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A Study of Shading Devices in Modern Architecture for the Hot Humid Climate of Phnom Penh, Cambodia

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ABSTRACT

Due to global warming caused by carbon dioxide emissions, for the last decade or longer, there has been a strong focus on reducing energy consumption. Among the many technologies, old and new, available for this purpose, one is a shading device, which is required in a hot and humid climates to protect building interiors from solar radiation that can penetrate the building, increasing the energy demand for the cooling load. Such shades are well-known and have been used widely since the dawn of the modern architectural era. In Phnom Penh, there are different kinds of shading devices in modernist architecture that demonstrate creativity in the shading of façades. To maximize their effectiveness in contributing to the fight against global warming, it is necessary to study their fundamental shadowing behaviors so that new technology can be developed and applied to today's buildings.

This study aims to explore the shading types in modern architecture in Phnom Penh, and evaluate different aspects of these shading devices in terms of shadow performance by using an extension tool in Sketch-UP, Shadow Projector V.7 by TIG.

The results show that shading devices on modern buildings in Phnom Penh are defined by a deep overhang, and horizontal louvers hung from the overhang. Vertical fins, slanted fins, and egg-crate patterns are also used on the façades. According to the evaluation results, egg-crate provided the best shading performance among all shading cases and orientations studied. It was also found that a horizontal louver hung from the overhang can increase shading performance by 20% in all directions, and that it is more efficient than vertical fins for East, West, SE, and SW orientations. Moreover, the overhang is the most efficient in north-facing façades. Vertical fin types, on the other hand, are unreliable for East, West, SE, and SW orientations. The vertical slanted fin type is also unreliable in any orientation or season due to the slanted position and the sun's travel path.

The results of this study will help designers optimize the shadowing behavior of shading devices, particularly with respect to building orientation. The research findings highlight the fundamentals, which can be enhanced future studies that focus on compatibility assessment of shading devices used in new-era buildings.

Keywords: shading device, shadow performance, modern architecture, hot and humid climate

INTRODUCTION

The world's population is projected to reach 8.5 billion by 2030, and to exceed 11 billion by 2100, according to the United Nations (2015), which will result in constantly increasing energy demands. Moreover, greenhouse gas emissions from energy consumption continue to exacerbate the problem of global warming. One of the areas of greatest energy demand is for air conditioning used for cooling indoor spaces. Taking steps to control the amount of power consumed by air conditioning is critical; however, nowadays, many buildings designs are less focused on solar protection, with traditional shading techniques being replaced with mechanical cooling systems.

A great deal of modern Cambodian architecture dates back to the 1960s, when air conditioning was rarely available. Prior to the advent of mechanical air conditioning, various passive elements, such as shading devices, were widely used, and many of these elements have been applied to modern buildings.

The 1960s are known as the 'Golden Age' of Cambodia's Modern Architecture. After Cambodia's Independence in 1953, King Norodom Sihanouk focused on modernizing the country. Over the following 15 years, several thousand buildings were constructed for the public and private sectors (Ross & Collins, 2006). In Phnom Penh, many buildings such as apartments, shophouses, and schools were designed and built with a concrete shading façade to protect against the direct sun for reduced cooling load and energy savings (Ty, 2017).

Shading devices, which are integrated with the building façade and window to protect indoor space from solar radiation, comprise various passive designs to reduce heat gain. They have been known and used wisely since the start of the modern architecture era. Hence, it is necessary to study fundamental shadowing behavior before new designs are developed and applied to today's buildings. Nowadays, shading device forms have been updated based on the materials available on the market, and, with the support of computer programs and technology, architects have developed more complex shading shapes to be applied to building façades. However, shading devices perform differently depending on the location of a building, and it is difficult to find a study that evaluates shading devices used in the climate of Cambodia.

Therefore, this paper aims to evaluate the shading devices (S1 to S5) used in modern architectural buildings in Phnom Penh between 1953 and 1970, based on type and orientations, with respect to their shadow performance. Furthermore, after comparing the shading façades, suggestions will be put forward for choosing appropriate shading devices based on building orientation and type.

Research Question

- What comprises the typical shading devices on modern architectural buildings in Phnom Penh?
- How do these shading types affect the shadow performance at different building orientations in Phnom Penh?

Research Objectives

- To identify the typical shading devices used on modern architecture buildings in Phnom Penh.
- To examine and compare the effect of different shading devices (S1, S2, S3, S4, S5) at eight building orientations (N, E, S, W, NE, NW, SE, SW) on shadow performance in Phnom Penh.

The results of this study can be used as a guideline to select the most effective shading types for buildings in different orientations. Additionally, architects can use the result graphs to help them understand the characteristics of shading device types before developing and applying new shading designs for today's building. Most specifically, the findings will help designers select the most beneficial shading devices for buildings in Cambodia based on each one's orientation.

LITERATURE REVIEW

History of Shading in The Modern Architecture Era

Among all famous architects, Le Corbusier is the one most likely to be linked to sun shading. In 1932 Le Corbusier designed a building known as Cité de Refuge in Paris. It was initially designed with full glass south façade to get sunlight to warm the residents. However, in June the building became unbearably hot. In order to correct this mistake, Le Corbusier invented a fixed sunshade known as a brise-soleil (sun-breaker), which led to a rise in popularity of sun shading in architecture. Le Corbusier integrated shading into modern architecture as a concrete structure (Lechner, 2015), a feature found in several buildings in the tropical zone, such as the Ministry of Education in Rio de Janieiro, Unite d'Habitation in Marseilles, and the Capitol Complex in Chandigarh.

Le Corbusier's arguments regarding the development of the brise-soleil are widely known as Brazil's contribution to contemporary construction in tropical climates, joining a variety of practical, moveable or stable, horizontal or vertical shade devices, as well as smaller-scale cellular and other features made of precast concrete, ceramic, or other materials that add adaptable artillery to modern architecture's façades to block the sun (Guedes, 2021).

Nowadays, shading is being developed based on the materials available on the market; these materials allow architects to explore more complex shading shapes with the help of computer programs and other related technology.

Modern Architecture in Cambodia

Modern Architecture in Cambodia is associated with the modernist architecture movement that developed after the country gained independence from France in 1953 (Ross & Collins, 2006). After Cambodia's independence, King Norodom Sihanouk focused on modernizing Cambodia, and brought both national and international architects to help develop the country's infrastructure. Since modern architecture had started in Europe, the style was not fully compatible with the hot and humid climate of Cambodia. The young Cambodian architects who had been trained in France attempted to combine modern and traditional architecture. They appropriated a variety of elements that allowed them to blend traditional Khmer elements with modern architectural styles.

Modern Khmer architecture combines traditional Khmer culture, modernist influence, and tropical designs capable of dealing with the topical South East Asian climate and environmental conditions. Furthermore, Ross and Collins (2006) report that the austere design of modern architect Le Corbusier was incorporated into Cambodian modern architecture, which is thought to be a confluence of traditional Cambodian cultural principles. As a result, it evolved into vernacular, and included the impact of global modernism and negotiation between many design sources.

Wong (2011) claims that Vann Molyvann, the foremost of a generation of architects who contributed to the unique style of architecture that emerged during this era, had a significant impact on his time by building cultural institutions like the National Theatre Preah Suramit. By utilizing wooden construction materials from the Khmer era and ornamentation inspired by the Angkor Wat stone culture. Additionally, according to Vann Molyvann himself, the architect was influenced by natural elements like water and wind, and this inspiration can be seen in his designs.

Dr. Roger Nelson, an art historian of Cambodian modern and contemporary arts, wrote in his introductory text, Modern Cambodian architecture was characterized as being on four elements:

- the use of new construction materials, chiefly reinforced concrete.
- the visual and structural references to pre-existing Cambodian construction techniques, especially the raising of buildings on stilts.
- a sensitivity to the tropical climate, expressed in the creative use of natural airflow and shading.

- the sparing use of ornamentation, chiefly bas reliefs inspired by Angkor Wat temple decorations (Sereypagna, 2017).

