Assessing the Effect of External Obstruction Parameters on Indoor Daylighting Performance in Desert Clear Sky Conditions

by
Sabry, H., Sherif, A., Shawky, S. and Rakha, T.

Abstract

This paper investigated the daylighting performance of a hypothetical living room facing a neighboring building. Distance of this external obstruction changes but with a constant sky view angle. The room is simulated in a desert environment with a clear sky condition. Changing the reflectance of the external surface of the neighboring building has been also studied. The paper concludes with guidelines for architects at initial design stages of housing developments aiming at an efficient and sustainable daylighting performance in these unique settings.

Keywords

Daylighting Performance, External Obstruction, Sky View Angle, Clear Sky, Desert

1. Introduction

The sustainability movement has brought the importance of utilizing natural lighting optimally to the forefront of responsible architectural practice. Therefore, daylighting should be considered the premium lighting source for as many building types as possible. Desert areas are considered a great potential for a successful sustainable environment, as they are endowed with an abundance of clear skies and excellent luminous settings. However, the urban fabric of deserts is characterized by its high density; offering shading through compactness that consequently improves thermal comfort in buildings. In these conditions, the availability of direct natural light from the sun and sky is scarce due to the existence of external obstructions. This makes the external reflected component more important as a factor affecting daylighting performance indoors.

2. Objective

This paper reports on a research that aims to arrive at desert housing design guidelines, which maximizes the efficient utilization of indoor daylight in such unique settings. It is investigating the effect of changing the distance of external obstructions and their surface reflectance on indoor daylighting performance of a hypothetical test case that represents a living room.

3. Literature Review

Literature is categorized into two areas; each identifies conducted research in regards to daylighting potential due to surrounding urban settings. Firstly, research that presents various methods to analyze daylight availability due to external obstruction. Secondly, shading effects in dense urban settings.

3.1. Methods of Analyzing Daylight Availability in Obstructed Environments

A rule of thumb for daylighting of rooms with external obstructions has been introduced, modifying existing formula to suit Sydney, Australia's geographical location (Ibrahim, Hayman and Hyde, 2009). This research utilized AGI-32 software to simulate a range of what is called the sky view angle (v) or sky exposure angle. It is the portion of the sky visible from the center of the window and measured in degrees (Figure 1) (Lawrence Berkeley National Laboratory, 1997). This research explored sky view angles ranging from 5^o to 80^o in medium and large sized rooms. It also examined the impact of different external surface reflectance (0% and 25%) on indoor illuminance. North orientation was chosen for obstructions in clear and overcast sky conditions. Under an overcast sky, illuminance values showed a decreasing trend as the sky view angle increased and beyond 30 degrees illuminance drops more significantly. However, under a clear sky the trend is different, as illuminance values increase with the increase of the sky view angle. This is due to the effect of reflected light from the obstructing wall surface with a large solar component due to orientation in that geographical location. Another research presented an average monthly variable, called the Obstruction Illuminance Multiplied (OIM) as a simple tool to investigate the potential of perfectly diffuse vertical south-oriented facades to reflect daylight onto the opposing facades (Tsangrassoulis et al, 1999). For the tested case, it was found that the monthly averaged values of the OIM have a linear relationship with three variables: the cosine of the Sun's maximum elevation on the middle day of each month, the reflectance of the reflecting wall and the angle of obstruction. This procedure could be applied to various locations and settings. Interior space illuminance based on high-rise opposing facades was investigated under clear sky conditions (Wa-Gichia, 1998). The performance of such opposing surfaces was found varying in each floor and for different building densities. This approach presented this façade as a passive daylighting device that could have implications on energy efficiency and conservation through utilizing solar radiation as a free source of daylight.

Much research has been oriented towards developing simple methods for architects during the initial design stage to determine daylight illuminance in heavily obstructed environments. A methodology has been proposed to help designers evaluate and understand the possibilities of using natural lighting from the early conceptual design stages. The influence of different obstruction patterns on daylighting performance of an office building in Israel has been shown to be approximately proportional to the "sky solid angle". It presents the solid angle subtended by the path of the sky visible from a point located at the center of the studied window (Figure 1) (Capeluto, 2003). Also, vertical daylight factor (VDF) has been used as a criterion to justify the provision of natural lighting in buildings. One study investigated the calculation approach of VDF in a heavily obstructed environment, where calculation tools in the form of simple equations and diagrams through computer simulation analysis were established. It was found that predictions from the proposed approach were in agreement with those produced by simulated results, providing architects with a simple method for early design stages as well (Li, D. et al, 2008). Another research reviewed an alternative to this method called the unobstructed vision area (UVA) method, and developed a similar process based on the orthographically project area (OPA) of all obstructions above the reference point. Case studies comparing the performance of both OPA and UVA methods were presented (Chung, T., Cheung, H. 2006).

