

Addressing hourly shading effectiveness in relation to solar control devices and solar geometry under tropical climates

Vanessa Gonzalez-Alvarez^{1,2} ; Dafni Mora^{2,3} ; Miguel Chen Austin^{1,2,3,*} 

¹Centro de Investigación e Innovación Eléctrica, Mecánica y de la Industria (CINEMI), Universidad Tecnológica de Panama, Panama City 0819-07289, Panama, vanessa.gonzalez1@utp.ac.pa

²Research Group Energy and Comfort in Bioclimatic Buildings (ECEB), Facultad de Ingeniería Mecánica, Universidad Tecnológica de Panama, Panama City 0819-07289, Panama, dafni.mora@utp.ac.pa

³Sistema Nacional de Investigación (SNI), Clayton 0816, Panama

*Correspondence: miguel.chen@utp.ac.pa

Abstract– In tropical climates, shading becomes an important variable to protect built environment from solar radiation. The shading performance becomes more important for windows, which are the most susceptible construction element. They perform as the major contributor to heat gain since they allow solar radiation to enter interior spaces. To protect windows from solar radiation, the concept of projection factor (PF) is commonly used since it facilitates the design process to determine the adequate length for shading devices, specifically overhangs. However, this approach does not account for other key factors, such as solar geometry, orientation, time of the year and hour of the day. Considering this, a parametric simulation using an octagon model facing eight orientations is performed to determine the effectiveness of different overhangs configurations. A base case was settled with no shading device, and two more scenarios with overhangs were settled with PF ranging from 0.5 to 1. Direct solar radiation on windows surfaces was extracted and normalized against the base case to determine the effectiveness of the shading devices for solstice and equinox seasons. Results show that overhangs with PF = 0.5 can perform similarly to overhangs with PF equal to 1 during specific hours, orientation and solar altitude conditions. These findings highlight that shading performance is highly dependent on temporal and dynamic factors, therefore, they cannot be fully characterized by fixed indicators. The approach provides a more grounded metric evaluation of shading performance and supports more efficient design decisions that enable material optimization in built environments located in tropical altitudes.

Keywords: shading devices, overhang, projection factor, solar control, solar geometry, shading effectiveness.

I. INTRODUCTION

Buildings represent a substantial share of global energy consumption, with space cooling serving as a primary end use in warm and tropical climates [1]. In these regions, solar radiation transmitted through glazed surfaces becomes a primary driver of indoor heat gains and is closely associated with peak cooling demand [2]. As a result, the control of solar gains at the building façade is a critical aspect of climate-responsive design, especially in warm–humid regions where solar intensity remains elevated for most of the year.

Fixed external shading devices, such as horizontal overhangs and vertical fins, are commonly used in passive design strategies to limit solar heat gain by blocking direct solar radiation before it reaches the glazing. The performance of these devices is not uniform; it is influenced by multiple interacting factors, including device geometry, façade orientation, solar altitude, and solar azimuth, which together determine when direct solar radiation is completely obstructed [3]. In other words, the shading device is effective during certain hours and how effective it is, depends on different conditions. Horizontal overhangs typically offer enhanced performance under high solar altitudes, while vertical fins are commonly adopted to reduce low-angle solar incidence during morning and late afternoon hours. Hence, shading effectiveness can vary significantly with façade orientation and time of day, even when the dimensions of the shading device remain unchanged [4].

Shading performance is often described using simplified indicators, such as projection factors (PF) or geometric ratios. While useful at early design stages, these indicators provide limited insight into the dynamic interaction between solar geometry and shading devices. Simulation-based studies commonly evaluate shading performance using physically based metrics, including incident solar radiation and solar heat gains, typically assessed through dynamic simulations with hourly or sub-hourly resolution. This allows shading performance to be interpreted as a time-dependent phenomenon linked to solar position (relative azimuth and altitude) and device geometry, rather than as a single aggregated coefficient [5].

Advances in dynamic building energy simulation tools, particularly EnergyPlus based platforms, have enabled more detailed analysis of the interaction between shading devices and solar geometry. Several studies have used these tools to examine the effects of shading geometry and façade orientation on building energy performance through dynamic simulations [4]. These investigations demonstrate that identical shading configurations can lead to different

performance outcomes depending on façade orientation and local solar geometry.

Despite these advances, shading effectiveness is still predominantly evaluated using annual or seasonal indicators, such as total cooling energy savings or carbon emission reductions, offering limited insight into the hourly distribution of solar protection. Recent review studies highlight that relatively few investigations explicitly address shading effectiveness at the hourly scale in relation to device geometry and solar azimuth, particularly in tropical contexts, where most studies focus on single-orientation façades and simplified building geometries [5], [6], [7]. Recent simulation studies have demonstrated that the effectiveness of fixed shading devices varies strongly with window orientation and shading geometry. For instance, [8] showed that overhangs and vertical fins perform differently on South, East, and West-facing façades, with optimal shading lengths depending on orientation and season. However, these analyses are primarily focused on seasonal or monthly indicators.

