WINDOW SHADING FOR COOLING LOAD REDUCTION IN COMMERCIAL BUILDING RETROFITS IN TROPICAL CLIMATES: THE CASE OF ACCRA, GHANA, AND MIAMI, FLORIDA

by

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THESIS ABSTRACT

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Title: Window Shading for Cooling Load Reduction in Commercial Building Retrofits in Tropical Climates: The Case of Accra, Ghana and Miami, Florida

This study investigated two shoebox models representing a typical office space with an area of 20m2, one without window shading and one with a fixed louvered overhang. The study explored the impact of the louvered overhang with projection factor of 0.7 for an east, west and south-facing window on cooling load reduction and daylighting performance for office building retrofits in Accra, Ghana, and Miami, USA. The results showed that, in both Accra and Miami, the fixed louvered overhang achieved a reduction in window transmitted solar radiation of 22.7% - 27.3% for the Accra model and 26.3% - 30.2% for Miami. Consequently, total annual cooling load was reduced by 6% - 9% in Accra and 10% - 12% in Miami. In all cases, the louvered overhang improved the Useful Daylight Illuminance of the office space by 3.9% - 5.4% in Accra and 1.9% - 3.4% in Miami.

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This research is dedicated to my loving husband Peter who has been a constant source of encouragement and solid support throughout all the difficult moments I faced in graduate school and in a completely new environment I knew very little of. You always inspired me to strive for excellence. To my sister Bubune and my friend Carin who have always been there for me. Finally, to my parents who have always prayed for me and inspired me to work hard towards my dreams.

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1. INTRODUCTION

Background

Increasing greenhouse emissions have led to rising global temperatures and an increase in energy demand for cooling buildings (Omer 2008). According to the International Energy Association it is predicted that global cooling service demand per square meter of built space will grow up to 50% by the year 2050 (IEA, 2020). One of the main sources of these emissions in tropical regions such as Ghana is energy required in cooling buildings. In Ghana, whiles the proportion of residential energy use has been on a decline from (3,473 Kilo tonnes) 62.5 % of the total energy consumption in 2000 to (3,423 Kilo tonnes) 42.9 % of the total energy consumption 2019, commercial energy consumption has seen an annual rise of 7.3 % within the same duration. Previous research survey has shown that 60 – 80 % of electricity consumption in commercial buildings in Ghana are due to cooling loads (Opoku et al, 2019).

In Accra, the capital city of Ghana, most old buildings are demolished and replaced with new development. Building retrofits are not popular on large scales (Oppong and Masahudu, 2014) and retrofitting is usually parallel to building expansions and facelifts that copy trends of contemporary western buildings with almost no emphasis on, climate, sustainability, and the ever-increasing demand for cooling energy (Ernest et al. 2016). Globally, window shading has proven to be one of the retrofitting measures that could substantially lower cooling energy demand. Particularly in hot and humid climates, one negative consequence of using shading devices is the risk of reducing daylight levels which consequently increases the use of electric lighting. It is important to understand that the performance of solar shading device depends on many factors but the most important is **the place of installation** and the **size** of the shield (Dudzinska, 2021). Existing research has established the relationship between shading devices and energy consumption. Haghighi et al. (Haghighi et al., 2015) investigated the effect of shading design and materials on building energy demand in multiply locations, including Miami, Seattle, Chicago, Atlanta, Duluth, and found that exterior shading devices were able to decrease energy consumption by **11.6 % in Miami**. In another study conducted by Alghoul and Alrijabo (Alghoul and Alrijabo, 2016) on the impact of external overhang window shading on energy requirement of office buildings in Tripoli, Libya, it was noted that window shading was only significant on the west, east and south direction. Projection factor is a terminology used to refer to the ratio of the depth of a horizontal shading device over a window to the height of the window. It is calculated by dividing the overhang depth by the window height (Ossen et al. 2005). Significant savings in energy consumption between 10 - 20 % was noted for shading device with projection factor of 0.5 to 1.0 (Alghoul and Alrijabo, 2016). In another study on optimum overhang geometry for building energy saving in tropical climates, maximum shading from direct solar radiation was achieved with overhang with projection factor of 0.6 to 0.8 in the south orientation. The results from this research also showed that an increase in projection factor for overhang shading has little impact on the amount of diffused solar radiation received through the window (Ossen et al., 2005).

This thesis seeks to understand how a shading device with projection factor of 0.7 (copied from contemporary buildings in Miami) compares in performance to a similar shading device in Accra. Solar heat gains through the window comprises of both diffuse solar radiation and beam solar radiation. The study will seek to understand the primary sources of solar heat gains through windows and how that affects the cooling load in Accra and Miami. Understanding the primary sources of heat gain in each location will help inform the practicality of a shading device used in Accra and compare that to Miami through its impact on the cooling load. Findings from this research can contribute to research-based guidelines for sustainably retrofitting commercial buildings in Accra while reducing heat gains and consequently reducing energy consumption.

Problem Statement

Research and practice have proven that retrofits to old buildings are beneficial in improving the energy performance, occupant satisfaction and increase economic returns of an old building (Lee et al., 2019). An upgrade/retrofit of the envelope system through effective window assembly and shading strategies could significantly reduce heat gains and subsequent cooling loads in a tropical climate. However, very little research exists with regards to the specific geometrical factors for window shading, especially for retrofitting buildings in Accra. Furthermore, little is known about the quantified impact specific window shading assemblies will have on key building performance parameters in the Accra context and how much it differs from the context of Miami. Simulation analysis will allow a specific understanding of the isolated condition of heat gains through windows between these locations.

Aim

The aim of this study is to explore cooling load reduction using window shading for office building retrofits in the ASHRAE zone 1A climate, exploring the impact of static shading on the building's thermal and daylighting performance within retrofit construction constraints. This is because in hot and humid climates, a risk of using poorly designed shading devices is that they may reduce daylight levels and increase reliance on electric lighting systems. This study looks to understand both the magnitude of cooling load reductions and the effect of the shading device on daylighting levels using Useful Daylight Illuminance (UDI) as the metric for daylighting performance.

Research Questions

To meet the aim of the study as stated above, the following questions guided this thesis:

1. What is/are the primary source(s) of heat gains through south, east and west facing windows for Accra (Lat 5.6°N) and Miami (Lat 25.7°N)?
2. To what extent does a fixed louvered overhang shading device impact the cooling load of an existing office space in Accra (Lat 5.6°N) and Miami (Lat 25.7°N) and the daylighting performance of the space?
3. Are cooling load reduction for Accra and Miami comparable? How do the same shading parameters affect the performance of baseline model in both locations given their respective climatic and contextual differences?

Objectives

1. To determine the main source(s) of heat gains through south, east and west facing windows for Accra (Lat 5.6°N) and Miami (Lat 25.7° N)
2. To investigate the impact a fixed louvered overhang with projection factor of 0.7 on a south, west and east-facing window will have on **cooling load reduction** and **daylighting performance** of an office space in Accra and Miami
3. To assess how comparable the effects of a fixed louvered overhang on cooling load reduction and daylighting performance are in Accra and Miami

Research Scope and Limitations

This study focuses only on exterior fenestration retrofitting options and will be limited to testing the effectiveness of a fixed louvered overhang shading in reducing the daily cooling load of office buildings. Considering practical construction limits for retrofitting an existing building, the projection factor of the tested shading device is limited to 0.7 in this study.

The study will not include a testing of the exterior wall material and insulation. Also, this research does not account for heat gains through the roof or ground.

2. LITERATURE REVIEW

Energy consumption for cooling in commercial buildings

In 2016, the total amount of carbon emissions from energy generation globally was 49.3 gigatons of CO_2 which forms about 50% of greenhouse gas emissions. With the effects of greenhouse gas emissions resulting in rising global temperatures and records of more humid heat waves in tropical climates recent times, it is predicted according to the International Energy Association (IEA, 2020) that global cooling service demand per square meter will grow up to 50% by the year 2050.

In Ghana, total energy consumption has been rising over the years due to increasing population. Although total energy consumption has risen over the years, residential energy use has dropped from 3,473 Kilo tonnes (62.5% of total energy use) in 2000 to 3,423 Kilo tonnes (42.9% of total energy consumption) in 2019. Commercial energy consumption however has increased at an annual average growth rate of 7.3% (EnergyCommissionGhana, 2020). A study done by Opoku et al., investigating the energy efficiency and cost saving opportunities in public and commercial buildings in developing countries, showed that 60 – 80 % of electricity consumption in commercial buildings in Ghana are due to cooling loads (Opoku et al., 2019). Optimizing energy efficiency in the design of buildings is a significant way of ensuring a better overall performance and a high energy efficiency after the building has been built (Shi et al., 2016).

Factors affecting indoor thermal performance and cooling energy

In Ghana, few studies have been conducted to explore means and methods of improving the energy performance and thermal conditions in buildings in Accra. There have been studies on the effects of thermal mass, window size and night-time ventilation on thermal performance in office buildings, the effects of mixed mode versus naturally ventilated office buildings on thermal performance and building energy efficiency assessment tools on office buildings in Kumasi, Ghana (Amos-Abanyie, Akuffo, Kutin-Sanwu, et al., 2013; Koranteng & Mahdavi, 2011; Nii et al., 2017). Meanwhile, advancements in parametric analysis methods to improve thermal performance have been completed for office buildings in Ghana (Koranteng 2010) measuring the efficiency of windows, natural ventilation, attic floor insulation as factors that significantly led to reduction in office building cooling loads. Studies in Italy with different climates have also showed that roof insulation, reflective external wall coating with R-value of 0.80 and using venetian blinds help reduce solar heat gains through the building envelope (Evola et al. 2015).

Window shading for solar heat gain reduction

Design variables considered in optimizing energy efficient building design include building envelope, shape, orientation and aspect ratio, form, type and operation of mechanical systems (Shi et al., 2016; Evola et al., 2015; Koranteng, 2010). Al-Tamimi & Fadzil (2011) compared the potential of shading devices and glazing assemblies for reducing cooling load in office buildings and argue that the first and most significant step to reduce solar heat gains through building envelope should be exterior shading, especially in the hot humid climate of Malaysia. Furthermore, in a study of solar shading devices for office buildings in Italian climates, Belia et al., (2013) also confirms that solar shading devices have shown the highest energy efficiency for warmer climates: the sunnier the climate, the higher the potential of heat gain reduction through shading.

Studies have been done on various shading devices and their effectiveness improving thermal and energy performance of office and residential buildings in different climates. Research has proven that perforated and louvered solar screens are most effective for hot deserts in Egypt and Spain and the Middle east compared to overhangs and vertical fins (Chi, Moreno & Navaro 2017; Sabry et al., 2014; Yassine & Abu-Hijleh, 2013; Freewan, 2014). Elzeyadi & Batool (2012) in their study of perforation ratios of solar screens in different climates revealed that with a 30% perforation ratio, solar screens performed best in hot arid climates but performed poorly in hot humid climates.

Optimal overhang projection factor for energy savings in tropical cities

In a study a done by Alghoul and Alrijabo, on the impact of external overhang window shading on energy requirement of office buildings in Tripoli, Libya (Lat 32.8 ºN), it was observed that the percentage of reduction in energy consumption was only significant in the east, west and south orientation. It was concluded that overhang shading was not beneficial in energy savings in the north direction. The study also established that for horizontal shading with projection factor of 0.5 to 1.0, energy saving reduction between 10 – 20 % was attainable. Projection factor of 0.7 attained as high as 18% energy savings for South-east window, 18.3% for south and southwest windows. Also, a projection factor of 0.8 achieved 19% annual energy savings for a southeast window and 19.2-19.3% for south and south-west windows. For direct west and direct east orientations, the deeper overhands with projection factor of 0.9 and 1 was the most effective yielding an energy savings of 15-16.4% compared to the overhangs with smaller projection factors.

In similar study by Ossen et. Al (2005), investigating the optimum overhang geometry for buildings energy saving in tropical climates, a typical office room in Malaysia was considered to evaluate the magnitude of solar heat gain and energy savings in north, south, east, and west orientations. It was also concluded the overhang had minimum effect in the north direction. The optimum projection factor for maximum energy saving between 8 – 12 % was found to be 0.8 for south, east, and west direction. An increase in the projection factor beyond 0.8 point caused a little reduction energy savings or an increase in the energy consumption.

Kim et al. (2017) studied the effectiveness of horizontal overhangs for passive solar control in South Korea, Lat. 35◦N, which has a temperate climate, but warm humid summers. In the hot humid climate, horizontal overhangs and its application on southern facades in the northern hemisphere have also been studied. Ossen et al., (2005) studied the impact of different overhang projection factors on building energy use in Malaysia, Lat 3.7◦N while (Ossen et al., 2005) concludes that the ideal overhang projection depth of 0.8meters for south window achieves more than 80% radiation reduction. Ghosh & Neogi (2018) proposed a new form of overhang design on a south façade in Kolkata, India, Lat 22.5◦N, studied effects of its geometrical factors on energy consumption and evaluated its visual performance compared to other similar hot humid climates, Hanoi, Lat.21◦N and Naples, Lat. 26.1◦N. The proposed shading device out-performed traditional horizontal overhangs, vertical fins, overhang with triangular fins and fins on all four sides. Despite the studies on window shading in other hot humid climatic locations, little scientific research has been done on shading of office buildings in Accra.

Sustainable building retrofits

Green retrofits and the market of sustainable renovations is growing annually in developed countries (Al-Kodmany, 2014; Ibrahim & Pelsmakers, 2018), however, this is not the case in Accra. Nik et. Al 2015 studied the long-term performance of four retrofitting measures in Europe: change in U-value of basements, attics/roofs, facades, and the replacement of windows.