3.2. Shading Effects due to External Obstruction

Solar access in dense urban fabrics has been investigated in new developments and in existing buildings (Littlefair, 2001). Guidelines have been drawn to overcome problems of existing obstruction and insure solar access in overcast sky conditions through combination of a simple technique named "Obstruction Angle" and defining an angular zone, where obstructions outside that zone can be ignored. This angle of obstruction (e) is defined as the angle between the mid-height of the window and the end of the facing obstruction (Figure 1) (Reid, E. 1984). Also, a procedure involving computer simulation techniques was used to evaluate the energy performance for office buildings with daylighting controls shaded by neighboring buildings (Li, Wong, 2007). It was found that for an individual floor, the electricity savings decreased from 40 to 28 kWh/m2 when the angle of obstruction varied between 25° and 30°.

Previous studies reinforce the importance of studying daylighting performance indoors in such dense settings, as it can become a tool for energy efficiency. Closely related research investigated various aspects in regards to external obstruction and opposing surfaces reflectivity in one orientation: the surface incident on direct solar rays. However, most of the research established in that area was done in overcast sky conditions. This paper is examining the distinct clear sky feature of desert environments in regards to urban density and its relationship to daylighting in the four main orientations. The sky view angle was kept constant and the height of the facing obstruction was increased as its distance moved further away from the test window.

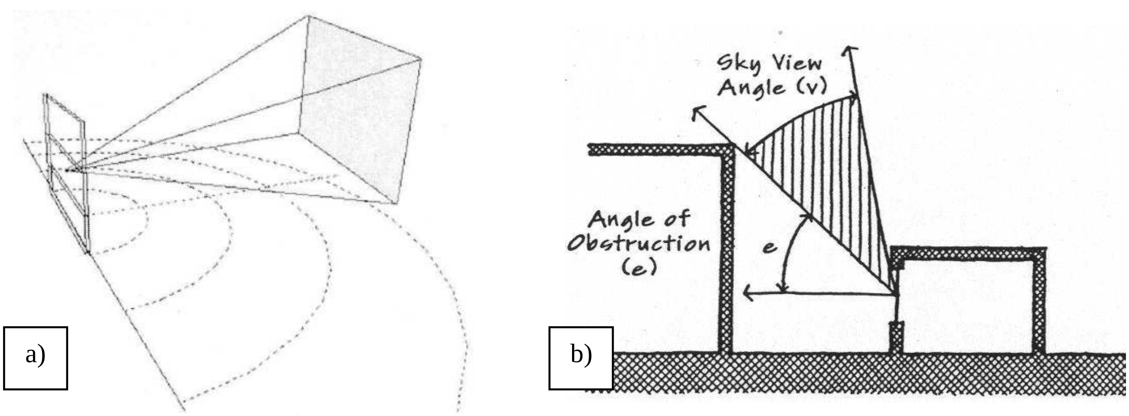


Figure 1: a) Sky Solid Angle (Capeluto, 2003),
b) Sky View Angle (v) and Angle of Obstruction (e) (Brown, G. Z., 2001)

4. Experimentation Methodology

Experiments were conducted using simulation software Radiance, which has been widely validated by different researchers (Merdaljevic J. 1995). The research is built on having a hypothetical indoor space with a number of assumed fixed architectural design parameters. These parameters have been chosen to suite the properties of a house living room in a desert environment. This indoor space was simulated as a base case or “reference case’ facing a neighboring building (external obstruction) that is at a distance of 3m with a 10^{o} sky view angle (Figure 2, 3). The effect of increasing the distance of the facing obstruction was analyzed only at three measurement points located on an axe perpendicular to the mid width of the indoor space. The first point is located 0.5m distance from the window (the near point), second point at mid length of the indoor space (the mid length point) and third point is 0.5 m distance from the rear wall (the far point).

