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The Impact of Alternative Window Glazing Types and a Shading System on the Daylighting of Hospital Patient Rooms: Simulation Analysis under a Desert Clear Sky

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Abstract

This paper aimed at identifying the most effective glazing type that suits different patient room layouts under desert clear skies. Year-round daylighting performance of three glazing types was compared with that of a 45 degree sun breaker for three different patient room layouts. Simulations were conducted for rooms facing south in Cairo, Egypt. The daylighting performance of the tested glazing types was less than that of a sun breaker. Electrochromic-60 and low E glazing were successful in the outboard bathroom design only, for large window sizes. The electrochromic-30 glass did not produce acceptable results in any of the tested cases.

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Keywords: Clear Sky; Daylighting; Desert; Glazing; Sun breaker.

1. Introduction

Hospital patient room windows can contribute positively to the healing process and reduction of pain. Provision of daylight and exposure to external view can reduce the length of stay in hospitals. However, large windows can result in unsuitably high levels of illumination in desert climates that are characterized by year round intense solar radiation.

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Architects have adopted a variety of glazing and shading systems for control of solar access into hospital patient rooms. The selection of the most suitable of these systems should be closely related to room shape layout.

Literature addressed the effect of environmental aspects on healthcare delivery. Ulrich noted that natural light improvement could help reduce stress and fatigue, while increasing the effectiveness in delivering care, patient safety and overall healthcare quality [1]. Several efforts were made to improve patient room designs for the creation of better healing environments, where the effect of natural daylight on patients' average length of stay in hospitals was investigated [2]. However, very little research effort addressed the effect of window glazing shading on the provision of adequate daylighting in patient rooms, especially with the solar exposure of desert environments.

Some research attempts focused on the development of new innovative glazing systems. In a similar study, a prototype for ceramic thin-film electrochromic window glazing was built to investigate its performance under clear, partly cloudy and overcast sky conditions. It was found that considerable daily lighting energy savings could be achieved by the use of this glazing [3]. Other studies focused on the utilization of shading techniques to provide adequate daylighting in specialized healthcare spaces, such as Intensive Care Units. Daylighting performance was investigated for a typical ICU space located in the desert. Successful window configurations were recommended for the different window to wall ratios, for each of the four main orientations [4]. In a study more related to this paper, the impact of using various window glazing and shading strategies on the annual energy consumption of a typical ICU space was examined. It was found that the overall energy performance could be improved by utilizing external shading systems rather than using advanced glazing types [5].

2. Objective

This paper addressed the impact of using alternative window glazing types on the daylighting performance of common hospital patient room layout designs. These were compared with a window having clear double glazing and a standard sun breaker on top. The study aimed at identifying the most effective glazing type that suits each patient room layout. Investigation focused on the design of windows facing the south orientation under the desert clear-sky of Cairo, Egypt.

3. Methodology

Analysis of daylighting adequacy was examined for three of the most common patient room layout designs. These were: Design A: the outboard bathroom patient room design; Design B: the nested bathroom patient room design; and Design C: the inboard bathroom patient room design. The tested rooms were assumed to have a similar floor area (22 m²). The floor plans, dimensions and parameters of the tested rooms are shown in Figure 1.

Design A: The Outboard Bathroom

Design B: The Nested Bathroom

***Design** C:* The Inboard Bathroom

Fig. 1 The tested patient room designs.

A base case window design was assumed. It included a double clear glazed window with VT=80 %. It was protected from sun on its top edge by use of a standard horizontal solid sun breaker having a reflectance value of 35% (Figure 2). The sun breaker's overhang provided a sun protection angle of 45°. This angle was based on the results of a previous publication [6]. The reflectance values of room walls, ceiling and floor were assumed to be 50, 80 and 20% respectively. The room was assumed to be located on the second floor level of a hospital building facing no external obstruction. The external ground surface was assumed to have a 20% reflectance value.

