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The Impact of Hospital Intensive Care Unit Window Design on Daylighting and Energy Performance in Desert Climate

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***Abstract*—**This paper addresses the design of hospital Intensive Care Unit windows for the achievement of visual comfort and energy savings. The aim was to identify the window size and shading system configurations that could fulfill daylighting adequacy, avoid glare and reduce energy consumption. The study focused on addressing the effect of utilizing different shading systems in association with a range of Window-to-Wall Ratios (WWR) in different orientations under the desert clear-sky of Cairo, Egypt.

The results of this study demonstrated that solar penetration is a critical concern affecting the design of ICU windows in desert locations, as in Cairo, Egypt. Use of shading systems was found to be essential in providing acceptable daylight performance and energy saving. Careful positioning of the ICU window towards a proper orientation can dramatically improve performance. It was observed that ICU windows facing the north direction enjoyed the widest range of successful window configuration possibilities at different WWRs. ICU windows facing south enjoyed a reasonable number of configuration options as well. By contrast, the ICU windows facing the east orientation had a very limited number of options that provide acceptable performance. These require additional local shading measures at certain times due to glare incidence. Moreover, use of horizontal sun breakers and solar screens to protect the ICU windows proved to be more successful than the other alternatives in a wide range of Window to Wall Ratios. By contrast, the use of light shelves and vertical shading devices seemed questionable.

***Keywords*—**Daylighting, Desert, Energy Efficiency, Shading.

I. Introduction

HOSPITALS are typically considered heavy energy consumers due to high internal loads. This is exacerbated in desert locations, due to the excessive cooling loads that result from the intense solar exposure. Hospital Intensive Care Unit (ICU) spaces pose a special challenge. Design guidelines require the provision of external windows in these spaces [1]. These provide daylighting and access to external view, yet at the same time increase solar penetration in the harsh desert environment. Careful design of the window and their shading systems can help in reducing the total energy loads without detriment effect on visual comfort.

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The positive effect of daylighting on hospital users was addressed in a number of publications. The impact of daylight and window views on patient pain levels, length of stay, staff errors, absenteeism, and vacancy rates were examined in [2]. In another study, it was recommended that natural light improvement could help reducing stress and fatigue, while increasing effectiveness in delivering care, patient safety and overall healthcare quality [3].

A limited number of publications addressed the energy and daylighting performance of hospital building spaces. In order to minimize life-cycle cost, a search and optimization technique of multi-objective genetic algorithm was used to investigate hospital energy performance in the hot environment of Thailand. The building envelope was found to be the most important factor contributing to the life-cycle cost [4].

Balancing between the provision of natural daylight and reduction of energy consumption by use of solar control systems in desert environments was addressed in a number of studies. However, a limited number of these addressed healthcare facilities. Another research examined the effect of vertical and horizontal shading devices on the quality of daylight in residential buildings and the associated energy saving [5]. It concluded that there is an optimal orientation for shading devices that keeps the internal illuminance level within an acceptable range while maintaining the amount of solar heat gain to the minimum. The papers [6] and [7] examined the formation of solar screens for providing adequate daylighting performance in different orientations in residential desert settings. In a more related research work, the impact of using various window shading systems and different window glazing types on the energy consumption of a typical ICU space in Aswan, Egypt was examined [8]. It was found that the overall energy performance could be improved by utilizing external shading systems rather than using advanced glazing types. Energy savings of up to 30% in the west and south orientations were achieved by use of externally perforated solar screens and overhangs positioned at a shading angle of 45°. In another study, daylighting performance was simulated for a typical hospital Intensive Care Unit space located in Cairo, Egypt [9]. Several window configurations were simulated. The effect of adding shading and daylighting systems on the provision of daylight was examined. Successful window configurations were recommended for different window to wall ratios, in each of the four main orientations.

The above literature review demonstrates that previous research did not address the balance between energy performance and daylighting in ICU spaces located in the desert. Configuring windows for provision of acceptable daylighting levels, while achieving energy efficiency, could pave the way for their utilization in reducing the energy consumption of hospital buildings and at the same time providing a supportive environment for healthcare.

II. Objective

This paper addressed the design of hospital Intensive Care Unit windows for the achievement of visual comfort and energy savings. The aim was to identify the window size and shading system configurations that could fulfill daylighting adequacy, avoid glare and reduce energy consumption. The study focused on addressing the effect of utilizing different shading systems in association with a range of window sizes under the desert clear-sky of Cairo, Egypt.

