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The Solar Chart for Designing Shading Devices For Tripoli City, Libya

Aida M. Ejroushi[1], Mohamed S. Smeda[1], and Faiz K. Bannani[2]

[1]Center For Solar Energy Research Studies

aidaejroushi@yahoo.com

[2]Faculty of Accounting, Al-Jabal Al Gharbi University

الملخص: تهدف هذه الدراسة لإيجاد أسلوب معتمد ونظامي لتصميم الكاسرات الشمسية. للوصول لهذا الهدف، تم في المرحلة الأولى مراجعة أبحاث ودراسات شملت تحديد أنواع الكاسرات الشمسية وتأثيرها على النوافذ، وموقع الشمس وزوايا الشمس وكيفية حسابها رياضياً، والجداول الشمسية وجدول حساب الظلال.

المرحلة الثانية تم فيها تحديد الفترات الحارة من السنة من خلال بيانات مصلحة الأرصاد الجوية لمتوسط درجات الحرارة لمدة سبع سنوات من 1989 إلى 1995 و ذلك لتحديد الفترات التي يجب أن تقوم فيها الكاسرات الشمسية بالحماية.

أما المرحلة الثالثة، فقد تم فيها تجهيز برنامج كمبيوتر مصغر لحساب زوايا الشمس، وزوايا الارتفاع، وزوايا الانحراف. وقد اتخذ خط العرض32.59 درجة مثالا لتطبيق هذه الدراسة. وتم تحليل البيانات الناتجة ورسمها باستخدام برنامج ستات جراف الحاسوبي وبالتالي تم استخراج الجدول الشمسي المطلوب الذي يمثل العلاقة بين زوايا الارتفاع وزوايا الانحراف لكل ساعات اليوم على مدار السنة، هذا بالإضافة لتوضيحه لكل من الانقلابين الصيفي والشتوي، والاعتدالين الخريفي والربيعي. ويعتبر الجدول الشمسي الناتج هو الأداة التي من خلال مطابقتها مع جدول الظلال العام سيتم تصميم الكاسرات الشمسية الفعالة لخط العرض الخاص بمدينة طرابلس.

تضمنت المرحلة الرابعة للدراسة أسلوب اختيار قيم زوايا الارتفاع وزوايا الانحراف التي ستعتمد عليها عملية التصميم.

أما في المرحلة الخامسة فقد تم وضع معايير محددة لطرق تصميم كل نوع من أنواع الكاسرات الشمسية، وبالتالي تم كتابة الخلاصة من الدراسة والتوصيات بالإضافة الى اقتراحات لدراسة تالية.

Abstract: Due to lake of standardized methods to design and validate sun shading devices in Libya, this study aims at developing a solar chart, which can be used as a practical and systematic methodology for designing sun-shading devices in the city of Tripoli. In order to achieve the objective of this study, this paper was divided into five sections. The first section is dealing with a focused literature review with respect to types of shading devices and their impact on the exterior wall openings, the position of the sun, sun's altitudes azimuths and how to mathematically be determined; the sun charts, and the shading calculator.

While the second section was dedicated for the determination of the overheated periods over the year in which shading devices should be in place. The third section presents a computer software developed in order to automatically calculate the sun angles (Altitudes and Azimuth angles). The north latitude of 32.59 was chosen as a validation example.

By using the Statgraphics software, the output data were analyzed and illustrated in a solar chart that presents the equinox, summer and winter solstices. The resulted solar chart serves as a tool, which will jointly be used with the shading chart to design accurate shading devices for the chosen North latitude 32.59.

The fourth section explains the methodology of selecting an effective solar altitude and azimuth angles which an architect would on while designing sun shading devices.

The fifth section, identifies and lists the methodology of designing each type of shading devices in the city of Tripoli. Libya. Finally, study conclusions were drawn, and further research studies were recommended to enhance the findings of this research paper.