In this context, the present study examines the relationship between the projection factor and the geometric characteristics of fixed shading devices, specifically the size of horizontal overhangs, window orientation, and solar position. Emphasis is placed on identifying the time ranges of effective solar protection for various façade orientations, at hourly scale under the tropical climate conditions of Panama City, Howard. This led us to the following research questions:

1. How can shadow device effectiveness be measured?
2. How do you relate it with its length, orientation, hour, day, and month?

These questions arise from the hypothesis that it is not enough to design shading devices, such as overhangs, by only considering projection factors and an alternative metric should be introduced.

II. METHODOLOGY

This study aims to evaluate the efficiency of different design configurations of horizontal overhangs facing eight orientations (North, Northeast, East, Southeast, South, Southwest, West, and Northwest). An octahedron-shape model was used with one window on each façade measuring 3.24 m (length) x 1.80 m (height) [9] (Fig. 1) and a simulation was executed using the DesingBuilder software v7.3.0.046 [10]. The climate data was set to Howard (Panama) location and to assess the performance shading devices, the model was set with three windows cases. The base case scenario contains windows without shading and two alternative cases were set with different overhang configurations. The overhang length for shaded windows was 0.90 m and 1.80 m for each facade. These three cases correspond to the projection factor that ranges from 0 to 1. For the simulation, the dates selected were June 21st (summer solstice), September 21st (autumn equinox) and December 21st (winter solstice) to represent the annual solar variations throughout the year.

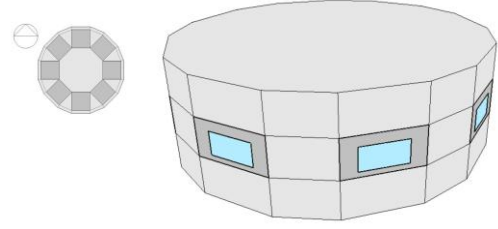


Fig. 1 Base case: Octagon model. Source: Seiscubos platform [9].

For all cases, the selected data output from the DesignBuilder Result Viewer was surface outside face incident beam solar radiation rate per area on windows. Although the analysis relied on this solar data, equation 1 from EnergyPlus [11] is included to document the underlying calculation framework used in this simulation software. This expression highlights the physical basis of the simulation, particularly the integration of direct and diffuse solar radiation. This study is focused primary on direct solar radiation since it is associated with solar heat gains and overheating during summer seasons [6]. This variable travels in a straight predictable path based on the local sun course and contributes on the overhang calculation to physically block critical sunlight angles [8].

$$Q_{so} = \alpha \left(I_b \cdot \cos \theta \cdot \frac{S_s}{S} + I_s \cdot F_{ss} + I_g \cdot F_{sg} \right) \quad (1)$$

Where α represents the material solar absorption characteristic, θ corresponds to the solar altitude angle, S and S_s are the total surface area of the wall and the surface area, lit up by I_b respectively. The view factors between the sky and ground with the surface are represented by F_{ss} and F_{sg} , respectively. In this case, the values for each parameter were 1 and 0.5 for S_s/S and F_{ss} , respectively. The value of α is not considered as the formulation is independent of the material type on the façade and windows. Following this, the obtained data were normalized and used to elaborate a polar hourly diagram for each overhang length and date. The phases of the methodology are detailed on Fig. 2.

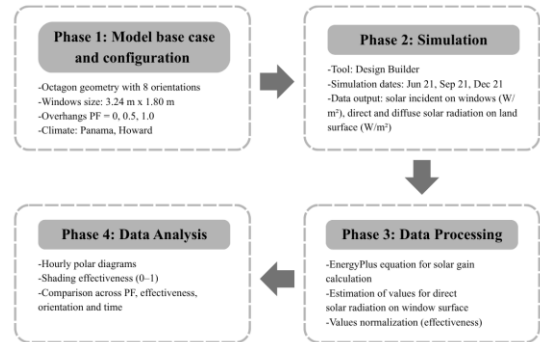


Fig. 2 Diagram for the methodology of the study.

The Octagon shape model was chosen due to its advantages of conducting the simulation for various façade orientations at the same time. The interior floor area is 36 m², with a façade area of 18 m² and an enclosed volume of 108 m³. Each orientation contemplates an identical unique zone with the same boundary conditions: One external wall with a window centered and three adjacent walls under an adiabatic condition. This adiabatic condition is also set to both horizontal walls (roof and floor).

A simple normalization was performed to estimate the effectiveness of the shading devices by comparing the results of the direct solar radiation rate over the window with and without such device for each façade. By taking the ratio of the direct solar radiation rate (I_{so}) with overhang and the direct solar radiation rate without overhang (maximum value), as proposed in equation 2, the effectiveness (ϵ) of the shading device is estimated.

$$\epsilon(\Phi, h) = 1 - \frac{I_{so}(\Phi, h)^{dx}}{I_{so}(\Phi, h)^{d0.0}} \quad (2)$$

Where dx represents the length of the shading device, overhang, i.e., overhang of length 1.8 m is represented by $d1.8$, and the 0.0 corresponds to the case of no overhang. The effectiveness of a shading device varies with façade orientation (Φ) and hour of the day (h), as evidenced in previous studies. An effectiveness of 1.0 means that the overhang blocks all direct solar radiation while a value of 0.0 exhibits three scenarios: no solar radiation is blocked (as in having no shadow device), zero solar exposure (nighttime), and shaded façade.