Local Climate of Cambodia

Cambodia is located at a latitude of 11° 59' 16.68" N and a longitude of 104° 58' 50.21" E. The country has a hot humid climate with two distinct seasons: a monsoon-driven rainy season (May-October) with south-west winds ushering in clouds and moisture that accounts for anywhere between 80%–90% of the country's annual precipitation, and a dry season (November-April), with cooler temperatures, particularly between November and January. Average temperatures are uniform across the country, and are highest in the early summer months before the rainy season begins, when maximum temperatures often exceed 35°C. The mean temperatures remain over 27°C throughout the rest of the year (The World Bank Group, 2021).

Hence, architects in Cambodia face many challenges in trying to deal with such a hot, humid climate. Shading devices are practical elements in passive strategies for tropical architecture that have been integrated into architecture for years.

Shading Device Design Theory

Types of Shading Devices

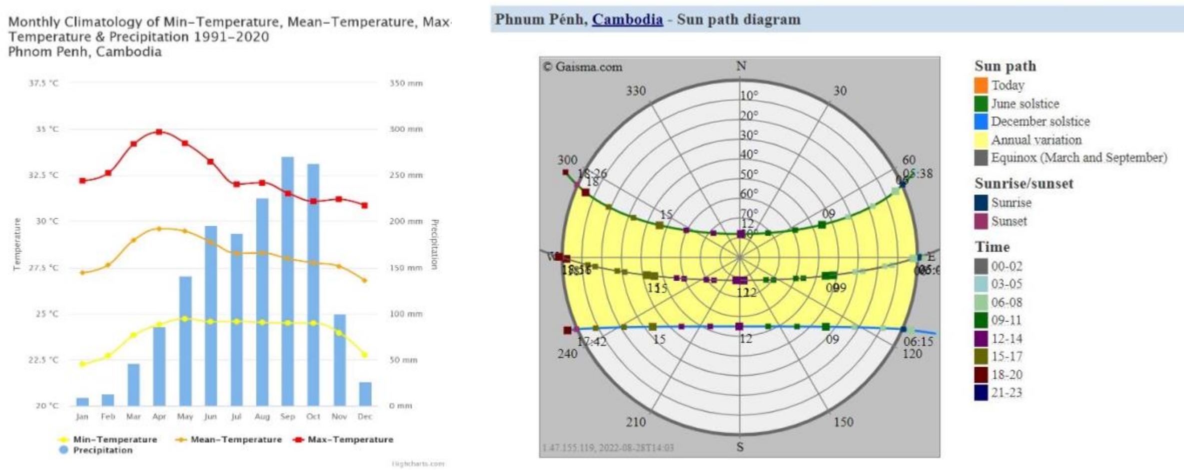
Shading devices are divided into two types based on application: internal shading and external shading. Further, these devices can be fixed or adjustable (And & Asimakkopoulos, 1996).

Fixed shading devices: These are external shading devices such as balconies, louvers, horizontal overhangs, vertical fins, or other devices that incorporate a combination of horizontal and vertical shapes (egg-crate type).

Adjustable shading devices: Outdoor shading elements can take the form of tents, blinds, or pergolas, while internal elements comprise such things as curtains, rollers, blinds, or shutters. Adjustable shading devices can automatically respond to solar radiation and daylight, or they can be adjusted manually.

Figure 1

Temperature and Sun Path Diagram for Phnom Penh



Note. (Left) *Temperature & precipitation 1991-2020 in Phnom Penh, Cambodia*. From Cambodia - Country Specific Information, The World Bank Group, (2021), The World Bank Group (https://climateknowledgeportal.worldbank.org/country/cambodia/climate-data-historical). Copyright 2021 by The World Bank Group. (Right) *Sun path diagram in Phnom Penh, Cambodia*. From Sun Path Diagram in Phnom Penh, Cambodia, Gaisma, (2022), Gaisma (https://www.gaisma.com/en/location/phnum-penh.html). Copyright 2022 by Gaisma.

Altitude and Azimuth Angle

In most practical work we consider our point of location on the earth's surface as the center of the world: the horizon circle is assumed to be flat, and the sky is a hemispherical vault. The sun's apparent position on this 'sky vault' can be defined in terms of two angles (Szokolay, 2007).

- *Altitude* (ALT): measured in the vertical plane, between the sun's direction and the horizontal, from horizontal (0°) to vertical (90°). In some texts this is referred to as 'elevation' or 'profile angle'.

- *Azimuth* (AZI): the direction of the sun measured in the horizontal plane from north in a clockwise direction (thus east = 90°, south = 180° and west = 270°, whilst north can be 0° or 360°).

- *Zenith angle* (ZEN): angle of the sun's direction, from the vertical (ZEN=90°-ALT).

Shadow Angle

Shadow angles express the sun's position in relation to a building façade. The design of such shading devices employs two shadow angles: HSA and VSA.

Horizontal shadow angle (HSA) is the angle from the surface normal, or azimuth difference, clockwise +ve, anticlockwise –ve. HSA is between -90° and +90°, when the sun reaches the building face. When the sun is directly opposite, AZI = ORI (HSA = 0°). The horizontal shadow angle describes the performance of a vertical shading device. Figure 2 shows that many combinations of vertical elements can give the same shading performance (Szokolay, 2007).

Vertical shadow angle (VSA) is a plane perpendicular to a vertical surface, from horizontal to the line of the edge of a shading device. (VSA = ALT) when the sun is sideways, and its altitude angle is projected parallel with the building face.

Shading Design Process

The process of designing shades may be divided into 3 steps:

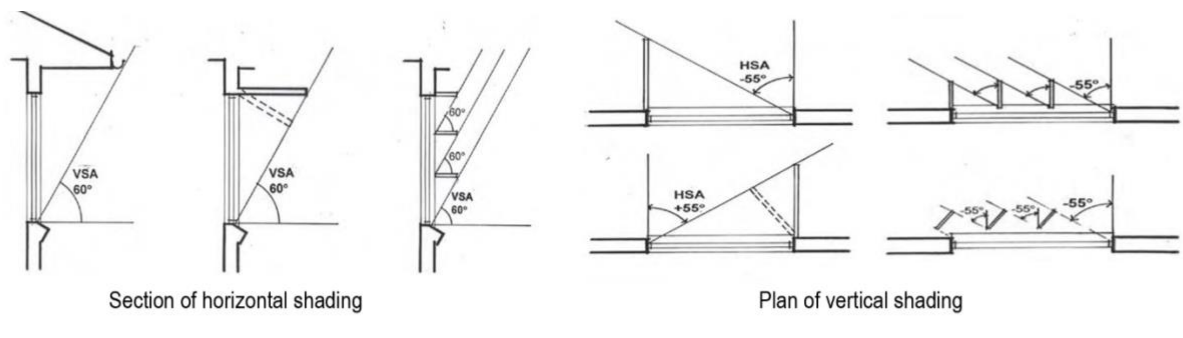
1. Determine the hours and days when shade should be given during the hot period. It is possible to consider this to be the moment when the monthly mean temperature exceeds the lower comfort level.

2. Establish the necessary horizontal or vertical shadow angles (or a mix of the two) as performance specifications for the device to be constructed by utilizing the relevant sun-path diagram and the protractor.

3. Create the actual shading device according to these performance requirements as shown in Figure 2 (Szokolay, 2007).

Figure 2

Shadow Angles and Combination of Shading Elements



Note. (Left) *Horizontal devices give the same VSA*, (Right) *Vertical shading devices give the same HAS*. From Solar Geometry (p.15, 16), by S.V. Szokolay, 2007, Department of Architecture, University of Queensland, PLEA: Passive and Low Energy Architecture International. Copyright 2007 by University of Queensland.

Shading in Tropic Climate

As there is no winter in the tropics, the entire year is typically the period of overheating. As a result, windows should always be shaded, both from direct and indirect solar radiation as well as from reflected or diffuse light. Considerable diffuse radiation from the sky is present in humid areas, and significant radiation is frequently reflected from nearby structures, or even the bare ground in extremely dry climates. External shade equipment should always be used to prevent the direct rays of the sun from reaching the interior (Lechner, 2015).