1. INTRODUCTION

The concept of solar control is based on allowing the sun's energy into the human environment during the cool or under heated periods of the year, and keep it out during the hot or over heated periods.

Since each building receives radiant energy through its external envelope (walls & roofs), either directly from the sun or indirectly by reflection, the amount of heat gain through these surfaces can be sufficiently reduced by design of the building form, proper orientation or by using improved building materials and insulation especially in some of the external surfaces.

One of the major causes of direct heat gain in buildings is the openings (windows and doors), as the radiant energy passes through these openings to the inside. This increased the importance of controlling and regulating the passage of this energy by intercepting it during the overheated periods to provide comfortable human environment. The first step in solar control is good orientation of the building. However, the north south orientation (the less in heat gain) is usually preferred over east west orientation. Then each elevation has to be separately well studied to decide when to provide walls with thermal insulation and to provide windows with shading devices.

Shading devices are construction elements that have an effect on protecting buildings from direct heat gain. Their advantage in allowing the low sun to enter the human environment during the overheated periods gave evidence to their importance in solar control.

The study at hand is intended to find a systematic and reliable process for designing sun shading devices. For an accurate, geometrical shape and dimensions, design process requires an availability of some graphical design tools called the sun charts and the shadow chart. It is important to point out that each sun chart is only usable for the latitude for which it was calculated, and accordingly, north latitude 32.59 has been chosen for this study.

2. SHADING DEVICES

Generally, shading devices have been classified into two main types: The first type is the interior shading devices, which involves shutting curtain, draperies, or blinds, while the second type is the exterior shading devices that include owning, shutters, and overhangs, [1] .

"Shading can be provided by natural landscaping or by use of building elements such as awnings, overhangs and trellises. Some shading devices can also function as reflectors, called light shelves, which bounce natural light for day lighting deep into building interiors" [10] . The second type is more effective than the first type because it intercepts and reflects the radiant energy before entering the building and it can reduce solar transmission by 80%. [1].

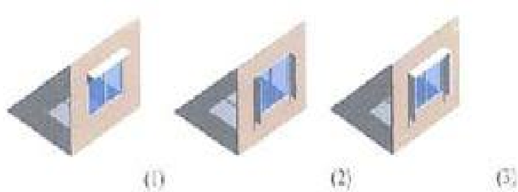


Figure (1). The three types of shading devices.

2.1. Exterior Shading Devices

They can be grouped into three categories:

1- The horizontal overhangs, Figure 1-1.
2- The vertical fins, Figure 1-2.
3- The overhang / fin combination, Figure 1-3.

2.1.1. The Horizontal Overhangs:

Horizontal overhangs are most effective against high sun and normally used on the southern elevations [1-3]. They are also used in northern elevations for protecting windows from the rainwater. A shading mask characterizes this type of shading devices with a curved shading lines running from one edge of the mask to the other, Figure 2 shows the shading mask for a full day because of the use of horizontal shading device.

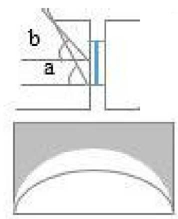


Figure (2). The shading mask of the horizontal shading device.

2.1.2. The Vertical Fins

Are useful against the low sun on the east and west facades and they are characterized by a shading mask with a vertical shading lines, Figure 3 shows the shading lines resulting from use of vertical shading devices.

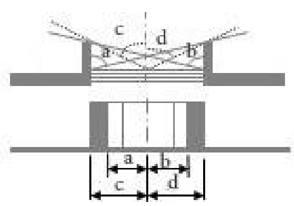


Figure (3). The shading mask of the vertical shading device.

2.1.3. The Overhang/ Fin Combination, (The egg crate):

This type of treatment can be effective for any orientation depending on the depths and dimensions of the openings. It is a combination of curved and vertical shading lines as illustrated in Figure 4.

