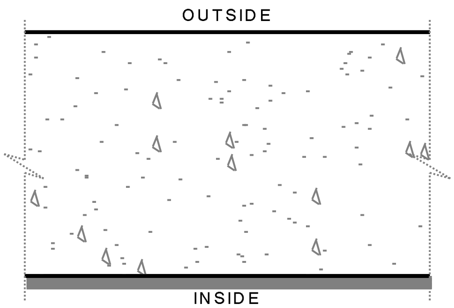

Figure 5. Roof section, Concrete 124mix

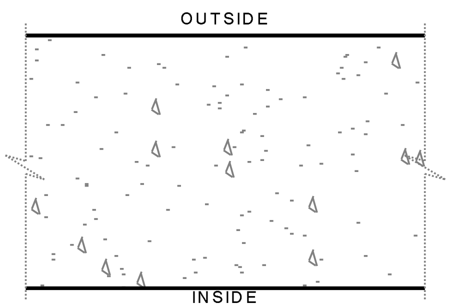

Figure 6. Concrete shading, Concrete 124mix

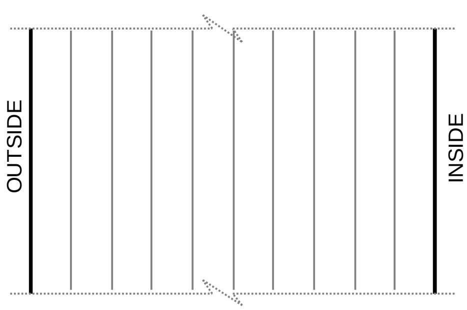

Figure 7. window Section, Single Glass

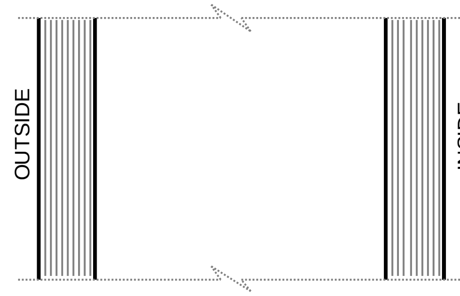

Figure 8. window Section, Double Glass

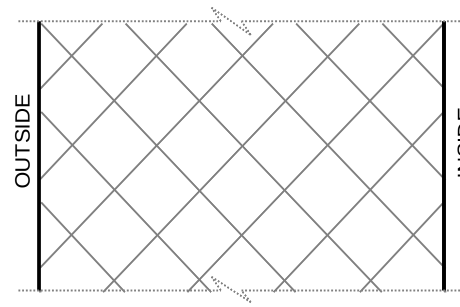

Figure 9. Door Section, Single Glass

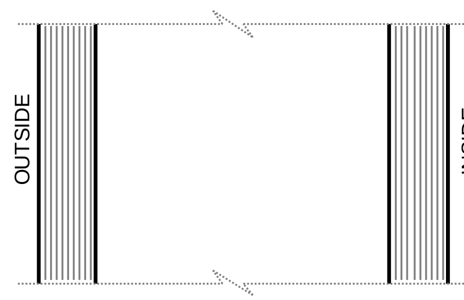

Figure 10. Door Section, Double Glass

A. Materials

- Horizontal Shading Devices: fixed shading devices.
- Simulation Software: Environmental energy software's and Modeling software.
- Data: To record temperature and within the test building.

B. Methods

The simulation modeling involved creating a digital twin of the test building in Revit and Climate analysis software. The models were calibrated using historical weather data and validated against actual building performance metrics. Installation of Shading Devices: Different horizontal shading devices were installed on the south-facing walls of the test building. The devices were positioned to optimize shading during peak sun hours while allowing for passive solar heating during colder months. Data Analysis: The collected data were analyzed to determine the impact of horizontal shading devices on solar heat gain and occupant comfort. Statistical methods were used to correlate. 3 Expected Outcomes: The study is expected to provide insights into the optimal design dimension and placement of horizontal shading devices to maximize energy efficiency and occupant comfort in buildings. This section outlines the framework for investigating the performance of horizontal shading devices in a real-world setting, combining both quantitative and qualitative research methods.

3. Theory and Calculation

The theoretical foundation of horizontal shading devices is based on solar geometry and building physics. These devices are designed to mitigate solar heat gain and control daylight in buildings. The primary goal is to block the high-angle summer sun, while allowing the low-angle winter sun to penetrate, thus contributing to passive heating and lighting [4]. The calculation of horizontal shading devices involves determining the correct depth and position to provide adequate shading during peak sun hours. Horizontal Shading equation:

$$D = H \times \tan(\theta) \qquad (1)\ [5]$$

Where:
(D) is the depth of the shading device.
(H) is the height from the bottom of the device to the top of the window.
(θ) is the solar altitude angle at solar noon during the summer solstice.
These calculations are essential for designing effective horizontal shading device of the building [4].