In a case study research Ibrahim & Pelsmakers (2018) examined the risk of overheating in low-energy retrofitted housing in England. The U-value of walls, ground-floor, roof, windows, and doors, and the amount of solar radiation that can be transmitted through the glazing were studied. However, performance of shading was not studied in these studies.

According to Nik et al. (2015), retrofitted buildings should not only offer energy efficiency, but also occupant comfort and should be robust enough against the dynamics of climate change. Awada and Srour (2018) concur to Nik.et al. (2015) and suggests that multi-objective optimization should be considered in retrofitting to maximize occupant satisfaction with IEQ. In a simulation and field study on office buildings in Kumasi Ghana, Koranteng & Mahdavi (2011) discovered that the application of envelope retrofitting and building control could reduce cooling loads by 20% to 35% and recommends that operable window shading should be considered.

The research contextualization above led to focus on exterior shading to limit heat gain and material reflection to enhance indoor environmental quality. Improved indoor environmental quality will strongly improve employee health, productivity, good turnover in sustainable retrofitted commercial building in Accra and Miami.

3. METHODOLOGY

Research Approach

This study took a quantitative approach. It was simulation-based-research on two building models with typical Miami and Accra office building characteristics. The independent variables for this study are orientation (east, west, and south) and location (Accra and Miami). The dependent variables are cooling loads for four key days in the year and Useful Daylight Illuminance. Simulations were conducted on a base model without shading and then on a model with a fixed louvered overhang shading device for all the independent variables respectively. Simulations were done based on the following objectives:

1. To determine the main source(s) of heat gains through south, east and west facing windows for Accra (Lat 5.6 °N) and Miami (Lat 25.7 °N)
2. To investigate the impact a fixed louvered overhang on a south, west and east facing window will have on daylighting performance and cooling load reduction of an office space in Accra and Miami

Tools for data collection

Modelling and simulation tools used were Rhinoceros 3D, Grasshopper with plugins, Climate studio, Euclid for SketchUp and Energy Plus software.

Study locations

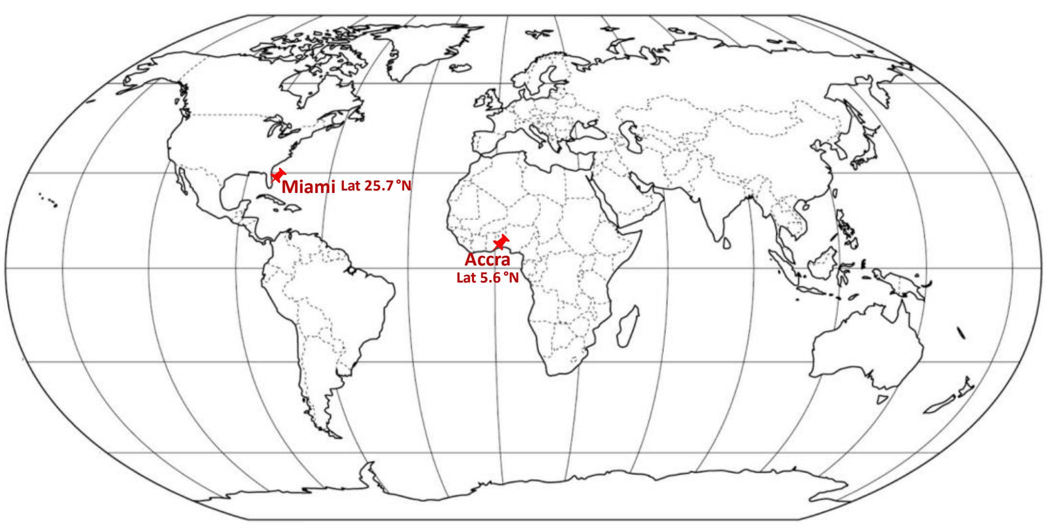


Figure 3. 1: World Map showing study locations (Worldmapblank.com, 2022)

Climatic Data of Study Locations

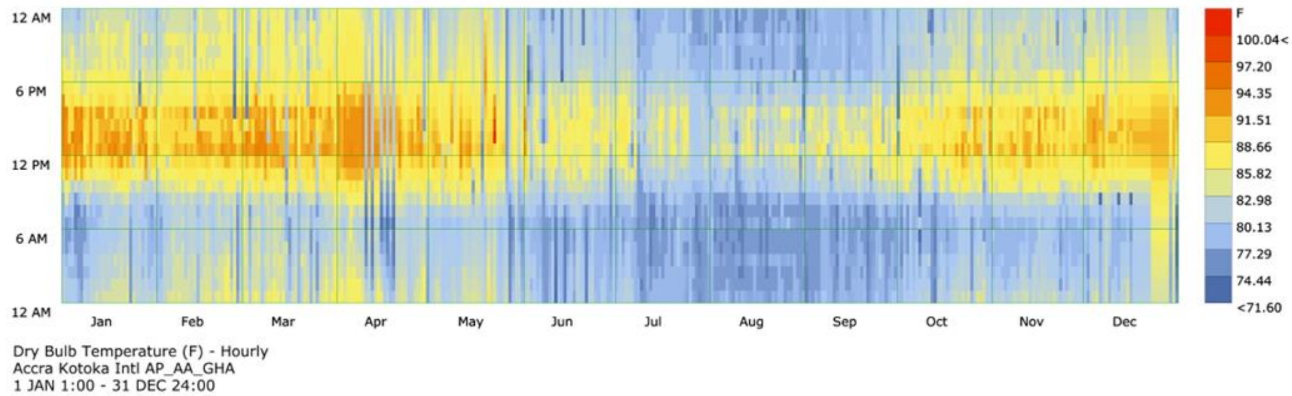


Figure 3.2: Year-round Hourly temperature pattern of **Accra** from TMYx 2004-2018, showing **December to May** as the months in the year with the **highest temperatures**

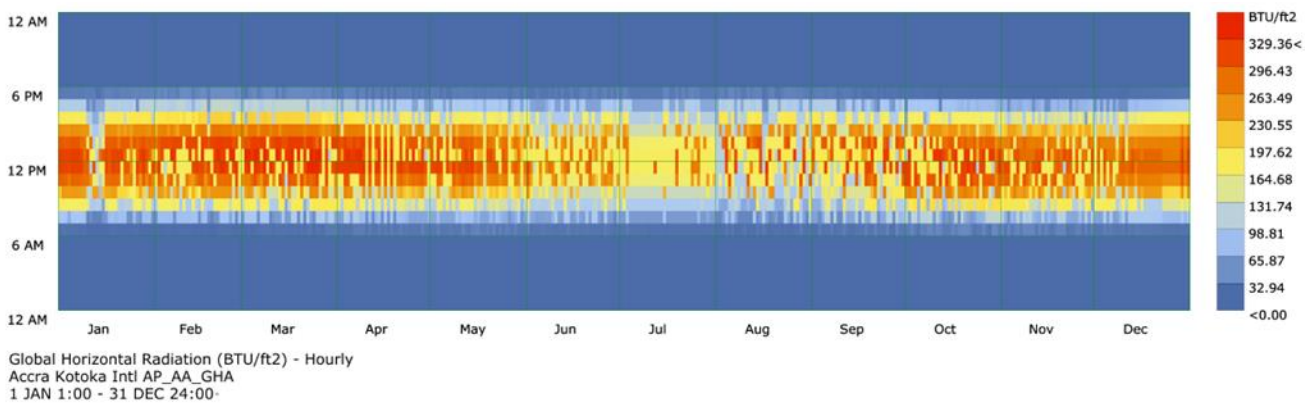


Figure 3. 3**:** Hourly global horizontal radiation pattern of **Accra** from TMYx 2004-2018, showing **October to April** as the months in the year with the **highest global horizontal radiation**.

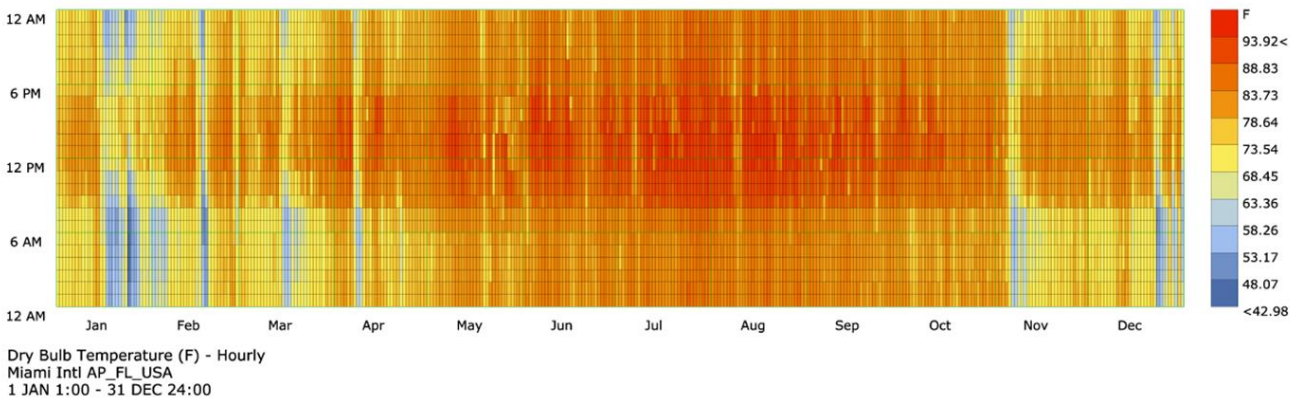


Figure 3. 4**:** Year-round Hourly temperature pattern of **Miami** from TMYx 2004-2018, showing **June to September** as the months in the year with the **highest temperatures**

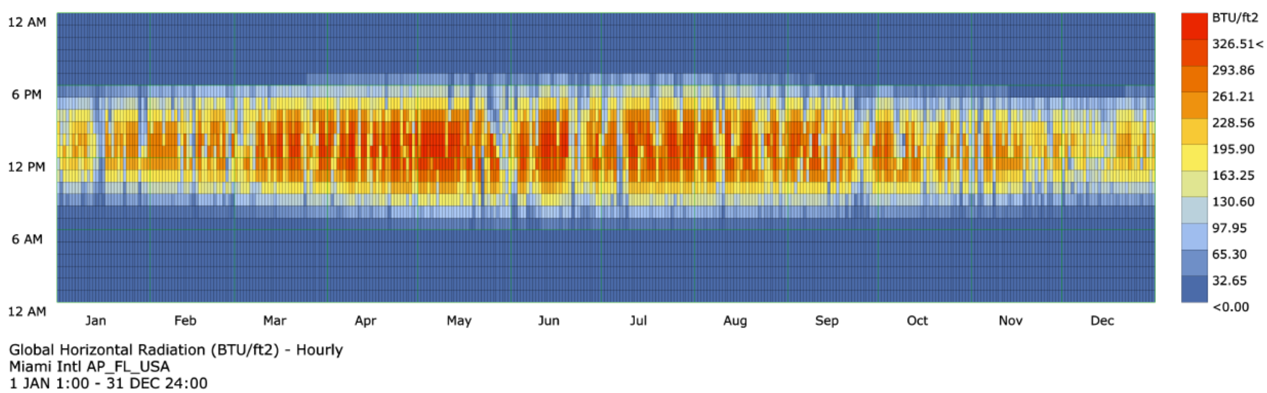


Figure 3. 5**:** Hourly global horizontal radiation pattern of **Miami** from TMYx 2004-2018, showing April to August as the months in the year with the highest global horizontal radiation.

It should be noted that although Accra and Miami are both generally identified as tropical cities, year-round seasonal patterns differ. The months that are of highest temperature in Miami, Lat 25.7°N are rather the months of lowest temperatures in Accra, Lat 5.6° N.

