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Energy Efficient Shading Strategies for Windows of Hospital ICUs in the Desert

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***Abstract*—**Hospitals, everywhere, are considered heavy energy consumers. Hospital Intensive Care Unit spaces pose a special challenge, where design guidelines requires the provision of external windows for daylighting and external view. Window protection strategies could be employed to reduce energy loads without detriment effect on comfort or health care. This paper addresses the effectiveness of using various window strategies on the annual cooling, heating and lighting energy use of a typical Hospital Intensive Unit space. Series of experiments were performed using the EnergyPlus simulation software for a typical Intensive Care Unit (ICU) space in Cairo, located in the Egyptian desert. This study concluded that the use of shading systems is more effective in conserving energy in comparison with glazing of different types, in the Cairo ICUs. The highest energy savings in the West and South orientations were accomplished by external perforated solar screens, followed by overhangs positioned at a protection angle of 45°.

***Keywords*—**Energy, Hospital, Intensive Care Units, Shading.

I. Introduction

HOSPITAL Intensive care units are crucial in patient's detailed observation and invasive treatment. Daylighting passing through windows coupled with external view can contribute significantly to patient's healing process in addition to reducing pain and length of stay at hospitals[1]. For optimal energy performance and overheating prevention, window treatment strategies could be utilized to reduce the total energy loads without detriment effect on comfort or health care.

Hospital energy performance was studied in the hot environment of Thailand to minimize life-cycle costs using a search and optimization technique of multiobjective genetic algorithm. The building envelope was found to be the most important factor contributing to increase or decrease in the life-cycle costs. It was found that significant energy savings can be achieved by improving three main building systems altogether, which were energy efficient building envelope, daylighting provision and efficient air-conditioning system [2]. In another study, energy efficient building envelope treatments for a generic reference hospital in Thailand were examined. A parametric analysis was conducted by using different techniques such as the overall thermal transfer value (OTTV), glazing materials, several Window-to-Wall ratios (WWRs) and external shading devices. The annual energy savings due to increasing the daylighting reached up to 15.4 and 11.3% for the electrochromic and green tinted glazing respectively [3].

Furthermore, acceptable window configurations that suit the requirements of hospital Intensive Care Units located in the desert were investigated in terms of daylighting to achieve daylight adequacy and visual comfort in a typical assumed ICU space, in Cairo, Egypt. Annual simulations were conducted using Diva-for-Rhino, a plug-in for Rhinoceros modeling software. Six window-to-wall ratios were investigated; in addition the effect of adding shading and daylighting systems. Successful window configurations were recommended for the different window to wall ratios, for each of the four main orientations [4]. The daylighting effect in health care facilities was analyzed in several other publications [5], [6]. It was recommended that natural light improvement could help reducing stress and fatigue, whereas increasing effectiveness in delivering care, patient safety and overall healthcare quality [7], [8]. The thermal comfort effect on health was studied in a comprehensive literature review conducted to assess the impact of thermal comfort on increasing the productivity in hospitals. The study highlighted the significance of considering different thermal comfort conditions needed by patients and hospital staff [9]. Moreover, a three-dimensional analysis for thermal comfort and contaminant removal in a hospital operating room was performed. Simulations modeling were conducted using computational fluid dynamics approach, where the distribution of airflow velocity, temperature, relative humidity, and contaminant concentration were studied. It was concluded that placing the supply grilles next to the vertical centerline of the wall provided an efficient performance. However, the exhaust grilles location was found insignificant [10].

In addition, HVAC and indoor thermal conditions in hospital operating rooms were investigated, where measured data indoor thermal conditions, audit results and main properties of 20 ORs in 10 major Hellenic hospitals were presented. The most common problems were identified. These included shortage in indoor air exchange, poor control on indoor thermal conditions, ineffective space ergonomics that affects the ventilation system operation, poor technical installations maintenance and understaffed technical departments. Measured indoor temperature ranged from 14 to 29°C, and relative humidity from 13 to 80%, whereas the number of air changes per hour ranged from 3.2 to 58 ACH. It was concluded that significant energy savings could be achieved, whereas preserving thermal comfort and high

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patient care quality [11].

II. Objective

This paper utilized simulation tools to evaluate the energy saving potential of using solar control methods and shading systems such as colored and reflective glass, solar screens and overhangs on the energy performance in a typical hospital Intensive Care Unit room. The cooling, heating and lighting energy loads at different window-to-wall-ratios (WWR) were analyzed in the West, North and South orientations. The larger aim was to arrive at satisfactory window configurations that achieve maximum energy savings in Intensive Care Unit settings, thus help improve the delivery of healthcare.

