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A DESCISION-MAKING MODEL OF SUN-SHADING DESIGN FOR ENHANCED SUN USAGE IN MODERATE CLIMATES

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ABSTRACT

Passive design strategies always aimed at providing thermal comfort through total blocking of the sun during summer and permitting warm sun in the winter. On the other hand total blocking of the sun proved to be a health and mind liability for people living in the cities who spend a big amount of their time inside buildings. In modern urban fabric we need to be able to live with the sun, allow it under control in our living spaces to promote good health and healthy indoor environment. This has to be achieved without allowing the penetration of sunrays to be a thermal liability in the interior, especially in hot-aired climates like Cairo. This research aims at providing guidelines and a tool for architects to design East, West and South facades in Cairo (latitude 30 N) that allows sun-in in favorable morning or afternoon hours while keeping the sun out in high thermal load hours during the day. The concept introduced in this research is useful in the early design phases for the architects to be able to design beneficial sun-in, adequate day lighting at a manageable level of thermal loads.

KEYWORDS: Shading, Sun- breakers, Moderate climate, Sun, Decision making, Light shelf.

1. INTRODUCTION

Thermal comfort and passive design strategies have always aimed at reducing the cooling loads inside hot and moderate climate regions. On the other hand sun is a major source in promoting good health and indoor environment for humans.

The importance of sun in the indoor environment for human health and social behavior is much greater than is usually recognized. A long deprivation of sun light for humans can contribute in many complications that modern urban human being suffers from. Sunlight is important for reasons of health and safety, for reasons of efficient productivity and for reasons of basic human development. Sunlight influences human both biologically and socio-economically.

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In 1991 the world health organization (WHO) issued a circular that warns from the adverse of ill indoor conditions on human health [1].

Sunlight plays a crucial role in promoting the immune and metabolism system in humans. It plays an important role in regulating the circadian rhythm and the wellbeing of the mood and mind. It is important in the production of vitamin D. Sunlight helps eliminate reservoirs of potential harmful micro flora. Some harmful shade-loving insects are discouraged by daylight. Sunlight promotes cleanliness and health. Total blocking of the sun inside spaces is a health risk especially at vulnerable groups of children, women and the elderly.

2. OBJECTIVE

The aim of this research is to suggest a plan or a limit for shading devices on the three main orientations that blocks sunlight at the disagreeable hours through the year while permitting sun into the space daily at low temperature hours. Designing any façade within these limits given by the horizontal and vertical suggested plans will provide the required shade at the non-agreeable hours and permitting it in the low temperature hours. A horizontal and vertical plan of a light shelf is also given to permit the maximum glare-free light in space.

3. LIMITATIONS

The location of the study is Cairo, Egypt, latitude 30.03 North, Longitude 31.2 East. All results are specific to this location; different locations will require other calculations.

A study model is constructed with the showed dimensions in Fig. 1. The suggested measurements of any shading device or light shelf can work with any window width, while different heights of the window sill can cause some differences in the suggested shading plan, but can be corrected easily by the designer. For example, the window sill used in 0.85 m, the measurement of the shading device will do for this sill height or higher. In case of a lower sill or a ground opening like a balcony, a slightly deep shading device will be needed.

The facades studied are west, east and south. North orientation is excluded as little sun is falling on it anyway. The research is limited to square and rectangular planes. Circular or curved walls as well as North East, North West, South East and South West facades are excluded and will be covered in further studies.

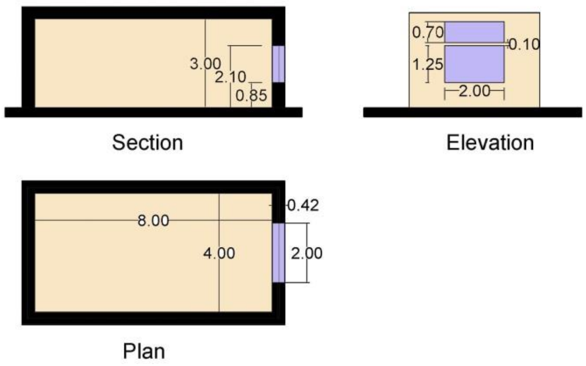


Fig. 1. Study model.

4. METHODOLOGY

The Graphical Equidistant Sun Chart is primarily used to measure the altitude and the azimuth for each orientation per hour. Then the required cut off sun angles is chosen so that the sun is permitted into the space is either early in the morning during 8-10 a.m.. or late in the afternoon 4-5 p.m.. where the thermal loads are at its least. In certain seasons and orientations when total blocking or total admitting of the sun is inevitable at some hours, insignificant direct sun patches are allowed only for the purpose to construct a shading device that is structurally reasonable to be implemented.

VSA and HSA are then measured graphically from the internal surface of the window using the shadow mask protractor to give vertical and horizontal planes for the shading device and the light shelf. A baffle is used with the ribbon window above the lightshelf to prevent direct solar gain and limit the light shelf to its purpose of reflecting diffused sunlight into the back of the room rather than permitting direct sunlight as shown in Fig. 2.

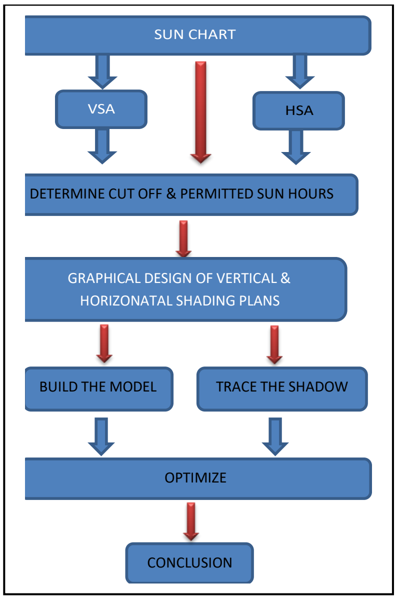


Fig. 2. Methodology.

5. CRITICAL ANGLE

It is a term used in this paper to define the cut-off and sun-in angels. VSA and HSA angels larger than this angle will be blocked while angels lower than this angle will be permitted. The suggested horizontal planes of the sun breaker are designed using this angle.