There may be some misconceptions because the shading techniques for north and south windows are reversed at the equator. Because of this, the discussion about shading north and south windows that follows will be presented as in Table`1, using two columns, with the left column representing the northern hemisphere and the right column representing the southern hemisphere.

East and west windows, in contrast to north and south windows, cannot be completely covered while keeping a view. The main exception is a location where nearby tall buildings or trees effectively obscure the windows. The poorer the view, the better the shade for permanent east and west shading devices. For instance, although it may block the view, an egg crate shading device nonetheless lets some daylight penetrate at specific times of day and year (Lechner, 2015). Using balconies as window protection is also a very efficient technique. Moreover, because they block both direct and diffuse solar radiation, provide protection from heavy rain, and allow more air to enter the structure, overhangs are particularly suitable for humid areas.

In tropical climates, east and west overhangs are designed similarly to those in temperate climates. Fixed-slanted fins are undesirable in the tropics, though. Because the summer sun rises in the northeast and sets in the northwest, slanting the fins toward the southeast or southwest is effective in the northern temperate zone. However, at the equator, the sun must be covered when it rises, both in the northeast and the southeast. Naturally, the setting sun presents the same issue. As a result, fixed fins are less helpful in the tropics than they are in temperate zones. While moveable fins are preferable to fixed fins, they obstruct the view significantly more than an overhang with backup mobile fins (Lechner, 2015).

Table 1

North and South Window Shading in the Tropics

For Northern Hemisphere	For South Hemisphere
South Windows: South windows get easier to shade as one moves toward the equator from the Tropic of Cancer because the sun is progressively higher in the sky. Thus, south windows in the tropics need larger shading devices at the Tropic of Cancer than at the equator. The best shading device for south windows continues to be the over-hang. In most cases, the overhang can be fixed rather than movable.	North Windows: North windows get easier to shade as one moves toward the equator from the Tropic of Capricorn because the sun is progressively higher in the sky. Thus, north windows in the tropics need larger shading devices at the Tropic of Capricorn than at the equator. The best shading device for north windows continues to be the overhang. In most cases, the overhang can be fixed rather than movable.
North Windows: North windows experience the opposite of south windows. North windows are easier to shade at the Tropic of Cancer than at the equator, where north and south windows experience the same solar exposure. At the Tropic of Cancer, small fins and a small overhang are sufficient. At the equator, the overhang is much larger while the fins are just a little bit smaller for full shading.	South Windows: South windows experience the opposite of north windows. South windows are easier to shade at the Tropic of Capricorn than at the equator, where south and north windows experience the same solar exposure. At the Tropic of Capricorn, small fins and a small overhang are sufficient. At the equator, the overhang is much larger while the fins are just a little bit smaller for full shading.

Note. Adapted from *Heating, Cooling, Lighting: Sustainable Design Methods for Architects* (p.885), (4th ed.), by N. Lechner, 2015, Hoboken, New Jersey, USA Jonh Wiley & Sons. Copyright 2015 by Norbert Lechner.

METHODOLOGY

Shading Cases Criteria

In choosing the shading cases for simulating shadow performance, a survey was conducted on the modern architecture shading in a survey area of Phnom Penh, and shading types were categorized. The selection criteria were developed in order to identify a representative shading from typical types found in Phnom Penh.

Using the criteria, 120 buildings were identified; they comprised apartment blocks, public schools, offices, and other buildings such as theaters and hotels. Figure 3 shows the location and types of modern architecture shading found in the survey.

Figure 4 illustrates the typical shading façades of modern architecture identified in Phnom Penh, which are defined by deep horizontal balconies. Almost fifty percent are combined with horizontal louvers hung from overhanging balconies. A small amount of egg crate and vertical patterns were also found in Phnom Penh. The primary material used for shading devices was found to be concrete, which was readily available in Cambodia in the 1960s.

The diversity of the different shading structures illustrates the creative potential of shading façades. The observation highlighted some issues with the original shading devices and structures such as the renovation of shading structures to allow for the addition of air-conditioning systems or expansion of room space. Some others are used as advertising space. Moreover, in many cases canopy extensions or sun blinds have been added to, which shows the insufficiency of the original shading device.

Shading Cases

Five shading device cases represent the types commonly found in Phnom Penh, as shown in Figures 5 and 6. They are:

- S1 used to be a pasture institute that has an egg-crate pattern
- S2 is an apartment block that has a horizontal louvers hung from the overhang
- S3 is an apartment block that has an overhang without a horizontal louver
- S4 is a public school that has a vertical fin type
- S5 is an office building that has a vertical slanted fin type

Figure 3

Results of the Shading Device Building Survey in the Study Area, Phnom Penh

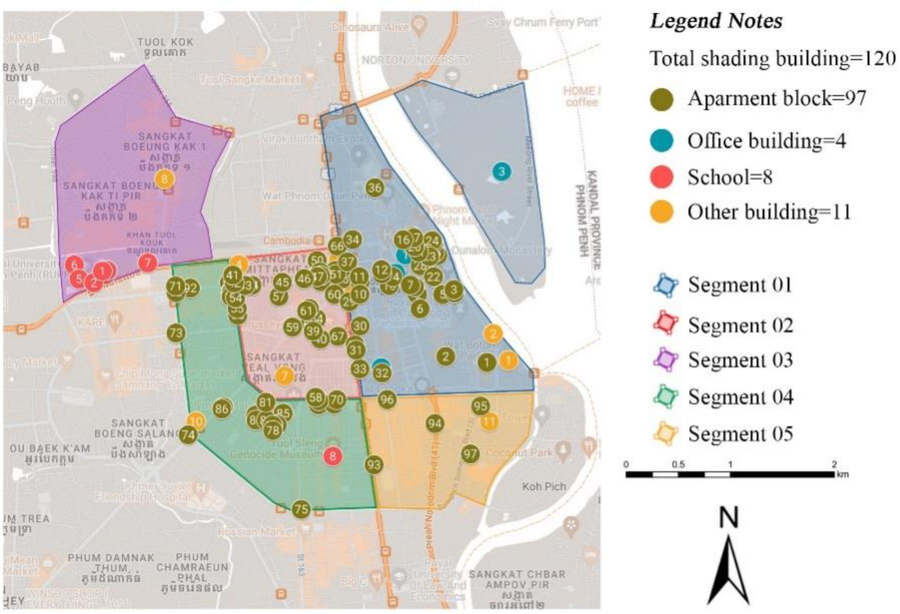


Figure 4

Typical Shading Façade of Modern Architecture Found in Study Area, Phnom Penh

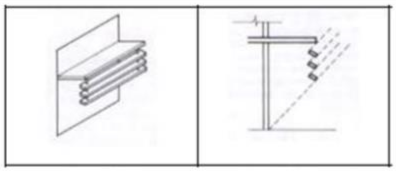
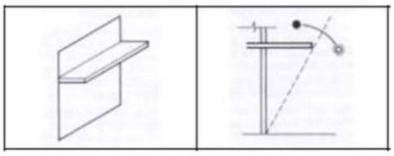
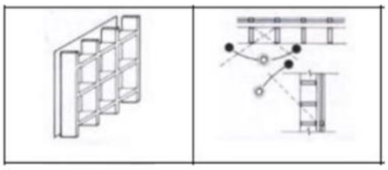
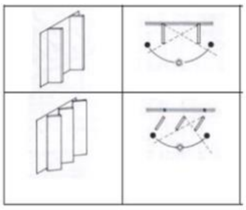
Type: Horizontal louver hung from overhang (55/120 Buildings or 46%)			 Example shading's plan and section
Type: Overhang (40/120 Buildings or 40%)			 Example shading's plan and section
Type: Egg crate (10/120 Buildings or 8%)			 Example shading's plan and section
Type: Vertical fins and slanted vertical fins (7/120 Buildings or 6%)			 Example shading's plan and section