III. Methodology

A computer model was created by the use of two computer simulation programs, Design Builder and EnergyPlus. The architectural parameters were selected according to the principal features of a typical ICU using the climatic data of the severe hot arid environment of Cairo, Egypt.

Specific building input parameters were as follows: An ICU having a floor area of 5.75m by 4.0m, with a height of 3.0m. This room was isolated from the external environmental thermal changes by assuming that all surfaces, other than the external tested wall, were adiabatic. Thus, three walls, floor and roof were assumed adiabatic. The fourth 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 a window at its center. A split unit type air conditioning system was assumed. Artificial lighting was set to be dynamically controlled by sensors according to daylighting adequacy. A Daylighting control was set up with an illuminance set point of 100 lux at the centre of the ICU. The internal occupants' load and ICU medical equipment were accounted for (Fig. 1).

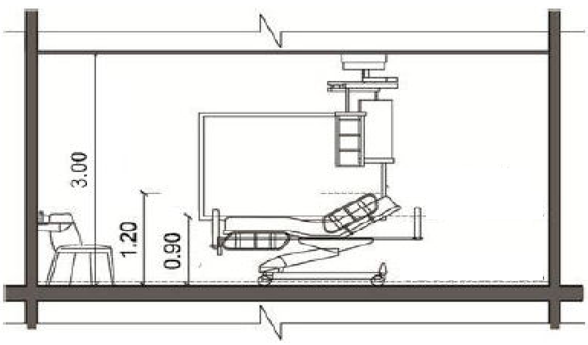
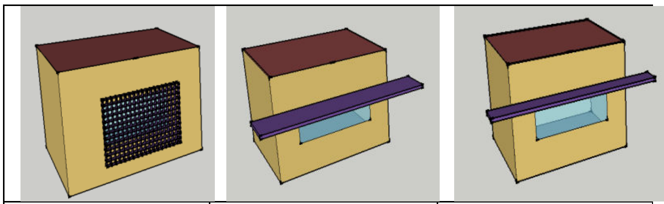


Fig. 1 Cross section of the tested ICU space



Screen 80% perforation and depth ratio of 1.	Overhang positioned at an angle of 45°.	Overhang positioned at an angle of 30°.

Fig. 2 Window shading treatments

A range of shading and glazing treatments were tested during all seasons in the West, South and North directions. These window treatments were as follows: single clear 3mm, single clear 6mm, double clear 3mm, single green 3mm, single grey 3mm, double clear 6mm with 6mm air gap, triple clear, single green 6mm, single blue 6mm, single grey 6mm, double argon filled with13mm, single reflective tinted, double grey, triple low-e argon filled, triple with mid panes, double electrochromic absorptive, overhang at 30°, overhang at 45°, solar screen on single clear 3mm and solar screen on double clear 3mm. Fig. 2 illustrates the tested shading configurations.

IV. Simulation Results

The annual energy consumption of a base case was calculated first. It was a typical ICU with an unprotected single clear window of 20% WWR. Then the annual energy consumption in KWh/m² for alternative window treatments in the West, South, and North orientations were calculated (Fig. 3). Simulation results revealed that the highest energy consumption was found in West orientated ICU windows, where the energy consumption of the unprotected single glazed clear window reached 300kWh/m². The energy consumption of ICU windows located in the South orientation had a similar trend to that of the West orientation, but with slightly lower values. For example, the energy consumption of the single glazed clear window reached 287kWh/m². The North orientation provided the lowest consumption as the energy loads by using simple clear window reached 223kWh/m² due to the limited solar exposure in this direction.

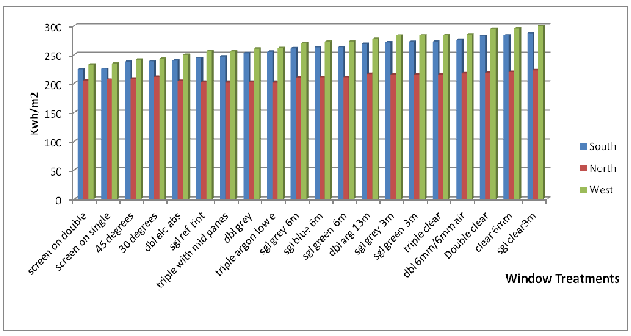


Fig. 3 Annual Energy Loads for a window of 20% WWR with different window treatment strategies in the West, South and North orientations

A comparative analytical study was drawn in reference to the base case of the simple clear window. The aim was to test the usefulness of window shading and glazing treatments in each orientation on energy savings.