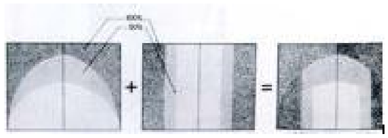


Figure (4). The shading mask of the horizontal shading device.

3. THE DESIGN OF SUN SHADING DEVICES:

The first step in designing shading devices is to define the period during which they will be in operation.

3.1. The Over Heated Periods

Summer season in Libya is defined [4] as the period between June 1st and August 31st. This is roughly the time when complete shading is needed and where the internal temperature of an unshaded building would exceed the comfortable level. 21°C had been recommended [4,5] to be the limit temperature for temperate regions and accordingly, this can be applied to Libyan conditions.

3.1.1. Temperature Records For Tripoli City

Due to lack of indoor temperature records [4], the records of the outdoor dry bulb mean hourly temperatures for each month for the duration of 7 years (from 1989 to 1995) have been compiled, see table 1. This table gives a visual simulation of the periods when buildings need shading in Tripoli city (latitude 32.59).

Based on that, shading devices should be designed to give protection from 11:00am to 20:00 pm during the months of May and October, and from 14:00 pm to 17:00 pm during November. While it should give full time protection during June, July, August, and September. The table also shows that shading is not required in December, January, February, and March.

Table (1). Mean Monthly Temperatures (Reference, Libyan Meteorological Department), An average of 7 years (1989-1995) -Showing the overheated periods

(Light) The overheated periods

(Dark) The periods during which shading devices should be in operation

Time L.T.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
02	11.25	12.20	14.30	16.38	19.10	22.61	24.44	25.78	25.34	22.14	16.94	12.82
05	10.18	11.07	13.25	15.24	18.94	21.74	23.40	24.45	24.15	20.92	15.94	11.85
08	9.80	10.62	13.17	15.64	19.60	**23.07**	**24.47**	**25.04**	**24.44**	20.78	15.55	11.44
11	13.44	15.38	17.92	20.52	**24.05**	**32.07**	**29.07**	**30.47**	**30.01**	**26.34**	20.57	15.48
14	16.07	17.71	19.82	**21.84**	**24.90**	**28.25**	**29.88**	**31.18**	**30.91**	**28.20**	**22.58**	18.37
17	15.62	17.12	19.04	20.75	**24.10**	**27.38**	**29.14**	**30.35**	**29.78**	**26.88**	**21.64**	17.75
20	14.02	15.12	16.90	18.67	**21.68**	**24.98**	**26.88**	**28.20**	**27.50**	**24.54**	19.68	15.80
23	12.48	13.65	15.45	17.44	20.37	23.50	25.12	26.87	26.35	23.22	18.00	14.18

According to the records of the monthly mean in Table 1, the limits of the comfortable zone for latitude 32.59° have been illustrated in Table 2 which shows the monthly average effective temperatures, taking in consideration that the comfort zone ranges from 21° C to 23°C.

3.2. The Position Of The Sun

The second step in the process of designing sun-shading devices is to define the position of the sun during the overheated periods.

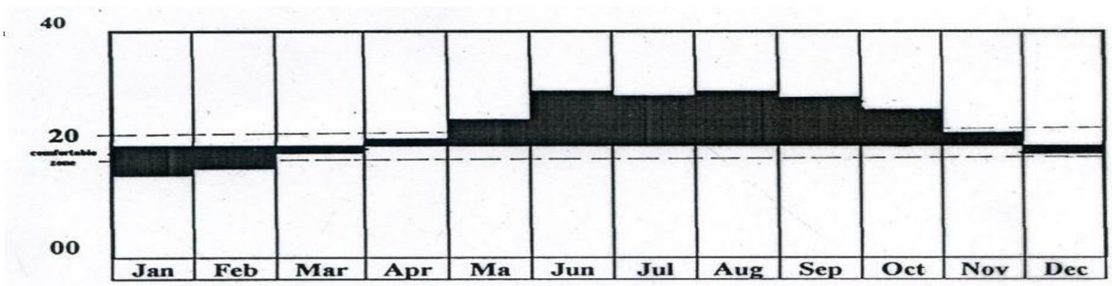
To locate the position of the sun in the sky at any moment, two coordinates are needed, they are called Altitude angle and Azimuth angle [2, 6,7], see Figure 5.