Figure 5

Configurations of Shading Cases (S1, S2, S3, S4, S5)

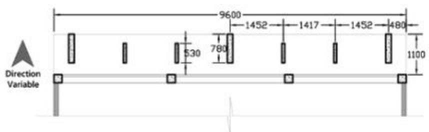
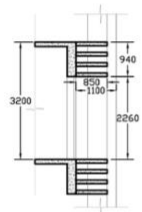
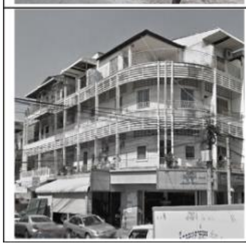
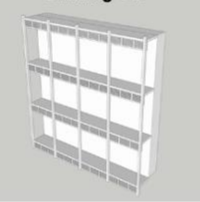
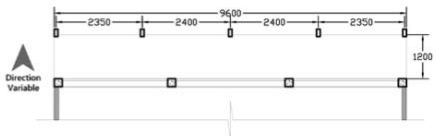
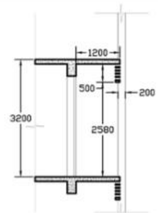
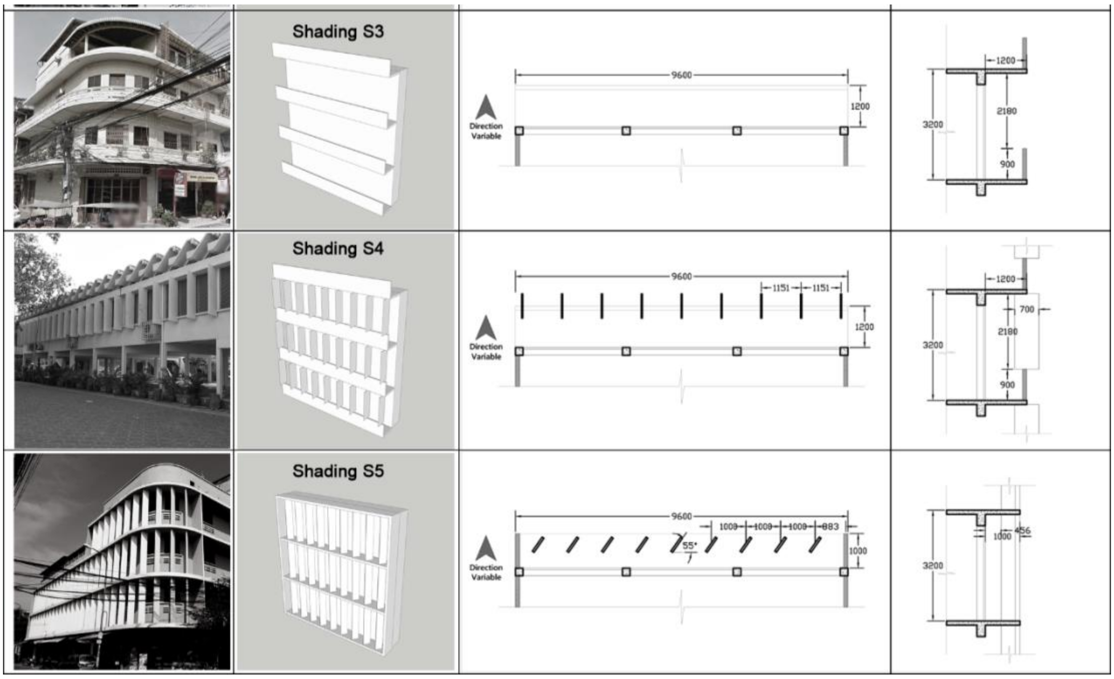
Shading facade of building	Shading in perspective view	Plan to illustrate the shading configuration	Section to illustrate the shading configuration
	Shading S1 		
	Shading S2 		

Figure 6

Configurations of Shading Cases (S1, S2, S3, S4, S5) (cont.)



Research Parameters

A parametric study was conducted to compare the performance of different shading devices in the façades of several buildings in the climatic region of Phnom Penh, Cambodia.

Constant Parameters

- *Location:* The location is in Phnom Penh, Cambodia (Latitude and Longitude).

- *Façade form:* It is set to be constant at 9.6 m by 9.6 m in order to compare the performance of the shaded areas of different shading devices. The floor height is 3.2 m, with the façade being 3 floors in height as was common of façades in that period. The width is 9.6m for the total 3-floor height.

Variable Parameters

- *Types of Shading Devices:* Different shading element categories were assessed, namely, S1, S2, S3, S4, and S5.

- *Façade Orientation:* The shading façades were tested in all orientations (North, East, South, West, Northeast, Northwest, Southeast, and Southwest) to investigate the influence and contribution of sun position to the shading device performance.

- *Simulation Timings:* All simulation cases were examined and three times per day on annual equinox and solstice days (21st of December, March, September, June). 9 AM represents the morning, 12 PM midday, and 3 PM the afternoon.

Simulation Tool

For accurate simulation and ease of experimentation, a computer simulation approach was chosen over alternative methodologies. Since the only resources required are basic software training and the cost of the program license, it is the most accessible and cost-effective strategy that any researcher can use. It also has the benefit of reducing the amount of time needed for research while giving the researcher the opportunity to gain exposure to a wide range of parameters. Finally, this method has a demonstrated history of very high levels of accuracy, although, the amount of error depends on the quality of the input provided.

The simulation tools that are used for building energy consumption were IES-VE, ECOTECT, Energy Plus, DOE-2, Green Building Studio, eQUEST, Energy Plus-SketchUp Plugin, and HEED. These tools helped architects and engineers to integrate design processes and evaluation of the buildings' performance with respect to factors such as energy consumption, thermal comfort, etc.

A Shadow Projector V.7 by TIG is an extension tool in Sketch-UP. This tool provides the output of the area and identifies the percentage of the shaded area created on the façade in a specific time set on Sketch-UP (TIG, 2019). Chaiyakul (2008) showed that Sketch-Up shadow is accurate and reliable for designing shading devices. Therefore, A Shadow Projector V.7 by TIG was selected for use in this study. It has the added benefits of affordable price, minimum time consumption, flexibility in variable testing, and accurate results. Moreover, this tool needs fewer input factors, i.e., material properties, Wall Window Ratio (WWR), which could have the benefit of reducing error input and time required. The simulation calculated the shading effect by Sketch-UP into shading area and calculated relevant percentages.

Simulation Stage

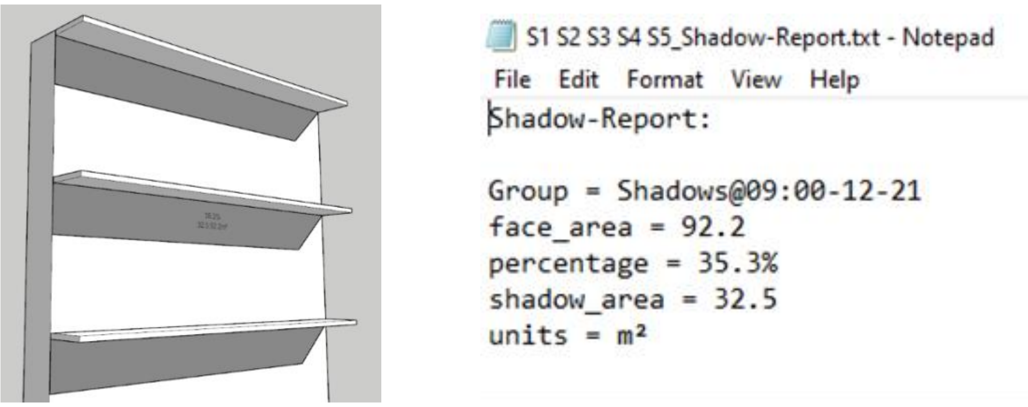
The first stage involved building the different shading device models and adjusting the study locations in Sketch-Up. Then, all variables were set up, including the type of shading devices, orientations, and simulation timings. Finally, tests were carried out by a Shadow Projector V.7 tool by TIG in order to identify the shaded area percentage. The following steps comprise the simulation process:

- Build shading case S1 in sketch-UP program
- Load a location in Phnom Penh (Latitude & Longitude) in the Sketch-UP
- Open shadow and run a simulation plug-in (Shadow Projector V.7 tool by TIG) on shading case S1 for each orientation (North, East, South, West, Northeast, Northwest, Southeast, Southwest) and each simulation time (9 AM, 12 PM, 3 PM) on the study dates (21st of December, March, June, and September). An example is shown in Appendix A
- Note down the results
- Repeat the stages above for each of the different shading cases S2, S3, S4, and S5

The analysis stage categorizes the output with respect to the types of shading devices. Afterward, output results are visualized as charts and graphs with Microsoft Excel version 2016 in order to compare the relative performance of the shading devices.