In the West orientation, the highest energy saving was 22.3%. This was achieved by shading ICU windows with externally perforated solar screens of 80% perforation percentage and depth ratio of 1 on a double glazed window. Window shading strategies proved to be more effective than window treatments with addition of glazing layers or changing its reflectivity and absorption. Shaded windows with overhang at 45° and 30° followed by double electrochromic absorptive windows provided a near optimum zone, where savings lied within 7% of the optimum saving percentage. However, electrochromic window may be considered a costly solution (Fig. 4).

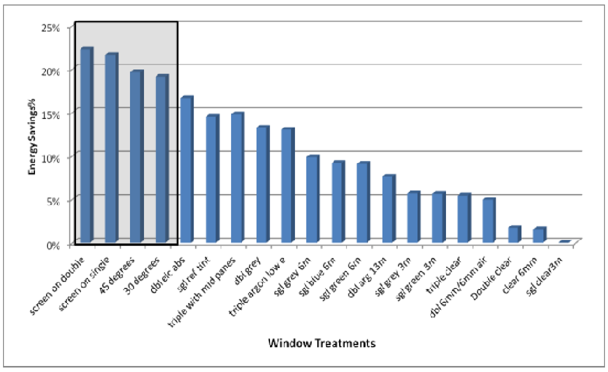


Fig. 4 Annual Energy savings for a West oriented window of 20% WWR with different window treatment strategies

For the South orientation, savings had a similar trend to that of the West orientation, but with lower percentages in which window shading strategies achieved significant energy savings compared to window treatments of double or triple layers or dark colors. Externally perforated solar screens of 80% perforation percentage and depth ratio of 1 on a double glazed window achieved the highest energy savings of 21.8%, followed by screen on single glazed window. Then, overhangs at 45° and 30° provided a near optimum zone (Fig. 5).

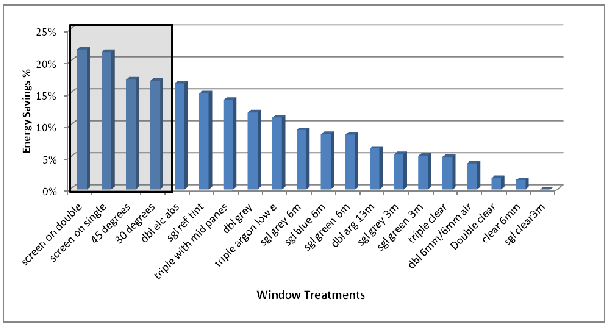


Fig. 5 Annual Energy savings for a South oriented window of 20% WWR with different window treatment strategies.

For the North orientation, different window treatments achieved comparable energy savings, where maximum energy savings reached only 10%. However, unlike the West and South orientations, it was found that the window treatments without adding shading devices may achieve better energy performance in the North orientation of Cairo ICUs. Energy efficient window treatments included double electrochromic absorptive, triple with mid panes, single reflective tinted, triple argon filled, triple low-e argon filled and double grey windows (Fig. 6).