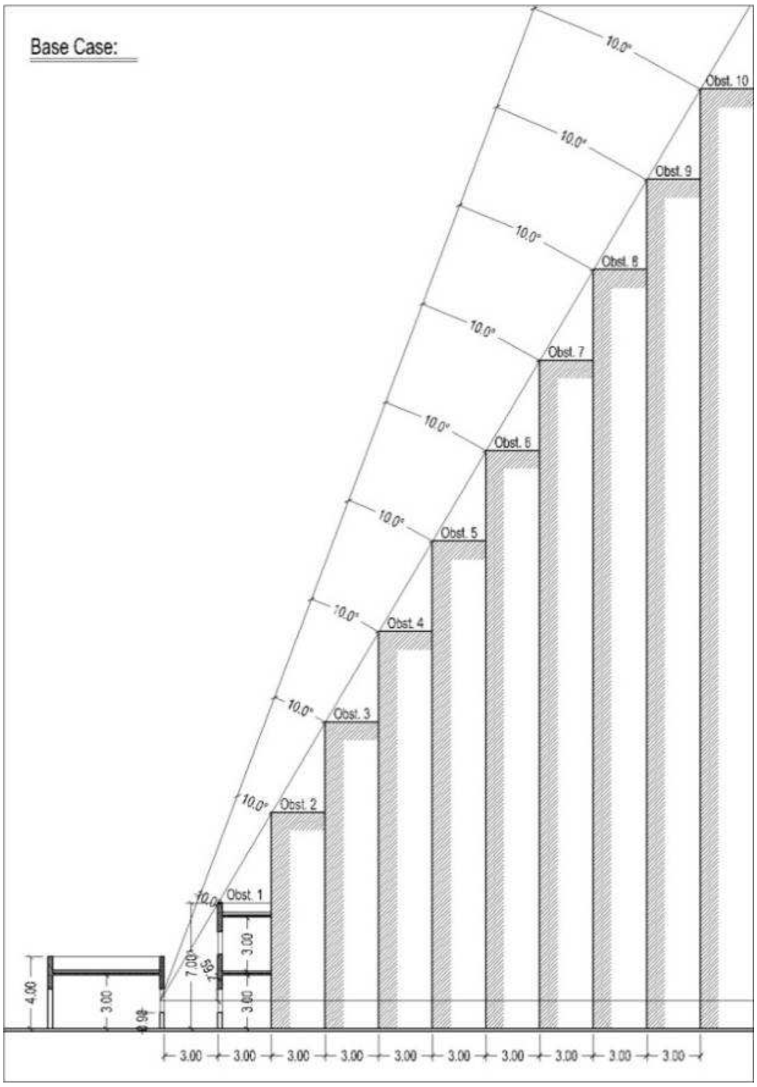


Figure 2: Sky view angle is kept constant at 10^{o} for a typical courtyard/street setup, while the distance of obstruction is increased at regular intervals (multiples of 3.00m)

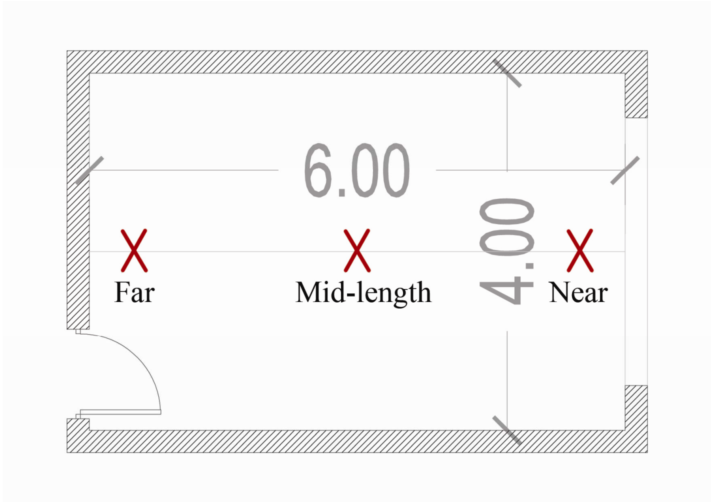


Figure 3: Base case spatial configuration and parameters with the three measuring points

4.1.Experimentation Parameters

The following table defines the hypothetical parameters of the base case:

Geographic Location: El Sadat City, Egypt		
Latitude	30.22.11	
Longitude	30.29.26	
Sky Condition	Clear sky with sunshine	
External Ground		
Reflectance	20%	
Material	Medium colored stone	
Working Plane Height		0.90 m
Simulated Experiment Time		12 Noon
External Obstruction Parameters		
Height	7.00 m	
Distance	3.00m	
External Surface		
Reflectance	60 %	
Material	Patterned concrete	

Indoor Space Parameters		
Floor level	Zero level	
Dimensions	4.00 m * 6.00 m * 3.00 m	
Internal Surfaces		
Walls	Reflectance	60%
	Material	Medium off-white color Paint
Ceiling	Reflectance	80%
	Material	White color paint
Floor	Reflectance	20%
	Material	Medium colored wooden floor
Window Parameters		
Dimensions	3.00 m * 1.30 m	
Visible Light Transmittance	85%	

Table 1: Details of experimentation parameters

Research was divided into two phases, the first investigated the relationship between different seasons (spring, summer, autumn and winter) and the three measurement points in different orientations (N, E, S and W) and different times (9:00, 12:00 and 15:00). The second phase studied the impact of different reflectivity values on illuminance values of the base case. Results were tabulated and comparative analysis was conducted to identify various potentials and limitations. If any difference reached less than or equal 10% in the results, it was neglected, and if any of the simulated results was found below 200 lux it was identified as "inadequate" for performance of any visual task (minimum recommended standard for a living room).

4.2.Phase One – Simulation Results

The first phase consists of three groups of experiments (Figure 4): an initial group that examines the behavior of illuminance values at the three measuring points, for different window orientations and during different seasons. From the results of the first group, one measurement point has been chosen in the second group to be further investigated in terms of daylighting performance. While in the third group, time of the day has been analyzed for one measuring point, one orientation and one season.