6. EAST ORIENATION

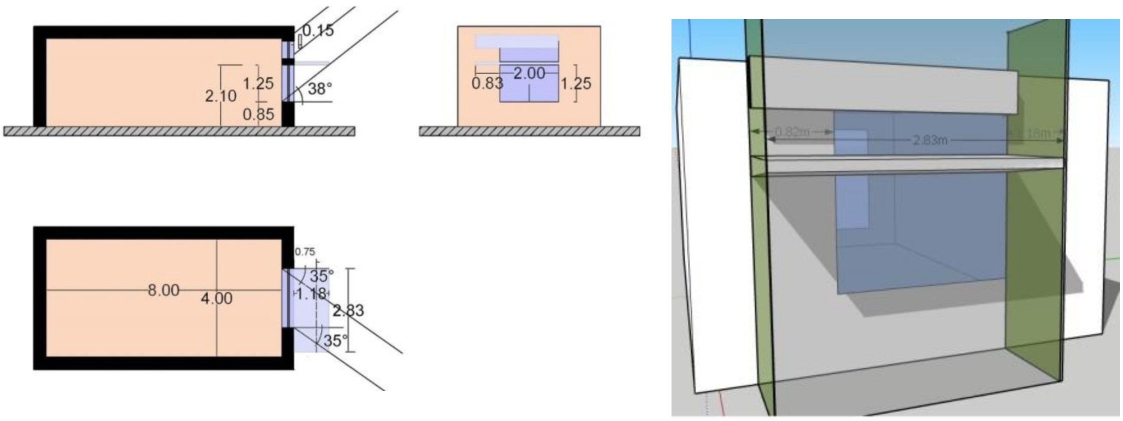
East orientation usually needs a horizontal and a vertical sun shade device for total shading which is not the scope of this research. Our scope is to let the sun daily as much as it is tolerable and does not accelerate thermal gain in the space within.

Examining the VSA and the HSA of the east orientation using Table 1, it is required to block the sun in the hot seasons roughly after 9 a.m. and in the cold season after 10 a.m. Midday sun is not always required or accepted by most people even in mild cold climates as in Cairo. The VSA and the HSA above which the sun will be blocked and below which the sun is admitted in the early morning are: VSA = 38 and HSA = +35.

Table 1. East facade VSA and HSA.

Season	Date/ Month		Hour 6	7	8	9	10	11	12
Summer	22 June	V	15	27	39	50	62	75	
		H	-23	-17	-10	0	+6	+25	
Spring/ Summer	15 May 30 July	V	13	25	37	49	62	75	
		H	-18	-10	-4	+5	+5	+35	
Spring/ Summer	15 Apr. 30 Aug	V	8	20	34	46	60	73	
		H	-10	0	-3	+22	+30	+55	
Spring / Fall	21 Mar 23 Sept	V		16	28	42	56	73	
		H		-3	+6	+29	+43	+64	
Fall/ Winter	28 Feb 15 Oct	V		12	25	38	53	70	
		H		+4	+22	+35	+50	+67	
Fall/ Winter	28 Jan 15 Nov	V		7	19	34	50	68	
		H		+21	+30	+41	+55	+70	
Winter	22 Dec	V		3	15	30	45	66	
		H		+27	+35	+45	+57	+75	

Implementing the measured VSA and HSA graphically to determine the limits of the shading device in the east orientation: Fig. 3a. The required shading device dimensions will be 2.83 width and 1.18 depth starting from the upper most left corner of the window. The light shelf will be 15 cm away from the plane of the ribbon window Fig. 3b.



(a)

(b)

Fig. 3. East orientation model and resulting limiting planes of the sun shading.

6.1 Examining the Results with Real Time Shadow Cast

Applying the above mentioned design limits and testing the results using real time shadow cast Table 2. It is obvious that the designed shading device limits was able to allow sun in the early morning hours from 8 to 10 A.M. in the cold seasons and allow sun is small patches during the equinox and it blocked the sun after 9 A.M. in the hot seasons. Only horizontal shading device was used which is considered an asset in designing east orientation shading devices.

7. WEST ORIENTATION

West orientation is always considered the most difficult orientation to shade because the sun hits the façade during the most heated hours of the day and the sun is incident on the western façade almost perpendicularly causing glare and penetrates deep in the space in the late hours. Usually a vertical and a horizontal shading devices are used together to totally block the sun. The vertical device is not always preferred as it limits the view to the outside. Fortunately, this can be avoided if a good compromise of the allowed sun-in is practiced.

Hot direct sunlight during the early noon hours is blocked from 1 p.m. to 3 p.m. during the cold season and up to 4 p.m. in the hot season while late evening warm sun is allowed in after 4 p.m. until sunset.

7.1 Process

Examining the values of the VSA and the HSA in Table 3. As the size of the shading device is not required to be very large. Allowing a small sun patch will not be a great thermal burden during the equinox. It is noticed that optimum cut-off angle will be: VSA = 41 and HSA = -38. Figure 4a Sun angels greater than this angle will be blocked while sun angels lower than these angels will be permitted. Planes are suggested in Fig.4b.

Table 2. East orientation.