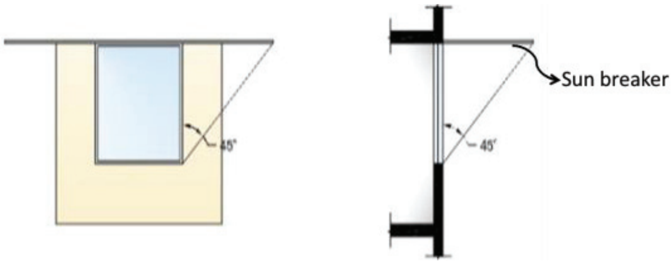

Fig. 2 The base case design having a solid sun breaker fixed on the top edge of the window.

The daylighting performance resulting from use of three glazing types was compared with that of the base case for each patient room layout. The glazing types were: electrochromic-30 (EC-30), electrochromic-60 (EC-60) and double pane low-E-Argon-filled glass (LE). The visual transmittance was set to (30%) for EC-30, (60%) for EC-60, and (65%) for LE glazing. Seventeen window size values, expressed as Window-to-Wall Ratios (WWR), were analyzed for each patient room design and glazing type. The WWR values ranged from 10% to 90%, at 5% increments.

Grasshopper, which is a plugin for Rhinoceros modeling software and a parametric modeling tool, was used to automate the daylighting simulation process. A parametric model was generated using Grasshopper plugin for each WWR and ran a climate based analysis through the DIVA interface. Daylight simulation was conducted using the Radiance and DAYSIM software. The Diva-for-Rhino plugin for the Rhinoceros modeling software was used as an interface. In each of the three tested patient room designs A, B and C, the reference plane contained 46, 54 and 53 measuring points respectively. The spacing of the analysis grid was set to 0.7m * 0.7m including four points on the bed level (Figure 1). The recommended illuminance value used in the tested patient room space was 300 Lx. Three Daylight Availability evaluation levels were used: “Daylit”, “Partially Daylit” and “Over lit” areas. The “Daylit” areas are those areas that received sufficient daylight at least half of the year-round occupied time. The “Partially Daylit” areas are those areas that did not receive sufficient daylight at least half of the year-round occupied time. The “Over lit” areas are those areas that received an oversupply of daylight, where 10 times the target illuminance was reached for at least 5% of the year-round occupied time. Due to current limitations of the Grasshopper interface with DIVA, the visual transmittance of the electrochromic glass was fixed at the set values described above.

Two acceptance criteria were adopted in this paper. First, the “Daylit” area should reach ≥50% of the room area. Second, 100% of the patient bed surface should be “Daylit”. The second criterion was introduced for insuring sufficient performance in this specialized healthcare setting. Cases having larger size and wider range of accepted WWRs were considered more successful, since they provide more window options and better external visual access.

4. Simulation Results

The daylighting performance of the three glazing types was compared with that of the base case of using the sun breaker for the two acceptance criteria. This is illustrated in the following tables (Tables 1, 2 and 3). In these Tables, the cases that failed to satisfy the required criteria (unacceptable) were darkened with a grey tone. The remaining were the accepted ones.

For Design A: The Outboard Bathroom Design, Table 1 reveals that acceptable daylighting performance could only be achieved at high WWR values (65%+). This could be related to the positioning of the bathroom alongside the façade in this room design. Furthermore, windows using LE and EC-60 glazing achieved results that are better or similar to those of the base case (Sun breaker). On the other hand, the windows having EC-30 glazing failed to produce acceptable results. The most promising case was the window having a LE glazing, where performance was better than that of the base case as it provided the designer with a wide range of WWRs (65% to 90%). Windows having an EC-60 glazing produced results similar to those of the base case (WWR 70-90%).

If we consider performance at patient bed surface as the only criterion, a larger range of WWRs would be acceptable. These reach between 45%-90% WWR with LE. They also reach between 50%-90% WWR with the EC-60 glazing and the base case of a standard sun breaker. The best provision of daylighting was achieved, with a 72% of the space "Daylit", by use of a sun breaker at 85% WWR.

Table 1. Percentage of "Daylit" area relative to the total room and bed surface areas in design A.