It is important to mention that the variations in the solar Altitude and solar Azimuth are the consequence of the daily rotation of earth about its polar axis, and the annual movement of the earth around the sun.

3.2.1. Solar Altitude Angle

It is the angle measured between the horizon and the position of the sun above the horizon, see Figure 6.

Table (2). Monthly Average Effective Temperatures For Tripoli City An average of 7 years (1989-1995) [12].



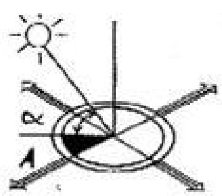


Figure (5). The Altitude and the Azimuth angle [11].

Mathematically, the solar Altitude angle can be defined in terms of the observer's altitude (location), the hour angle (time), and the sun's declination (date) as follows:

$$\alpha = \sin^{-1}\begin{pmatrix} \sin\delta\sin\phi + \\ \cos\delta\cos\omega\cos\phi \end{pmatrix}$$

Where:

δ is the declination angle

φ is the observers latitude angle

ω is the hour angle

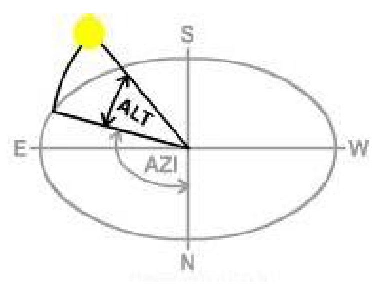


Figure (6). The Altitude angle [11].

3.2.2. Solar Azimuth Angle (Bearing angle)

It is the angle measured from the south to the east or west according to the position of the sun and its projection on the horizontal plane, the reference plane for the solar Azimuth is the vertical plane running north south through the poles, see Figure 7.

Mathematically, the solar Azimuth (A) depends on location, time of day, and the season, and is expressed as:

$$A = \sin^{-1}\left(\frac{-\cos\delta\sin\omega}{\cos\alpha}\right)$$

It is important to mention also that earth follows an elliptical path with the poles inclined at an angle of 23.4 degrees to the plane of the ellipse traversed. This raises the importance of knowing other related angles.

3.2.3. The Declination Angle

The plane that includes the earth's equator is called the equatorial plane, see Figure 10. If a line is drawn between center of earth and the sun, the angle between this line and earth's equatorial plane is called the Declination angle (6).

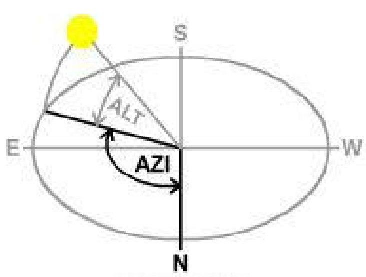


Figure (7). The Azimuth angle [11].

Due to the yearly orbit of earth around the sun, the value of the declination angle changes according to the seasons, see Figure 8.

Mathematically, the declination angle can be defined according to the day's number. For many solar design purposes, an approximation for the declination angle is:

$$\delta = 23.45\, sin\left(\frac{360}{365}\, 284 + n\right)$$

Where: n is the number of the day (from 1 to 366)

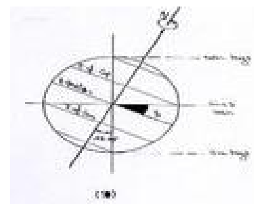


Figure (8). The changes of the declination angle.

3.2.3.1. The Summer Solstice

It is observed in June 21 when the noontime sun is at its highest point in the sky and the declination angle δ =23.45°, see Figure 9.

3.2.3.2. The Winter Solstice

In December 22, the noontime sun is at its lowest point in the sky, that means that the declination angle is at its most negative value δ = - 23.45°.