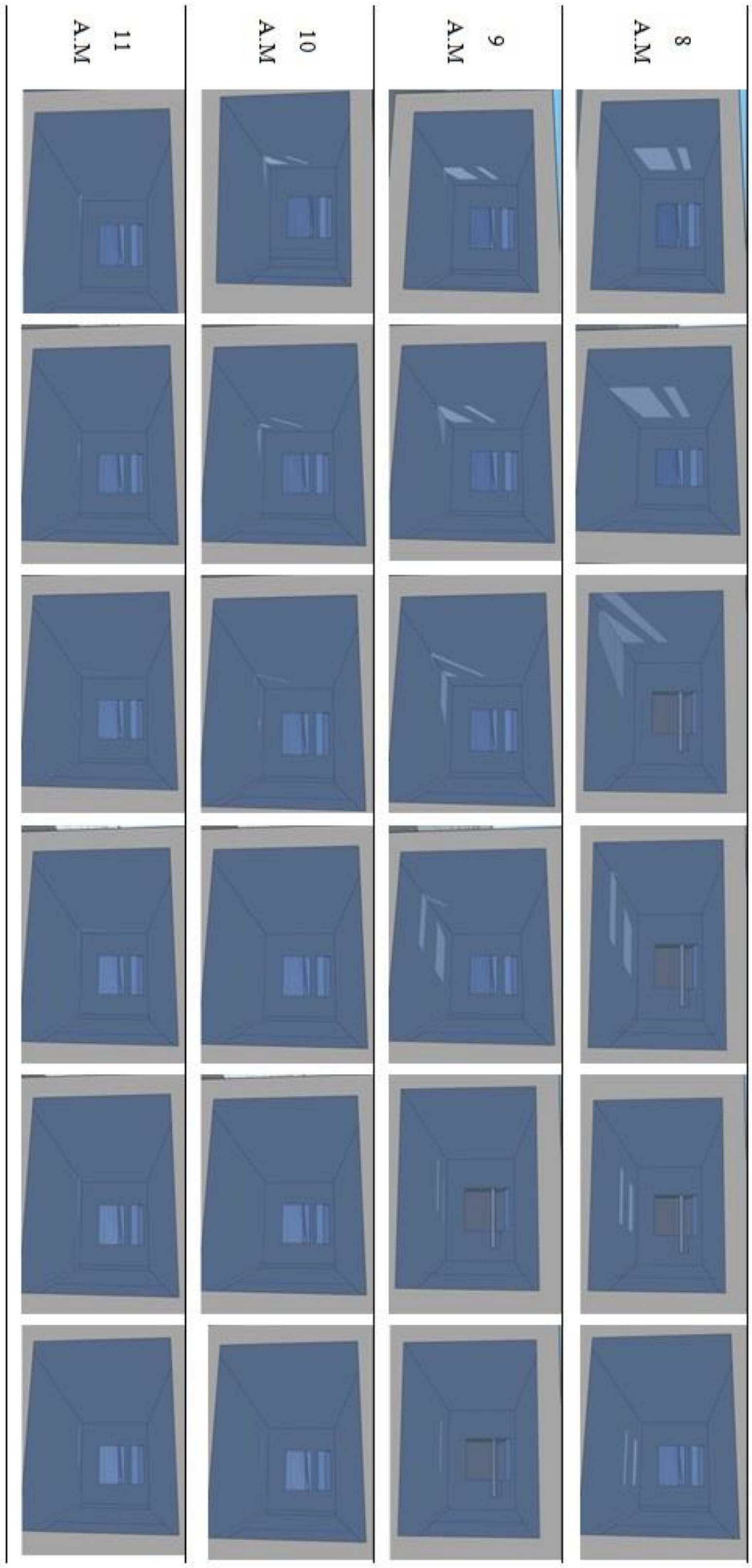


Table 2. East orientation, (Cont.).

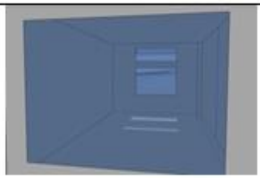
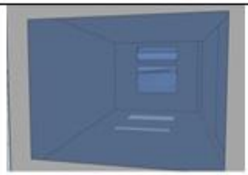
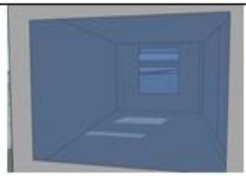
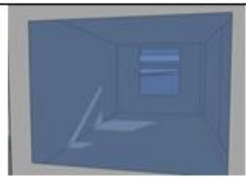
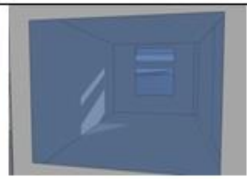
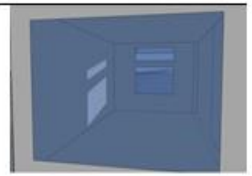
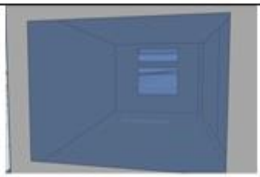
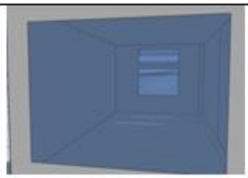
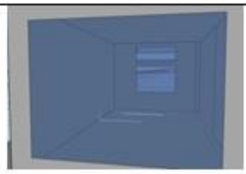
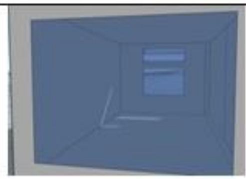
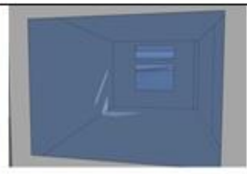
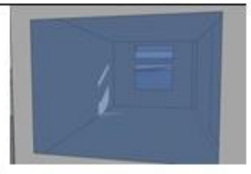
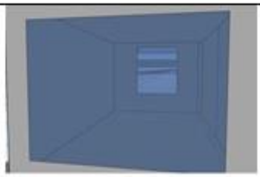
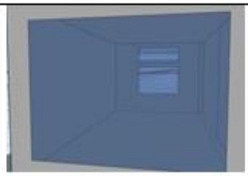
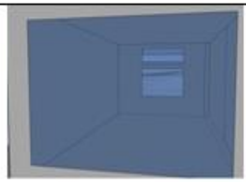
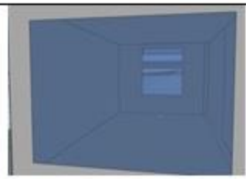
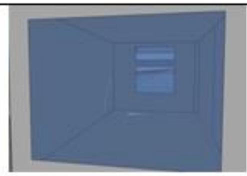
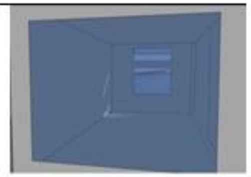
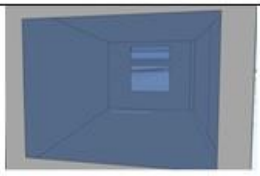
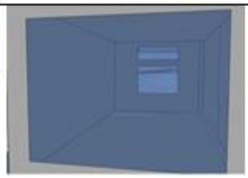
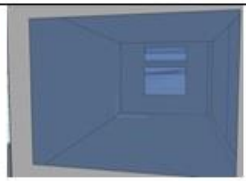
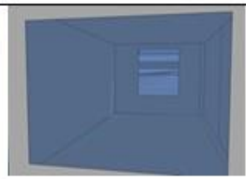
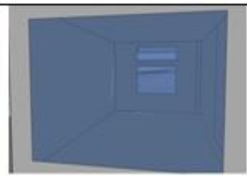
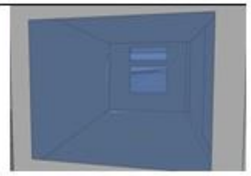
	July	August	September	October	November	December
8 A.M						
9 A.M						
10 A.M						
11 A.M						

Table 3. West facade VSA and HSA.