Artificial intelligence was used exclusively to assist the data handling for elaborating the graphical representation. Subsequently, the resulting diagrams were used as the basis for the data analysis.

III. RESULTS ANALYSIS AND DISCUSSION

The meteorological condition of Panama is characterized for intense solar radiation due to its location in the Northern latitude of the tropical zone. In this zone, the sun path is more uniform throughout the year, and it shifts into both North and South skies. As a consequence, North-facing facades are also susceptible to solar radiation. Figure 3 gives insights of the solar altitude. As Panama is the Northern Hemisphere the sun predominates on the South and, due to its tropical latitude, the sun reaches the zenith around April, meaning that the sun shifts to the northern sky. In August the sun has a second zenith passage, marking the sun returning to the Southern.

Additionally, equatorial zones have less seasonal variations and, as a result, Panama manifest two main season throughout the year: dry season (from December to April) and rainy season (from May to November) [12], [13].

Figure 4 illustrates the range of mean and maximum solar radiation for an entire year. High values remain for January and December months, indicating clear sky for these months typical from dry season where cloud coverage is limited.

While May and August have lower direct radiation values, suggesting the presence of clouds. Figure 5 demonstrates the behavior of diffused solar radiation for the twelve months, where it can be observed that has a stable performance throughout the year compared to direct solar radiation.

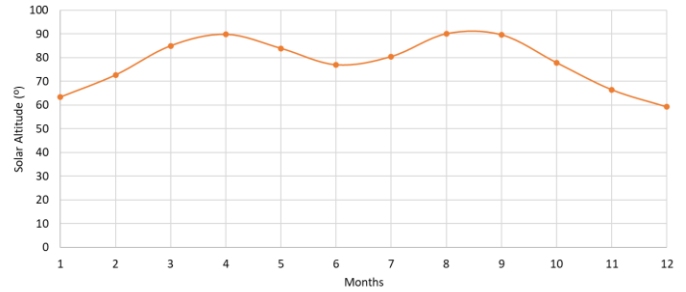


Fig. 3 Monthly solar altitude (°).

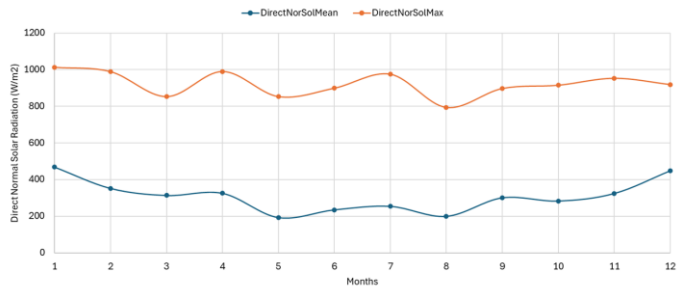


Fig. 4 Monthly mean and maximum direct normal solar radiation (W/m²).