For fabric gain equation:

$$Q_f = \sum(U \times A \times \Delta T) \qquad (2)\ [6]$$

Where:
(Q_f) is the total fabric heat gain,
(U) is the U-value or thermal transmittance of the building element,
(A) is the area of the building element,
(\Delta T) is the temperature difference between the outside and inside air.
This equation is utilized by architects and engineers to design buildings that are energy-efficient and maintain comfortable indoor temperatures for occupants. By understanding and managing fabric gains, it is possible to minimize the need for active heating and cooling, leading to reduced energy consumption and costs. It's a fundamental part of sustainable building design and energy modeling.

4. RESULTS AND DISCUSSION

A. Horizontal Shading Device:

In the context of hot climates and specifically during the summer month of July, research has shown that horizontal shading devices can significantly alleviate overheating in buildings. A study examining residential buildings in various climate zones found that external horizontal shading could effectively reduce indoor overheating during summer. In one case, the reduction in overheating in Harbin was by 64 hours, which is 16.5% of the total overheating duration [7]. In the context of Tripoli, Libya's hot climate, the study demonstrates that horizontal shading devices are highly effective for south-facing elevations. Such devices, including eaves and overhangs, are strategically designed to obstruct the intense high-angle sunlight during the summer months, while permitting the gentler winter sun to enter and warm the interior spaces. The research specifically utilized fixed overhangs as the shading solution. These permanent structures, mounted above windows and doors, cast shade effectively when the sun is at its zenith, significantly reducing solar heat gain during the peak heat hours. For the windows in this study, with a height of 1 meter, width variable, and a sill height of 1 meter, it was found that a horizontal shading device with a depth of 0.30 meters on the south elevation provided complete shading. Moreover, the study suggests that the shading device could be extended up to 0.8m meters if it aligns with the roof structure, offering additional protection. On the north elevation, both vertical and horizontal shading devices were considered suitable, with a maximum depth of 0.30 meters for the shading elements. The simulation presented in figure 8 and 9 of the study illustrates that the space is bathed in diffuse light, effectively eliminating any direct sunlight penetration. This approach underscores the importance of tailored shading strategies to enhance indoor comfort and energy efficiency in the unique climatic conditions of Tripoli, Libya.

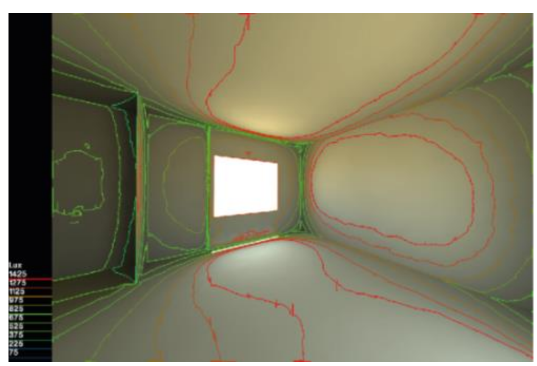

Figure 11. Living Room, Showing Lux levels

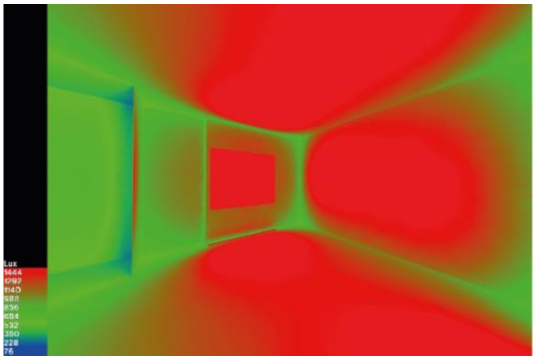

Figure 12. Living Room, false colors showing Lux levels

Comparative analysis indicates that vertical shading devices outperform horizontal ones in effectiveness in east, west and north. Additionally, they are significantly more economical. Utilizing horizontal shading devices on east and west elevations is suboptimal. Instead, an array of vertical shading elements can be employed across the windows to effectively mitigate and diffuse sunlight. However, this particular arrangement of vertical devices may not be advantageous in residential architecture. To optimize the design of shading devices for buildings in hot climates, consider the following guidelines:

South Elevation: It's recommended to have fixed horizontal shading devices with a maximum depth of 0.8 meters for windows facing south. This measure is particularly effective from April 1st to August 1st, providing protection against the direct sunlight of summer.

East Elevation: This side is subject to solar radiation from sunrise at 06:17 until 13:15. During these hours, as the temperature typically increases, shading solutions should be customized to the sun's intensity. A vertical shading device with a depth of 0.3 meters is suitable.