Season	Date/ Month		Hours 1	2	3	4	5	6	7
Summer	22 June	V	76	63	51	40	30	18	16
		H	-45	-10	-2	+5	+14	+21	+21
Spring/ Summer	15 May 30 July	V	75	62	50	38	27	15	
		H	-45	-20	-10	0	+9	+16	
Spring/ Summer	15 Apr. 30 Aug	V	75	59	45	35	22	10	
		H	-60	-35	-20	-10	-2	+2	
Spring / Fall	21 Mar 23 Sept	V	73	55	41	25	11		
		H	-60	-45	-38	-28	-18		
Fall/ Winter	28 Feb 15 Oct	V	70	50	37	29	16		
		H	-70	-50	-39	-21	-11		
Fall/ Winter	28 Jan 15 Nov	V	68	47	33	19	5		
		H	-73	-56	-45	-35	-25		
Winter	22 Dec	V	65	45	28	15			
		H	-75	-50	-49	-40			

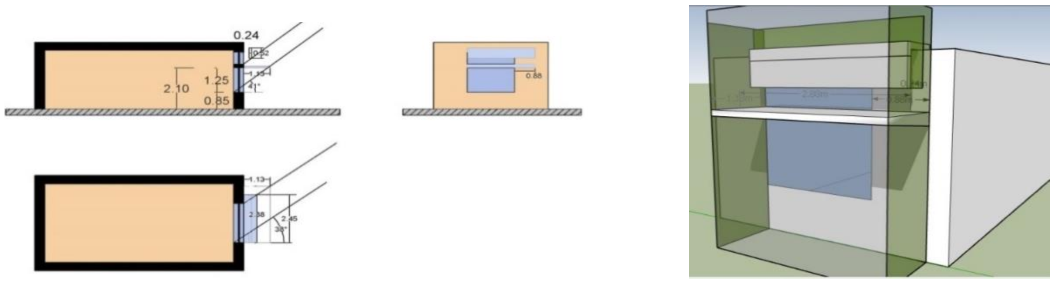


Fig. 4. West orientation model and resulting limiting planes of the sun shading device.

7.2 Examining the Results with Real Time Shadow Cast

Applying the above mentioned design limits and testing the results using real time shadow Table 4. The given planes was able to keep the sun out in the high thermal load noon hours and allow it after 4 p.m. Note that certain inevitable sun batches exist in the equinox, only for the purpose of not constructing a very large shading device.

8. SOUTH ORIENTATION

The south orientation though it is not difficult to shade using just a horizontal device. The principal of total shading during summer and total sun exposure during winter is not the aim of this research.

Table 4. West orientation.