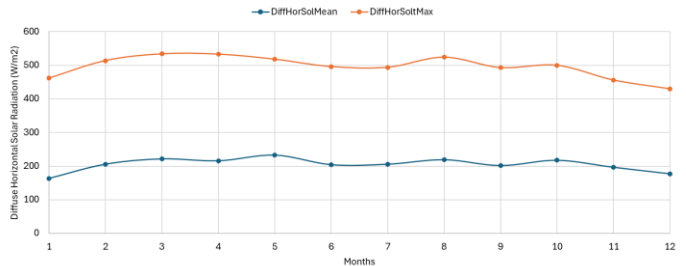


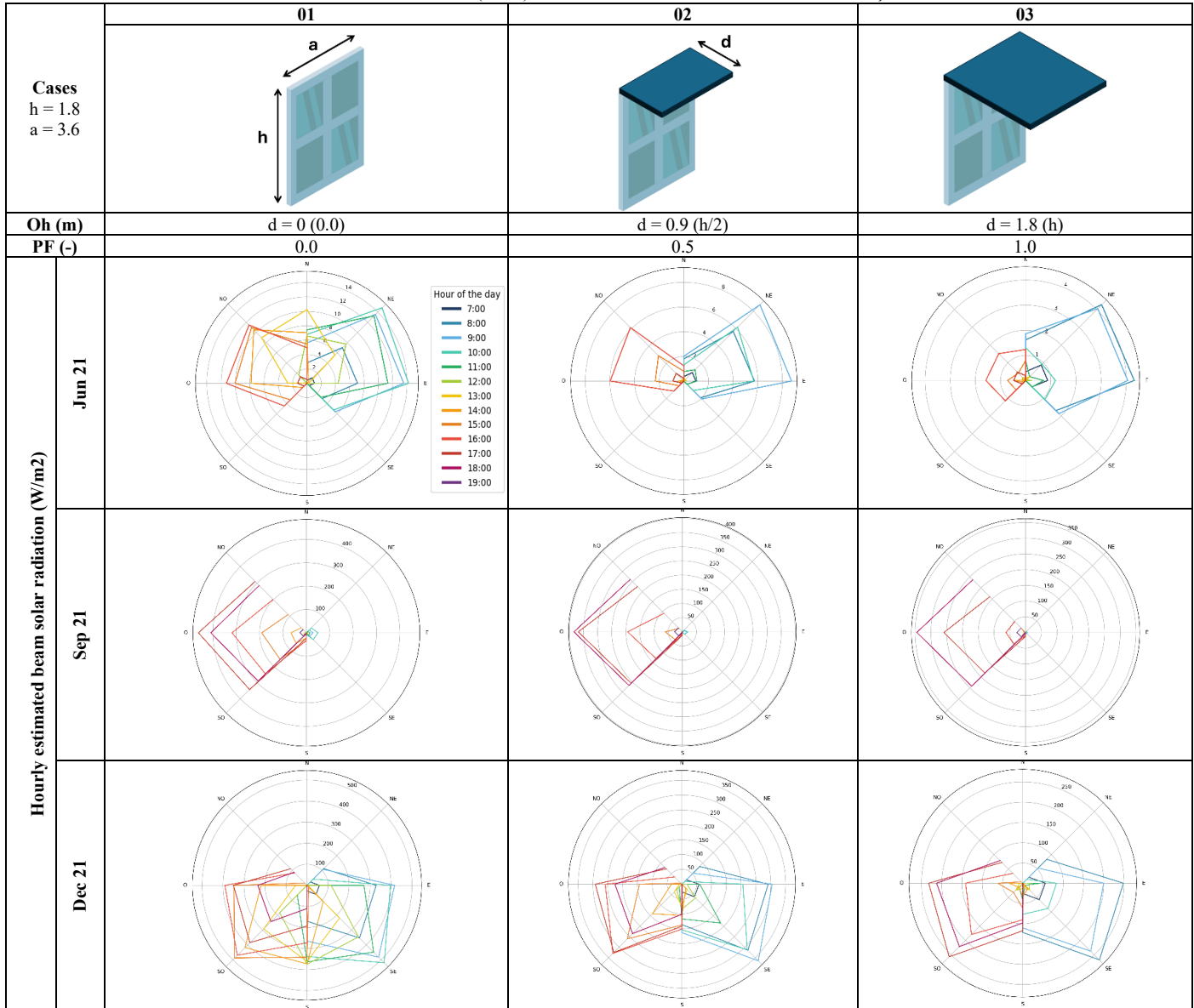
Fig. 5 Monthly mean and maximum diffuse horizontal solar radiation (W/m²).

Hereafter, the term solar radiation will be used to refer to Direct solar radiation rate (W/m²) or beam solar radiation rate. None of the data presented here includes diffuse solar radiation values.

A. Radiation vs. orientation

The performance for all overhang configuration and orientation to reduce solar direct radiation on windows across different periods of the year is displayed on Table 1. Here, to have a first glance at their performance, hourly estimated beam (direct) solar radiation when having the 0.9 m and 1.8 m overhangs are shown in hourly polar diagrams along the

TABLE I
DIRECT SOLAR RADIATION INTENSITY (W/M²) PER OVERHANG CASE AND FOR ALL FAÇADE ORIENTATION.



hourly beam solar radiation for the case of no overhang. This type of graph allows showing the solar radiation rate in W/m² at each façade orientation, where each concentric circle represents the amount of solar direct beam radiation on windows, starting from the lowest level at the center and the highest when it reaches the perimeter. The hourly behavior is represented by colors, from 7:00 to 19:00 each time has a unique color designation.

Case 01 provides a visual representation of the solar exposure windows with no overhang experience throughout the year. This case reflects the worst-case scenario since solar exposure means high irradiance on vertical surfaces. The absence of any type of shading device allows facades to be vulnerable to solar radiation during daylight hours. When having no overhang, a pattern is observed where all Northern-

side facades are highly exposed to direct solar radiation on June 21st and the contrary is observed for all Southern-side facades on December 21st. During summer solstice, predominates direct solar radiation towards the North façade, especially during morning hours at the East. Also, the intensity of solar radiation received on December 21st is higher than on June 21st.

On September 21st, a different behavior is observed where only the East and West facades are exposed to solar radiation with higher values on the latter façade as near as for the solar radiation intensity reached on December 21st. Such behavior is expected for all façade orientations because of the sun position in each day. Moreover, these results indicate that an overhang of any size located at the South façade might not be of any use from June to September. The contrary is observed in

December. During September, any overhang on the North and South façade are neither useful.

Now, the impact of having overhangs is clearly observed on cases 02 and 03, giving insights into the solar radiation windows with 0.90 m and 1.80 m overhang length, respectively. Compared to case 01, diagrams from case 02 present a moderate overhang extension that improves the capacity to block solar rays with high altitude. However, this protection is limited against low solar altitude angles and remains as an insufficient stand-alone strategy to control solar radiation. A study developed in the hot climate of Kuwait achieved significant improvement on energy performance by assessing different design alternatives of horizontal overhangs.