III. Methodology

The methodology adopted in this paper is divided into three phases. These are as follows:

- Phase one: Analysis of the daylighting adequacy and avoidance of glare resulting from use of the tested window sizes and shading systems.
- Phase two: Analysis of the energy savings resulting from the use the tested window sizes and shading systems in comparison with a base case.
- Phase three: Identification of the balanced solutions which produced acceptable daylight distribution, avoidance of glare and lowest energy savings.

A typical ICU patient space was assumed for investigation. Its layout, dimensions and parameters were based on standard ICU space requirements [1]. These are illustrated in Fig. 1 and Table I. The space was assumed to be located on the first floor level of a hospital building in the outskirts of Cairo, Egypt which enjoys a year-round desert clear-sky. No external obstruction was assumed. An external ground reflectivity of 20% was assumed.

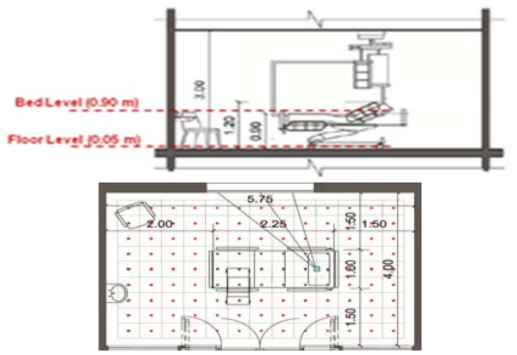


Fig. 1 Floor plan and cross section of the tested ICU space

TABLE I
Indoor Space Parameters of the Tested ICU Space

Floor level	First floor (+4.00 m)
Dimensions (m)	5.75*4.00*3.00
Walls reflectance	50% (medium coloured off -white)
Ceiling reflectance	80% (white coloured)
Floor reflectance	20% (wooden floor)
Glazing	Double clear glazing

Six values of window sizes, expressed as Window-to-Wall Ratios (WWR) were investigated. These were WWR = 8%, 16%, 24%, 32%, 40% and 48%. Their shape and location in the external wall of the ICU space are illustrated in Fig. 2.

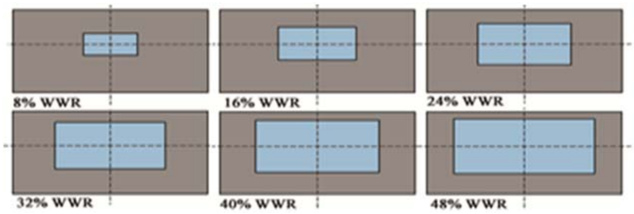
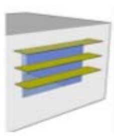
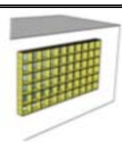
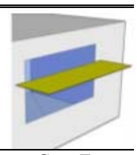


Fig. 2 Shapes of the tested windows in the ICU space external wall

Five shading systems were tested for each of the above WWRs, in all orientations. The shapes of these shading systems are illustrated in Table II. They were identified in this paper as Cases A to E as follows:

- Case A: A single horizontal sun-breaker. It extends above the window to provide a 45° cut-off sun shading angle (reflectance = 50%).
- Case B: Three horizontal sun-breakers spaced. These were spaced in a way that provides a 45° cut-off sun shading angle (reflectance = 50%).
- Case C: Four vertical sun-breakers. These were spaced to provide a 45° cut-off sun shading angle (reflectance = 50%).
- Case D: An external perforated solar screen. It was formed to provide openings having a 1:1 aspect ratio and 90% perforation rate (reflectance = 50%)
- Case E: An external light-shelf. It was located at 2/3rd of the window height (upper surface reflectance = 90%).

TABLE II
Shapes of the Tested Shading Systems

				
Case A	Case B	Case C	Case D	Case E

The configuration of these shading systems was based on the results of two publications which addressed the provision of daylighting and energy conservation in ICU spaces in the desert [8], [9]. The shading configurations that were found to be either most effective in conserving energy or providing sufficient daylighting in these papers were selected for investigation.