Design A: The Outboard Bathroom																			
WWR			10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
DoublePane LowE	Daylit area %	Room	0	7	7	9	13	17	20	24	30	33	35	54	57	61	65	67	65
		Bed	0	0	0	0	0	0	50	100	100	100	100	100	100	100	100	100	100
Electrochromic 60	Daylit area %	Room	0	4	4	9	9	17	20	22	24	30	35	39	52	57	57	61	63
		Bed	0	0	0	0	0	0	50	75	100	100	100	100	100	100	100	100	100
Electrochromic 30	Daylit area %	Room	0	0	0	4	7	2	2	7	7	4	7	11	11	11	13	13	13
		Bed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sun breaker	Daylit area %	Room	2	4	17	22	26	26	26	28	35	39	43	48	54	61	63	72	70
		Bed	0	0	0	0	0	0	0	25	100	100	100	100	100	100	100	100	100

For Design B and C: The Nested and Inboard Bathroom Designs, Tables 2 and 3 demonstrate that, none of the tested glazing types produced acceptable performance according to the criteria adopted in this study. This is due to the failure of the majority of the tested cases in satisfying the second criterion (100% of the patient bed surface should be "Daylit"). Thus, the space was not adequately "Daylit" as a result of the high "Over lit" area percentage.

A limited number of window cases having an EC-30 glazing passed this criterion. This includes one case for Design B (a 40% WWR window) and two cases for Design C (windows with 35-40% WWR). However, this limited number of cases did not satisfy the first criterion ("Daylit" area ≥50% of total area).

On the other hand, if we consider satisfaction of the first criterion ("Daylit" area ≥50% of total area) as the only condition, some windows with glazing types would be considered acceptable. For Design B, this includes windows with a LE glass, at 40-70% WWRs and windows with an EC-60 Glazing at 55-70% WWRs. For Design C, this includes windows with an LE glass, at 55-70% WWRs and windows with an EC-60 Glazing at 65-90% WWRs. None of the window cases having an EC-60 Glazing passed this criterion for Designs B and C.

Table 2. Percentage of "Daylit" area relative to the total room and bed plane areas in design B.

Design B: The Nested Bathroom																			
WWR			10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
DoublePane LowE	Daylit area %	Room	4	13	22	26	35	43	54	56	56	56	56	56	50	46	46	44	46
		Bed	0	50	50	50	25	25	0	0	0	0	0	0	0	0	0	0	0
Electrochromic 60	Daylit area %	Room	2	9	22	19	30	37	48	54	56	56	56	56	56	56	54	54	50
		Bed	0	50	50	50	50	25	0	0	0	0	0	0	0	0	0	0	0
Electrochromic 30	Daylit area %	Room	0	0	4	7	15	11	19	19	22	22	26	28	30	30	31	37	39
		Bed	0	0	0	0	75	75	100	50	50	25	25	0	0	0	0	0	0
Sun breaker	Daylit area %	Room	7	19	37	41	54	57	65	80	80	74	69	67	67	67	69	70	72
		Bed	0	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

The use of a shading device, as that of the base case (Sun breaker), appears to be of great usefulness in desert conditions. It resulted in a large number of accepted cases. This could be attributed to the high solar penetration possibility resulting from the layout design of B and C rooms. Acceptable daylighting performance was achieved for 30-90% WWRs for these designs. This range extended to 20-90% if we consider performance at patient bed surface only. The best provision of daylighting was achieved, with an 80% of the space "Daylit", by use of a sun breaker at 45-50% WWR in room B, while in room C a 74% "Daylit" area was attained at 90% WWR.

Table 3. Percentage of "Daylit" area relative to the total room and bed plane areas in design C.