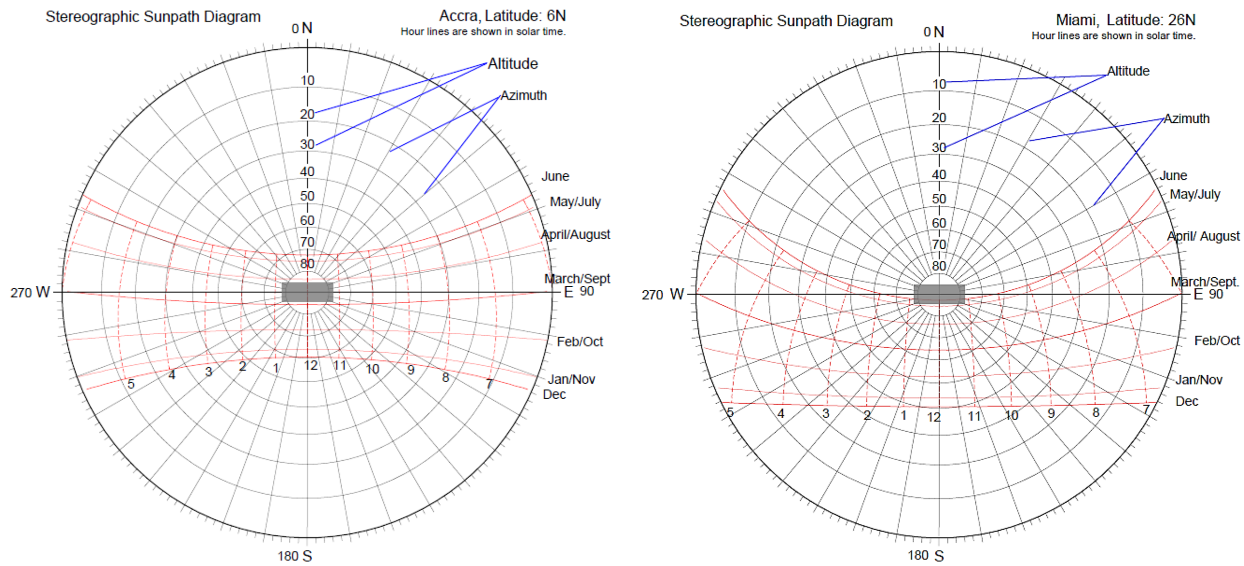


Figure 3. 6**:** Stereographic sun-path diagram for Accra (left) and Miami at right (Jaloxa.eu, 2011)

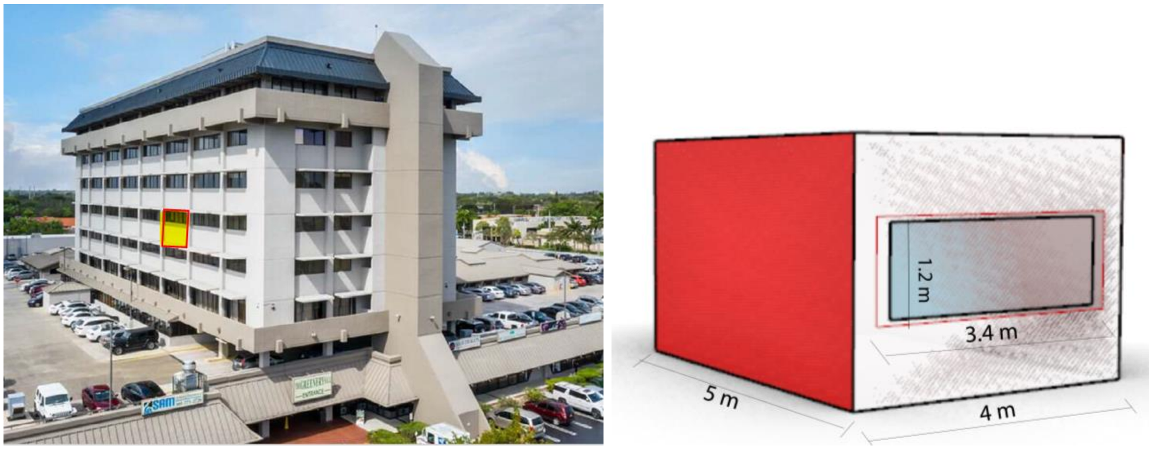
From the sun-path diagrams above, the south, east, and west facades of buildings have the most direct exposure to solar radiation during months with high temperatures. In retrofitting existing buildings, it makes the most sense to consider all four building orientations and introduce solar heat gain reduction strategies to the facades that have significant solar exposure. In Accra, the hottest periods where the building experiences peak cooling demand are between December and April. In Miami, this period lies between May and August. Hence the simulations focused on a southern, eastern, and western façade study.

Study Period

To determine the primary sources of heat gains, global horizontal radiation, incident radiation falling on vertical surfaces and total window transmitted solar radiation were examined for a full year. However, in the shadow study of the shaded windows, four key days in the year were studied: March 21st, June 21st, September 21st, and December 21st. For each of these days, the time of interest was from 6am to 6pm. Also, for the analysis of cooling loads and heat balance analyses, total annual heat gains and losses were studied for a full year.

Shoebox model design

In the context of retrofitting an existing office building under a limited budget, the extent to which thermal performance improvements can be made to the building fabric is limited to the replacement and reinstallation of simple shading devices. In designing shading devices that can be attached to the windows of an existing office building, the structural properties of the host envelope material and material of the shading device should be taken into consideration such that the chosen material and dimensional characteristics can be supported by the existing building structure.



Building: 7700 Kendall Dr. Miami, Florida

Figure 3.7: Image of Base model

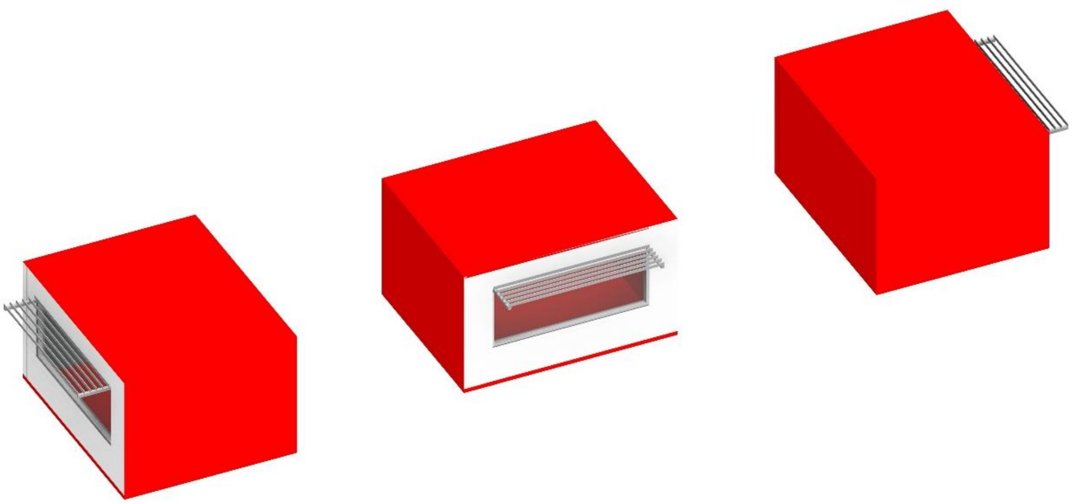


Figure 3. 8: Image of shoebox model with louvered overhang modeled in Rhinoceros 3d

The model exterior envelope features:

The model had a floor area of $20m^2$, gross wall area of $12m^2$ and a room height of 3m. It had one exterior wall and window with area of $2.14m^2$ which faced south, east, or west. The exterior envelope material was assumed to be of stud construction in Miami and concrete masonry units in Accra. Tables 1, 2 and 3 shows the Reflectance, U-value, area, solar transmittance, conductivity, and solar heat gain coefficient (SHGC) of the fenestration, interior surfaces, and exterior surfaces. The fenestration U-factor, visible transmittance, conductance, solar heat gain coefficient determines how much heat and daylight is allowed into the interior space. The reflectance and U-factor of exterior and interior envelope material also determines how much heat is transmitted through the material into the interior space. The floor, ceiling and remaining 3 enclosing walls were considered adiabatic surfaces. The zone was fully airconditioned with no mechanical ventilation.

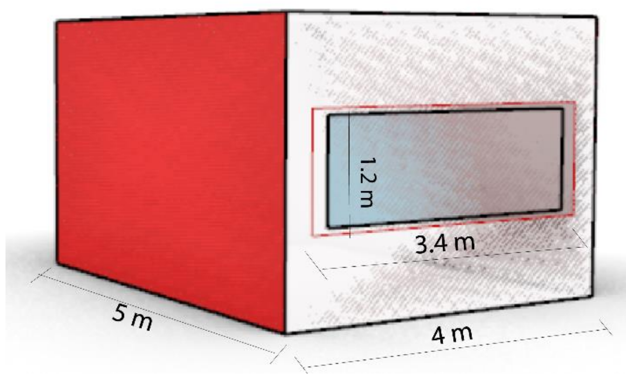


Figure 3. 9: Image of Base model

Construction	Reflectance	U-Factor with Film [Btu/h-ft2-F]	U-Factor no Film [Btu/h-ft2-F]	Gross Area [ft2]	Net Area [ft2]
Concrete Masonry Wall for Accra	0.3	0.348	0.494	129.18	85.5
Steel Frame Non-Res Ext Wall for Miami	0.22	0.124	0.139	129.18	85.5

Table 1: *Exterior opaque surface characteristics for Accra and Miami model*

Construction	Reflectance	U-Factor with Film [W/m2-K]	U-Factor no Film [W/m2-K]	Gross Area [m2]	Net Area [m2]	Tilt [deg]
UVAL_0.2_MASS	0.3	0.197	0.207	15	15	90
UVAL_0.2_MASS	0.3	0.197	0.207	12	12	90
UVAL_0.2_MASS	0.3	0.197	0.207	15	15	90
SLAB_MASS_FLIPPED	0.3	2.358	10	20	20	180
SLAB_MASS	0.3	3.176	10	20	20	0

Table 2: Interior opaque surfaces characteristics

	UNZ_0:F0:W0
Construction	CLEAR
Glass Area [m2]	3.26
Frame Area [m2]	0.42
Divider Area [m2]	0
Area of One Opening [m2]	3.69
Area of Multiplied Openings [m2]	3.69
Glass U-Factor [W/m2-K]	5.808
Glass SHGC	0.82
Glass Visible Transmittance	0.877
Frame Conductance [W/m2-K]	5
Divider Conductance [W/m2-K]	5

Table 3: Fenestration characteristics

Window louvered overhang shading characteristics:

The shading device tested was a fixed louvered overhang with vertically arrayed slats with slat interval of 0.15m Medium reflectance low transmittance. Full depth of the overhang was 0.85m

Solar Transmittance	Solar Reflectance	Visible reflectance	Conductivity	Slat Thickness
0.1	0.5	0.5	0.1	0.005m

Table 4: Louvered overhang characteristics

Simulation set-up

Ground reflectance was set to 20%, an average reflectance value for a paved exterior ground surface for both Accra and Miami. Window size was constant and the projection factor (pf), which is the overhang depth divided by window height was also constant. The projection factor of 0.7, with a shading depth of 0.85m was tested for all three orientations in Accra and Miami.

Occupancy capacity and schedules:

The occupancy schedules were set to daytime working hours between 8:00 am to 6:00 pm using DOE medium office 1A building equipment and light Schedule templates. Lighting power density set to 6W/m^2 and equipment power density set to 7W/m^2

Climate data of the study locations were obtained from Energy Plus weather TMYx 2004 - 2018 files reflecting typical meteorological year from climate.onebuilding.org.

Cooling setpoint temperature

The cooling setpoint temperature for the simulations were set at a minimum of 24°C and a maximum of 26.7°C

Research Process

BASELINES: To achieve the first objective, thermal simulations were conducted for three shoebox models without any shading, with east, west and south-facing windows each for Accra and then for Miami. The results of the simulations were analyzed for each case to determine the amount of heat energy gained or lost through people, lights, electrical equipment, total heat gains and losses through window, opaque surfaces of the building envelope, infiltration, and ventilation. Also, the global horizontal radiation and incident radiation falling on the surfaces of the shoebox model for both locations at the period of study were simulated and visualized using Grasshopper Ladybug visualization.

FIXED LOUVER: To meet the second objective, to investigate the impact of a fixed louvered overhang on a south, west and east-facing window on daylighting performance and cooling load reduction, the shoebox models were built in Rhino and Grasshopper and climate studio was used as the initial thermal simulation tool. Due to limitations of Climate Studio for thermal simulations such as inability to specify modeled louvered overhang shading and shading material properties, the second part of the thermal simulations were done in Energy Plus software using the IDF file from Climate studio. The louvered overhang shading device was modeled in Euclid for SketchUp, and shading material properties were specified in Energy Plus to make up for the limitation of Climate studio.

4. RESULTS AND DISCUSSION

This section discusses the outcomes of data collected from simulations and an analysis of the results in relation to the following objectives:

1. To understand the main source(s) of heat gains through south, east and west facing windows for Accra (Lat 5.6°N) and Miami (Lat 25.7°N) respectively
2. To investigate the impact a fixed louvered overhang on a south, west and east-facing window will have on daylighting performance and cooling load reduction of an office space in Accra and Miami
3. To understand how comparable the effects of a fixed louvered overhang on cooling load reduction and daylighting performance are in Accra and Miami

The results and discussions are presented first for Accra and then for Miami. Discussions from the two locations are then compared afterwards to meet the third objective.

RESULTS AND DISCUSSION FOR ACCRA

Primary source of window heat gains

Evaluations were conducted to understand the main sources of heat through the south, east and west-facing windows of an office space in Accra including global horizontal radiation, incident solar radiation falling on vertical building surfaces and a shadow study of shaded window on each orientation. To understand the source of heat, the heat balance analysis of the shoebox model was conducted, and the solar radiation transmitted into the space through the window was analyzed.

Global horizontal Radiation - Accra

Figure 4.1 below shows the pattern and amount of solar energy radiated on an exterior horizontal surface per square meter from 8am to 6pm everyday in the year, presented on a sun-path diagram for Accra. From the sun path diagram, the periods of peak global horizontal radiation are between 11am and 3pm from December through to April.

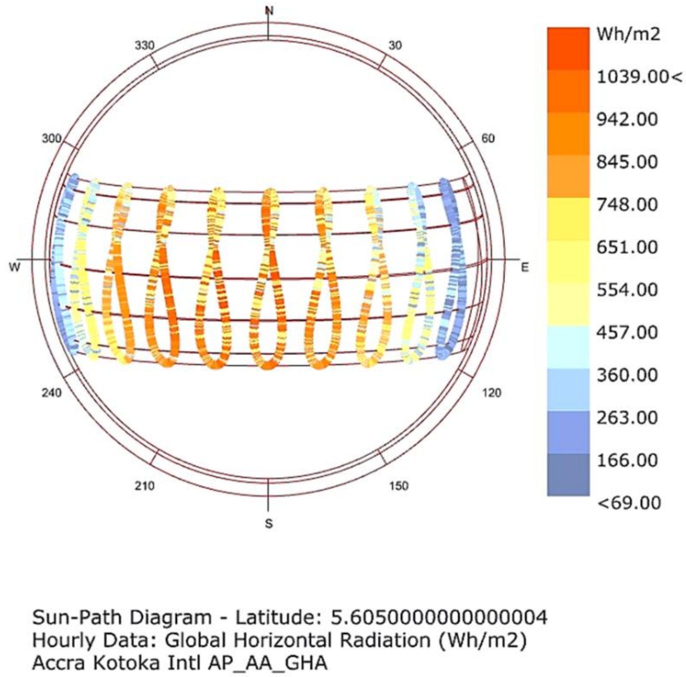


Figure 4.1: Global horizontal radiation for Accra

Shadow study of shaded window

From the global horizontal radiation chart above, it was noted that the critical periods of high solar radiation for analysis of shadow was at noon in March and December. From Figure 4.2, at noon, 100% of the east-facing window is completely shaded in December. At 12 noon in March, the window is in shade due to the sun's position almost overhead. The louvered overhang also casts a shadow on about 30% of the east-facing window at noon in March.