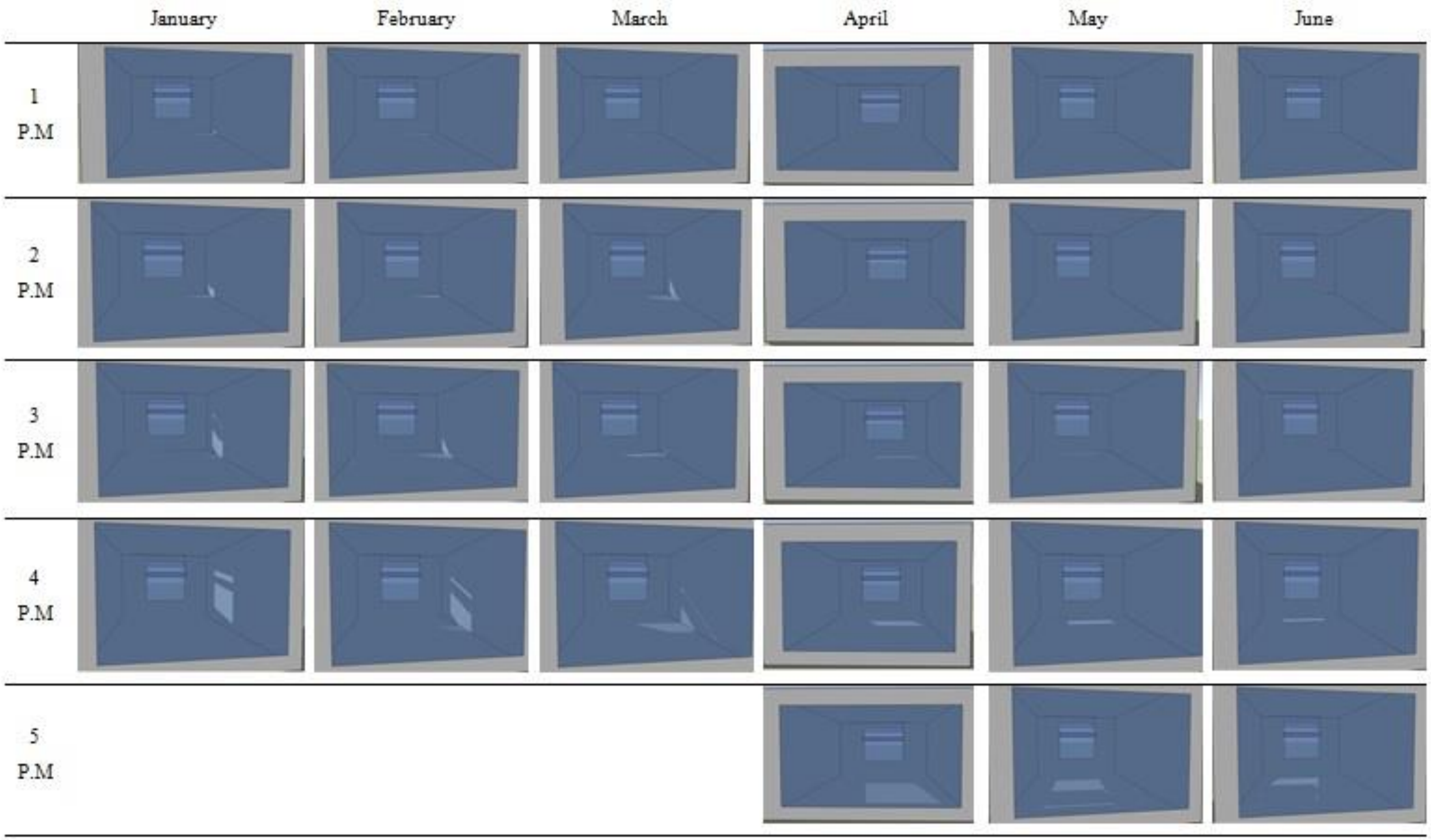
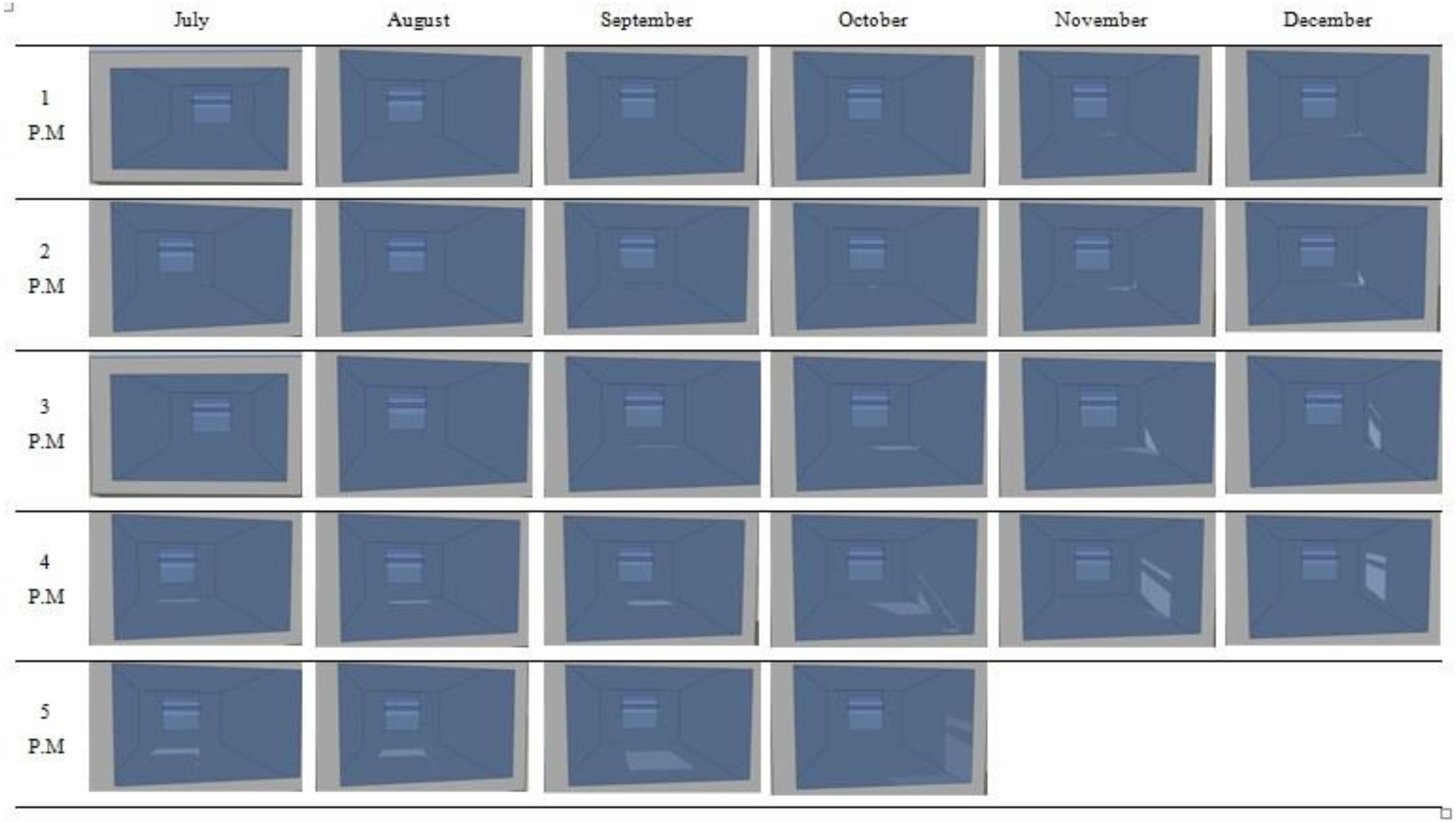


Table 4. West orientation, (Cont.).



The goal is to partially allow the sun in during all months and have the high thermal loads hours shaded. Since this will require a large sun breaker on the south facade, certain optimizations have been made. The sun of the early morning and late afternoon have been allowed, while the sun between 10:30 to 3:30 have been blocked or at least insignificant sun patches are allowed in the winter season and early equinox months.

8.1 Process

Using the sun path diagram we will notice that there is a big difference in the sun altitude angle in the south façade between summer and winter that reaches about 47° during the solar window that ranges from 9 a.m. to 3 p.m. throughout the year. Referring to Table 5 of the VSA and HSA of the south façade, the VSA angles at the required sun-in times in the early morning and late afternoon is larger than the VSA angels of the required sun-off hours. This means that any breaker designed can keep the sun-off hours, but will also keep out the sun-in hours. Thus, the process adopted is to consider the VSA of the cooling (summer) season separately than the heating season (winter). Thus designing the breaker planes with more than one critical angel.

8.1.1 Blocking the sun in the summer/spring period during the period starting from 22 June up to 22 Sept

Because the sun altitude is highest in summer, the sun-in angels are almost 90° above the building, while the sun-off angels are lower. To solve this, the average angel of the sun-off period is first selected which is in this case VSA = 70° & HSA = ± 60. This will be the first summer plane of the sun breaker.

The second dimension of the breaker will then be the least angel in the sun-off angels, which will be: VSA = 59° and HSA = ± 50° as shown in Fig. 5(a). It is to be noted that HSA in the sun-in angels in the early morning or the late afternoon is very wide on the south façade, almost grazing the façade surface. The same VSA in the noon and during the hot hours have a much narrower HSA, thus it can be blocked by the horizontal breaker without the need of a vertical breaker.

Table 5. South facade VSA and HSA.