Figure 7

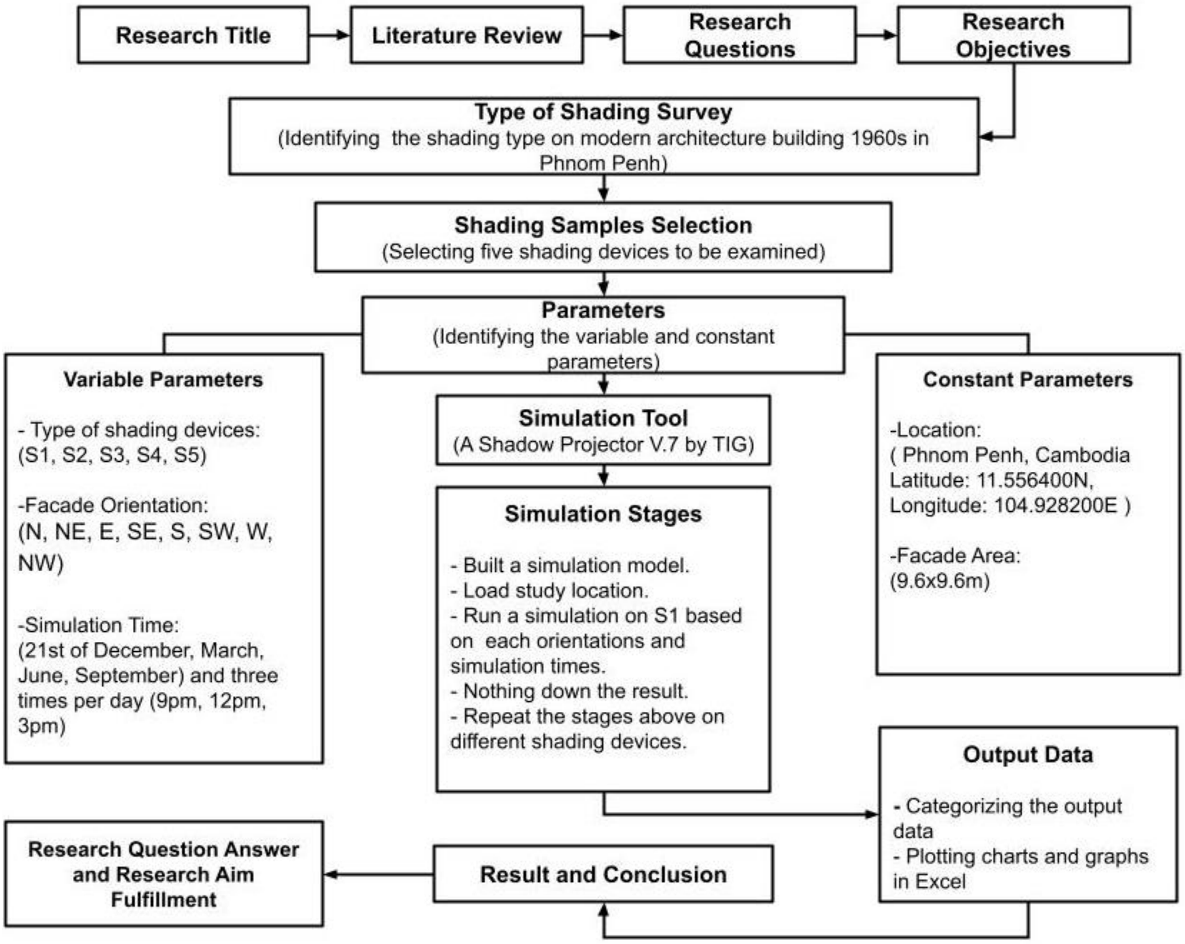
Shadow Area and Percentage Output of Shadow Projector V.7 by TIG



Note. (Left) shadow projection by Sketch-Up and the shadow area by Shadow Projector V.7 *(*Right) the shadow area & percentage data at 9 AM on 21st December.

Figure 8

Research Flow Diagram



RESULTS AND DISCUSSIONS

North and South orientation

The results show that, in all shading cases, façades facing north received the least sunlight year-round compared to the other orientation. This is because Cambodia is in the northern hemisphere, where the sun spends more time above the horizon in the South than it does the North. The graphs in Figures 9-12 demonstrate that the most significant shadow percentage completely shades the façade in all shading cases at 9 AM, 12 PM, and 3 PM in December, March, and September, and noon in June. Also, S5 was completely shaded from 9 AM to 3 PM in June. However, S2, S3, and S4 indicated a minor and equal decrease in the percentage of shadows to 86% at 9 AM and 3 PM. S1 provided shade at 94%.

When South-oriented, the façades received a considerable amount of solar radiation compared to the other orientation year-round throughout all shading cases. In December, unsurprisingly, S1 (the egg crate) had the highest performance on the south facade, with percentages ranging from 70% to 80%, followed by S3, S2, and S4 respectively. Noticeably, at 9 AM and 3 PM, the shadow percentage results were mirrored for cases S1, S2, S3, and S4. However, S5 had different results of 90% and 65%, respectively. This happened because S5 has a vertically slated fin toward the southeast, and an open façade to the southwest, as shown in Figure 6. Meanwhile, on the June solstice day, the sun rises and sets toward the north. All cases are fully shaded with the sun behind them. On the equinox days in March and September, both graphs show similar results. At noon, all shading cases are 100% shadow. Additionally, at 9 AM and 3 PM, S5 had was in complete shadow, followed by S1. S2, S3, and S4 all had the same result, which was the lowest percentage of 85%.

This demonstrates that horizontal shading plays a vital role in shading performance of the north and south facades. By comparing the graphs of S2 and S3, it can be seen that the horizontal louver hung from the overhang increased the shadow performance by 20%. However, in the north, a single overhang is enough shading as Cambodia is in the northern hemisphere, which is consistent with the literature review, which had highlighted previous studies claiming that the north window is easier to shade, while the south window needs larger shading devices (Lechner, 2015).

East and West orientation

The east and west-oriented façades seem to receive considerable solar radiation compared to the other orientations. Overall, S2, with the egg crate pattern, still had the best performance throughout the year. In December, because it is the time of the lowest sun path, the S3 overhang had the lowest shading levels (35% on the east and 34% on the west). By adding a horizontal louver, the S4 percentages increased to 54% and 53%, respectively. In other words, the horizontal louver enhanced the shadow performance by almost 20%.

Considering the vertical fins of S4, they performed well on both east and west orientations. However, the performance was less effective on equinox days because the sun travels almost due east and due west. Interestingly, the S5 graph shows asymmetry between east and west, resulting from the vertical slanted fins. In December, S5 is strong in the west but weak in the east, and vice versa in June. This is because the sun travels toward the south in December and toward the north in June. As a result, the vertical slanted fins on the east façade rotate toward the NE, and on the west facade, the fin slants toward the SW, as shown in Figure 6. Therefore, the findings support the literature; fixed fins are less helpful in the tropics than they are in temperate zones (Lechner, 2015).