3.2.3.3. The Equinox

There are two times a year during which the sun is visible for 12 hours and not visible for 12 hours. They are called the Autumnal Equinox on about September 23 marking the start of the Fall, and the Vernal Equinox on about March 22, marking the beginning of the Spring. At these conditions the declination angle δ =0°.

3.2.4. The Hour Angle

It is the angle measured between the plane of the meridian containing the point of interest and the meridian that touches the earth sun line, see Figure 10. The hour angle is zero at solar noon (when the sun reaches its highest point in the sky).

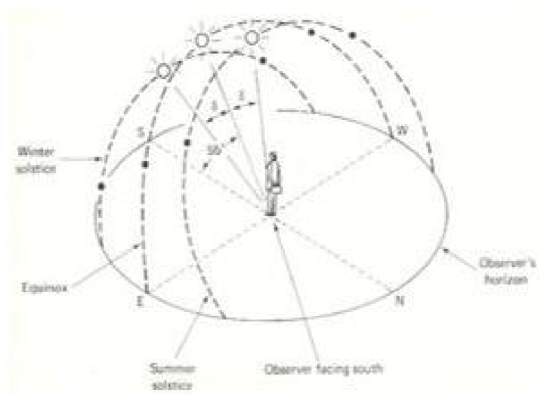


Figure (9). The Equinox [11].

The unit of angular measurement of time is the hour angle. The basic conversion is that 24 hours equal 360-hour angle degrees, [6].

$$\omega = 15(t_s - 12)^o$$

As (t_s) is the solar time in hours

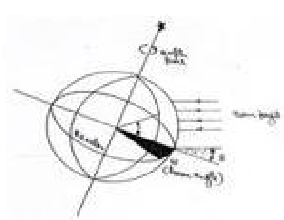


Figure (10). The Hour angle [11].

3.3. Design Aids For Shading Devices

The third step in the process of designing shading devices is to look for design tools that simplify the process of defining the position of the sun in order to determine the geometrical shape and the dimensions of the shading device. The main design tools for this purpose are the sun charts and the shadow charts, see appendix A.

3.3.1. Sun Charts

The sky dome is the visible hemisphere of sky above the horizon in all directions, the vertical angles of the whole sky dome can be represented by the grid of the chart. It is as if there were a clear dome around an observer then the chart was peeled off this dome, stretched out and laid flat, see Figure 11.

The horizontal lines on the sun charts represent Altitude angles in 10 degrees increments above the horizon; the reference plane for solar altitude is the horizontal plane.

The vertical lines on the sun charts represent Azimuth angles in 30 degrees increments measured from the south, with negative sign towards the east direction, and with positive sign towards the west direction.

Sun charts (or the sun path diagram) give graphical simulation to the path of the sun across the sky on several chosen days of the year. Each sun path diagram is good for the latitude for which it was made.

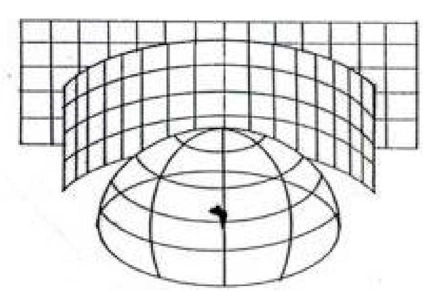


Figure (11). The Sun charts.

Due to lack of sun charts for the considered latitude [4], and relating to the objective of the study at hand, all of the above-mentioned equations were applied in a small computer software. However, it is significant to mention that the sun chart that represents the twenty first day of each month is considered the most important, it shows the equinox, summer , and winter solstices.

Summer solstice represents the longest summer day of the year, and the sun path diagram of this day records the highest values of the Altitude angles of each hour in that day. Thus, the design of shading devices has to be based on these values so that they give protection for the rest of summer days. This will be discussed later in section (4).