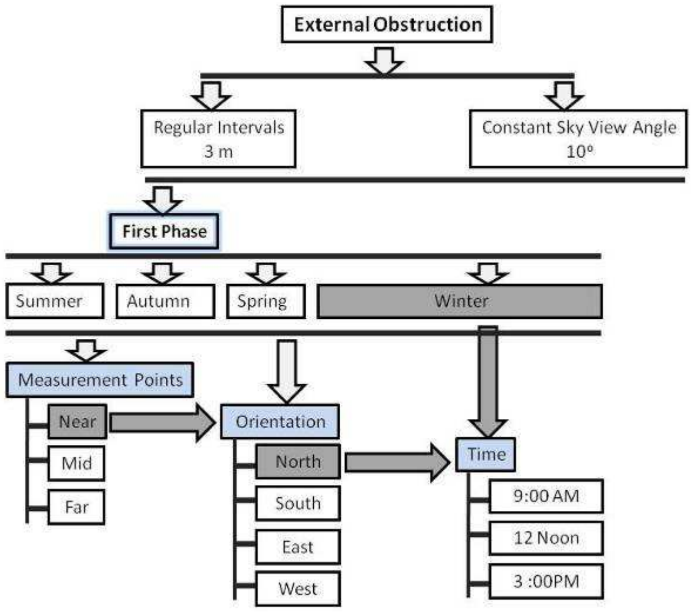
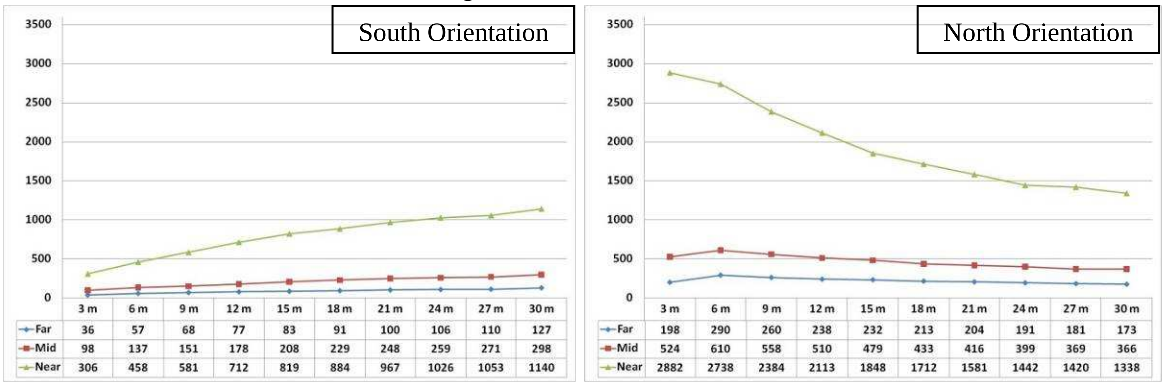


Figure 4: The three groups of experiments of the first phase

a) Simulated Measurement Points: The initial group of experiments, concentrated on investigating illuminance levels at the three measurement points at 12 noon time, in different orientations (N, E, S and W) during different seasons (spring, summer, autumn and winter).

• Near and mid points**:** Both have an almost similar increasing rate of change with a difference of maximum 10% in all orientation except for North. The highest decreasing rate of change is in the North orientation at the near point with different ranges. However, when the distance reaches 18m, this decreasing rate of change is almost constant (Figure 5). Illuminance values are considered adequate in the North and South orientations in all seasons, but for the West and East orientation, the midpoint becomes adequate only after doubling the distance from the simulated obstruction.

• <u>Far point</u>**:** The increasing rate of change differs according to season and orientation; however it becomes almost constant until the distance reaches 21m. On the other hand, all illuminance values are inadequate for all situations except for the North orientation in all seasons excluding summer.



South Orientation:

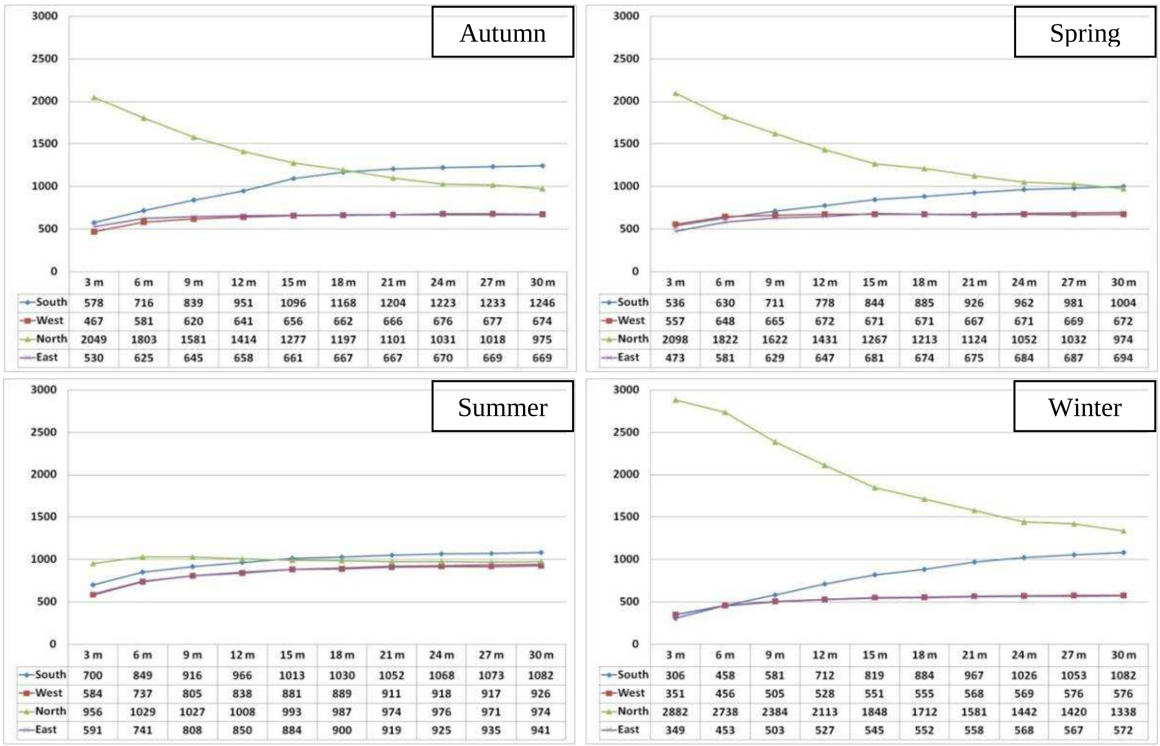
	3 m	6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
Far	36	57	68	77	83	91	100	106	110	127
Mid	98	137	151	178	208	229	248	259	271	298
Near	306	458	581	712	819	884	967	1026	1053	1140