Season	Date/Month		Hour 7	8	9	10	11	12	1	2	3	4	5
Summer	22 June	V				85	83	82	83	85			
		H				-80	-70	0	+55	+80			
Spring/ Summer	15 May 30 July	V			85	80	78	78	77	79	85		
		H			-85	-75	-60	0	+50	+73	+85		
Spring/ Summer	15 Apr. 30 Aug	V		83	73	70	69	69	69	70	73	74	
		H		-83	-75	-60	-40	0	+36	+60	+73	+80	
Spring / Fall	21 Mar 23 Sept	V	60	59	60	59	59	59	59	59	59	69	59
		H	-84	-75	-65	-50	-30	0	+27	+50	+63	+74	+75
Fall/ Winter	28 Feb 15 Oct	V	30	40	46	49	50	50	50	49	47	43	30
		H	-75	-68	-56	-43	-25	0	+22	+41	+55	+66	+75
Fall/ Winter	28 Jan 15 Nov	V	5	27	36	40	43	43	43	40	36	29	5
		H	-69	-61	-51	-38	-21	0	+20	+36	+50	+59	+68
Winter	22 Dec	V		17	29	37	36	35	35	34	30	20	
		H		-54	-46	-34	-18	0	+5	+32	+45	+55	

SUN-IN, Hrs. **SUN-Off, Hrs.** **SUN-IN, Hrs.**

8.1.1 Blocking the sun in the summer/spring period during the period starting from 22 June up to 22 Sept

Because the sun altitude is highest in summer, the sun-in angels are almost 90° above the building, while the sun-off angels are lower. To solve this, the average angel of the sun-off period is first selected which is in this case VSA = 70° & HSA = ± 60. This will be the first summer plane of the sun breaker.

Then second dimension of the breaker will be the least angel in the sun-off angels, which will be: VSA = 59° and HSA = ± 50°, Fig. 5(a)

Note that HSA in the sun-in angels in the early morning or the late afternoon is very wide on the south façade, almost grazing the façade surface. The same VSA in the noon and during the hot hours have a much narrower HSA, thus it can be blocked by the horizontal breaker without the need of a vertical breaker.

8.1.2 Blocking the sun in the equinox period

The VSA between 59° and 43° will be blocked which will be the noon hours, Fig. 5a.

8.1.3 Blocking the sun in the winter season

Due to the low altitude angle at that season a larger horizontal sun breaker can be used, to avoid using an unpractical size sun breaker a lower angle was chosen that have a wider HSA that can help block the low altitude angle sun during the sun-off hours as shown in Fig. 5a.

The VSA between 37° and 30° will be blocked which are the noon hours of the cold season.

To cut it short VSA between 70° and 59° will admit the sun while VSA between 59° and 43° will block (noon summer time), VSA between 43° to 37° will admit the sun (favorable early morning and late noon sun) and VSA between 37° and 30° will be blocked (noon hours in winter), as shown in Fig. 5a. A fin shaped louver breaker will result, as shown in Fig. 5b. A louvered sun breaker with the louvers parallel to the window plane can be designed using the given dimensions and optimizing the spaces between the louvers to best suit the design. Note that the given dimensions of the breaker/ light shelf planes are the least required to achieve the purpose, larger dimensions will give the same result while smaller dimensions will allow more sun-in, the architect’s decision will solely depend on the purpose of the breaker/light shelf.

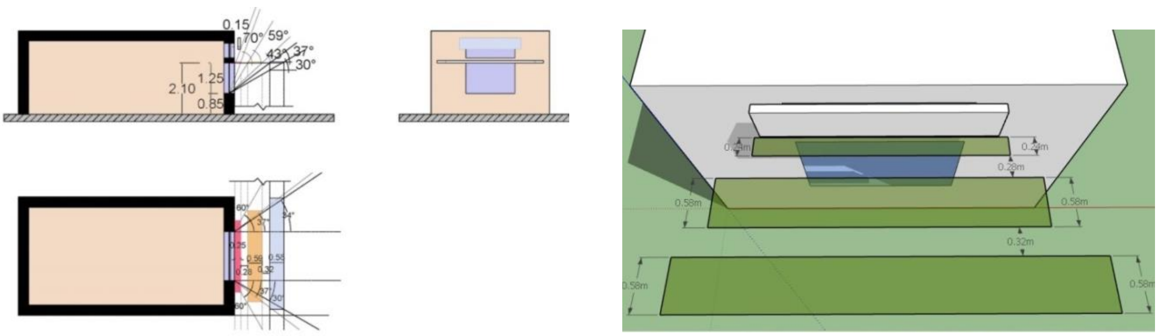


Fig. 5. South orientation model and resulting limiting planes of the sun shading device.

8.2 Examining the Results with Real Time Shadow Cast

Table 6 shows that sun admission is limited in the required periods and allowed in early and late hours insuring sun in with no severe thermal loads.

Table 6. South orientation.