Similarly, winter solstice represents the shortest winter day of the year in which the lowest values of the Altitude angles might be recorded for each hour.

The Stat graphics software has been used in creating the chart shown in Appendix (A). The created chart represents the sun path diagram for north latitude 32.59**.**

3.3.2. Shading Calculator

The shading calculator represents the vertical and the horizontal angles. In more terms that are precise, this chart shows the various combinations of Azimuth differences and solar altitude angles. It can be used as an overlay to all of the solar charts in the process of the design of shading devices. When adjusted to the orientation of the facade, it reads the vertical and the horizontal shadow angles, see Appendix (A).

3.3.2.1. Horizontal Shadow Angle: (HSA)

It is the angle between the direction of the facade azimuth and the solar azimuth (2), and characterizes a vertical shading device, see Figure 12, the created shading mask can be identified whether it is 50% or 100% shading.

$$HSA = A_s - A_w \ ^{\circ}$$

A_s=solar azimuth in degrees
(east -ve, west +ve)

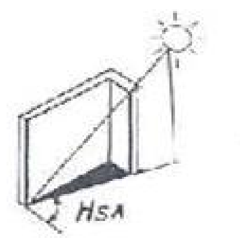


Figure (12). The Horizontal shadow angle.

3.3.2.2. Vertical Shadow Angle (VSA)

It is calculated from the solar altitude, and the horizontal shadow angle HSA. It can be defined as the angle between the direction of the sun, resolved in the plane of the elevation and the horizontal plane, see Figure 13.

$$VSA = \tan^{-1}\left(\frac{\tan\alpha}{\cos HSA}\right)$$

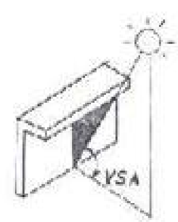


Figure (13). The Vertical shadow angle.

4. THE SELECTION OF THE ALTITUDE AND AZIMUTH ANGLES FOR EFFECTIVE DESIGN

The forth step in the process of design, is the determination of the dimensions of the horizontal and the vertical devices. To do so, the effective values of the Altitude and the Azimuth angles have to be determined. For the horizontal shading devices, the effective value of the Altitude angle can be selected as follows:

1. Table 1. indicates the periods in which shading device is needed during the months of June, July, August, and September. Shading is required from 8:00 am to 20:00 pm during these periods.
2. The gradual increase and decrease of the values of the altitude angles for considered periods can be seen from the output data, see appendix (A). Table 3 summarizes the above-mentioned steps.

The above mentioned table shows that the higher values of the solar altitude angles (for each month in the overheated period) were at 12:00 noon, all of the other values were less than these magnitudes. To choose the required angle for design purposes, the smallest value has been selected, which was in September and equals (68.8^{O}), this would give protection from 11:00 am to 13:00 pm in June and August, and only at 12:00 hours in September.

Table (3). The Magnitudes of the Altitude Angles in the Over Heated Period, (From sunrise to sun set)

	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Jun	0.82	12.4	24.5	36.9	49.5	62.1	73.9	80.9	73.9	62.1	49.5	36.9	24.5	12.4	0.82
Jul	-	10.8	23.1	35.6	48.2	60.6	71.9	77.8	71.9	60.6	48.2	35.6	23.1	10.8	-
Aug	-	10.7	23.0	35.6	48.2	60.6	71.8	77.7	71.8	60.6	48.2	35.6	23.0	10.7	-
Sep	-	6.11	18.7	31.3	43.7	55.3	64.7	68.8	64.7	55.3	43.7	31.3	18.7	6.11	

If more protection is needed in September, the value of the required altitude angle can be determined by choosing another angle in the same month with smaller value. If the angle (55.3^{O}) was chosen, this would give protection from 10:00 am to 14:00 pm in the months of June, July, August, and September. It is significant to mention that as the period of protection is increased by the designer, the dimensions of the shading device, also, should be increased. However, the designer should take that into consideration to achieve an effective and economical design. On the other hand, and for vertical shading devices,

the smallest magnitudes of the azimuth angles (for each month) in the overheated period were selected, see table 4.