Northeast, Northwest, Southeast, and Southwest orientation

Regarding the sub-directions, the southeast and southwest received more significant sun radiation than did the northeast and northwest. The shadow proportions of S1, S2, S3, and S4 when oriented to the NE is likely to equal NW, and SE to SW. However, due to the vertical slanted fins, S5 provides the unequal shadow. S1 performed better than any case. At the same time, S3, the overhang type, provided the weakest shading for SE and SW. However, 20% improvement was achieved by applying a horizontal louver (S2). The vertical fin, S4, is also weak for SE and SW orientation in December, and vice versa in June, when the percentage is reduced in NE and NW. For S5, the vertical slanted fin, the results were unequal between SW and SE, and NW and NW as the result of the vertical slanted fin facing toward a different direction.

Figure 9

Shadow Performance Results of S1 in December, March, September, and June

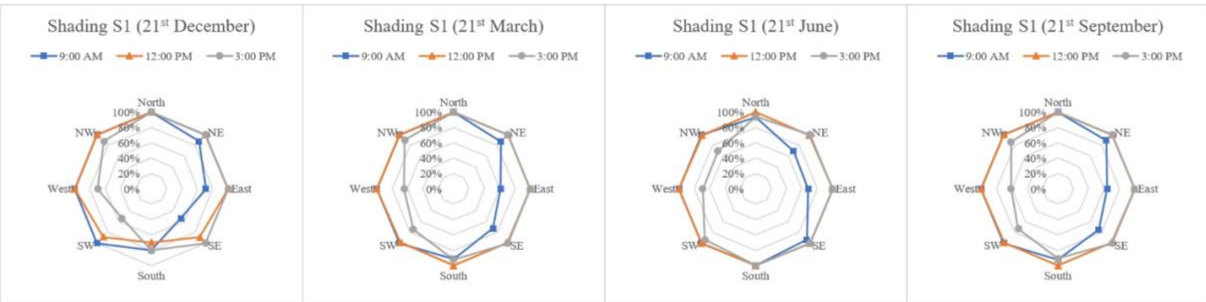


Figure 10

Shadow Performance Results of S2 in December, March, September, and June

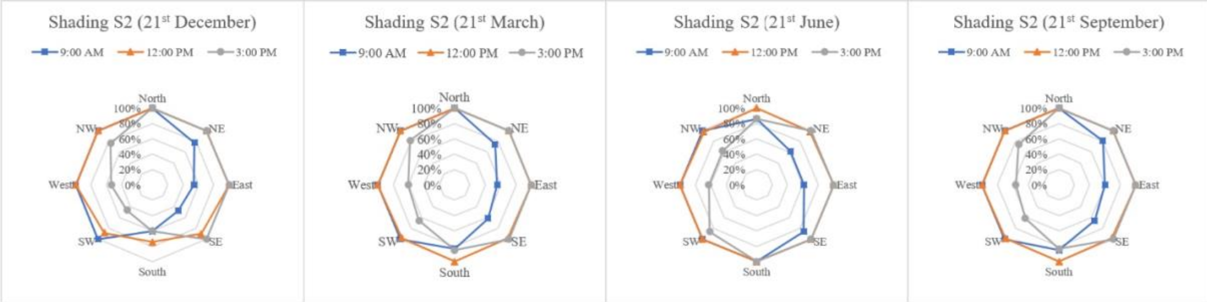


Figure 11

Shadow Performance Results of S3 in December, March, September, and June

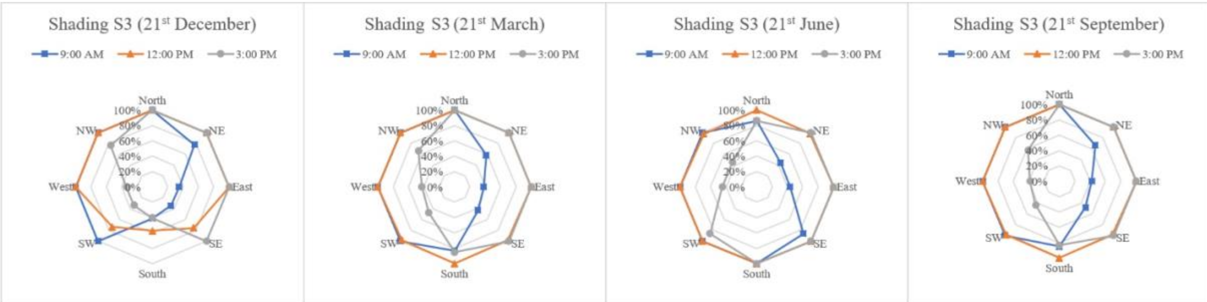


Figure 12

Shadow Performance Results of S4 in December, March, September, and June

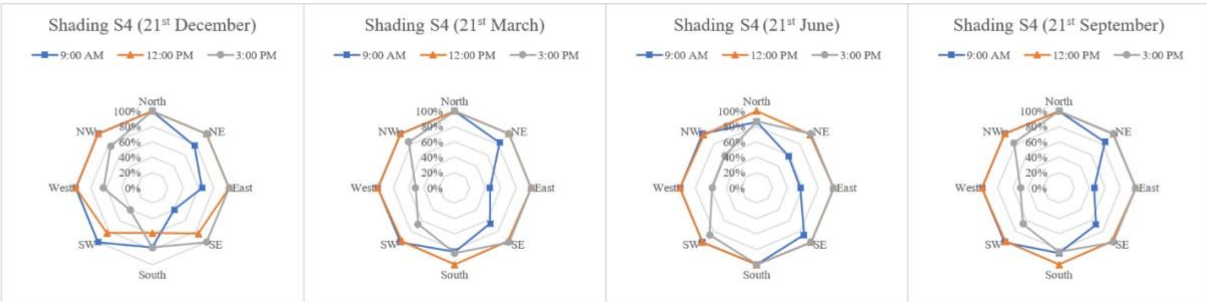
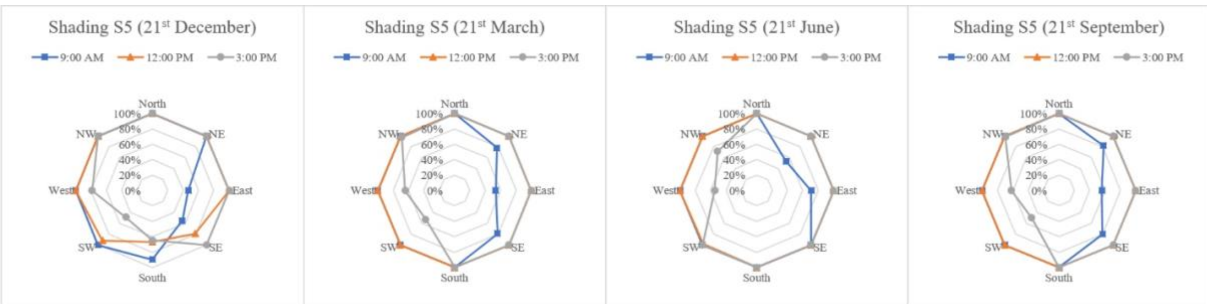


Figure 13

Shadow Performance Results of S5 in December, March, September, and June



CONCLUSION AND RECOMMENDATIONS OF FUTURE RESEARCH

This research studied the characteristics of shading devices in modern architecture in Phnom Penh, specifically, shading types (S1 to S5) integrated into the buildings designed or Cambodia's climate. The study aimed to examine shadow performance through the Extension tool in Sketch-UP (A Shadow Projector V.7 by TIG) in different orientations, three times a day on 4 specific dates annually (the solstices and equinoxes).

To conclude, the results show that shading devices in modern architectural buildings in Phnom Penh, Cambodia, are defined by a deep horizontal overhang and the horizontal louver hung from the overhang. They are used in 3- or 4-stores apartments and shophouses. In addition, vertical and egg-crate patterns are used in schools, offices, and other public buildings.