North Orientation:

	3 m	6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
Far	198	290	260	238	232	213	204	191	181	173
Mid	524	610	558	510	479	433	416	399	369	366
Near	2882	2738	2384	2113	1848	1712	1581	1442	1420	1338

Figure 5: Illuminance against obstruction distance, comparison between values of South and North orientations for the three measured points in winter.

b) Orientation in Different Seasons: The near point has been chosen for further investigations in various seasons, as it has been found to be of adequate performance and response to change in various experimentation parameters. For all orientations, illuminance values are directly proportional with the spacing of the obstruction, except for North orientation, where illuminance values are inversely proportional. However, values of the simulation results fluctuated greatly in different seasons of the year in each orientation (Figure 6).



Autumn:

	3 m	6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
South	578	716	839	951	1096	1168	1204	1223	1233	1246
West	467	581	620	641	656	662	666	676	677	674
North	2049	1803	1581	1414	1277	1197	1101	1031	1018	975
East	530	625	645	658	661	667	667	670	669	669

Spring:

	3 m	6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
South	536	630	711	778	844	885	926	962	981	1004
West	557	648	665	672	671	671	667	671	669	672
North	2098	1822	1622	1431	1267	1213	1124	1052	1032	974
East	473	581	629	647	681	674	675	684	687	694

Summer:

	3 m	6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
South	700	849	916	966	1013	1030	1052	1068	1073	1082
West	584	737	805	838	881	889	911	918	917	926
North	956	1029	1027	1008	993	987	974	976	971	974
East	591	741	808	850	884	900	919	925	935	941

Winter:

	3 m	6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
South	306	458	581	712	819	884	967	1026	1053	1082
West	351	456	505	528	551	555	568	569	576	576
North	2882	2738	2384	2113	1848	1712	1581	1442	1420	1338
East	349	453	503	527	545	552	558	568	567	572

Figure 6: Illuminance against obstruction distance, comparison between values of all orientations in different seasons

Illuminance values of the base case and other spacing obstructions in all orientations during different seasons were tabulated (Table 2), then compared and analyzed.

		3 m	6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
North	Summer	956	1029	1027	1008	993	987	974	976	971	974
	Autumn	2049	1803	1581	1414	1277	1197	1101	1031	1018	975
	Winter	2882	2738	2384	2113	1848	1712	1581	1442	1420	1338
	Spring	2098	1822	1622	1431	1267	1213	1124	1052	1032	974
East	Summer	591	741	808	850	884	900	919	925	935	941
	Autumn	530	625	645	658	661	667	667	670	669	669
	Winter	349	453	503	527	545	552	558	568	567	572
	Spring	473	581	629	647	681	674	675	684	687	694
West	Summer	584	737	805	838	881	889	911	918	917	926
	Autumn	467	581	620	641	656	662	666	676	677	674
	Winter	351	456	505	528	551	555	568	569	576	576
	Spring	557	648	665	672	671	671	667	671	669	672
South	Summer	700	849	916	966	1013	1030	1052	1068	1073	1082
	Autumn	578	716	839	951	1096	1168	1204	1223	1233	1246
	Winter	306	458	581	712	819	884	967	1026	1053	1140
	Spring	536	630	711	778	844	885	926	962	981	1004

Table 2: Illuminance values against obstruction distance, comparison between values of all orientations in different seasons.

- North Orientation**:** Obstruction placed facing the north orientation were found to be the most effective in terms of daylighting performance.

• In summer, illuminance values are not affected by distance of obstruction. However, it slightly decreases insignificantly. While in winter, values decreased significantly, reaching about 54% of the base case at 21 m and then remained almost constant.

• In autumn and spring, there is a significant decrease in illuminance values by an average of 56% of the base case in both seasons as an average (Table 3).