A base case with no overhang was set and results from the optimization process, using an overhang ratio of 0.5, demonstrated to reduce building cooling load by 9%-24%. Instead of only evaluate fixed straight overhangs, the study also considered tilted overhangs as a design parameter to adapt it with the dynamic sun path, find the optimum orientation and to replace simplified formulas to calculate shading devices. The overhang tilted with 135° demonstrated superior performance compared to a straight overhang in 90°, moreover, a better energy performance of overhangs on East orientation is observed. However, overall energy savings are still low compared to other shading configurations such as louvers and side fins [14]. These findings provide insight into potential implementation of tilted overhangs on the West façade to enhance solar control for case 02 during June and September periods.

Case 03 illustrates the maximum projection depth with substantial reduction of solar radiation across most orientation. In general, this overhang extension significantly reduces the direct solar radiation on windows surfaces compared to the case of no overhang. The 1.8 m overhang nearly achieves the complete suppression of direct solar radiation on all facades, especially between June to September. Such an overhang effectiveness in blocking the entire incident solar radiation is associated with its length equal to the windows height.

Solar radiation interacts with buildings in multiple ways; it is not limited to the amount of direct radiation blocked by overhangs. Results from case 03 are consistent with previous research on shading performance, where energy savings by shading is assessed by using projection factor equally to 1 along with solar heat gain coefficient (SHGC). In this context, a study developed a shading coefficient that adjusts the effective SHGC of glazing as a function of the projection factor and orientation to quantify impact of external overhangs. This relation helped to establish the idea that increased overhangs reduce the need for high-performance glazing. In other words, this projection factor significantly reduce solar heat gain by effectively lowering the SHGC [15]. In case 03, design considerations all around windows are not only based on shading devices but must be complemented with good glazing properties to reduce radiation on NE, E, SE, SO and O orientations from June to December. While horizontal shading devices have limited protection on low

angle sun path, glazing with optimal SHGC works as a different design solution if vertical fins are not feasible.

Overhangs' length of the same window height results in a projection factor of 1.0 (d/h). With the 0.9 m overhang the projection factor is reduced to 0.5. However, either overhang successfully block solar radiation for orientations N, NO, O, SO, and SE, on June 21st, for instance. The 1.8 m overhang outperforms the 0.9 m overhang at the E and NE orientations. This is worth highlighting since a significant reduction in construction materials might be achieved, where an overhang half the size, or smaller, of the window height can have similar performance even if the projection factor is significantly lower than 1.0 (window fully blocked with overhang shadow).

B. Shading device effectiveness comparative

To fully express the impact of the shading devices (overhangs) based on the aim of blocking direct sunlight on windows, the effectiveness concept is employed here as an alternative from the commonly known projection factors. This effectiveness corresponds to the normalized magnitude of the direct solar radiation received on each orientation for either overhang compared to the magnitude of the direct solar radiation received on each orientation of a case with no overhang. In other words, the shading device effectiveness estimates the percentage of the blocked direct solar radiation on the façade. This approach is consisted with previous shading assessment studies that evaluates the extent to which shading devices reduce solar admittance on windows surfaces and, therefore, works as a fundamental mechanism to reduce heat gains because of the shading device effectiveness [16], [17].

Fig. 6 shows the results of the effectiveness behavior for both overhangs on each day at the North façade. Here, it is observed that both overhangs are highly effective on June 21st despite having very different projection factors. This indicates a favorable alignment between the solar altitude and shading geometry when the sun is towards the North. For the later months, a significant decrease is observed. This is not because of the poor performance of the overhang, but because no direct solar radiation is incident on the North façade during equinox and winter solstice season. Therefore, for this façade overhangs are strongly seasonally effective during summer solstice.

In contrast, South façade (Fig. 7) demonstrates a more extended period of effectiveness compared to the North orientation, especially on Sept 21st and Dec 21st. A particular behavior is observed on Dec 21st, where the effectiveness of an overhang half the height of the window is lower than one fully extended as the window height.

This particular behavior on winter solstice is related to the low altitude of the sun at this period, which can indicate that other design requirements, beyond the length of the overhang, are required for the last months of the year since even larger PF fails to significantly improve performance. However, it is worth mentioning that at the North-South axis overhangs with the highest PF reaches the same pattern of effectiveness.

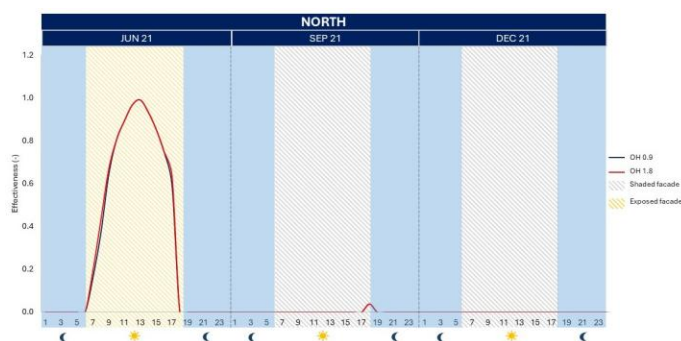


Fig. 6 Hourly solar effectiveness of the shadow device at the North façade by size and month (solar position). OH: Overhang size in meters.