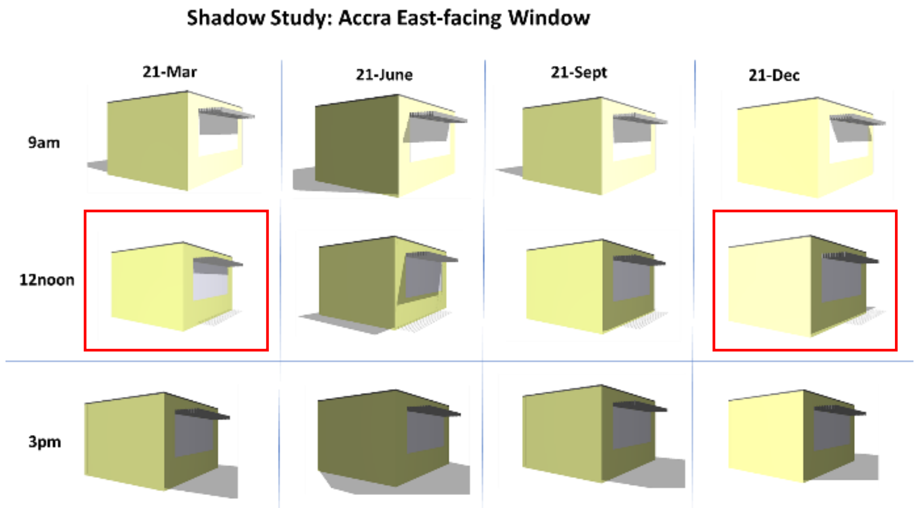


Figure 4.2: Study of shadow cast by louvered overhang on an east-facing window in Accra

On the south-facing window at noon, the louvered overhang casts a shadow on about 40% of the window in March and 100% of the window in December at noon as seen in Figure 4.3.

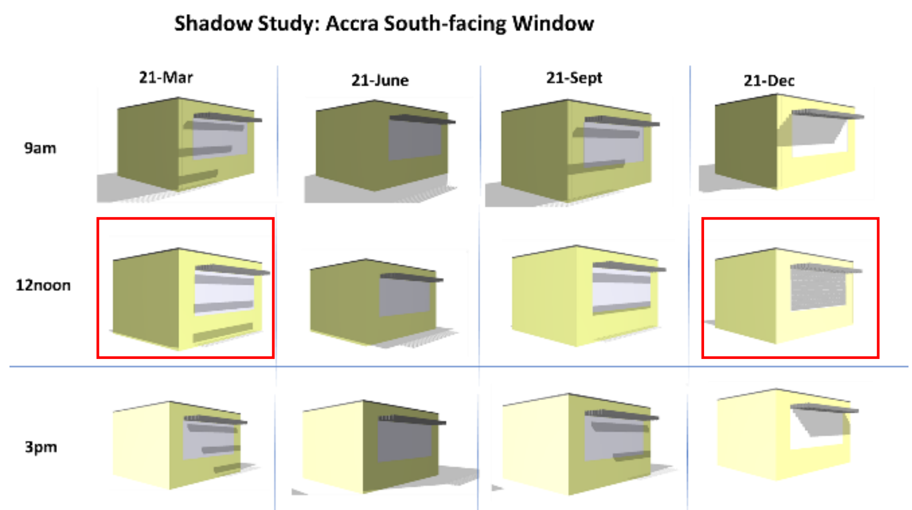


Figure 4.3: Study of shadow cast by louvered overhang on a south-facing window in Accra

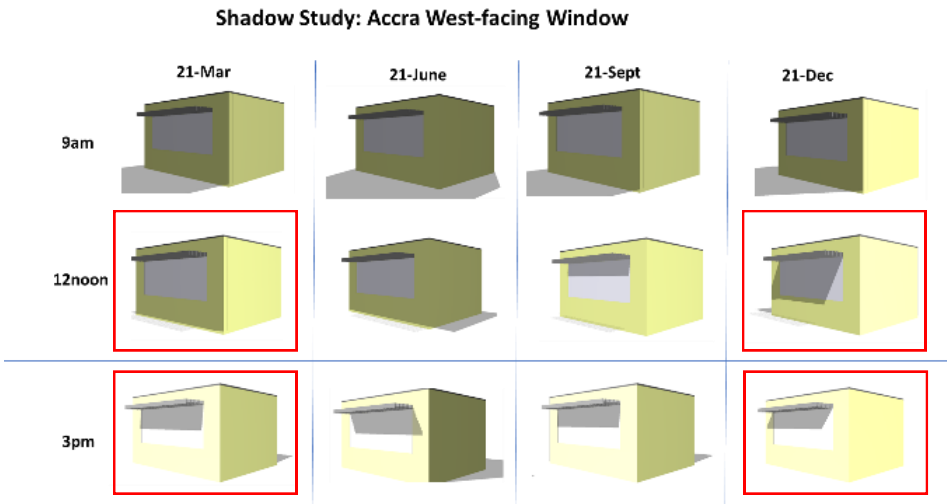


Figure 4.4: Study of shadow cast by louvered overhang on a west-facing window in Accra

As seen Figure 4.4, 100% of the west-facing window was in shade at noon in March whiles 90% of it was shaded by the louvered overhang at noon in December. At 3pm, 80% of the west-facing window is shaded in March and about 60% is shaded in December.

Generally, based on the window shaded fraction of all twelve images for the three window orientations, the louvered overhang provided best shading on the east window, followed by the west window. The south window overall, had the least shadow cast from the louvered overhang.

Incident radiation falling on vertical surfaces

Figure 4.5 shows the total incident radiation falling on east, south and west-facing surfaces of the model in Accra for the whole year in kilo Watt hour per square meter. The east and south surfaces each receive a total annual incident radiation exposure of between 720 kWh/m^2 to 840 kWh/m^2 whereas the west side receives a higher incident radiation of 840 to 960 kWh/m^2 in the year.

Figure 4.5: Total annual incident solar radiation on east, south and west orientation of a typical building (Accra)

Window transmitted Solar Radiation

The total solar radiation transmitted into the space through the shaded and unshaded window for every month of the year in Accra is shown in Figure 4. *6* below. From this figure, it can be observed that the west-facing window has a consistently high exposure to solar radiation as compared to the south-facing and east-facing window. However, from November to February, the unshaded south-facing window had the highest transmitted solar radiation compared to the east and west, and the lowest transmitted solar radiation in the other months from March to September.

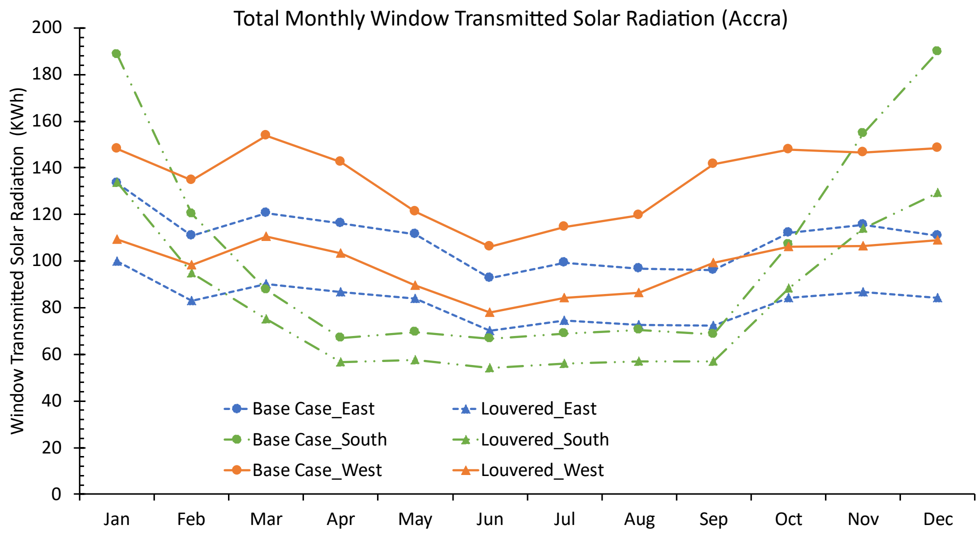


Figure 4. 6: Total monthly transmitted solar radiation (kWh) through east, south and west-facing windows with and without shading in Accra

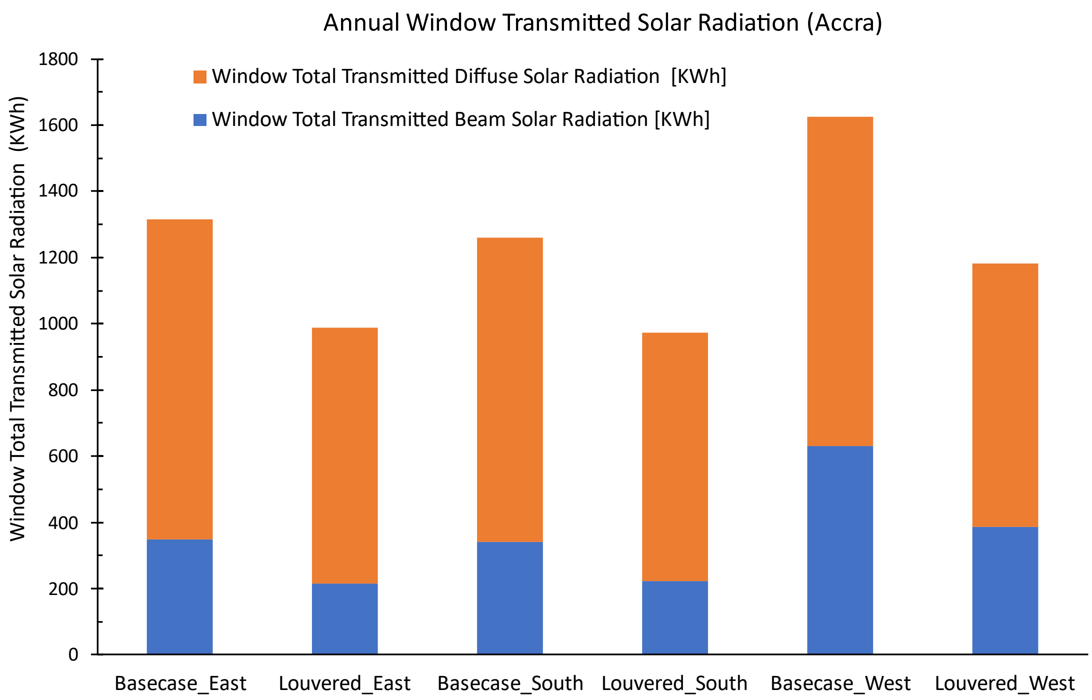


Figure 4. 7: Annual Total Window Transmitted Beam & Diffused solar radiation through east, south and west-facing windows with and without overhang shading (Accra)

The west unshaded window had the highest total transmitted solar radiation for the entire year of 1,625.3 kWh followed by the east unshaded window with an annual transmitted solar radiation of

1,315.51 kWh. The unshaded south-facing window overall had the least annual total transmitted solar radiation of 1,259.24 kWh. Figure 4. *7*, Table 6 and Table 7 below shows the proportion of beam solar radiation and diffused solar radiation that constitutes the annual total transmitted solar radiation values stated above. For the east-facing window, beam solar radiation made up 26.4% of the total transmitted solar radiation while diffuse solar radiation made up 73.6% of the total transmitted solar radiation. For the south-facing window, beam solar radiation made up 27% of the total transmitted solar radiation while the diffuse solar radiation made up 72.9% of the total transmitted solar radiation. Lastly, the proportion of transmitted beam and diffuse solar radiation through the west-facing window were 38.8% and 61.2% of the total transmitted solar radiation. Comparatively, the west-facing window had a relatively higher beam solar radiation, approximately 1.81 times that of the east-facing window and 1.85 times that of the south facing window.

Window transmitted solar radiation of shaded window

After the windows for each orientation were shaded with a louvered overhang, the transmitted solar radiation reduced for each orientation. Total transmitted solar radiation was reduced by 24.9% in the east-facing window, 22.7% in the south-facing window and by 27.3% in the west-facing window. The beam solar radiation for the west-facing window was reduced by 38.7%, whiles the south and east facing window had 34.5% and 38.4% reduction respectively. The louvered overhang also resulted in a reduction of the total diffuse solar radiation by 20% for the east-facing window, 18.3% for the south-facing window and 20.1% for the west-facing window. This order of reduction matches the visual shadow cast by the louvered with east and west having the most window shaded fraction.