Overall, the shading devices used in modern architectural buildings in Phnom Penh effectively shaded the facades. The best performance shading among all shading cases and orientations is the egg-crate pattern. The horizontal louver hung from the overhang can increase the shading performance by 20% in all directions. Also, it is more efficient than vertical fins for East, West, SE, and SW orientations. Moreover, the overhang is the most efficient in the north direction. However, because the sun's path is in the tropical zone, the vertical fin types are unreliable for East, West, SE, and SW orientations, although it provided more shadow for facades facing the South, NE, and NW. In addition, the vertical slanted fin type is also unreliable in any orientation or season due to the slanting and the sun's travel path. Therefore, a moveable vertical fin would be more beneficial than a fixed fin because the fin angle can be controlled with respect to the sun's position in any season.

The study suggests:

- *North-facing windows:* use a short overhang or horizontal fin shading.

- *South-facing windows:* use a larger overhang or horizontal fin shading, or overhang combined with a horizontal louver, or the egg-crate pattern. Vertical shading is also helpful when it is combined with a balcony or overhang. However, avoid using vertical slanted fins.

- *East- and West-facing windows:* using an overhang might not be helpful due to the low angle of the sun. Egg-crate pattern would be the best choice, however, the more effective its shading performance the greater the view loss. The use of vertical fins alone should be avoided; shadow performance could be enhanced by combining vertical fins with a horizontal louver. It is not recommended to fix vertical slanted fins; moveable vertical fins would be more beneficial.

- *SE- and SW-facing windows:* SE and SW are the hardest orientations for achieving effective shading performance. Egg-crate pattern can provide the best shadow, but it minimizes the view and natural daylight. A deep balcony combined with a horizontal louver hung from the overhang could enhance the shadow performance. However, avoid using vertical shading alone.

- *NE- and NW-facing windows:* Shading for NE- and NW-facing facades is similar to north-orientation. Horizontal louvers hung from the overhang or balcony are suitable in these directions.

This study explored the shadowing behavior of shading devices in Cambodia with respect to variations in time of year, time of day and orientation of facade. The result will help designers optimize the various benefits of shading devices for buildings. Additionally, the research findings can be enhanced in the future by focusing on the compatibility assessment of shading devices used in new-era buildings.

This study had some limitations; it was, for example, limited to Phnom Penh, Cambodia, and the selected study area. It was also limited to the examination of shade performance five types of shading devices. Another limitation of this research is the period; more variable parameters and cases could have been evaluated in more time. The study was also limited to the impact of shading material and properties, window to wall ratio (WWR), and type of shading device. The other limitation of this study only concerns shadow performance. Therefore, it is suggested that further research should consider various factors such as thermal comfort, ventilation, daylight, energy, and visual or acoustic comfort performance.

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Appendix A

Figure 14

Step by Step Use of Shadow Projector V.7 tool for S1 on 21st December, 9 AM on South

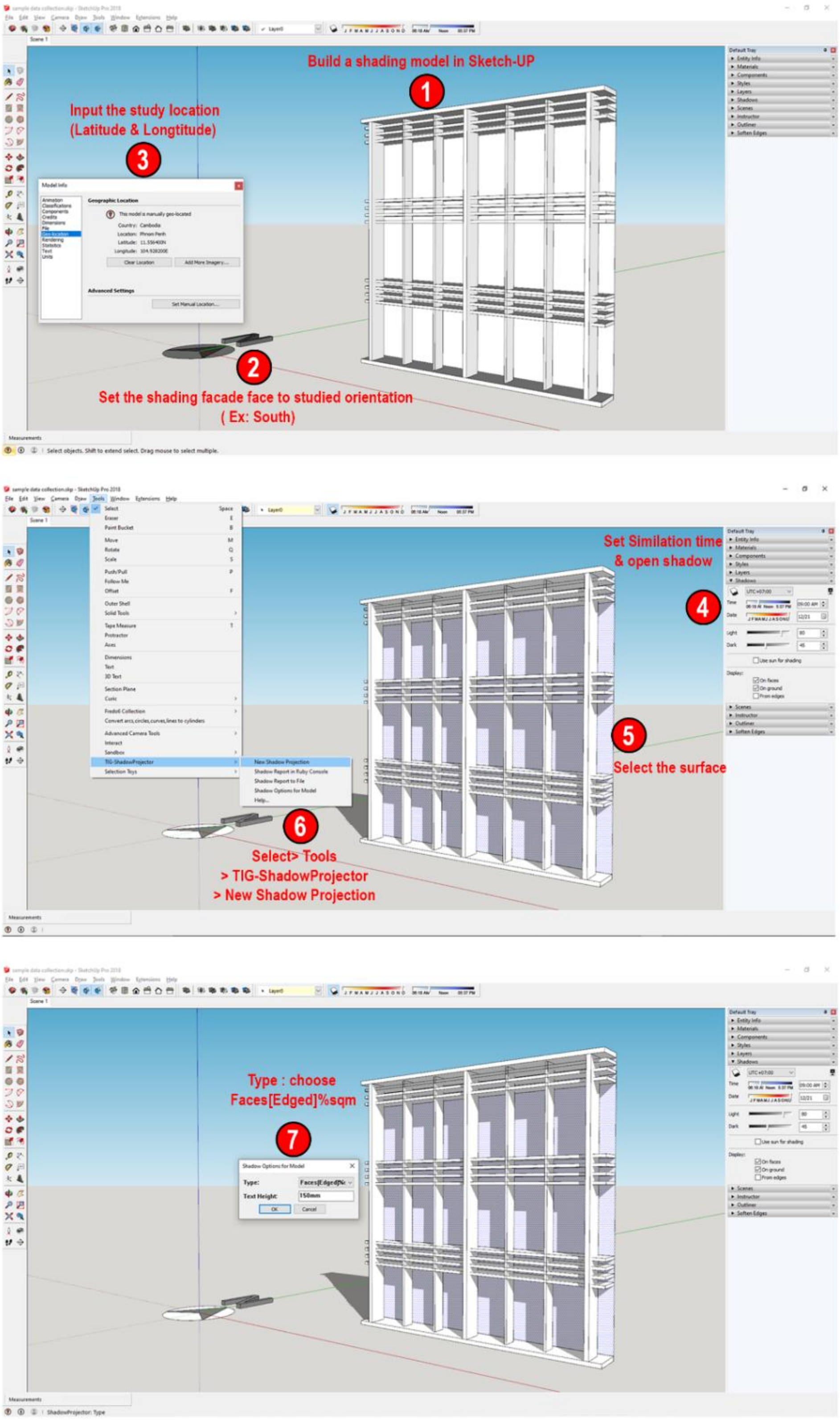
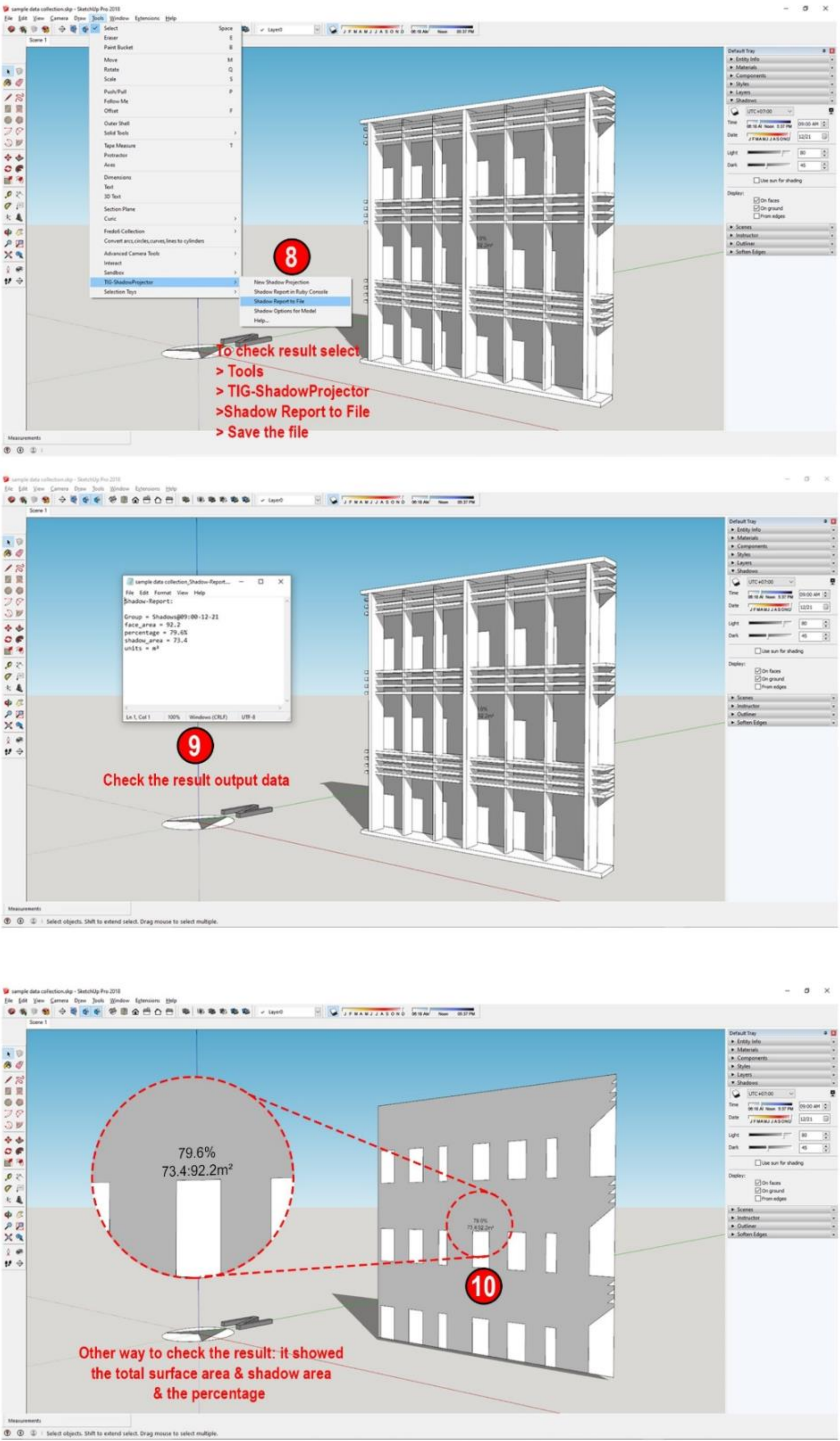