		6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
North	Summer	108	107	105	104	103	102	102	102	102
	Autumn	88	77	69	62	58	54	50	50	48
	Winter	95	83	73	64	59	55	50	49	46
	Spring	87	77	68	60	58	54	50	49	46

Table 3: Comparing percentile change in daylighting performance of the base case with different obstruction at the North orientation in different seasons (The highlighted parts indicate the consistency of percentages values)

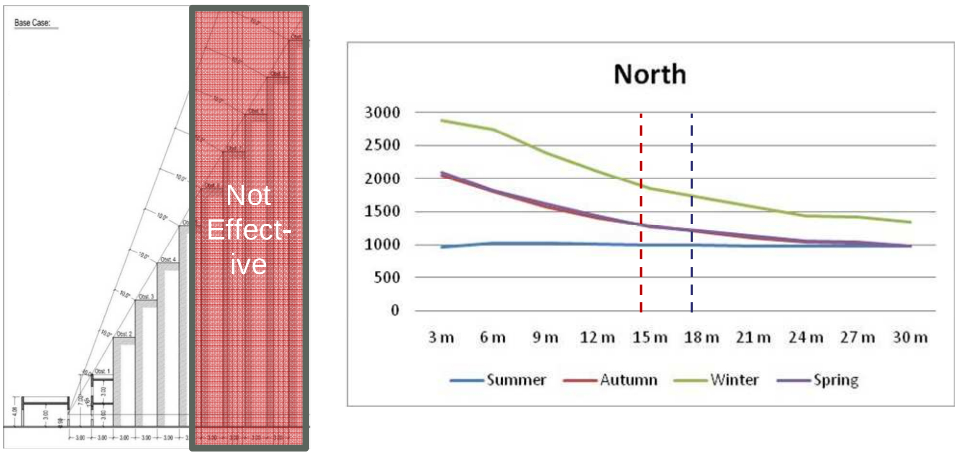


Figure 7: (left) Highlighting the average ineffective obstruction distance. (right) Illuminance against obstruction distance at the North orientation, showing consistency of percentages values during different seasons.

As a general result, placement of obstructions closer to the tested space affected daylighting performance positively in terms of illuminance values. Obstructions placed facing the north orientation have no significant impact on daylighting performance starting from a distance of 14m as an average of all seasons (Figure 7).

- East and West Orientation: Both have a similar behavior regards to daylighting performance according to change in obstruction distance

• In summer and winter, illuminance values increased regularly to reach an average of 153% of the base case at a distance of 15 m (Table 4).

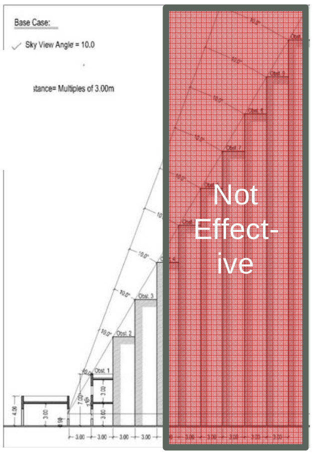
• In autumn, illuminance values are not affected by distance of obstruction, it increases slightly by an average of 124% of the base case. While in spring, illuminance values increased with the increase of the obstruction distance. These became constant at about 137% of the base case starting at a distance of 12 m.

		6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
East	Summer	125	137	144	150	152	156	157	158	159
	Autumn	118	122	124	125	126	126	127	126	126
	Winter	130	144	151	156	158	160	163	163	164
	Spring	123	133	137	144	142	143	144	145	147

		6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
West	Summer	126	138	143	151	152	156	157	157	159
	Autumn	124	133	137	140	142	142	145	145	144
	Winter	130	144	150	157	158	162	162	164	164
	Spring	116	119	121	120	120	120	120	120	121

Table 4: Comparing percentile change in daylighting performance of the base case with different obstruction at the East (top) and West (bottom) orientation in different seasons

Obstructions placed facing the east/west orientations have no significant impact on daylighting performance starting from a distance of 10 m as an average of all seasons (Figure 8).



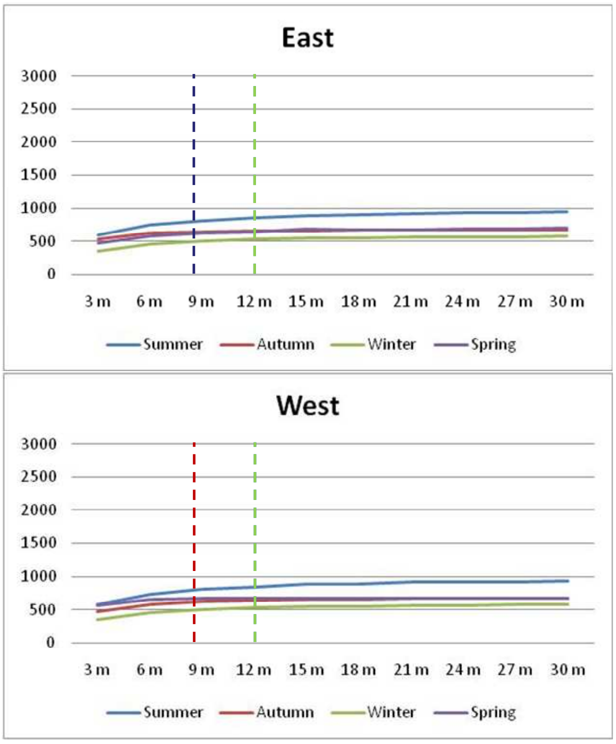


Figure 8: (left) Highlighting the average ineffective obstruction distance. (right) Illuminance against obstruction distance at the East and West orientation, showing consistency of percentages values during different seasons.