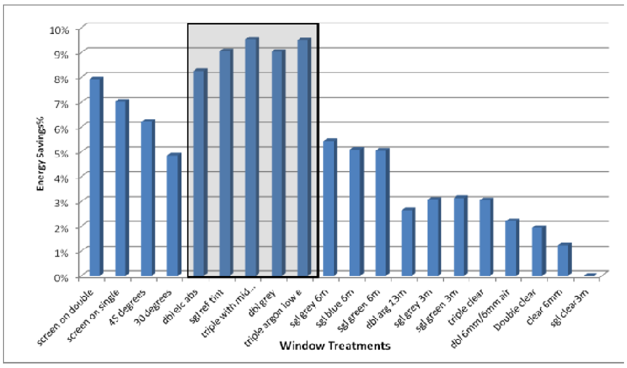


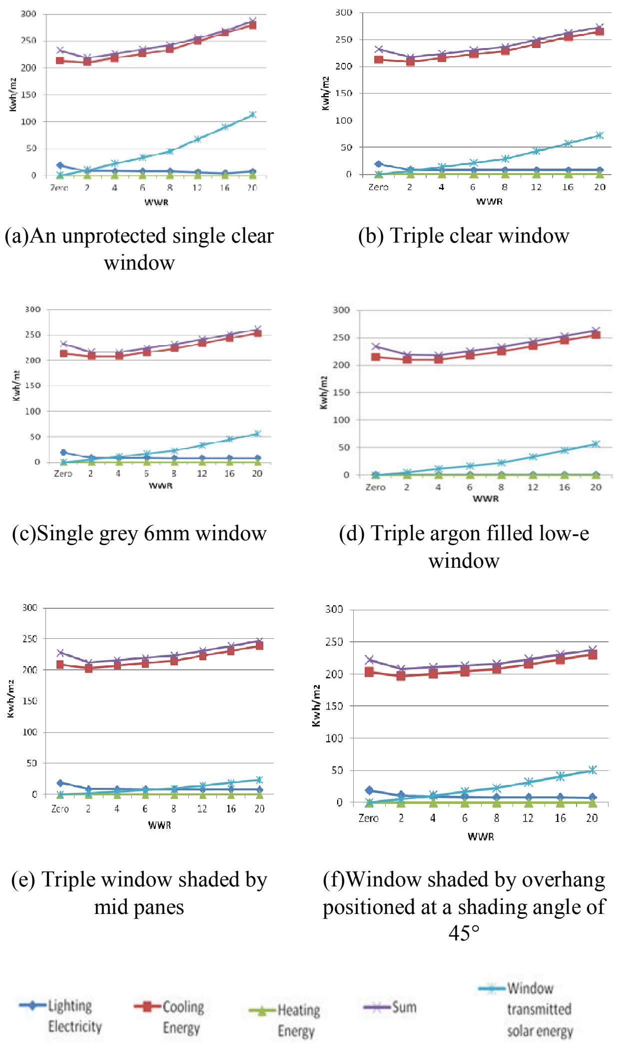
Fig. 6 Annual Energy savings for a North oriented window of 20% WWR with different window treatment strategies

V. Discussion

To explain the behavior of window treatment alternatives, the energy use contributors (Lighting, Cooling, Heating) were analyzed in the South orientation. As expected for desert environments, cooling represented the highest component, followed by lighting electricity then heating loads which were almost negligible. Window transmitted solar energy, which is the amount of beam and diffuse solar radiation entering the ICU through the window was also plotted to help clarify the shading effect in the South orientation.

The transmitted solar energy increases with the increase of window to wall ratio (WWR). For example, in the single clear window, the transmitted solar energy increased significantly with the increase of WWR at high rates. The performance of the cooling energy load is almost parallel to this pattern. On the other hand, the lighting electricity load decreased with the increase of WWR at a low and almost constant rate. This could be attributed to the fact that the daylighting increased resulting in a reduced amount of artificial lighting use.

Fig. 7 illustrates the effectiveness of using overhang positioned at a shading angle of 45° on reducing the energy consumption. This allows the use of larger windows of up to 20% WWR with an energy use equivalent to that of the 8% WWR of the simple single unprotected window. Adding shading to the 8% WWR window didn't significantly affect the energy use, the overhang positive effect is evident in larger windows of 20% WWR. It could be noted that the improvement in the transmitted solar energy as a result of using window treatments lead to the enhancement in the cooling and the total energy use. This is observed in the decrease of the curve slope of the transmitted solar energy for the triple clear window, followed by single grey window, triple low-e argon filled and triple window shaded by mid panes. Then, window with overhang positioned at a shading angle of 45°, where the curve is almost flattened.



(a)An unprotected single clear window

(b) Triple clear window

(c)Single grey 6mm window

(d) Triple argon filled low-e window

(e) Triple window shaded by mid panes

(f)Window shaded by overhang positioned at a shading angle of 45°

Fig. 7 Annual Energy loads for different window configurations-South orientation

It could be noted that using shading devices such as solar screens with a 1.0 depth ratio and large overhangs shade the window most of the time. The change of solar incidence angle provides deeper screens with better chance for shading. Although they prevent solar radiation totally, only a small portion of energy reaches the window. However, glazing treatment by changing its reflectivity or adding layers pass much more solar radiation.

VI. Conclusions

Energy performance for a typical hospital Intensive Care Unit space (ICU) located in Cairo, Egypt was simulated. Several window treatments were tested in the South, West and North orientations. The energy saving potential of using different window treatment strategies was evaluated and the window configuration that achieves the highest savings was identified for each orientation. The use of shading systems were found to be more effective in conserving energy in comparison with glazing of different types in the South and West orientations of Cairo ICUs. The highest energy savings were accomplished by external perforated solar screens, followed by overhangs positioned at a protection angle of 45°.

The energy savings resulting from the use of solar screens reached almost 22% for the West and South orientations in comparison with a non-shaded window. The energy savings were barely significant in the North orientation, where gazing treatment by changing the color and reflectiveness of glass can be more effective due to limited solar exposure in that orientation.

VII. Further Research

This paper reported on the investigation of different energy efficient window treatment strategies in Cairo ICUs. Their applicability in the ICUs of other similar or different environments is under investigation.

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