West Elevation: The duration of sunlight is comparable to the east, but after 13:30, there is a marked rise in direct solar radiation, leading to swift heating. The strategic planting of trees and vegetation can substantially diminish both direct and scattered radiation, thus providing a cooling effect. Although shading devices are useful, they do not offer the same level of protection as the natural shield created by plants. A vertical shading device with a depth of 0.3 meters is advisable.

North Elevation: This elevation receives the smallest amount of solar radiation. Sunlight hits this side from 17:00 to sunset at 20:00, with the rays being less intense. This allows for the option to build a vertical shading devices ranging from 0.3 to 1.0 meters in depth, which can facilitate a cozy outdoor seating area next to the building.

B. Psychrometric Chart

The Psychrometric Chart is a crucial tool for understanding the thermodynamic properties of air in various climates, including hot ones. In hot climates, the chart is particularly useful for determining strategies to cool and dehumidify indoor air efficiently, which is essential for maintaining comfort levels and managing energy consumption. For example, a study on bioclimatic design discusses the use of the chart to correlate basic climate data with appropriate bioclimatic strategies and design measures, evaluating the effectiveness of each measure in providing indoor thermal comfort [8]. In this case study focused on Tripoli, Libya, the psychrometric chart indicates that the comfort zone for the month of July falls within a temperature range of 26-31 degrees Celsius. This range represents the ideal thermal conditions for comfort during this time of the year in Tripoli, Libya.

C. Illumination and Thermal analysis

The lighting conditions of the sky dome can change swiftly, often in just a few minutes, mainly due to the formation of clouds. Therefore, rather than trying to mimic an exact sky condition, standardized sky models are used as substitutes. These models represent the typical environmental settings for certain design situations. For example, a standard summer day is usually characterized by a bright and clear sky, which justifies the selection of a Sunny Sky model. In the case of an overcast sky, the CIE Overcast Sky model with a luminance of 8555 lux is applied [9]. For information regards indirect solar gain and fabric gain in the study zone (living room) see table (1-2).

TABLE 1. INDIRECT SOLAR GAINS – MONTHLY AVERAGE

Hour	*Apr*	*May*	*Jun*	*Jul*	*Aug*
	(Wh)	*(Wh)*	*(Wh)*	*(Wh)*	*(Wh)*
0	336	560	638	707	594
1	92	110	130	139	114
2	24	52	61	65	48
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	1	6	7	5	2
9	24	40	49	45	29
10	63	71	79	71	61
11	101	92	82	69	90
12	134	141	137	117	128
13	324	390	456	423	358
14	669	691	741	750	717
15	914	896	912	899	944
16	1030	1009	1003	1008	1065

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17	1071	1034	1049	1002	1077
18	999	984	955	893	954
19	1119	1137	1118	1051	1085
20	1201	1198	1216	1208	1222
21	1154	1146	1152	1164	1223
22	1022	1037	1119	1152	1151
23	794	893	979	1042	965

D. Solar Exposure

Solar exposure plays a critical role in architecture, particularly in hot climates where managing heat gain and natural light can significantly impact building performance and occupant comfort. Here are some key research paper that explore different aspects of solar exposure in architecture: The Impact of Solar Geometry on Architectural Strategies: Authored by Andres Salazar Del Pozo, this thesis examines how solar geometry influences key architectural decisions, including shading techniques, daylighting, and the proportion of glass used in structures [10]. It underscores the necessity of grasping solar geometry principles to elevate a building's efficiency. For an in-depth analysis of the living room area, this part of the study measures the incident, absorbed, and transmitted solar energy throughout an entire year. Refer to Table 2 for comprehensive data and Graph 2 for a depiction of the total incident solar radiation.

TABLE 2. DIRECT SOLAR GAINS – MONTHLY AVERAGE

	Direct	*Absorbed*	*Transmitted*
	Wh/m2	*Wh/m2*	*Wh/m2*
Jan	41989	24235	5178
Feb	39857	23265	4576
Mar	50368	30150	4166
Apr	55755	34442	2704
May	54470	34534	1222
Jun	62247	39612	924
Jul	77990	49408	1366
Aug	76815	48040	2725
Sep	57872	35106	4129
Oct	50718	29851	5181
Nov	37300	21502	4719
Dec	30647	17482	4210

5. CONCLUSION

- we could see tree the and plants on the south side of the west elevation and north side of the east elevation, which helps to shade the windows and walls
- We should minimize openings on the west elevation as much as possible. For the east elevation we could use windows put in small amount considering the high temperature
- Export to radiance for more detailed analysis
- these images show the amount of light falling on each surface, this is a pure analytical image show lux level
- The optimum horizontal shading device dimension for the south elevation is 0.3m
- The optimum dimension of vertical shading device is 0.3m

ACKNOWLEDGMENTS

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