East Window	Base case	Louvered	Percentage reduction
Window Total Transmitted Beam Solar Radiation [kWh]	347.52 (26.4%)	214.18 (21.7%)	38.4%
Window Total Transmitted Diffuse Solar Radiation [kWh]	967.99 (73.6%)	774.13 (78.3%)	20.0%
Window Total Solar Radiation [kWh]	1,315.51	988.32	24.9%

Table 5: Percentage reduction of solar radiation after louvered shading was introduced to east window

South Window	Base case	Louvered	Percentage reduction
Window Total Transmitted Beam Solar Radiation [kWh]	340.24 (27.1%)	222.75 (22.9%)	34.5%
Window Total Transmitted Diffuse Solar Radiation [kWh]	919.00 (72.9%)	751.15 (77.1%)	18.3%
Window Total Solar Radiation[kWh]	1,259.24	973.90	22.7%

Table 6: Percentage reduction of solar radiation after louvered shading was introduced to south window

West Window	Base case	Louvered	Percentage reduction
Window Total Transmitted Beam Solar Radiation [kWh]	630.14 (38.8%)	386.25 (32.7%)	38.7%
Window Total Transmitted Diffuse Solar Radiation [kWh]	995.16 (61.2%)	794.67 (67.3%)	20.1%
Window Total Solar Radiation [kWh]	1,625.30	1,180.92	27.3%

Table 7: Percentage reduction of solar radiation after louvered shading was introduced to west window

The analysis demonstrates that the reduction in beam solar radiation by the louvered overhang was most significant in the west-facing window, followed by the east-facing window. The louvered overhang was most effective at the windows with the higher beam solar radiation. Also, the shadow cast by the louvered overhang was able to create a cooler microclimate over the window in the east, and west orientation. This mechanism aided the higher percentage reduction in the diffused solar radiation for the east and west facing window as compared to the south.

Heat balance Analysis of Model

The energy balance demand was examined for the model with east, south and west facing window, as seen in Figure 4.8. The heat gain or loss was estimated for seven categories comprising of people, equipment, lights, windows, opaque surfaces, infiltration, and ventilation. The heat gain for the base case (unshaded) condition remained constant for all categories, except for window and envelope. The window heat gain was 1486.43 kWh, 1429.60 kWh and 1807.4 kWh for east, south and west facing window model respectively. The higher heat gain in the west direction can be attributed to the high total transmitted solar radiation from the west orientation as explain in Figure 4. *7*.

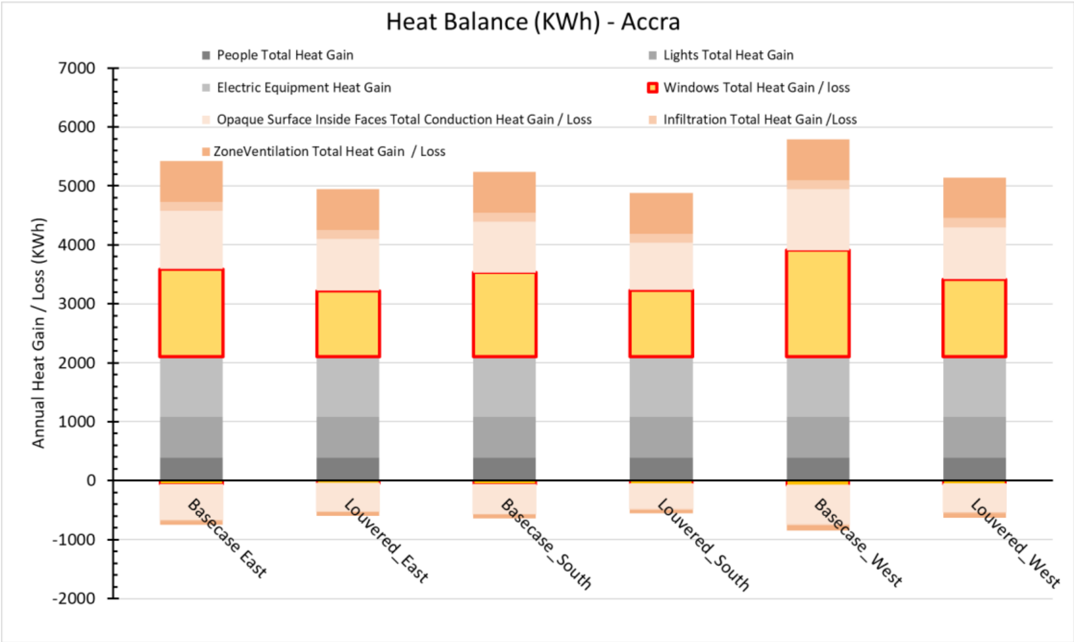


Figure 4.8: Influence of Louvered overhang on the heat balance of building with east, south or west-facing windows (Accra)

The effect of the louvered overhang on the heat gain in the windows was evaluated in all three orientations. In all cases, the louvered overhang resulted in a reduction in the heat gain through the window. The percentage reduction in the total heat gains through the east, south and west-facing windows were 24.8%, 20.8% and 27.2% respectively. These percentage reductions matched the percentage reduction of 24.9%, 22.7% and 27.3% observed in total transmitted solar radiation because of the louvered overhang in the east, south and west orientation, as seen in Table 6 and Table 7. It can therefore be concluded that a reduction in the transmitted solar radiation corresponded to a similar reduction in the heat gain through the window.

Impact of louvered overhang on cooling load

Figure 4. *9* shows the total annual cooling load in Accra for the three window positions for the base case (unshaded) and the louvered overhang condition. The graph shows that the west facing window has the highest cooling load of 5017.1 kWh for the base case. This value was greater than the cooling load in the east and south orientation by 7.8 %. The higher cooling load can be attributed to the high amount of total surface window transmitted solar radiation.

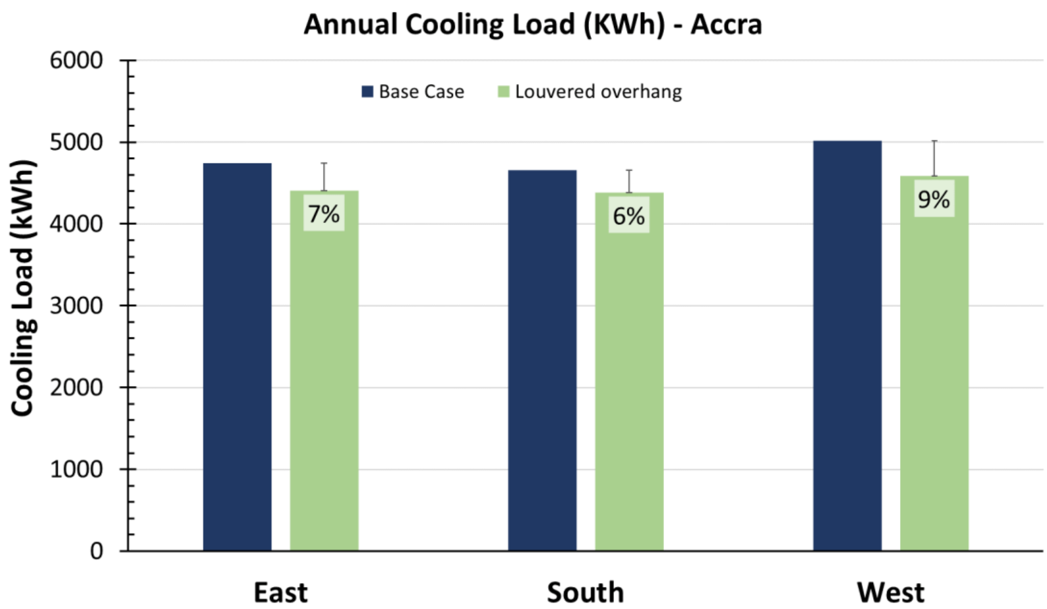


Figure 4. 9: Annual Cooling Load demand for an east, south and west facing window with and without Louvered overhang

All simulation cases with the louvered overhang had a cooling load reduction when compared to the base case (unshaded). This confirms that the exterior reduced the building cooling load. From Figure 4. *9*, the cooling load reduction in the east, south and west facing window was 7.0%, 6.0% and 9.0% respectively. This reduction, though significant in all positions, was more noticeable in the west-facing window. A possible reason for this is because the horizontal louvered overhang was able to block a high proportion of the beam solar radiation. Also, the overhang produced large shadow overcast which created a cool microclimate over the window surface, thereby reducing the solar heat gain and consequently the cooling load.

Effect of Louvered overhang on daylighting

A daylighting analysis of the space was done to assess the effect of the louvered overhang on the model's Useful Daylight Illuminance (UDI) and Annual Sunlight Exposure (ASE). The analysis measured the percentage of the room that receives an acceptable illuminance (UDI) for an office space ranging from 300 lux to 3000 lux across the year and the sunlight penetration into the space (ASE). Figure 4.10 to Figure 4.12 shows the UDI & ASE for the space with and without shading. The UDI of the space without shading was between 74.5% - 79.2%. It was observed that the addition of the louvered overhang improved the UDI in all cases of the louvered overhang on the window. The UDI improved by 3.9%, 2.6% and 5.4% in the east, south and west-facing window respectively. The ASE on the other hand, reduced by 18.8%, 4.5% and 11.6% in the east, south and west orientation which is a significant improvement especially for the west and east facing windows. It can be concluded that the louvered overhang improved the daylight penetration and distribution in the space and reduced the percentage of areas receiving excessive illumination above 3000 lux.

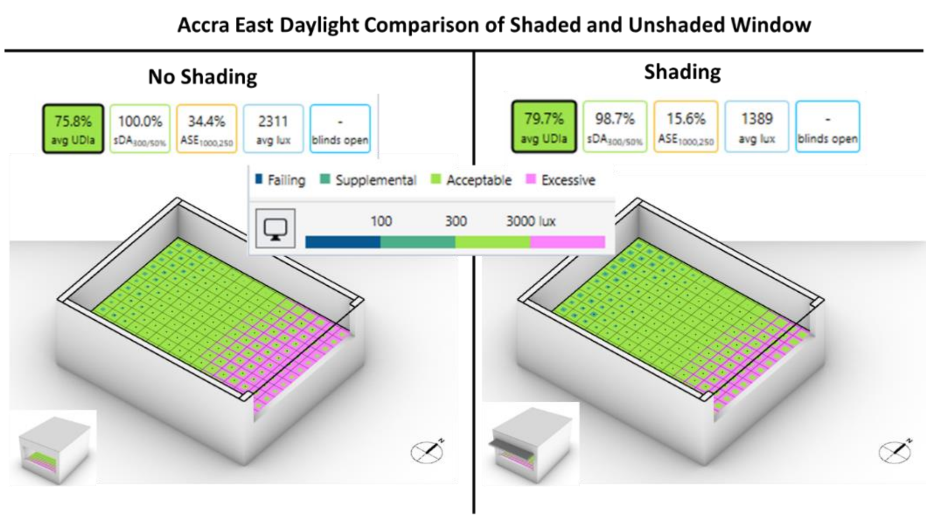


Figure 4.10: UDI calibration of model with or without shading for East-facing window

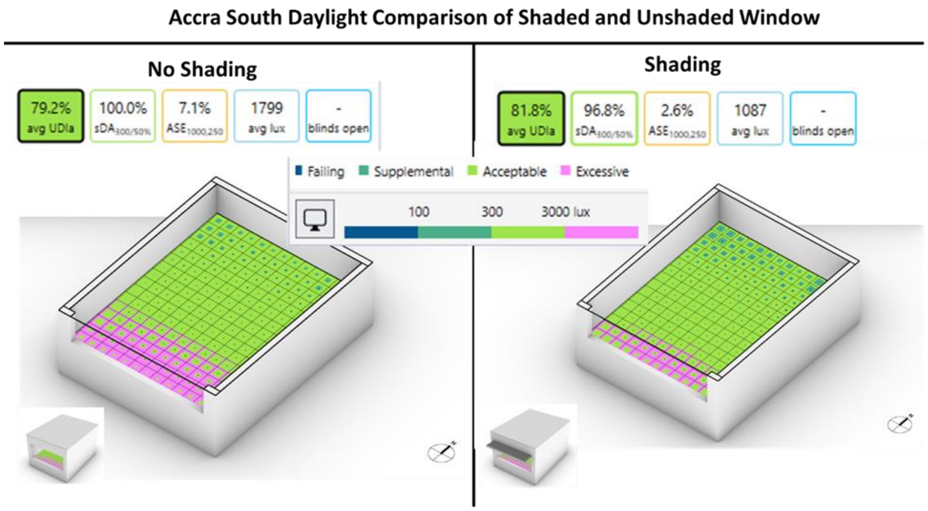


Figure 4.11: UDI calibration of model with or without shading for South-facing window

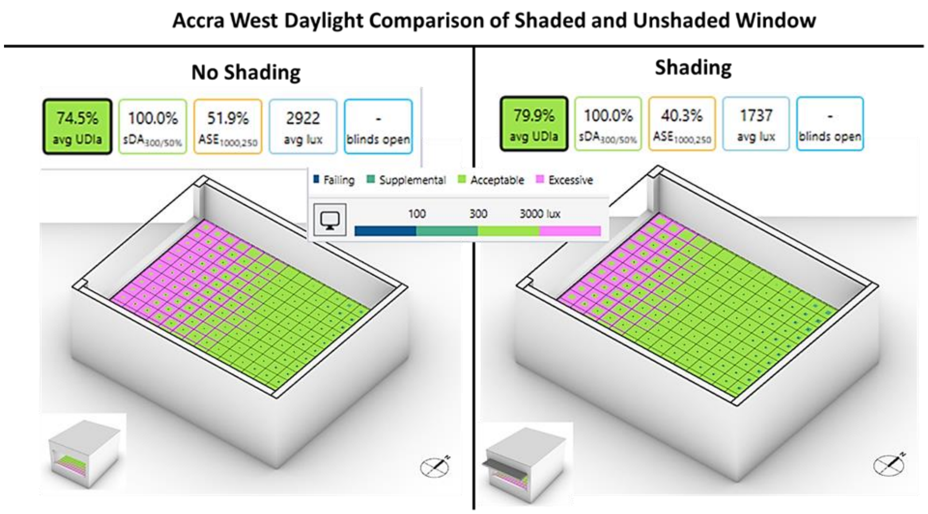


Figure 4.12: UDI calibration of model with or without shading for West facing window

Daylight Analysis - Accra		
East	ASE Reduction	-18.8
	UDI Increase	+3.9
South	ASE Reduction	-4.5
	UDI Increase	+2.6
West	ASE Reduction	-11.6
	UDI Increase	5.4

Table 8: Percentage change in UDI & ASE with shading.