TABLE III
SOUTH: PERCENTAGE OF "DAYLIT" AREA RELATIVE TO THE TOTAL AREA ON BOTH MEASURING REFERENCE PLANES

WWR	Case A		Case B		Case C		Case D		Case E	
	Bed	Floor	Bed	Floor	Bed	Floor	Bed	Floor	Bed	Floor
8	28%	0%	37%	18%	42%	22%	1%	0%	70%	0%
16	30%	0%	**84%**	**100%**	48%	100%	56%	33%	**76%**	**100%**
24	32%	0%	**50%**	**67%**	23%	72%	**84%**	**78%**	23%	67%
32	34%	0%	21%	61%	4%	39%	**77%**	**94%**	5%	33%
40	40%	0%	5%	50%	0%	6%	**79%**	**83%**	1%	28%
48	47%	0%	2%	44%	67%	48%	**56%**	**67%**	61%	23%

Simulation was conducted using the climatic data of the city of Cairo (30°6'N, 31°24'E, alt. 75 m). The typical meteorological year (TMY3) weather data of Cairo was used in the simulation. According to Climate and Temperature [10], Cairo is classified as a subtropical desert / low-latitude arid climate (Köppen-Geiger classification: BWh) that is hot year round. The annual average temperature is 21.4°C. The average maximum temperature during the summer months is 35°C, while the average minimum temperature in the winter months is 9°C. Annual sunshine averages 3451 hours. Simulation was conducted for the north, east and south orientations. These were selected to represent the three distinct sun penetration patterns that distinctly affect daylighting performance.

A. Methodology of Phase One: Analysis of Daylight Availability and Glare Probability

Phase one consisted of two consecutive stages. In the first stage, year-round daylighting performance was analyzed. While in the second stage, the possibility of glare occurrence in the cases that were found acceptable in the first stage was examined.

1. First stage: Daylight Availability Analysis

The aim of this stage was to investigate the daylighting performance of the five window size and shading configurations represented as cases A, B, C, D and E. Experimentation was conducted for year-round performance using the "Dynamic Daylight Performance Metrics (DDPM)". The DIVA plugin was used to perform the daylight analysis via integration with Radiance and DAYSIM. DIVA (which stands for Design Iterate Validate Adapt) is an environmental analysis plugin for the Rhinoceros 3D Nurbs modeling program. The occupied time of the simulations was from sunrise to sunset. The sunset and sunrise times were determined for each day using the sunset calculator for city of Cairo [11]. Ambient bounces were assumed to be 6, while the Ambient divisions were 1000.

Simulations were carried out at the patient bed plane (at a 0.90 m height). In addition, simulations were carried out at the floor plane (at 0.05 m height) in order to examine the daylighting adequacy for nurse movement, which might be at sometimes urgent. The Lx threshold levels were 300 Lx at the bed plane and 100 Lx at the floor plane [12]. At each reference plane, measurement was calculated for points spaced at a grid of 0.50 m x 0.50 m intervals. The grid and reference planes were illustrated in Fig. 1. 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 [13]. The acceptance criterion adopted in this paper assumed that the cases where the "daylit" area reached ≥50% of the tested space were considered having "acceptable" performance. This criterion was to be satisfied at the both the floor and the patient bed planes.

2. Second stage: Glare Probability Analysis

The aim of this stage was to examine patient visual comfort for the cases which achieved acceptable performance in the first stage. A special focus was made for the cases that posed a high potential for glare occurrence at the patient bed surface, where the "overlit" areas were present at ≥ 30% of the patient bed reference plane (1/3 patient bed area).

Annual glare predictions were simulated for these cases using Daysim, which employs the Daylight Glare Probability (DGP) metric [14]. DGP represents the probability that a person is disturbed by glare and is derived from a subjective user evaluation [15]. Annual DGP uses a simplified method that calculates the vertical illuminance at the eye level as a parameter which can affect the brightness of the space. In this method, glare was divided into four categories: intolerable glare (DGP ≥ 45%), disturbing glare (45% > DGP ≥ 40%), perceptible glare (40% >DGP ≥ 35%), and imperceptible glare (DGP < 35%). In this paper, a fish-eye camera was located at the patient eye level (1.20 m above the floor) and facing the window. Acceptance criteria assumed that when the combined values of disturbing and intolerable glare reached ≥ 10% of the year-round simulation occupied time, the patient view was considered to be "visually uncomfortable".