- <u>South Orientation:</u> Daylighting performance is sensitive to change in obstruction distance, especially in winter.

• In summer, illuminance values increased regularly to reach an average of 145% of the base case at a distance of 15 m. beyond that, change in distance has an insignificant effect on daylighting performance. While in winter, illuminance values increased regularly from a value of about 150% of the base case at 6 m distance, until they reached about 373% of the base case value at 30 m (Table 5).

• In autumn and spring, there is a significant increase in illuminance values starting from 6m distance by an amount of 124% and 117% more than the base case in autumn and spring respectively, till it reaches 208 % and 173% at a distance of 21m and then values become almost constant.

		6 m	9 m	12 m	15 m	18 m	21 m	24 m	27 m	30 m
South	Summer	121	131	138	145	147	150	153	153	155
	Autumn	124	145	165	190	202	208	212	213	216
	Winter	150	190	233	268	289	316	335	345	373
	Spring	117	133	145	157	165	173	180	183	187

Table 5: Comparing percentile change in daylighting performance of the base case with different obstruction at the South orientation in different seasons

Starting from a distance of 20 m, obstructions placed facing the south orientation have no significant impact on daylighting performance as an average of all seasons, except in winter where values increase regularly (Figure 9).

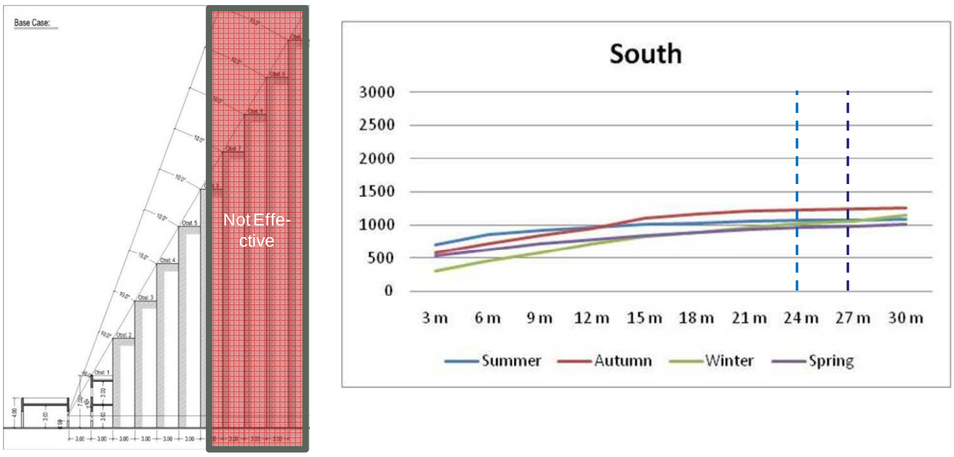


Figure 9: (left) Highlighting the average ineffective obstruction distance. (right) Illuminance against obstruction distance at the South orientation, showing consistency of percentages values during different seasons.

c) Time: The effect of changing times of the day is investigated for the near point at the north orientation in winter time, as it was found to be the most responsive zone at the most effective orientation. At 9:00am and 3:00pm, illuminance values are almost equal and coincide in behavior. While at 12:00 noon illuminance values are greater than that of previously mentioned time by an average amount of 55% (Figure 10).

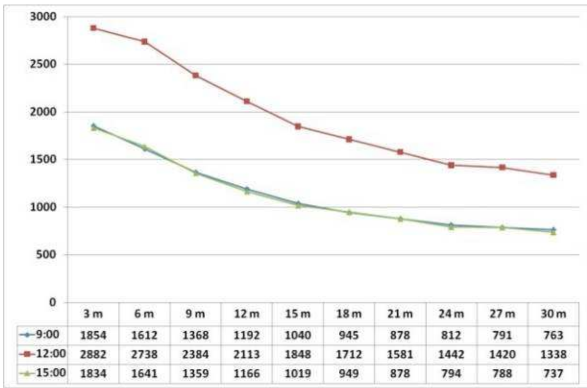


Figure 10: Illuminance values against obstruction distance at different time of the day (winter)

4.3.Phase Two – Simulation Results

The second phase concentrates on investigating the effect of different obstruction surfaces reflectivity values on illuminance. This was applied for the case of north orientation in winter, which showed highest indoor illuminance levels in the previous experiments. Two materials were used as alternatives to that of the base case; gray painting and white painting (30% and 86% reflectance respectively), (Figure 11).