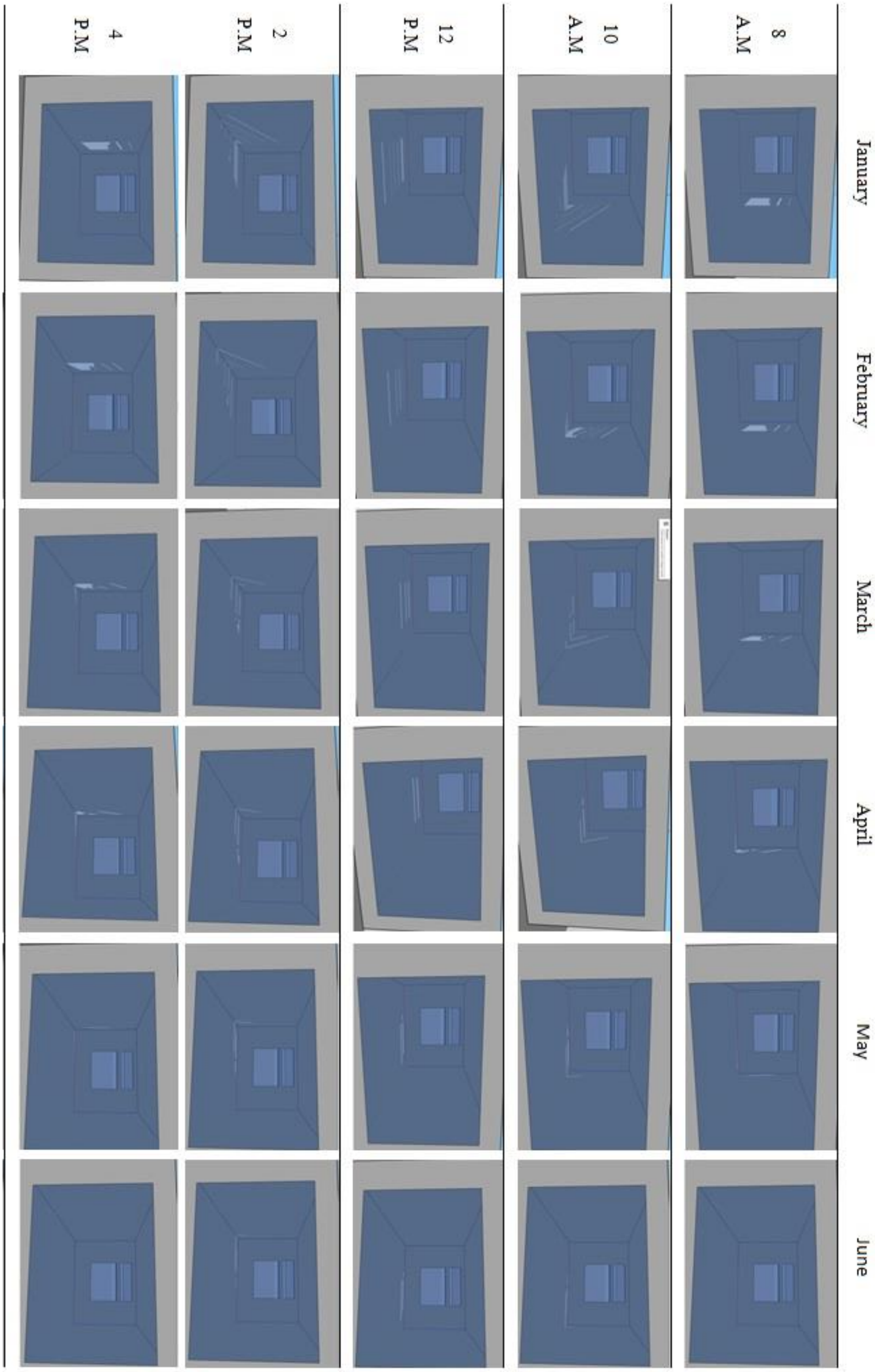
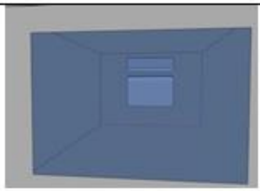
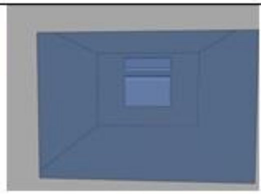
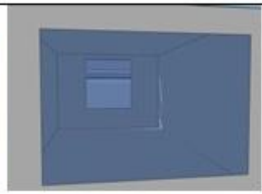
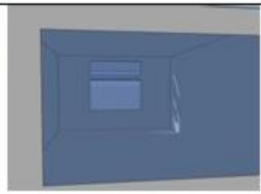
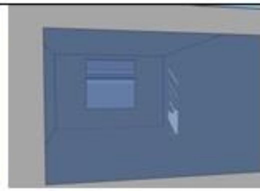
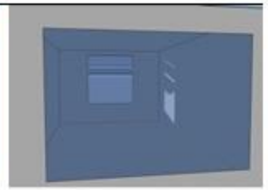
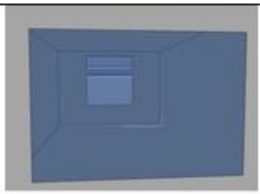
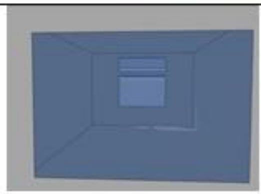
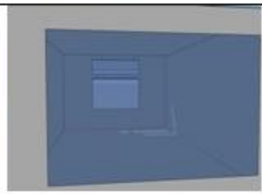
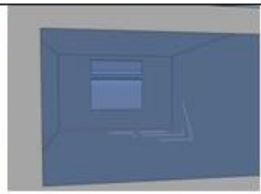
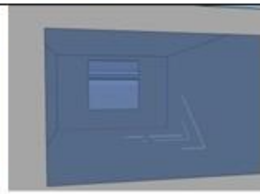
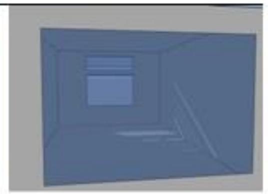
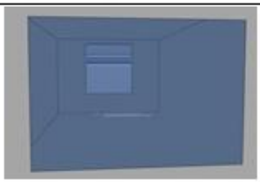
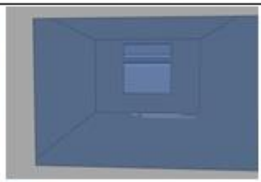
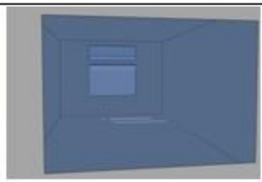
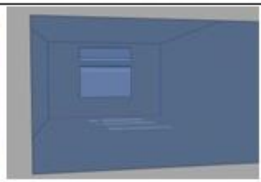
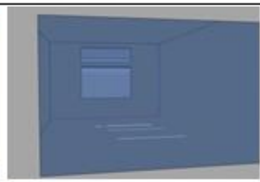
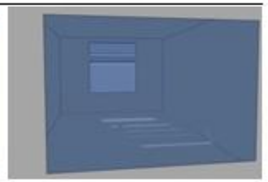
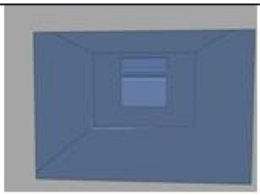
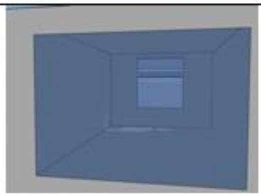
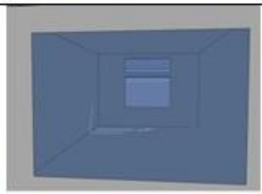
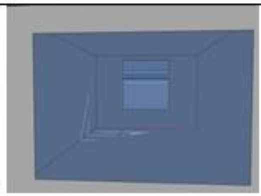
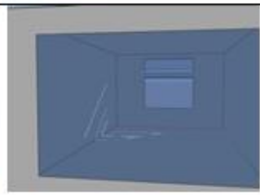
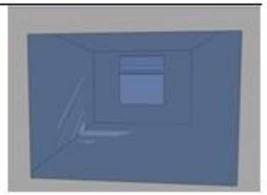
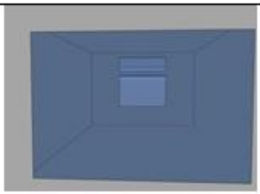
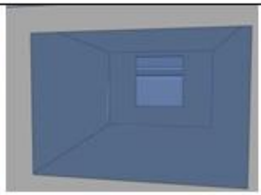
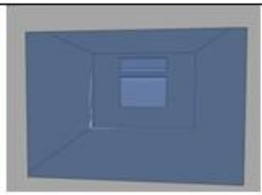
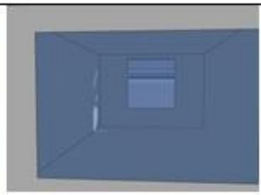
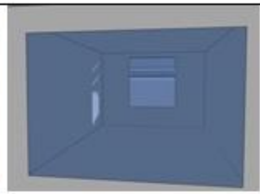
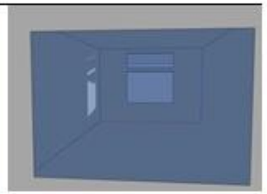