B. Methodology of Phase Two: Analysis of Energy Savings

The aim of this phase was to investigate the energy savings resulting from the adoption of the five window size and shading configurations that were tested in phase one. The yearly energy consumption of each case was calculated by use of the EnergyPlus software (V7.0). It included the cooling, heating and lighting energy consumption values. These values were compared to the results of those of a base-case. The base-case ICU space and its window had the same exact parameters, but with a window without any shading protection.

Energy modeling and simulation was conducted by the use of two software programs: Design Builder and EnergyPlus. In order to focus on studying the performance of the tested window sizes and shading systems, the effect of thermal transmittance through walls and ceiling from the adjacent spaces was neutralized. Thus, the thermal transmittance from all walls and ceiling, except that of the widow wall, were set to be adiabatic. The window wall was defined as a 350 mm thick double brick insulated cavity wall with a U- value of

0.475 W/m² –k that carried the tested window at its center. The effect of the adjacent rooms is considered to be of no relevance to the thermal performance sought in this comparative study. The building is fully air conditioned and minimal thermal transmittance is expected from the other internal spaces that would have identical set conditions. The ICU air conditioning system heating and cooling set points were assumed to be 22°C/26°C respectively. The occupancy time of the studied ICU space was chosen to be all day, at a rate of 10 m²/ occupant. Artificial lighting was set to be dynamically controlled by sensors according to daylighting adequacy. The internal occupants' load and ICU medical equipment were accounted for. The cooling, heating and lighting energy consumption values were calculated and compared to those of the base-case. The cases which produced energy savings of more than 10% were considered acceptable.

TABLE IV
EAST: PERCENTAGE OF "DAYLIT" AREA RELATIVE TO THE TOTAL AREA ON BOTH MEASURING REFERENCE PLANES

WWR	Case A		Case B		Case C		Case D		Case E	
	Bed	Floor	Bed	Floor	Bed	Floor	Bed	Floor	Bed	Floor
8	29%	17%	5%	0%	24%	6%	0%	0%	33%	0%
16	**71%**	**89%**	**62%**	**50%**	42%	22%	23%	0%	**62%**	**50%**
24	**59%**	**61%**	48%	33%	30%	0%	48%	0%	32%	39%
32	35%	17%	26%	33%	9%	0%	**66%**	**50%**	9%	0%
40	17%	6%	10%	0%	3%	0%	**56%**	**72%**	2%	0%
48	12%	0%	3%	0%	0%	0%	27%	39%	0%	0%

IV. SIMULATION RESULTS

A. Results of Phase One: Analysis of Daylight Availability and Glare Probability

1. Daylight Availability Analysis

Tables III-V summarize the Daylight Availability results in the south, east and north orientations. They illustrate the percentage of "daylit" area relative to the total area on both measuring reference planes for the 5 tested cases, at different WWRs. The cases that achieved the required threshold at both measuring reference planes were identified.

In the south orientation, three of the tested window shading systems showed promising results (Table III). The most promising case was Case D, where an external solar screen was used to protect the window. This case provided the designer with large window sizes having a wide range of WWRs to choose from. These ranged from 24% to 48%. In these solutions, the "daylit" areas reached impressive results, up to 94% of the area, and consistently higher than the threshold of 50% on the two tested planes. The second promising case was Case B, where three horizontal sun breakers were placed in front of the window. In this case, two windows WWRs showed promising results. These were WWR 16% and 24%, where the "daylit" areas ranged from 50% to 100% at the tested planes. Case E, which utilized an external light shelf, which prevents solar access while reflecting light deep into the space, provided acceptable performance at only one WWR (16%). On the other hand, adequate daylighting was unattainable in Cases A and C where a single horizontal sun breaker and vertical sun breakers were used. The "daylit" areas on the floor plane were short of reaching the threshold of 50% of the total area in all WWRs.

For the east orientation, simulation results were more diversified (Table IV). The "daylit" area ranged between 0% and 71% at the bed surface area in many WWRs. However, the "overlit" and "partially daylit" areas were dominant in all WWRs. Very low unacceptable "daylit" values (less than 30%) were also observed on the floor and the bed surface when shading was provided by vertical sun breakers (Case C). The most promising case in the east orientation was Case D, where an external solar screen was used. This case provided the designer with large window sizes having two options for WWRs (32% and 40%). In these solutions, the "daylit" area reached reasonable results, between 50% and 72% of the total area. Other WWRs failed to provide acceptable performance, where the "daylit" area was below the 50% threshold value. The other cases (Cases A, B and E) achieved acceptable performance at specific small WWR values (16% and 24%).