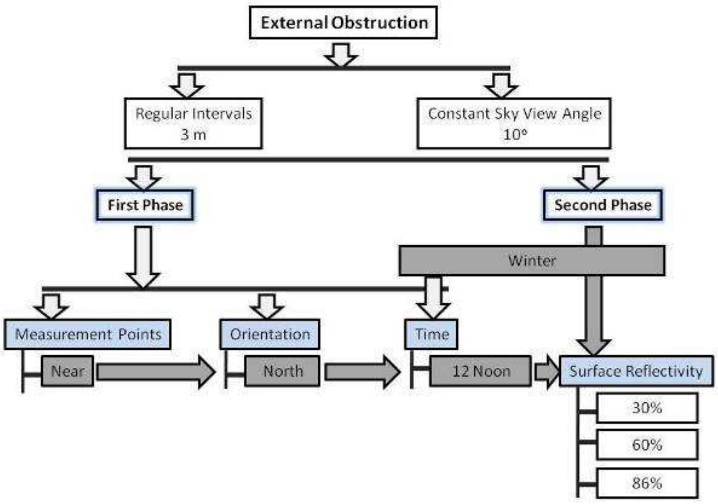


Figure 11: The process of the two experimentation phases

When the reflectance of the obstruction surface decreased from 60% (Base Case) to 30%, the percentage of decreasing rate of change is approximately the same till it became almost constant at a distance of 21m. However, when comparing illuminance values at each obstruction distance in regards to the base case, values decreased by an average of 62%. On the other hand, when the obstruction reflectance increased to 86%, illuminance values at each obstruction distance were found to be increasing by an amount of 176% at the distance of 3m, then this percentage gradually decreased as the distance increased till the difference became 125% at 30m distance. The effect of external surface reflectance decreased as the distance of the obstruction increased (Figure 12).

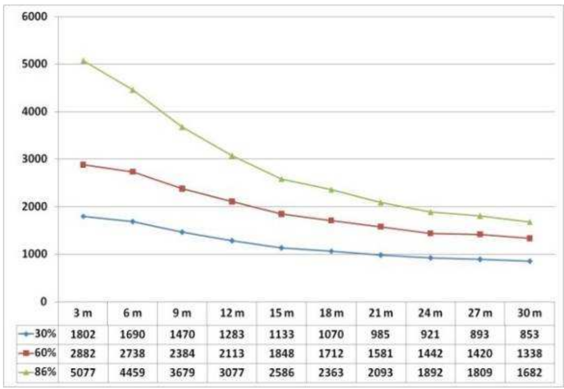


Figure 12: Illuminance values against obstruction distance for different reflectance values.

5. Discussion and Conclusion

A series of experiments were performed and daylighting performance was analyzed for a designed base case with an external obstruction in a clear sky condition, where the illuminance levels of three points in the room were measured in different seasons for different window orientations, during different times of the day. The resultant quantity of room daylighting was investigated in each of these cases and then an upgraded base case was also examined in terms of obstruction surfaces reflectivity values. Outcomes showed a significant difference in daylighting performance when increasing the distance of the obstruction, even though the sky view angle was kept consistent. This makes the dependence on sky view angle only in estimating daylighting performance not possible in clear sky conditions, as many other aspects affect outcomes, including parameters of ground reflectivity, surfaces reflectivity and proximity of obstructions.

Guidelines for architects at initial design stages of housing developments in desert environments were drawn for areas near the window, where:

- Obstructions placed at the north orientation are considered a design tool for indoor illuminance in adjacent spaces. It is recommended to choose suitable materials of high reflectivity values to depend on natural light in such a setting.
- External obstruction has a different impact according to orientation, whether east and west at a distance before 10m, or its double in the south. It is recommended to keep a suitable distance, as illuminance values increase proportionally with the distance of the obstruction.

The most affected area of the room is the furthest away from the window in terms of illuminance values, and it was found inadequate in most cases. Therefore, further investigation could be directed towards proposing daylighting systems that would deliver light into the depth of obstructed spaces.

6. Acknowledgment

This publication is based on work supported by Award No. C0015, made by King Abdullah University of Science and Technology (KAUST).

7. References

1. Brown, G. Z. (2001), Sun, wind & light: architectural design strategies, New York: Wiley.
2. Capeluto, I. (2003), The influence of the urban environment on the availability of daylighting in office buildings in Israel, Building and Environment. 38, 745 – 752.
3. Chung, T., Cheung, H. (2006), Assessing daylighting performance of buildings using orthographically projected area of obstructions. Journal of Light & Visual Environment. 30, 74 – 80.
4. Ibrahim N., Hayman S., Hyde R. (2009), Rule of thumb for daylighting of rooms with external obstructions. Architectural Science Review. 52 (2), 151-160.
5. Lawrence Berkeley National Laboratory. (1997). Tips for daylighting with windows. [Berkeley, Calif.]: The Program.
6. Li, D., et al. (2008). Simple method for determining daylight illuminance in a heavily obstructed environment, Building and Environment. 44, 1074 – 1080.
7. Li, D., Wong, S.L. (2007), Daylighting and energy implications due to shading effects from nearby buildings, Applied Energy. 84, 1199-1209.
8. Littlefair, P. (2001), Daylight, sunlight and solar gain in the urban environment, Solar Energy. 3, 175-185.
9. Merdaljevic, J. (1995), Validation of a lighting simulation program under real sky conditions, Lighting Research and Technology. 27(4), 181 – 188.
10. Reid, E. (1984). Understanding buildings: a multidisciplinary approach. Cambridge, Mass: MIT Press.
11. Tsangrassouliss, A., et al. (1999), A method to investigate the potential south-oriented vertical surfaces for reflecting daylight into oppositely facing vertical surfaces under sunny conditions. Solar Energy. 66 (6), 439-466.
12. Wa-Gichia, M. (1998), The high-rise opposing façade in clear sky conditions – not always an “obstruction” to daylight. Solar Energy. 64 (4-6), 179-188.