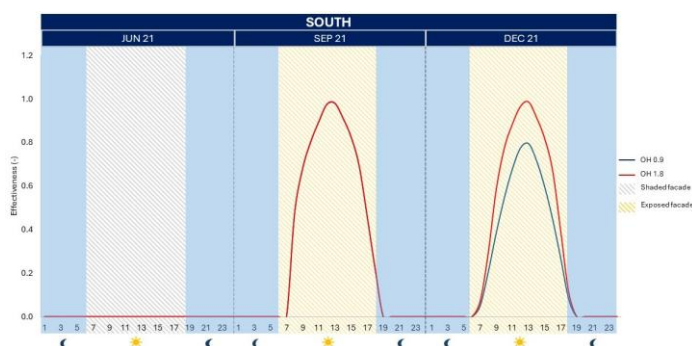


Fig. 7 Hourly solar effectiveness of the shadow device at the South façade by size and month (solar position). OH: Overhang size in meters.

Given that the projection factor of 0.5 reveals a reduced effectiveness on the South façade during December season, the implementation of tilted overhang in this orientation might improve shading performance to enhance energy savings as found in [16]. This enables an overhang with projection factor of 0.5 to a comparable performance to an overhang with a projection factor of 1 across all orientations.

The performance of overhangs for the following facades reveals that shading effectiveness is not linear in time and that there is a strong dependence on orientation and solar path, not just the overhang size. To illustrate, on the East (Fig. 8) and West facades (Fig. 9) the effectiveness is strongly related to noon hours and, either when the sun rises up or sets down, the effectiveness of both overhangs decreases. On one hand, at the East façade the 1.8 OH reaches effectiveness first at 10:00 h and is followed by the 0.9 OH that achieves it 11:00 h. On the other hand, at the West façade both overhangs also demonstrate effectiveness in different daytime. The 0.9 OH effectiveness stays still at noon time until 14:00 h and the 1.8 OH maintains its effectiveness level until 15:00 h. This pattern is observed consistently regardless of the date. Considering this, an overhang length similar to the window height (PF=1) does not successfully block the solar radiation either morning or afternoon hours in none of the yearly seasons in these facades. As a result, efficacy of overhang gets lowered as long as it turns either towards the East or West orientation. This

indicates that different shading devices configurations have to be considered to reduce solar incidence to windows facing these orientations.

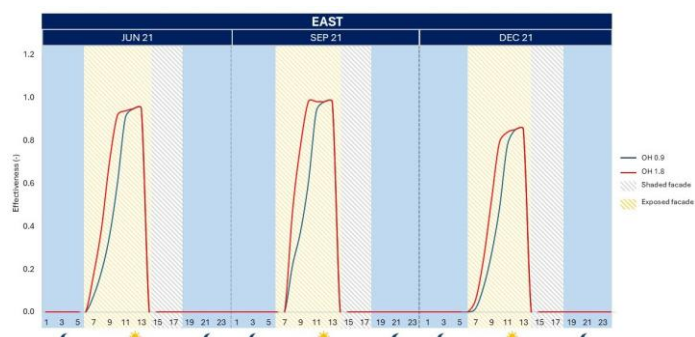


Fig. 8 Hourly solar effectiveness of the shadow device at the East façade by size and month (solar position). OH: Overhang size in meters.

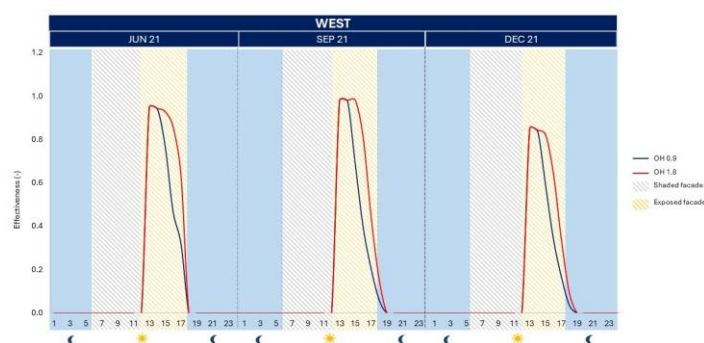


Fig. 9 Hourly solar effectiveness of the shadow device at the West façade by size and month (solar position). OH: Overhang size in meters.

Shading devices can be determined as the primary strategy for reducing solar radiation in North and South facing facades. Studies developed in near-equatorial regions support the relevance of these devices in similar climatic conditions. For the tropical climate of Indonesia, which latitude is 6°S, horizontal overhangs are the chosen strategy to protect from intense solar radiation. These devices can block up to 80% of incoming solar radiation, which leads to energy savings ranging from 29% - 51%. Moreover, movable overhangs were also evaluated achieving a better cooling load reduction range of 15.75% - 18.83% compared to fixed overhangs which cooling load reduction maintained to a static 15.82% [16]. However, it should be noted that Indonesia is located in the southern hemisphere, and Panama is in the northern hemisphere (latitude 9°N). Both locations share comparable solar trajectories and, as a result, in both contexts north oriented facades are exposed to solar radiation during certain dates. This supports the idea that shading devices remain as an effective strategy in tropical climates regardless of the hemisphere.