In the north orientation, all cases achieved the required threshold at the two measuring reference planes (Table V). All tested window configurations were successful in this orientation which receives very little direct sun rays at limited times of the year. All solutions were successful in offering the designer with a wide range of WWRs to choose from. The only exception was the 8% WWR, where none of the cases was successful.

In contrast to the south and east orientations, Cases A and B proved to be more useful in this orientation. In these cases, use of horizontal sun breakers, either one or several ones, provided the widest range WWRs (from 16% to 48%) and large window sizes. The "daylit" area reached 100% at WWR of 32% and 40% in Case B at the tested bed surface area, while the "daylit" area reached 100% in WWRs from 24% to 48% at the tested floor plane in both Cases A and B. Cases C, D and E also provided very good performance, where the range of acceptable WWRs was between 16% and 40% in Cases C and E, and between 32% and 48% in Case D. The "daylit" area reached 100% in the majority of acceptable cases at the tested floor and bed surface area. Use of external solar screens (Case D) was the least successful among all alternatives, especially in small WWRs, due to the limited solar penetration in this orientation. It is worth noting that some cases achieved a 100% daylit area on both reference planes in the North orientation. These were: Case B at 32% and 40% WWRs, Case D at 48% WWR and Case E at 24% WWR.

2. Glare Probability Analysis

In the south orientation, two of the accepted cases from the previous stage results were identified as having a high potential for glare occurrence and were, thus, analyzed: Case B, at a 24% WWR; and Case D, at a 48% WWR (Fig. 3). These were the cases where the "overlit" area percentage exceeded 30% of the bed surface area. In these cases the "overlit" area reached 33% of the bed surface area. Annual Daylight Glare Probability was acceptable in the two analyzed cases. In Case B (at a 24% WWR), the disturbing glare and

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intolerable glare were only present in only 4% of occupied simulation time collectively. The imperceptible glare was 93% of the occupied simulation time. As for Case D (at a 48% WWR), it achieved a slightly lower result. The disturbing glare and intolerable glare were present in only 6% of occupied simulation time collectively. The imperceptible glare reached 90% while the perceptible glare was found to be 4% of the occupied simulation time. In the east orientation, three of the four accepted cases in stage one were identified as having a high potential for glare occurrence: Case B, at a 16% WWR; Case E, at a 16% WWR; and Case D, at a 32% WWR. Case B at a 16% WWR did not succeed in satisfying the required criteria.

TABLE V
NORTH: PERCENTAGE OF "DAYLIT" AREA RELATIVE TO THE TOTAL AREA ON BOTH MEASURING REFERENCE PLANES

WWR	Case A		Case B		Case C		Case D		Case E	
	Bed	Floor	Bed	Floor	Bed	Floor	Bed	Floor	Bed	Floor
8	0%	0%	0%	0%	20%	0%	0%	0%	9%	0%
16	**61%**	**56%**	**77%**	**83%**	**79%**	**89%**	20%	0%	**92%**	**61%**
24	**87%**	**100%**	**97%**	**100%**	**92%**	**100%**	72%	33%	**100%**	**100%**
32	**96%**	**100%**	**100%**	**100%**	**81%**	**100%**	**93%**	**100%**	**87%**	**100%**
40	**79%**	**100%**	**100%**	**100%**	**60%**	**100%**	**98%**	**100%**	**56%**	**100%**
48	**70%**	**100%**	**98%**	**100%**	39%	100%	**100%**	**100%**	26%	100%

TABLE VI
SOUTH: ENERGY SAVING PERCENTAGES, RELATIVE TO THE BASE CASE

WWR	Case A	Case B	Case C	Case D	Case E
8	9.4%	9.0%	1.6%	**11.9%**	1.6%
16	**14.3%**	**13.4%**	4.6%	**17.5%**	4.8%
24	**21.2%**	**17.4%**	8.1%	**27.8%**	8.4%
32	**28.6%**	**22.6%**	**12.1%**	**33.3%**	**12.9%**
40	**32.2%**	**24.9%**	**12.5%**	**38.8%**	**14.8%**
48	**36.1%**	**30.2%**	**13.7%**	**45.0%**	**15.3%**