Figure 15

Step by Step Use of Shadow Projector V.7 tool for S1 on 21st December, 9 AM on South(Cont.)



Appendix B

Table 2

Shadow Performance of Shading Devices S1, S2, S3, S4, and S5 on 21st December

Date: 21st December									
Shading	Time	North	NE	East	SE	South	SW	West	NW
S1	9:00 AM	100%	88%	71%	54%	80%	100%	100%	100%
	12:00 PM	100%	100%	100%	89%	70%	88%	100%	100%
	3:00 PM	100%	100%	100%	100%	80%	54%	70%	87%
S2	9:00 AM	100%	77%	54%	48%	60%	100%	100%	100%
	12:00 PM	100%	100%	100%	90%	74%	88%	100%	100%
	3:00 PM	100%	100%	100%	100%	60%	47%	53%	77%
S3	9:00 AM	100%	77%	35%	34%	41%	100%	100%	100%
	12:00 PM	100%	100%	100%	76%	57%	74%	100%	100%
	3:00 PM	100%	100%	100%	100%	41%	34%	34%	77%
S4	9:00 AM	100%	77%	65%	40%	78%	100%	100%	100%
	12:00 PM	100%	100%	100%	85%	59%	84%	100%	100%
	3:00 PM	100%	100%	100%	100%	78%	41%	64%	77%
S5	9:00 AM	100%	100%	47%	55%	90%	100%	100%	100%
	12:00 PM	100%	100%	100%	79%	67%	92%	100%	100%
	3:00 PM	100%	100%	100%	100%	65%	49%	79%	100%

Table 3

Shadow Performance of Shading Devices S1, S2, S3, S4, and S5 on 21st March

Date: 21st March									
Shading	Time	North	NE	East	SE	South	SW	West	NW
S1	9:00 AM	100%	87%	61%	73%	91%	100%	100%	100%
	12:00 PM	100%	100%	100%	99%	100%	99%	100%	100%
	3:00 PM	100%	100%	100%	100%	92%	74%	65%	90%
S2	9:00 AM	100%	75%	56%	62%	83%	100%	100%	100%
	12:00 PM	100%	100%	100%	98%	100%	98%	100%	100%
	3:00 PM	100%	100%	100%	100%	85%	66%	60%	82%
S3	9:00 AM	100%	58%	38%	43%	83%	100%	100%	100%
	12:00 PM	100%	100%	100%	98%	100%	98%	100%	100%
	3:00 PM	100%	100%	100%	100%	85%	48%	43%	67%
S4	9:00 AM	100%	83%	46%	66%	83%	100%	100%	100%
	12:00 PM	100%	100%	100%	98%	100%	98%	100%	100%
	3:00 PM	100%	100%	100%	100%	85%	67%	51%	85%
S5	9:00 AM	100%	78%	53%	79%	100%	100%	100%	100%
	12:00 PM	100%	100%	100%	100%	100%	100%	100%	100%
	3:00 PM	100%	100%	100%	100%	100%	53%	64%	97%

Table 4

Shadow Performance of Shading Devices S1, S2, S3, S4, and S5 on 21st June

Date: 21st June									
Shading	Time	North	NE	East	SE	South	SW	West	NW
S1	9:00 AM	94%	69%	69%	94%	100%	100%	100%	100%
	12:00 PM	100%	99%	100%	100%	100%	100%	100%	99%
	3:00 PM	94%	100%	100%	100%	100%	94%	69%	70%
S2	9:00 AM	86%	62%	61%	86%	100%	100%	100%	100%
	12:00 PM	100%	98%	100%	100%	100%	100%	100%	98%
	3:00 PM	86%	100%	100%	100%	100%	86%	63%	63%
S3	9:00 AM	86%	44%	43%	86%	100%	100%	100%	100%
	12:00 PM	100%	98%	100%	100%	100%	100%	100%	98%
	3:00 PM	86%	100%	100%	100%	100%	86%	45%	45%
S4	9:00 AM	86%	58%	57%	87%	100%	100%	100%	100%
	12:00 PM	100%	98%	100%	100%	100%	100%	100%	98%
	3:00 PM	87%	100%	100%	100%	100%	87%	58%	59%
S5	9:00 AM	100%	54%	71%	100%	100%	100%	100%	100%
	12:00 PM	100%	100%	100%	100%	100%	98%	100%	100%
	3:00 PM	100%	100%	100%	100%	100%	100%	55%	72%

Table 5

Shadow Performance of Shading Devices S1, S2, S3, S4, and S5 on 21st September

Date: 21st September									
Shading	Time	North	NE	East	SE	South	SW	West	NW
S1	9:00 AM	100%	89%	64%	75%	92%	100%	100%	100%
	12:00 PM	100%	100%	100%	99%	100%	99%	100%	100%
	3:00 PM	100%	100%	100%	100%	91%	73%	61%	87%
S2	9:00 AM	100%	81%	60%	66%	85%	100%	100%	100%
	12:00 PM	100%	100%	100%	98%	100%	98%	100%	100%
	3:00 PM	100%	100%	100%	100%	83%	62%	56%	74%
S3	9:00 AM	100%	66%	42%	48%	85%	100%	100%	100%
	12:00 PM	100%	100%	100%	98%	100%	98%	100%	100%
	3:00 PM	100%	100%	100%	100%	83%	44%	38%	58%
S4	9:00 AM	100%	85%	46%	68%	85%	100%	100%	100%
	12:00 PM	100%	100%	100%	98%	100%	98%	100%	100%
	3:00 PM	100%	100%	100%	100%	83%	66%	50%	83%
S5	9:00 AM	100%	82%	56%	80%	100%	100%	100%	100%
	12:00 PM	100%	100%	100%	100%	100%	100%	100%	100%
	3:00 PM	100%	100%	100%	100%	100%	50%	62%	98%