Summary

For Accra, the highest range incident solar radiation of 840-960 kWh/m^2 occurs on the west facing surfaces. This eventually results in high annual total window transmitted solar radiation of 1,625.3 kWh on the west facing window of the buildings, of which 38.8% was direct beam solar radiation. The east and south facing windows, aside from having low incident radiation, have lower proportion of beam solar radiation transmitted through the window. When louvered overhang was installed on any of these window orientations, the overhangs are most effective at intercepting solar radiation in the west orientation compared to the other orientations because the west orientation had more beam solar radiation. The percentage reduction in the window transmitted solar radiation was directly proportional to the percentage reduction in the heat gain reduction in the room. The louvered overhang was most effective on the west facing window of the building reducing the cooling load by 9.0% when compared to the unshaded base case. In addition, the louvered overhang had the best improvement in UDI of 5.4% from the base case (unshaded) in the west-facing window and an ASE reduction of 18.8% in the east orientation.

RESULTS AND DISCUSSIONS FOR MIAMI

Primary source of window heat gains in - Miami

Evaluations were conducted to understand the main sources of heat through the south, east and west-facing windows of an office space in Miami including global horizontal radiation, incident solar radiation falling on vertical building surfaces and a shadow study of shaded window on each orientation. To understand the source of heat, the heat balance analysis of the shoebox model was conducted, and the solar radiation transmitted into the space through the window was analyzed.

Global horizontal radiation - Miami

The pattern and amount of solar energy radiated on an exterior horizontal surface per square meter from 8am to 6pm everyday in the year, as presented on a sun-path diagram for Miami can be seen in Figure 4.13. It was observed that, the periods of peak global horizontal radiation are between 11am and 3pm from March to September.

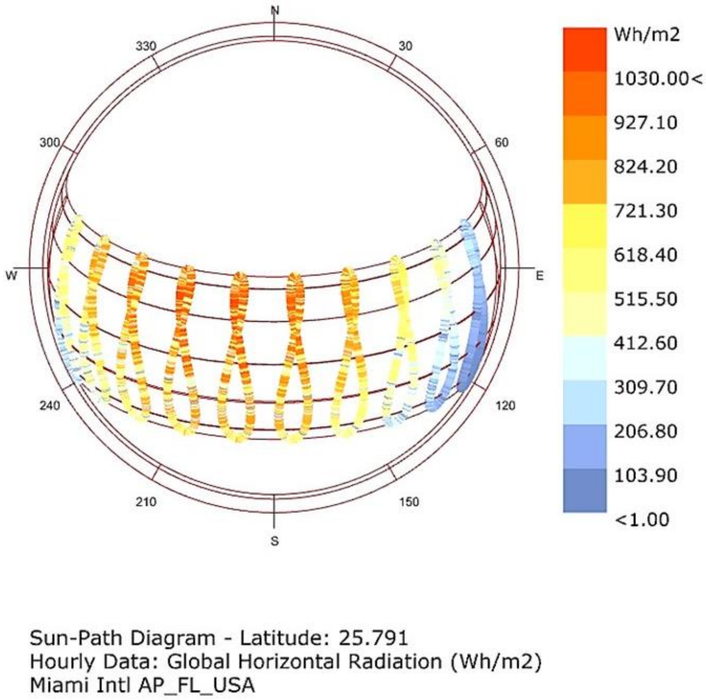


Figure 4.13: Global horizontal radiation for Miami produced in Ladybug Grasshopper

Shadow study of shaded window - Miami

From the global horizontal radiation chart above, the main periods of concern in analyzing shadows cast by the louvered overhang are March, June, and September at noon and 3pm. The east-facing window as seen in Figure 4. *14* is completely shaded at 3pm all year. The louvered overhang cast a shadow on about 30-15% of the window from March to September.

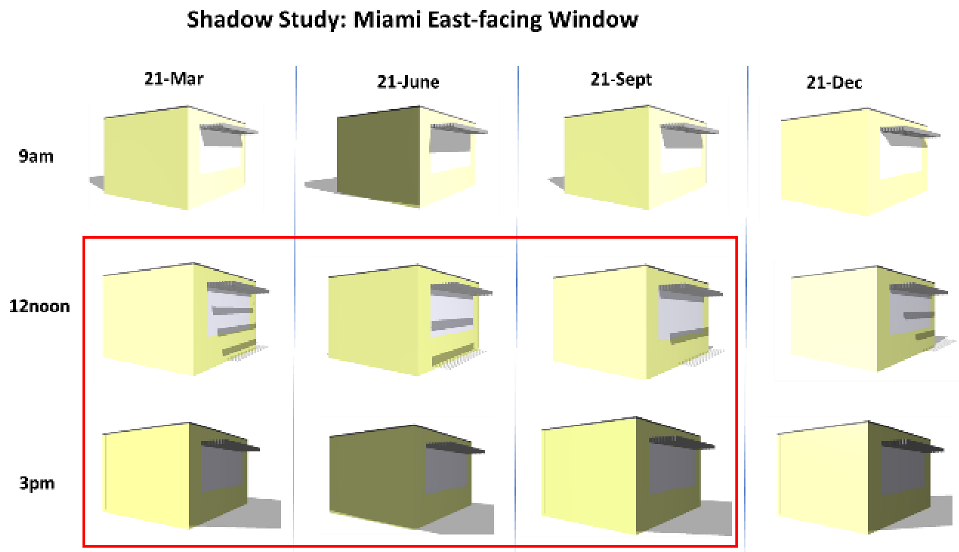


Figure 4. 14: Shadows cast by louvered overhang on east-facing window in Miami

For the south-facing window, the louvered overhang cast a shadow on about 97% of the window in March and September and shaded only about 30% of the window in June at noon. At 3pm, the louvered overhang shaded 80% of the window in March and September and 100% of window in June as seen in Figure 4. *15*.

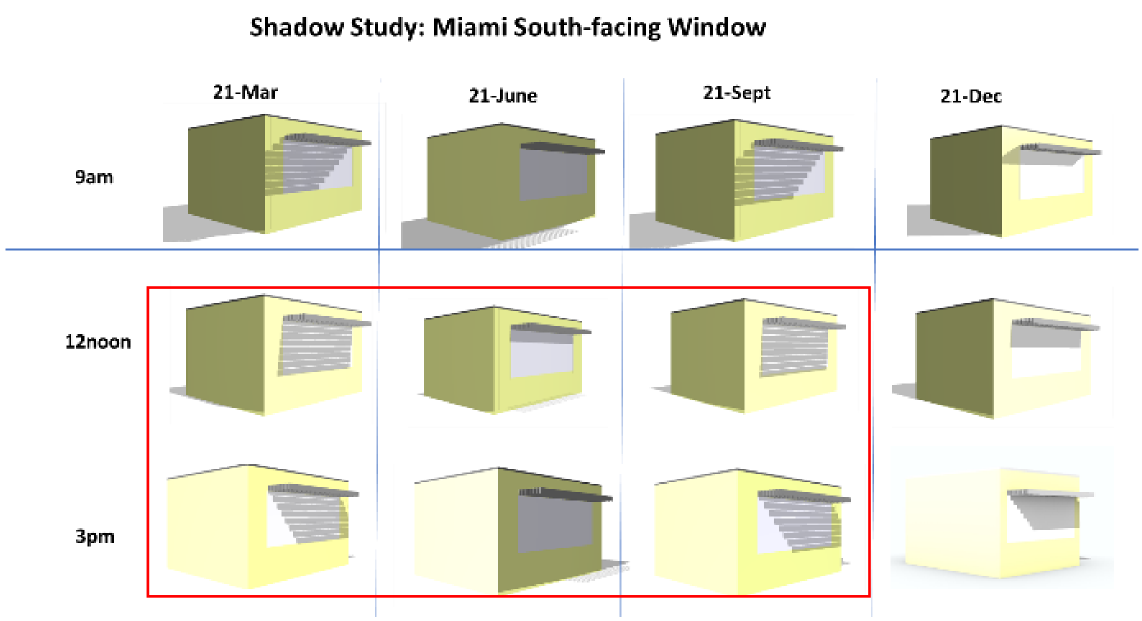


Figure 4. 15: Shadow cast by louvered overhang on south-facing window in Miami

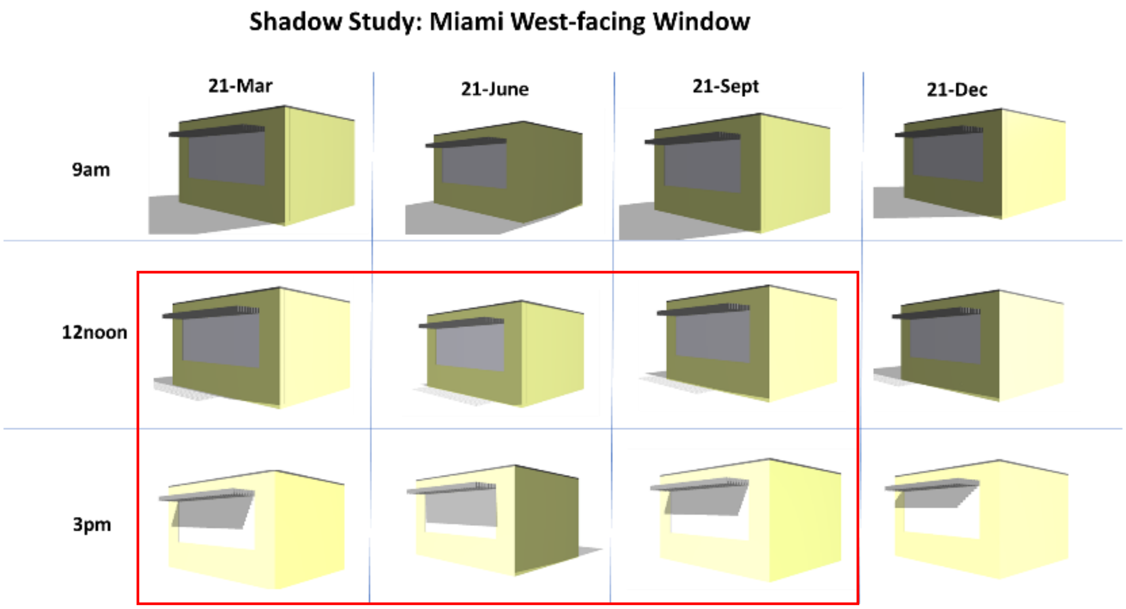


Figure 4. 16: Shadow cast by louvered overhang on west-facing window in Miami

The west-facing window was 60 - 80% shaded by the louvered window at 3pm from March to September and at noon, it was completely in shade as seen in Figure 4. *16* above.

In General, based on the window shaded fraction all twelve images for the three window orientations in Miami, the louvered overhang provided highest area of shading on the west window, followed by the south window. The east window overall, had the least shadow cast from the louvered overhang.

Incident radiation falling on surfaces

Figure 4.17 shows the annual incident radiation falling on all sides of the building orientation in Miami. Maximum solar incident radiation of 1080 kWh/m^2 was observed on the south orientation, 960 kWh/m^2 on the west and 840 kWh/m^2 on the east orientation. Generally, the analysis shows that the south orientation receives the most solar incident radiation, followed by the west and the east respectively, each compared to their baseline condition.

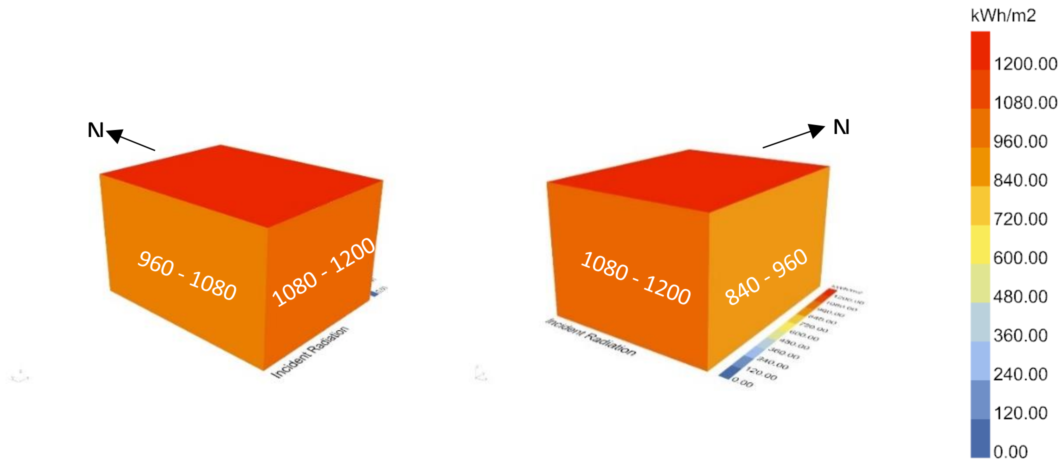


Figure 4.17: Annual incident solar radiation on east, south and west orientation of a typical building (Miami)

Window transmitted Solar Radiation of unshaded window in Miami

The monthly total transmitted window solar radiation on all three-window orientation with or without louvered overhang for Miami is shown in Figure 4.18. The monthly window transmitted solar radiation for the east-facing window started with the lowest low window transmitted solar radiation of 48.31 kWh from January and gradually rose to peak value of 76.87 kWh in May, then dropped down steadily back to 44.81 kWh by December. The south facing window on the other hand had the reverse behavior. The highest solar transmitted radiation value range of 132.45 – 151.28 kWh was observed from November to February and a shape decline April to October with the lowest of 0.23 kWh in the month of June.