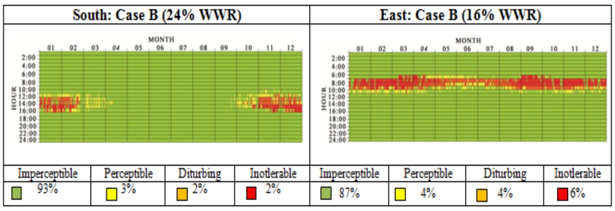

Fig. 3 Example: Annual Daylight Glare Probability Percentages of Case B in South (Accepted) and East (not Accepted) Orientations

The disturbing glare and intolerable glare were found at 10% of the occupied simulation time. The imperceptible glare was present at 87% of the time, while the perceptible glare was present at only 4%. As for Case E (at a 16% WWR), it achieved an acceptable better result. The disturbing glare and intolerable glare were present at only 6% of the occupied simulation time. The imperceptible glare reached 89%, while the perceptible glare was present at only 5% of the time. As for Case D (at a 32% WWR), it achieved a slightly lower result. The disturbing glare and intolerable glare were present at only 8% of the occupied simulation time. The imperceptible glare reached 88%, while the perceptible glare was present at only 4% of the time. Glare probability was not tested in the north orientation, since this façade does not receive direct solar penetration almost all year round (Fig. 3).

B. Results of Phase Two: Analysis of Energy Savings

In this phase, the annual energy savings resulting from adopting the tested window sizes and shading systems were calculated in comparison with the base-case. Tables VI-VIII illustrate the results. In these tables, the cases which achieved energy savings of more than 10% are shown in bold.

In the south orientation (Table VI), the external solar screens (Case D) demonstrated impressive effectiveness in reducing energy consumption. These provided acceptable energy savings in all WWRs. Also, they produced the highest energy saving values, reaching up to 45%. Use of the sun breakers in Cases A and B also provided very good results, where the energy savings exceeded 10% for all WWRs, except for 8%. These savings reached an impressive 36% and 30% saving rates for Cases A and B respectively. Using light shelves or vertical sun breakers (Cases C and E) was not as effective in reducing the energy consumption in this orientation. Their performance was acceptable only in large WWRs (from 32 to 48%). The energy savings were only 12.1% - 15.3% in these cases.

In the east orientation, performance of the shading systems was generally similar to that of the south (Table VII). Several shading alternatives can save energy in the different WWRs. The external solar screens and horizontal sun breakers, either single or triple, produced the highest energy saving values. Although use of the external solar screens may achieve energy savings up to 37%, the sun breakers of Cases A and B provide similarly impressive results, in which maximum energy savings reached 36 and 30% respectively for the 48% WWR. Similar to the south orientation, light shelves and vertical sun breakers (Cases C and E) provided the lowest energy savings. They were relatively effective only in the large WWRs ranging from 32 to 48%. Energy savings were only 11.3% - 15.3% in these cases.

In the north orientation, the savings that resulted from use of all of the tested shading systems were marginal in comparison with those of the other directions (Table VIII). The highest energy saving was only 19%. This was achieved when an external solar screen (Case D) was used with a 48% WWR. The second best performance was produced by Case A, with a saving of 16%. Cases B, C and D achieved lower savings. Use of the light shelf provided the lowest energy savings in this orientation, followed by the vertical sun breakers.

C. Results of Phase Three: Balancing Between Daylighting and Energy Performance

In this phase, the balanced solutions which produced acceptable daylight distribution, avoidance of glare and best energy savings were identified (Fig 4).

The table indicates that the use of external solar screens (Case D) provided a balanced acceptable performance in all orientations. The use of a single and three horizontal sun breaker systems (Cases A and B) produced a good performance as well. Both cases provided acceptable performance in north orientation. While in south and east orientations, only the 16% and 24% WWRs achieved the accepted criteria. Case E (light shelf) provided the lowest number of options. Its performance was accepted only at 40% WWR in the north direction, where no sun penetration was expected. Case C (vertical sun breaker) also failed to provide good performance except in the north orientation.