Table (4) The Magnitudes of The Azimuth Angles in the Over Heated Period, (From sunrise to sun set)

	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Jun	118	110	103	96.3	88.8	78.6	59.1	0.00	59.1	78.6	88.8	96.3	103	110	118
Jul	-	107	100	92.7	84.3	72.7	51.0	0.00	51.0	72.7	84.3	92.7	100	107	-
Aug	-	99.6	91.8	83.5	73.4	59.3	36.5	0.00	36.5	59.3	73.4	83.5	91.8	99.6	-
Sep	-	-	81.3	72.2	61.1	46.5	26.1	0.00	26.1	46.5	61.1	72.2	81.3	-	-

The above table shows that the smallest values of the solar azimuth angles for each hour were recorded in September. Then one of the highest values in that month can be selected for design. If the angle (72.2^{O}) has been chosen, it would give protection from 10:00 am to 14:00pm in June, July, August, and from 8:00 am to 16:00 pm in September. If less protection was needed, the designer would select smaller angle to reduce the protected periods in each month.

5. HOW TO DESIGN AN EFFECTIVE SHADING DEVICE?

After the sun chart has been created and drawn, the following steps can be described as the fifth step in the process of designing the sun shading devices.

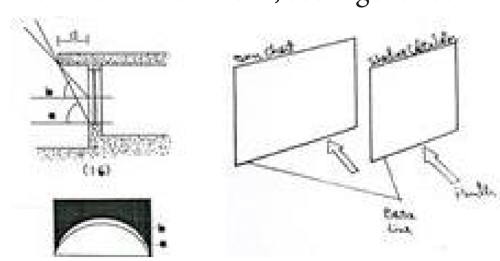
For the three types, some essential information should be available before starting the last step in the design process, these are:

- The latitude
- The sun chart of the same latitude
- The shading calculator (with same scale as the sun chart)
- The wall azimuth
- The selected altitude angle
- The selected azimuth angle

Then the following steps have to be followed to determine the proper dimensions of shading devices.

1. Two points should be considered and determined, the base of the window, and the midpoint of the window for 100% and 50% shading.
2. The vertical shadow angle (a) from the base of the window gives the requirement for 100% horizontal shading, while the vertical shadow angle (b) from the middle of the window gives the 50percentage shading line.
3. The shading mask can be drawn using the shading calculator overlay shown in appendix (A), see Figure 14.

Next, that has to be superimposed on the solar chart shown in appendix (A), the centerline of the overlay has to be lined up with the wall azimuth, see Figure 15.



Figures (14), (15). The Vertical shadow angle [11].

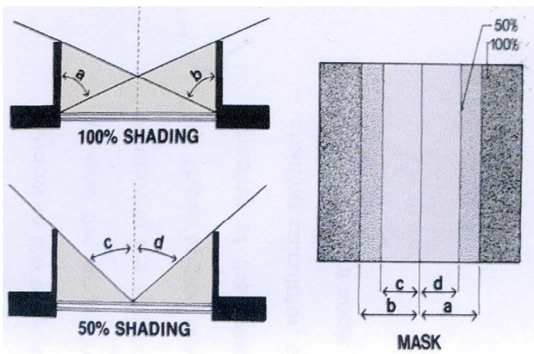
5.2. The Vertical Shading Device

An accurate plan of the window opening and any vertical shading device has to be drawn to scale, Figure 16.

The conditions for 100% shading and 50% shading should be identified.

Using the shading calculator as an underlay, the shading mask can be drawn to scale, see Figure 17.

Then the shading mask has to be superimposed on the solar chart for the appropriate latitude, taking in consideration that the centerline has to be oriented to coincide with wall azimuth.



Figures (16), (17). Shading mask.