Design C: The Inboard Bathroom																			
WWR			10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
DoublePane LowE	Daylit area %	Room	4	15	23	28	34	40	42	42	45	51	55	53	51	45	45	45	43
		Bed	0	75	50	50	25	25	0	0	0	0	0	0	0	0	0	0	0
Electrochromic 60	Daylit area %	Room	2	9	21	17	32	38	38	42	42	45	47	53	55	55	55	51	53
		Bed	0	50	50	50	25	25	0	0	0	0	0	0	0	0	0	0	0
Electrochromic 30	Daylit area %	Room	2	0	4	8	11	13	19	21	25	23	26	28	30	30	32	32	34
		Bed	0	0	0	0	50	100	100	50	50	25	25	0	0	0	0	0	0
Sun breaker	Daylit area %	Room	5	17	38	43	60	58	62	60	64	62	64	64	64	70	68	70	74
		Bed	0	25	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

5. Discussion

In order to understand the daylighting behavior in the tested cases, the “Partially Daylit, Daylit and Over lit” area percentages were compared relative to the total room area. The discussion will focus on the results of patient room Design A "Outboard Bathroom" and B "Nested Bathroom". Provision of daylighting proved to be more challenging in the desert, as the risk of “Over lit” situations is more paramount. Accordingly, design A where the bathroom is located on the façade resulting in having the bed further spaced from the window, provided acceptable performance for most of the tested glazing types (Figure 3). However, sufficient shading (by use of a sun breaker) was required for design B to mitigate the risk of “Over lit” situations that resulted from having a larger solar exposure due to locating bathroom away from the façade and a placing the bed at a closer distance to window (Figure 4).

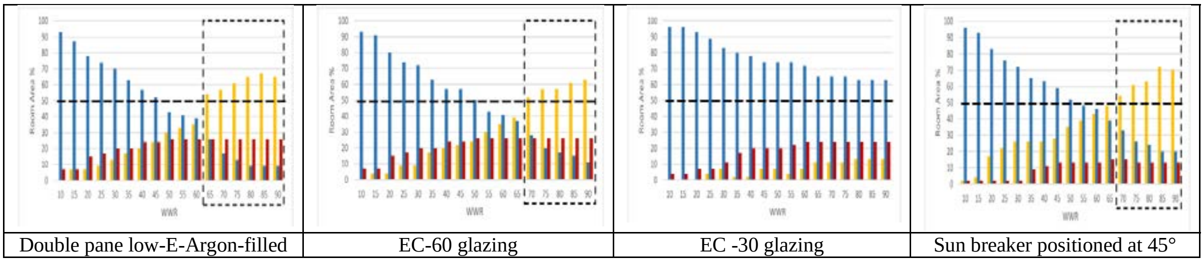

Fig. 3: The “Partially Daylit, Daylit and Over lit” area percentage relative to the total room area in patient room of design A.

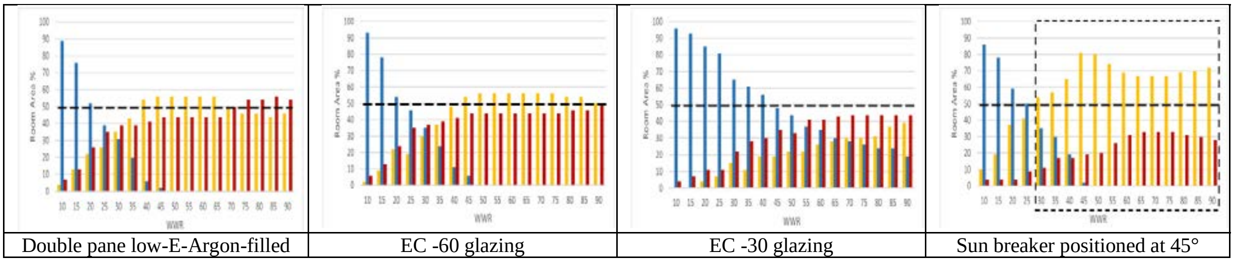

Fig. 4: The “Partially Daylit, Daylit and Over lit” area percentage relative to the total room area in patient room of design B.

The performance of windows using the two glazing types that achieved acceptable performance (LE and EC-60 glazing) was almost identical. Due to the location of the “outboard bathroom” along the façade wall, this room design lacked sufficient daylight, especially at the low WWRs. The “Partially Daylit” area percentage was above 50% in WWRs from 10 to 45%. Accordingly, the “Daylit” area percentage was unacceptable. The “Daylit” area percentage reached acceptable levels only at high WWRs, where the “Partially Daylit” area percentage became very low. The “Over lit” area percentage was considerable, but not dramatically affecting performance. An almost similar pattern was observed in the base case (Sun breaker), where the use of a sun breaker successfully controlled solar access. However, in this case, the “Over lit” area percentage was negligible. The performance of windows having an EC-30 glazing -where none of the cases was acceptable- was rather different. The glazing effect seems to have been too effective in limiting solar access into the space. As a result, the “Partially Daylit” area percentage was very high in all WWRs, limiting the “Daylit” area. Its lowest value was more than 60% of the total space area.