East and West facades may contribute to significant cooling challenges due to intense exposure of low solar angles, despite this, effective performance can still be achieved under certain design parameters. Various studies

examine and propose several design configurations for these facades. For instance, tilted horizontal overhang on East orientation reduce total energy consumption while horizontal overhang combined with side fins creates a box frame effect around the window called “egg-crate”. Side fins alone with an extension half the windows width, block lateral sun light [14], [16]. An egg-crate configuration with a 1.0 m depth was determined as the best solution for a West facing building in Bangladesh, however, this decision involves considerations beyond the capacity of blocking low solar angles since it also reflects diffuse daylight to the interior. This study highlights the fact that careful design decisions must be taken against completely shading facades since natural daylight is affected. Completely shading opening lead occupants to rely on artificial lighting, therefore, a balance between shading to reduce solar heat gain and natural light to allow diffuse light entrance should be considered [18].

To investigate closely the relationship among the variables shading device effectiveness, overhang size, orientation, hour, day, and month, (Fig. 10) is drawn to express this relation. Here, it can be seen that there are hours where both overhangs have similar effectiveness for specific orientations. The figure shows that 0.9 and 1.8 OH achieve similar results during central hours of sunlight, especially between 11:00 h and 14:00 h. This suggests that, under high solar altitude, increasing overhang projection factor from 0.5 to 1 provides limited effectiveness. Therefore, for these hours a smaller overhang may be sufficient, specifically for North, North-East and North-West facades. This knowledge can help designers when specific-hour shadow is needed for a particular façade. In such a case, smaller overhang sizes should be prioritized to reduce construction materials and costs.

Fig. 11 expresses the effectiveness variation with the date. Panama is characterized by having only two thermal seasonality, with no pronounced variation of the four conventional annual seasons. However, results demonstrated that solar position variation throughout the year still influences the shading performance of overhangs. Results showed June 21st to be the month with highest efficacy values across most orientations. This is not because of the maximum altitude reached during this period but because it is the period where the sun reaches its maximum angular declination towards the North. On September 21st the effectiveness values are slightly lower but still with high effectiveness and on December 21st lowest effectiveness is exhibited overall. The latter might be attributed to the solar position at this time of the year, as it is the lowest. Thus, highlighting again that using the projection factor only as a design reference is not enough and this might be solved by including vertical fins. In addition, both graphs together demonstrate that none of the overhangs is capable of successfully blocking entirely the direct solar radiation on all orientation on December 21st.

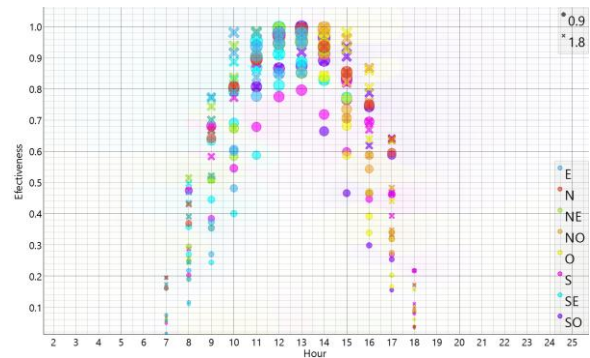


Fig. 10 Hourly solar effectiveness of the shadow device by size and orientation. OH: Overhang size in meters.

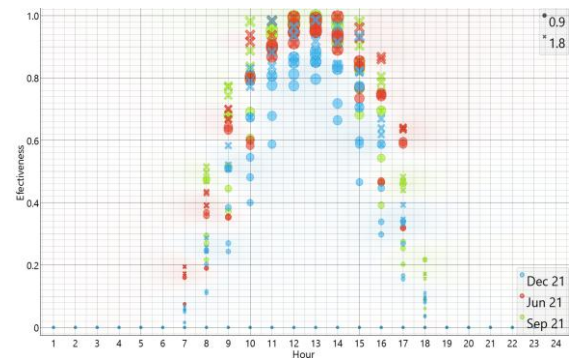


Fig. 11 Hourly solar effectiveness of the shadow device on all facades by size and day. OH: Overhang size in meters

Fig. 12 illustrates the hourly solar effectiveness of horizontal shading device as a function of orientation, overhang size, and month, reflecting changes in solar position throughout the year. Overall, effectiveness levels remain high during sun hours, especially during noon hours. Seasonal effects are evident. During months when the solar elevation reaches its highest apparent position in the Northern (e.g., June), larger red icons appear over a wider range of hours at this date, indicating higher and more sustained shading effectiveness. In contrast, months with lower solar paths (e.g., December) appear as a larger blue icon size, with effectiveness concentrated near noon, reflecting limited shading under low solar angles. Figure 13 highlights more the effectiveness of overhangs on certain orientations. The figure shows that shading effectiveness varies across orientations, with peak performance occurring at different hours of sun exposure.

Horizontal overhangs are highly effective only at South and North facing orientations during noon hours. In light of this, unifying tilted overhangs across orientations can be proposed to achieve effectiveness on all facades.

The designing process for a repeated building prototype facing different orientation can be time consuming and costly since each façade will require unique design solutions.