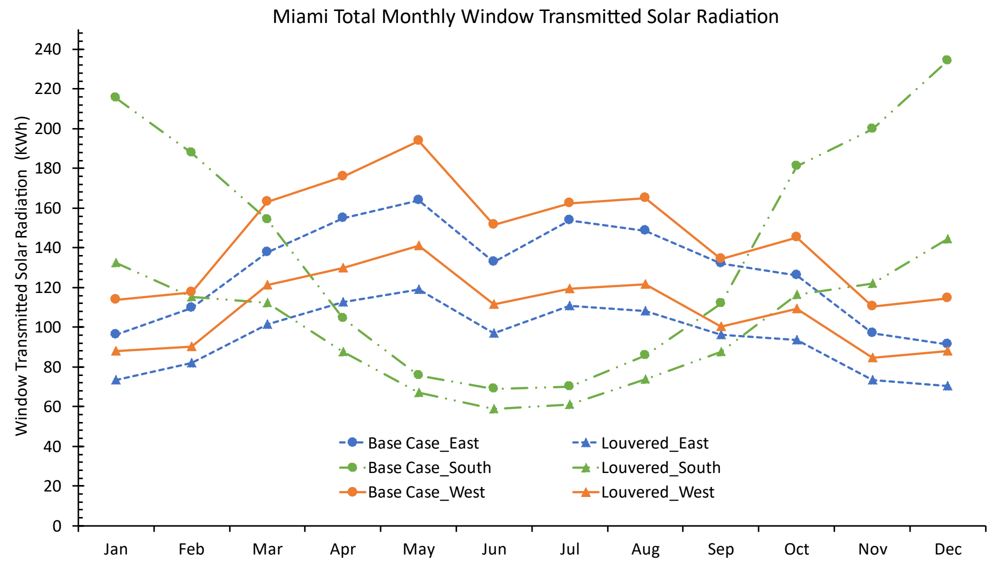


Figure 4.18: Total monthly transmitted solar radiation through east, south and west-facing windows (Miami)

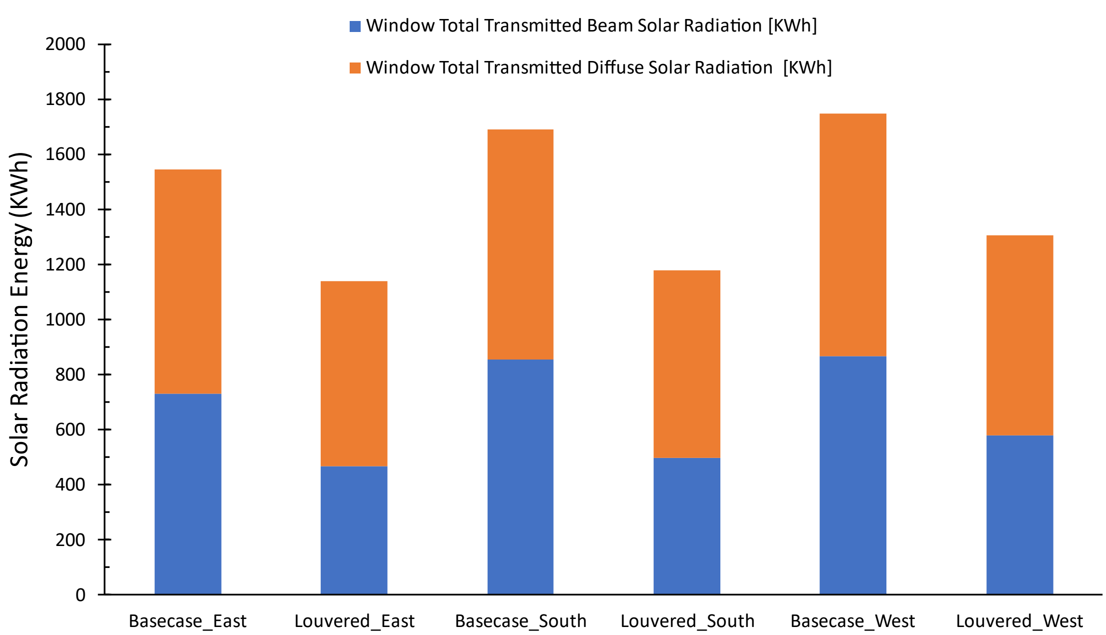


Figure 4.19: Annual Window Transmitted Beam & Diffused solar radiation through east, south and west-facing windows with and without overhang shading (Miami)

The south and west unshaded windows had high annual total transmitted solar radiation of 1,748.05kWh and 1,688.99 kWh while the east facing window had an annual total transmitted solar radiation of 1,543 kWh. For the east-facing window, beam solar radiation made up 47.4% of the total transmitted solar radiation while diffuse solar radiation made up 52.6% of the total transmitted solar radiation. For the south-facing window beam solar radiation made up 50.5% of the total transmitted solar radiation while the diffuse solar radiation made up 49.5% of the total transmitted solar radiation. Lastly, the proportion of transmitted beam and diffuse solar radiation through the west-facing window were 49.5 % and 50.5 % of the total transmitted solar radiation. It can be observed there was almost an even distribution of the total solar radiation into beam and diffused solar radiation. Comparatively, the west and south-facing window had the most beam solar radiation of 265 kWh/m^2 and this value was approximately 1.18 times that of the east facing window.

Window transmitted solar radiation of shaded window in Miami

The introduction of a shadow from the louvered overhang resulted in a reduction in the total solar radiation across all orientations as seen in Figure 4.19. The most reduction was recorded in the south facing window which had 30.2% reduction, followed by east and west with 26.3% and 25.4% respectively. The effect of the overhang was most pronounced in beam solar radiation reductions. The east, south and west facing windows had reductions of 36.3%, 41.8% and 33.1% in the beam solar radiation. The louvered overhang also resulted in a reduction of the total diffuse solar radiation by 17.3% for the east-facing window, 18.4% for the south-facing window and 17.8% for the west-facing window. The south and west-facing windows which had the most diffused solar radiation reduction matched the orientations with the most window shaded fraction.

East Window	Base case	Louvered	Percentage reduction
Window Total Transmitted Beam Solar Radiation [kWh]	731.73 (47.4%)	466.40 (41.0%)	36.3%
Window Total Transmitted Diffuse Solar Radiation [kWh]	811.99 (52.6%)	671.23 (59.0%)	17.3%
Window Total Solar Radiation [kWh]	1,543.71	1,137.63	26.3%

Table 9: Percentage reduction of solar radiation after louvered shading was introduced to east window

South Window	Base case	Louvered	Percentage reduction
Window Total Transmitted Beam Solar Radiation [kWh]	853.24 (50.5%)	496.73 (42.1%)	41.8%
Window Total Transmitted Diffuse Solar Radiation[kWh]	835.75 (49.5%)	682.13 (57.9%)	18.4%
Window Total Solar Radiation [kWh]	1,688.99	1,178.85	30.2%

Table 10: Percentage reduction of solar radiation after louvered shading was introduced to south window

West Window	Base case	Louvered	Percentage reduction
Window Total Transmitted Beam Solar Radiation [kWh]	865.27 (49.5%)	579.21 (44.4%)	33.1%
Window Total Transmitted Diffuse Solar Radiation [kWh]	882.78 (50.5%)	725.40 (55.6%)	17.8%
Window Total Solar Radiation [kWh]	1,748.05	1,304.61	25.4%

Table 11: Percentage reduction of solar radiation after louvered shading was introduced to south window

The results suggests that the louvered overhang was most effective at blocking the beam solar radiation, most noticeable on the south facing window. Also, high amount of shadow cast by the louvered overhang resulted in a cooler microclimate over the window in the south and west orientation. This mechanism aided the higher percentage reduction in diffused solar radiation for the south and west facing window.

Heat balance Analysis of room with and without louvered overhang in Miami

Figure 4.20 shows the heat balance for the base case (unshaded) and the louvered overhang condition for seven categories: people, equipment, lights, windows, opaque surfaces, infiltration, and ventilation. The louvered condition showered significant reduction in the heat gain across all window orientations. The most heat gain reduction occurred on the south facing window which was 29.7 % lower than the base case condition. The east and west facing window also had significant reduction of 26.7 % and 25.5 %. Once again, these values matched the corresponding reduction observed for the total annual transmitted solar radiation of 30.2 %, 26.3 % and 25.4 %

in the south, east and west window orientation. It can therefore be concluded that a reduction in the transmitted solar radiation would correspond to a similar reduction in the heat gain through the window.

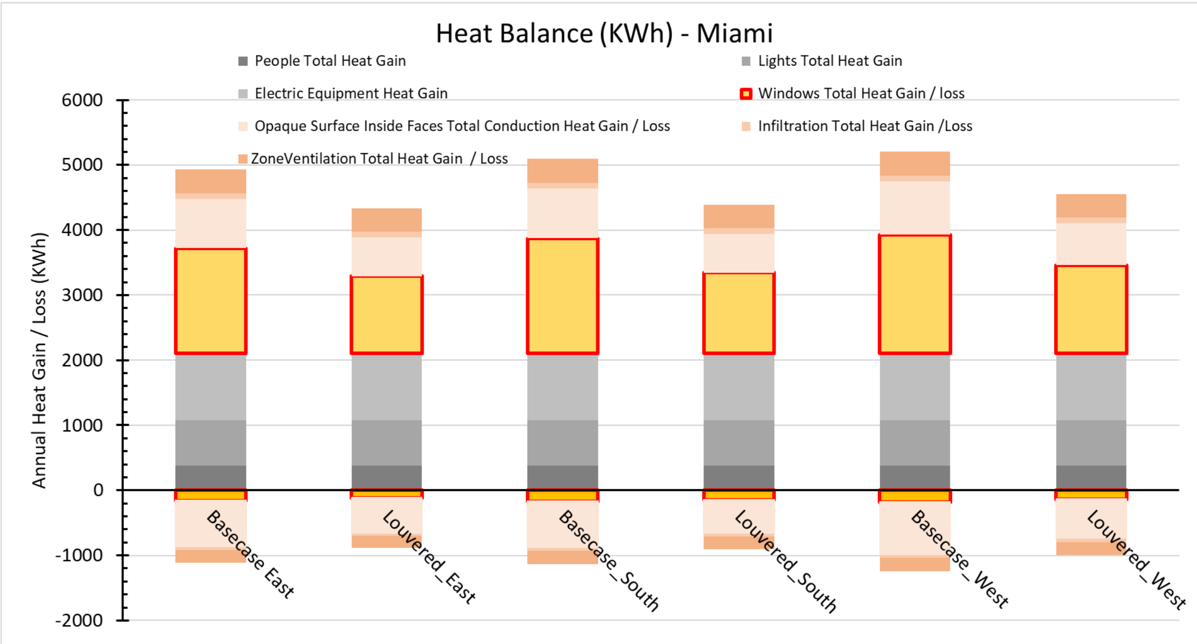


Figure 4.20: Influence of Louvered overhang on the heat balance of building with east, south or west-facing windows (Miami)

Impact of louvered overhang on cooling load in Miami

The cooling load demand for the base case (unshaded) and the louvered condition is shown in Figure 4.21. The louvered overhang resulted in cooling load reduction of 10.0%, 12.0% and 10.0% in the east, south and west window orientations. This confirms that the exterior shading was helpful to reduce the building cooling load. The highest reduction was observed in the south facing window. The possible reason for this observation is because the horizontal louvered overhang blocked the highest proportion of the beam solar radiation while creating shadow cast over the window surface. This consequently resulted in lowering the window solar heat gain and the space cooling load.