In Design B “Nested bathroom”, since the area of the external wall is larger, use of the tested glazing types resulted in a high “Over lit” area percentage. Shading by a sun breaker was found to be the most effective configuration. For windows using the LE and EC-60 glazing types, a similar performance was observed, where the “Partially daylit” area percentage decreased gradually until it disappeared at 50% WWR. To the contrary, the “Over lit” area percentage increased until it reached its maximum value (50% as an average) in the cases of 85% and 90% WWR respectively. Although the “Daylit” area percentage was acceptable for a wide range of WWRs (40-70% for LE) and (40-85% for EC-60), the substantial “Over lit” area percentage drastically affected the whole performance. On the other hand, use of the sun breaker provided sufficient protection from having “Over lit” situations and adequate daylighting performance for WWRs from 30 to 90%, while “Partially Daylit” areas were only found at low WWRs. For windows having an EC-30 glazing, the “Partially Daylit” and the “Over lit” area percentages were high in all WWRs. “Partially Daylit” areas dominated the space area from 10% WWR until 50%, while “Over lit” areas were significant from 55 to 90% WWR. This resulted in an insufficient daylighting performance.

6. Conclusion

Daylighting performance was evaluated for three common hospital patient room layout designs located in Cairo, Egypt, which enjoys a desert clear-sky. The year-round daylighting performance resulting from use of three common window glazing types was compared with that of a window having a clear double glass with a sun breaker. Several Window-to-Wall Ratios were modeled and simulated for a south oriented façade. Table 4 illustrates the range of accepted cases for each of the patient room designs and the reasons for not achieving the required performance.

Table 4. The accepted WWRs for glazing type, in each of the patient room layout designs.

Patient Room Layout Design	Double Low-E-Argon-Filled	Electrochromatic-60	Electrochromatic-30	Base Case (Sun Breaker)
Design A: Ouboard Bathroom	65% - 90%	70% - 90%	None: (partially Daylit)	70% - 90%
Design B: Nested Bathroom	None: (Over lit)	None: (Over lit)	None: (partially Daylit)	30% - 90%
Design C: Inboard Bathroom	None: (Over lit)	None: (Over lit)	None: (partially Daylit)	30% - 90%

The three tested glazing types were not as successful in providing acceptable daylighting performance as a standard shading sun breaker. The sun breaker was found to be the most effective window configuration in providing daylighting adequacy for the three patient room layouts under the desert clear-sky of Cairo, Egypt. Its use achieved acceptable performance in a wide range of WWRS for the nested and inboard bathroom designs, and achieved adequacy only with large WWRs in the case of the outboard bathroom design.

The electrochromic glazing with 30 % visible transmittance (EC-30) seemed to fail in providing sufficient daylighting performance in any of the patient room designs. This was attributed to the large “Partially Daylit” areas resulting from its use. On the other hand, utilization of double pane low-E-Argon-filled glazing and electrochromic glazing with 60 % visible transmittance (EC-60) glazing proved to be successful in one of the room layout designs only (the outboard bathroom design) for large windows having 70-90% WWRs. The use of these glazing types resulted in a high percentage of “Over lit” areas in the other two patient room designs. The best provision of daylighting was achieved by use of a sun breaker at a medium sized window in room design B (nested bathroom).

This study demonstrates that analysis of daylighting performance in hospital patient rooms should not be limited to the common methodology of studying the daylight adequacy along the whole room area. A special attention should be given to the patient bed surface area where critical healthcare activities occur. Daylighting at the bed surface area was found unacceptable in several cases whereby the overall room daylighting was adequate. Future research should address the effect of utilizing the full range of electrochromic glass visual transmittance properties.

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