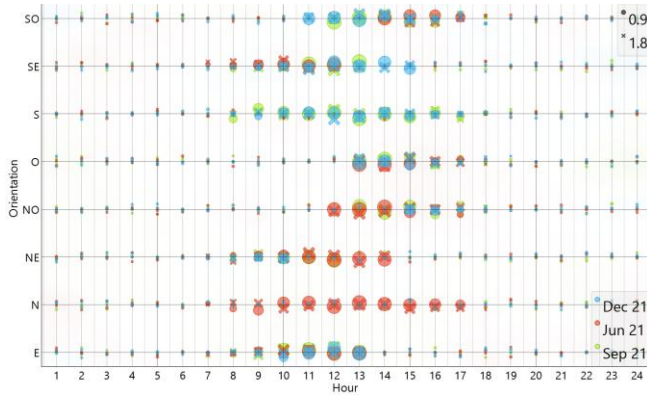


Fig. 12 Hourly solar effectiveness (size of the icons) of shading devices at every orientation by overhang size and month (solar position).

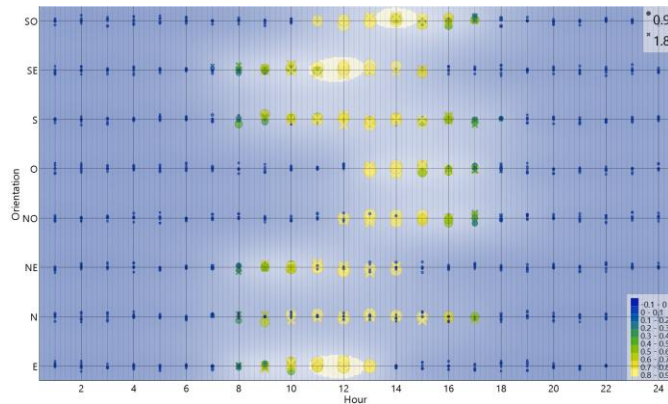


Fig. 13 Hourly solar effectiveness (size and color of the icons) of shading device at every orientation by overhang size.

This integrated approach to overhang design parameters in a large scale project contributed to reduce decision-making over which is the adequate shading devices and simplifies construction process while ensuring energy efficiency [19]. These design suggestions can improve shading effectiveness across multiple facades orientations and sunlight hours.

C. Limitations and similar studies comparison

The results presented above give clear evidence to state that focusing the shading devices design solely on the so-called projection factor proved insufficient, and a more physical based metric related to the physical impact of the device is needed. Nevertheless, the study itself presents various limitations that need to be addressed to expand and deepen the investigation.

An important limitation of this study is the building model employed for conducting the simulations: the Octagon. This is because only some of the existing orientations were analyzed, with fixed window shapes and sizes on all facades, knowing that real building designs might have several combinations of orientations and window sizes, increasing the complexity of the analysis and shadow device design.

The results and analysis presented applies to tropical regions only; but enriches the lack of studies conducted via

dynamic simulation in such regions without conventional metrics to quantify shadow devices performance.

Finally, this study presents the results only for one shading device configuration: overhangs. Other shading devices, such as vertical fins, vertical and horizontal louvers, brise-soleil and egg-crate dispositions are excluded from this study. Also, the selected shading configuration is limited to only two sizes, covering a small part of the spectrum of possible overhangs' lengths, either larger than the window's height or smaller than half of the window height to provide exhaustive numerical evidence.

IV. CONCLUSION

This study addresses the widely subject of investigation regarding solar geometry and passive design strategy: design of shading devices. As a conventional practice, such design is based on a so-called projection factor which is supposed to quantify the overhang shadow projection over the window. When the window is needed to be fully protected from direct solar radiation, an overhang design with a projection factor of 1.0 is considered adequate. However, such a factor is estimated by geometrical dimensions as the ratio of the overhang length over the window height, assuming that the shading device is dimensionally aligned with the window's opening. Even if the projection factor represents a coherent way to estimate the portion of the window covered by the overhang shadow, this study shows that this is not always the case when the solar position variation, throughout the year and hours, is considered.

To address this, implementing the effectiveness concept of the shading device comes as an alternative. Results showed that overhangs with projection factors (PF) of 0.5 and 1.0 have slightly different effectiveness in blocking the direct solar radiation on North and South orientations. This indicates that an overhang with PF of 0.5 could perform similarly to an overhang with PF of 1.0. Such a statement becomes important when construction material and cost restrictions are significant.

Difficulties in employing the effectiveness concept were identified on the West – East orientations for both projection factor values. These results highlight the limitations of relying solely on horizontal overhangs for comprehensive solar control and different shading devices configurations were proposed to improve overhang performance. Several studies developed in similar latitudes helped to identify that, under specific design considerations, tilted overhangs and combined horizontal devices with vertical fins as solutions to protect windows from early morning and later afternoon sunlight.

Results from this study help to understand façade design considerations for overhangs in tropical conditions. Nevertheless, this evaluation was restricted to direct solar radiation and other variables, that can also affect building performance such as indoor thermal conditions, cooling loads or daylight performance, were not quantified. Further studies should explore dynamic shading devices; this will help to

provide insights into optimal shading performance in tropical environments.

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