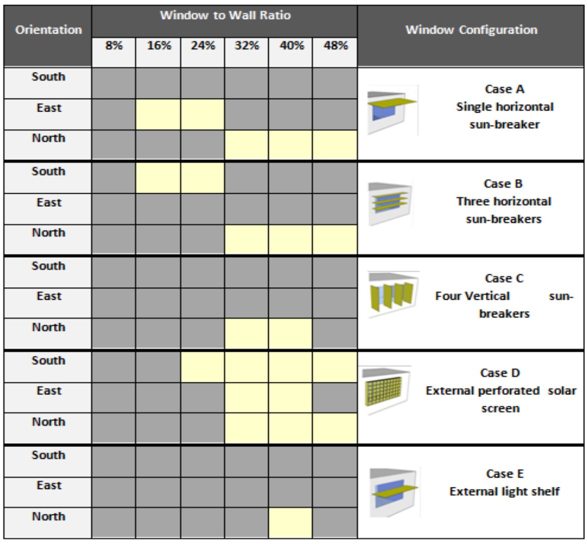

Fig. 4 The Accepted WWRs for each Shading System in Each Orientation are Highlighted

TABLE VII
EAST: ENERGY SAVING PERCENTAGE, RELATIVE TO THE BASE CASE

WWR	Case A	Case B	Case C	Case D	Case E
8	8.2%	7.1%	2.1%	9.5%	2.9%
16	**12.6%**	12.1%	5.4%	**14.3%**	5.6%
24	**20.2%**	**14.4%**	8.5%	**21.3%**	8.5%
32	**25.0%**	**16.0%**	**11.3%**	**27.6%**	**11.8%**
40	**29.6%**	**22.4%**	**13.3%**	**32.0%**	**14.2%**
48	**32.0%**	**25.4%**	**14.1%**	**37.5%**	**15.3%**

TABLE VIII
NORTH: ENERGY SAVING PERCENTAGE, RELATIVE TO THE BASE CASE

WWR	Case A	Case B	Case C	Case D	Case E
8	4.7%	5.1%	4.9%	4.0%	4.4%
16	5.3%	6.0%	6.2%	8.3%	5.0%
24	8.4%	7.7%	8.1%	**10.9%**	6.4%
32	**12.5%**	**10.4%**	**11.1%**	**15.3%**	9.0%
40	**14.9%**	**11.7%**	**12.0%**	**17.0%**	**10.1%**
48	**16.0%**	**12.4%**	**12.3%**	**18.9%**	**10.6%**

V. CONCLUSION

The daylighting and energy performance of a typical hospital Intensive Care Unit space was simulated. The performance resulting from use of several window shading systems was tested for a range of window sizes under the clear-sky desert sun of Egypt.

Results of this study demonstrated that solar penetration is a critical concern affecting the design of ICU windows in desert locations, such as Cairo, Egypt. Use of shading systems is essential in providing acceptable daylight performance and energy saving. Also, careful positioning of the ICU window towards a proper orientation (S, E or N) can dramatically improve performance.

It was observed that ICU windows facing the north direction enjoyed the widest range of successful shading system possibilities at different Window-to-Wall Ratios (WWR). Also, ICU windows facing south enjoyed a reasonable number of options as well. By contrast, the ICU windows facing the east orientation had a very limited number of options that provide acceptable performance. These still require additional movable shading measures at certain times, due to glare incidence at these times. It was also observed that ICU windows facing the north direction can successfully enjoy large windows having WWRs between 32% and 48%, with a variety of shading systems. This can prove useful in the provision of access to external view. The WWR of 40% was the most successful ICU window size in this direction, as it provides the largest shading options for the designer to choose from. Directing the ICU windows towards south provided a wider range of successful size options. The ICU windows in this direction can successfully be sized between 16% and 48% of the external wall. However, acceptable performance in this orientation was limited to the cases where three horizontal sun-breakers and external solar screens were used. As for the ICU windows facing east, the range of successful WWRs was limited between 16% and 40%, with the use of only two shading systems. These were a horizontal sun breaker and an external solar screen.

Moreover, results demonstrated that use of horizontal sun breakers and solar screens to protect the ICU windows proved to be more successful than the other sun shading system alternatives in a wide range of Window to Wall Ratios. These showed acceptable performance in all orientations, with a minimum occurrence of glare. By contrast, the use of light shelves and vertical shading devices seemed questionable. They failed to provide acceptable performance, except in the north where direct sun rays rarely penetrate the ICU space.

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