5.3. The Overhang/Fin Combination

In this case, the two created shading masks (vertical and horizontal) should be merging, see Figure 18.

Figure (18). Vertical and horizontal shading masks.

6. EXAMPLE:

"3.00x1.80m" window,, see Figure 19 lies on a wall facing 45^{O} west sized to admit maximum winter solar gaining for a passive solar building in (32.59NL site), this window has a severe problem on thermal comfort due to admitting of solar gain when it is not needed. As an architect, you are asked to solve this problem. In words and sketches, present your solution.

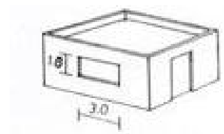


Figure (19). A window lies on a wall facing 45^{O} west.

The Solution:

Since the window is facing the west direction, so it requires both vertical and horizontal shading devices. For proper use and design of shading devices, some essential information have to be available, these are:

*The latitude (32.59^{0})

*Sun chart for the same latitude (see appendix A)

*Shadow chart (see appendix A)

*The wall azimuth (45^{0} west)

*The selected altitude angle (55.3^{0})

*The selected azimuth angle (72.2^{0})

1) The horizontal shading device:

As seen in the above sketches, the length of the shading device reached 1.25m for 100% shading mask, while it is 0.65m if 50% shading was required, see Figure 20.

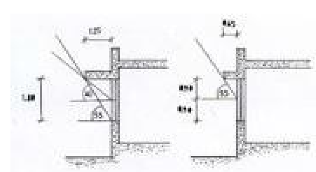


Figure (20). A shading device with 100% and 50% shading mask.

2) The vertical shading device

For 100% shading, the distance from the wall to the edge of the shading device reached 0.90m while it reached 0.50m if 50% shading was required, see Figures 21 and 22.

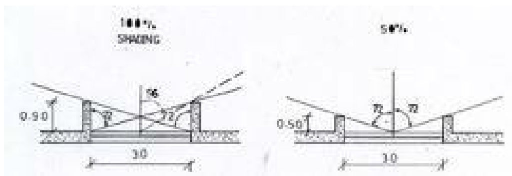


Figure (21). vertical shading device with different shading masks.

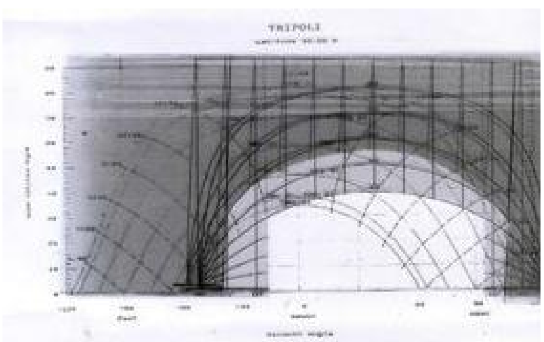


Figure (22). The Resulted Shading Mask.

The periods of isolation at different dates can be read off for 100% shading and 50% shading

7. CONCLUSIONS

1. Shading devices are important construction elements; they have an impact on protecting buildings from direct heat gain. They can allow the low sun to inter the human environment during the cool periods, while keeping the high sun out during the hot periods; these advantages are considered important especially in the temperate regions such as Libya.
2. The process of designing shading devices starts by identifying the overheated periods of the considered latitude. This information identifies the months when complete shading is required, and when shading is not required.
3. The previous information requires the availability of sun path diagram for the considered latitude, or latitude under consideration.
4. Sun charts and shading calculator can be used to draw up the required shading devices directly.

8. RECOMMENDATIONS

In this study, Tripoli city was selected as an example for determining the design process of shading devices. However, sun charts for the various latitudes of Libya should be produced (using the same computer software).

9. SUGGESTIONS FOR FURTHER STUDY

The efficiency of shading devices is slightly affected by the materials of which they are made. Thus, the proper materials that have low thermal capacity can be identified and compiled. This can be an extension to the study at hand.

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