Table 6. South orientation, (Cont.).

	July	August	September	October	November	December
8 A.M						
10 A.M						
12 P.M						
2 P.M						
4 P.M						

9. CONCLUSIONS

After implementing the previous measurements and experimenting the resulted dimensions in real time shadow cast, Table 7 summarizes the results. It can be used by architects as a guide line to design sun friendly facades. Putting any shape or design of a sun breaker or light shelf within the given planes and dimensions will give the previously mentioned results within latitude 30° N. Exceeding the dimensions will also provide the required results. Decreasing the dimensions has to be calculated and will depend on the architect's vision of the project and its uses, for example you may not need to shade summer sun in schools or not to worry about evening sun in office buildings. Figure 6 illustrates the variables described.

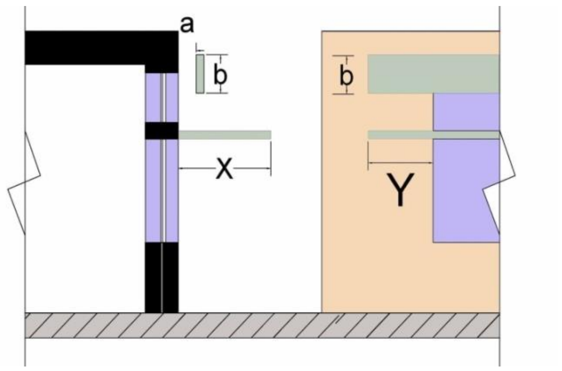


Fig. 6. Sun breaker variables.

Table 7. Sun breakers min. limits and variables.

Façade	Season	Sun-in Hrs.	Sun-off Hrs.	X	Y	Direction of Y	a	b
East	Summer	7-9 a.m.	After 10 a.m.	1.18 m	0.83m	Left (West)	0.15 m	0.45
	winter	8-10						
West	Summer	4 p.m.	Before 3 p.m.	1.13 m	0.91 m	Right (East)	0.24 m	0.52
	Winter	3 p.m.						
South	Summer	7-9 a.m. 4-6 p.m.	10 a.m. up to 4 p.m.	Depths	In Between Distances	Both directions	0.14m	0.45
				0.25				
					0.28 0.46 m			
	Winter	7-10 a.m. 3-5 p.m.	10 a.m. up to 4 p.m.	0.59	0.85 m			
					0.32 1.37 m			
				0.58				

10. RECOMMENDATIONS

Using a louvered sun breaker parallel to the window plan is the best practice in the south façade. Spacing the louvers can be designed using the given dimensions of the sun-in, sun-off angels. Louvered sun shades parallel to the window plane can be easily designed to shade seasonally depending on the sun altitude, while louvered sun breakers perpendicular to the window plane will work on the daily change of the azimuth which is not recommended.

Try to always use materials in the sun breaker that will not heat easily and radiate heat through the glass of the windows.

As the sun breaker will affect the daylight coming inside the building it is best used as a light shelf at the same time to bounce daylight deep within.

The ribbon window facing the light shelf should always be baffled using the same VSA and HSA used to design the sun breaker to avoid direct sunlight penetration.

Architectural scale sun shade devices is always better than fitted shading devices because it is easy to maintain and contributes in sculpting the building form.

DECLARATION OF CONFLICT OF INTEREST

The authors have declared no conflict of interests.

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نموذج لأداة مساعدة لصنع القرار لتصميم الكاسرات الشمسية بغرض تعزيز الاستخدام الأمثل للشمس داخل الفراغات

يهدف البحث الى تقديم نموذج لأداة تساعد على اتخاذ القرار التصميمي للغلاف الخارجي للمبنى بحيث تنظم دخول الشمس الى داخل الفراغ بدون منعها كليا وذلك من اجل تعظيم الاستفادة من الجوانب الصحية والتطهيرية للشمس خاصة بالنسبة للمناطق الحضرية التي يقضى فيها اغلب الناس نهارهم داخل المباني. يأتي ذلك مع مراعاة حجب الشمس في اوقات الأحمال الحرارية العالية لتحقيق الراحة الحرارية. وتظهر النتائج امكانية اقتراح مستويات تحدد ابعاد الكاسرات بحيث يمكن للمعماري ان يصمم أي شكل للكاسرة محدد بهذه المستويات فتحقق تنظيم دخول الشمس الى داخل الفراغ فى الأوقات المطلوبة دون الحاجة الى إعادة الحسابات من قبله مرة اخرى. وتم اتخاذ مدينة القاهرة خط عرض ٣٠ كنموذج للتطبيق. تم التطبيق على الثلاث واجهات الرئيسية الشرقية والغربية والجنوبية ودراسة المستويات المحددة لأبعاد الكاسرات المقترحة بهم.