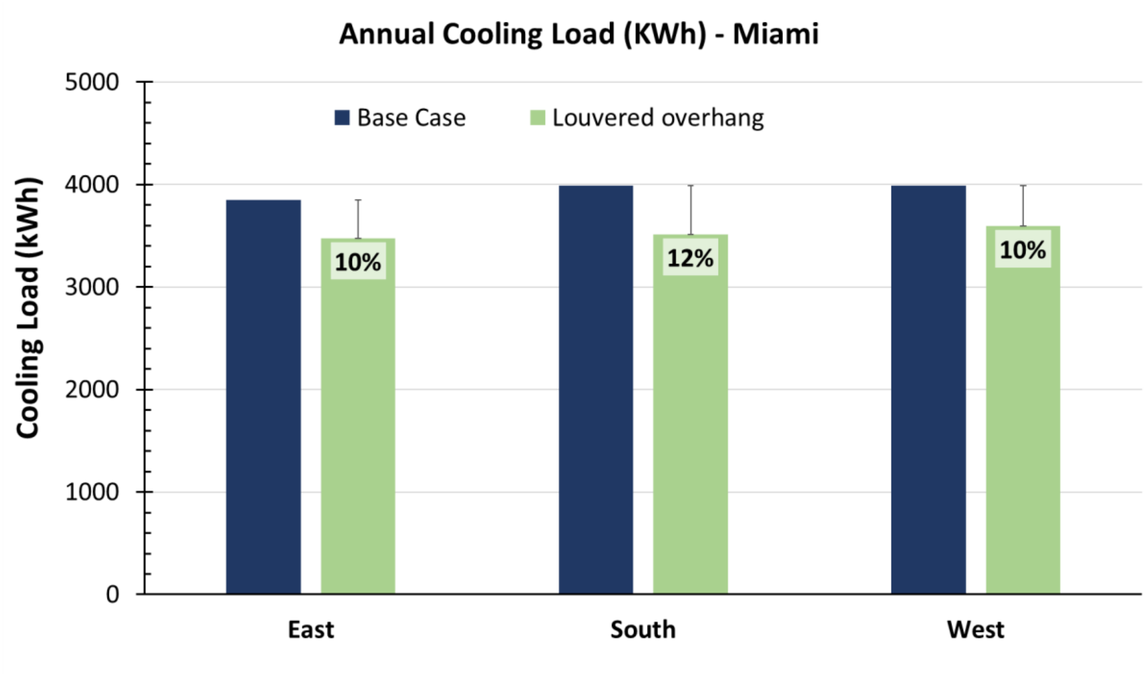


Figure 4.21: Annual Cooling Load demand for an east, south and west facing window with Louvered overhang

Effect of Louvered overhang on daylighting in Miami

Figure 4.22 to Figure 4.24 show the UDI in the model space for the three orientations with and without shading. The unshaded models have UDI within the range of 74.5 to 75.8 %. The addition of louvered overhang improved the UDI in all cases of the window orientation. The maximum improvement was observed in the south orientation with 3.4 % increase in UDI followed by 2.4 % in the east and 1.9 % in the west direction. This shows the louvered overhang was most effective in reducing cooling load and improve UDI in the south orientation than the east and the west-facing window.

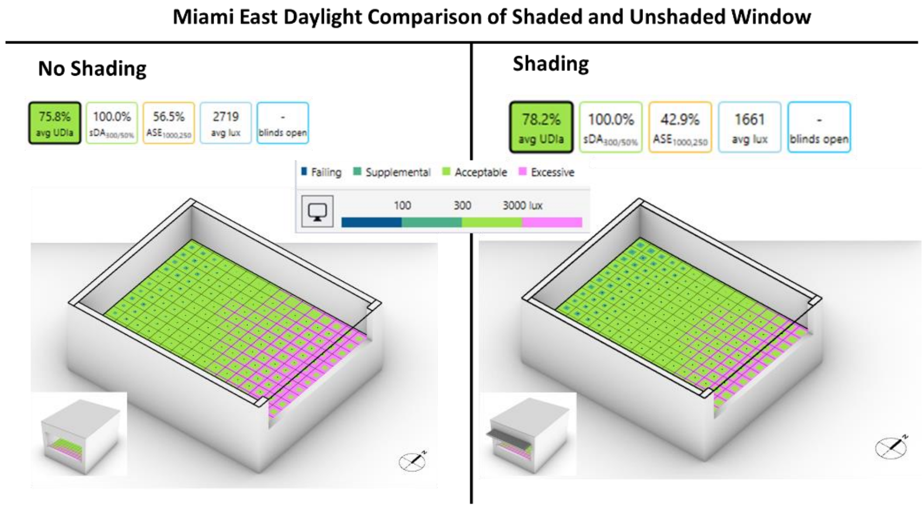


Figure 4.22: UDI for model with and without shading for east-facing window in Miami

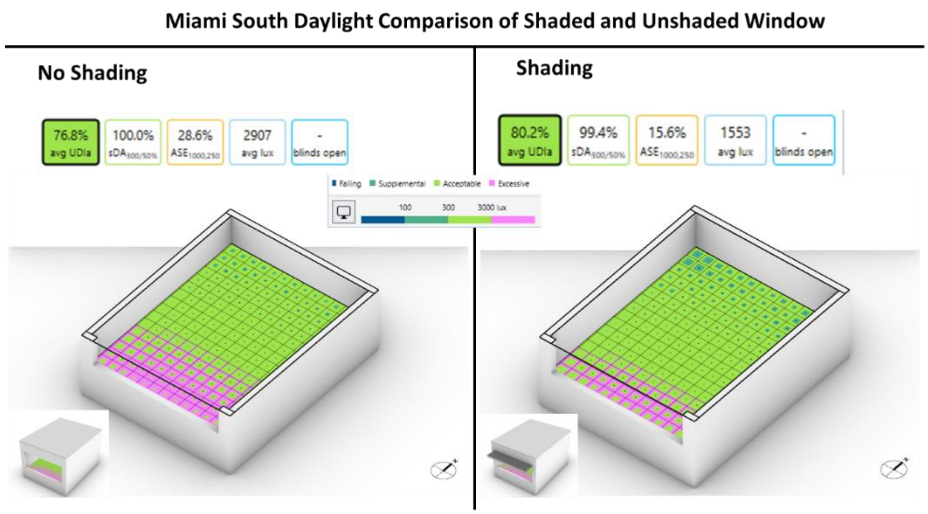


Figure 4.23: UDI for model with and without shading for south-facing window in Miami

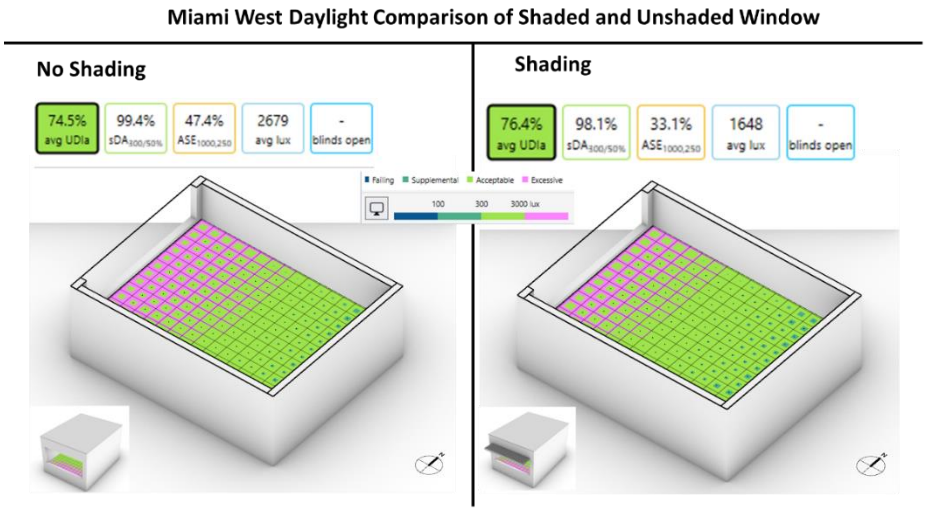


Figure 4.24: UDI for model with and without shading for west-facing window in Miami

Daylight Analysis - Miami		
East	ASE Reduction	-13.6
	UDI Increase	+2.4
South	ASE Reduction	-13.0
	UDI Increase	+3.4
West	ASE Reduction	-14.3
	UDI Increase	1.9

Table 12: Percentage change in UDI & ASE with shading.

Summary

In summary, Miami's highest range of incident solar radiation of 960 - 1080 kWh/m^2 occurs on the south and west facades of the building. This results in high annual total window-transmitted solar radiation of 1,748.05kWh and 1,688.99 kWh on the south and the west facing windows, of which about 50.0% was beam solar radiation in all orientations. When the windows were analyzed with the louvered overhang, the shading device had the most effect on the south facing window, reducing window total transmitted solar radiation by 30.2% and most noticeably reducing the beam solar radiation by 41.8%. The corresponding window heat gain reduction of 29.7% closely matched the reduced total window transmitted solar radiation of 30.2%. This gives extra credence to the correlation between window total solar radiation and total window heat gain. The louvered overhang was most effective on the south facing window of the building reducing the cooling load by 12.0% when compared to the unshaded base case condition. Also, the improvement in the UDI after the addition of the louvered overhang was best in the south orientation with a 3.4% increase in UDI compared to the UDI of the space without shading.

COMPARISON BETWEEN ACCRA AND MIAMI

While Accra is classified as a climate 0A zone and Miami is classified as climate 1A zone, Miami has a higher incident radiation than Accra.

- The highest incident radiation in Miami of 1080 to 1200 kWh/m^2 occurs on the south side whiles the highest radiation of 840 to 960 kWh/m^2 occurs on the west side of the building for Accra. The high incident radiation on vertical surfaces in Miami relative to that of Accra can be attributed to the low solar angle at Miami.
- The months of high window transmitted solar radiation in Miami are from April to August whiles the months with high window transmitted solar radiation in Accra are October to March.
- Beam transmitted solar radiation constitute about 26 - 38% of the total window transmitted solar radiation in Accra whiles about 50% of the total window transmitted solar radiation in Miami was from beam transmitted solar radiation.
- The louvered overhang had maximum window heat gain reduction of about 27.3% in west for Accra whiles Miami had a maximum reduction of 30.2% in the south orientation.
- The corresponding total cooling load reduction was 9% for Accra at the west orientation and 12% for Miami in the south orientation.
- It should also be noted that the exterior envelope type for Accra was concrete masonry construction which had no insulation layer while that of Miami was stud wall construction with insulation. This could possibly account for the lower corresponding reduction in cooling load despite the greater reductions in window transmitted solar heat gains in Accra. This is an opportunity for future research on exterior envelope assemblies and its cooling load reduction potential particularly in Accra.
- For Miami, the unshaded models have UDI on all three orientation was within the range of 74.5 to 75.8% whiles that of Accra was within the range of 74.5% - 79.2%. The low

UDI in Miami is due to the low solar angle which causes more glare from all the three window orientations than the that for Accra. The louvered overhang improved UDI by 3.4 %, 2.4 % and 1.9 % south, east, and west when compared to the base case for Miami. Whiles for Accra, UDI was improved by 3.9%, 2.6 % and 5.4 % in the east, south and west-facing windows.

5. CONCLUSIONS

Impact of Louvered overhang on Solar Heat Gain and Cooling Loads

Accra

For Accra, the primary source of heat gain is through *diffused solar radiation*. This made up 61.2 – 73.6% of the total window-transmitted heat gain. The louvered overhang caused a reduction of 18 – 20% in the total diffused solar radiation. *Beam solar radiation* which constituted about 26.4 – 38.7% of the total window-transmitted heat gain saw the most reduction of 34.5% - 38.7% from the base-case with the louvered overhang. The west-facing window experienced the most beam solar radiation. It can be concluded that the louvered overhang was more effective in reducing the beam solar radiation than the diffused solar radiation. Also, louvered overhang resulted in the cooling load reduction of 6.0 – 9.0% from the base-case where the west facing window had the most reduction of 9% from the base-case when compared to the east and south. It should also be noted that the exterior envelope type was concrete masonry construction which had no insulation layer. This could possibly account for the lower corresponding reduction in cooling load in spite of the greater reductions in window transmitted solar heat gains. Generally, horizontal shading mechanisms, which was most effective at reducing beam solar radiation, can be targeted on the west-facing window of building retrofits. Future research should explore shading devices that may help further reduce diffuse solar radiation The shading systems studied were normative, but not optimal. The simulation-based approach of this study could be used to study more shading geometries and find even more optimal solutions.

Miami

For Miami, the primary source of heat is an even 50% - 50% split of *diffused solar radiation* and *beam solar radiation*. *Diffused solar radiation* had 17.3% - 18.4% reduction whiles the beam solar radiation had a reduction of 33.1% - 41.8% from the base-case after introducing the louvered overhang. The south-facing window which had the most beam solar radiation also had the most reduction of 41.8% from the base-case model. The cooling load reduction from the base-case range from 10.0% - 12.0% after introduction of the louvered overhang to the model. It can be concluded that horizontal shading mechanisms though effective on all three window orientations, would be most effective in reducing heat gain when installed on the south-facing window in retrofit office buildings in Miami.

Impact of fixed louvered overhang on UDI

The study was able to prove that the louvered overhang shading device was able to reduce excessive sunrays and eliminated sources of glare by protecting the space from direct sun. For Accra the introduction of the louvered overhang provided 79.7% to 81.8% annual daylit areas in the tested spaces whiles in Miami the annual daylit areas was 76.4% to 80.2%. These values were an improvement from the base case condition, a prove that the louvered overhang help improved daylight distribution, prevent glare, and improved energy conservation.

Recommendations and areas for future study

Considering the potential of window shading as a retrofitting measure to reduce energy consumption, and the low popularity for building adaptation and retrofitting as opposed to demolishing and new construction, it is recommended that government of Ghana puts policies in place to incentivize retrofitting so as to encourage retrofitting.

It should be noted that the study was based on a simulation-based study. Field tests are important to confirm the validity of the results especially for Accra since we lack simulations that have been field-validated for this location. Moreover, there are more areas of untapped knowledge which could be investigated. Below are lists of areas which can be explored in future research work.

- Field tests to measure the cooling load reduction with horizontal louvered overhang for office space in Accra
- Diffused solar transmitted radiation constitutes about 70% of the total transmitted solar radiation for Accra. Tilting the slats of the louvered overhang or otherwise designing a system with optimal shading geometry could give the windows more shade during peak periods of solar radiation. Investigating the effect of form and tilt on a louvered overhang could further reduce cooling load.
- Research on exterior envelope assemblies including insulated and uninsulated concrete masonry construction and its cooling load reduction potential particularly in Accra

- Building on the findings of this research, future studies should also explore cost benefit analysis of optimal shading geometries and material for all window orientations. This will help ascertain the most efficient retrofitting measures and will be a good basis for government policies to incentivize building retrofits in Accra.

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