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Simulation-Based Study for Healing environment in intensive care units: enhancing daylight and access to view, optimizing an ICU room in temperate climate, the case study of Palestine.

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ABSTRACT

The quality of the healthcare in intensive care unit (ICU) is directly influenced by its design. Daylight and access to the outside views are key factors to improve the healing environment for patients and working conditions for healthcare providers. In addition, augmenting the use of natural light not only helps with sustainable solutions, but also reduces energy costs. Beside the geographic location, natural lighting in any space is affected mainly by five parameters: window orientation, window level, window to wall ratio, walls light reflectance and the used shading device. This study aims to optimize these parameters using DesignBuilder software to achieve the optimal daylighting while minimizing the heating and cooling loads without restricting patients' access to view. The results show that the South was the optimum orientation. 2.5 m was the optimum window lintel level height. Furthermore, the shading device's type and depth differed according to window orientation.

1. Introduction

The concept of 'healing environment' becomes a widespread idea in the design of hospitals. Which are complex systems where there are many factors influencing the patient's outcome at the same time affecting the effectiveness and the wellbeing of the healthcare providers. Many studies showed that hospital design and physical environment are closely linked to the stress levels of the health care providers, patients and their families as well as to the staff effectiveness and patient safety. This is particularly essential in critically ill patients who are at high risk of developing a disturbance of mental abilities such as delirium, and more precisely when the indoor environment lacks natural light and the accessibility to outdoor views.

Since the 1990s, there has been a great enhancement of the health care, which is mainly due to the development of practicing medicine that is based on evidence 'evidence-based medicine'. Which started as a call for medical decisions depending on critical thinking and integrated to personal clinical expertise, related scientific research and patient's preferences and satisfaction [1]. Although a lot is known in this filed, it is still unclear how this can be applied on the hospital design and its relation to the health care system. Evidence-based design provide the focus on how designs can be best utilized to help patients recovery while providing safe environment for the staff allowing them perform better [2]. This focus is believed to improve the overall healthcare quality and reducing the costs [3]. Daylight and natural views are of the most important physical aspects that can positively affect patients and staff as it has therapeutic and healing properties [4].

Daylight maximizes the visual performance more than most of artificial lightening does as it has broad spectrum of wavelength delivered in large amounts [5]. It is a cheap source of light, and has a positive impact on patients, especially critical ill patients [6].

The intensive care unit (ICU) is the most complex place in the hospital, where patients with critical illnesses are treated, and most at risk [7]. This makes it a highstress place for patients, medical staff and even for patients' families. Therefore, healthcare designers must consider all factors that enhance the ICU

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environment in terms of reducing stress and improving the efficiency of treatment [2]. Indeed, physical factors such as daylight and access to outdoor views play a positive role in creating this'healing environment' for users [8]. That is why, the appropriate size and characteristics of windows are essential aspects to be considered to insure that patients are not deprived of seeing the outside and enjoying natural light, which decreases their sense of isolation and therefore decreases the incidence of delirium [9]. However, large windows may lead to an undesirable rise in indoor temperature, which may cause a noticeable increase in cooling loads [10]. Therefore, the balance between the daylight and the heating and cooling loads is crucial to have a better function. How to maintain this balance is still unclear taking in consideration that the design is variable according to the geographic and climatic status of hospital location.

Palestine has in general warm climate with better daylight sources in winter and autumn when compared to western country. There are no previous studies in Palestine investigating the effect of the ICU design on lightening achieved by daylight and the access to outdoor environment through windows. Simulation is one of the most important method that used to assess and enhance daylighting. Most previous studies based on assumptions of some parameters to investigate the impact of others; Sherif, Sabry, Elzafarany, Gadelhak, Arafa, and Aly (2015) investigated the appropriate window size and the shading system of an ICU room in different orientation while wall reflectance and window level are constant [11]. Mangkuto, Rohmah and Asri (2016) conducted a simulation study to clarify the impact of window-to-wall ratio (WWR), wall reflectance, and window orientation of simple buildings in the tropical climate on different daylight metrics and the energy consumption for artificial lighting without considering the use of shading device, and while the window level is constant [12]. Sherif, Sabry, Wagdy, Mashaly and Arafa (2016) conducted a study to determine the appropriate shapes of the horizontal blind slats for a hospital room that achieve the best daylighting as well as patient access to outside view when the orientation is assumed toward south, and window to wall ratio, window level and wall reflectance are constant [13]. Englezou and Michael (2020) used a simulation tool to investigate the impact of different window configurations and shading devices of two inpatient rooms on daylight performance in Cyprus when window orientation is assumed toward south [14].

In this research, the main objective is to investigate and optimize the parameters that affect natural light quantity in ICU by following successive steps, so that the result of each step was used as a simulation input for the next one; to consider the relationship of the parameters to each other. This aims at end to set criteria and recom-mendations to be considered in the design of an ICU single room, in Palestine to achieve desirable lighting and access to outside view, while reducing the heating and cooling demands as much as possible.

1.1. Healing environment

Providing 'a healing environment', which is defined as a healthy environment that is physically and psychologically appropriate, should be taken into account in the design of healthcare facilities. A healing environment would enhance patients' outcome and increase staff productivity and performance [8,15].

Applying that requires a comprehensive study of psychological, physical and social aspects of the healthcare building and its occupants. Some studies classified thermal comfort, natural light, indoor air quality, noise control, visual comfort and access to natural views as physical aspects that should be considered in healthcare design process [15–17]. This makes hospital design a complex mission that is not only limited to functional aspect, but also encompasses physiological and social aspects. This task might be more critical when the design targets patients with restricted mobility particularly patients in ICUs. In this case, providing appropriate indoor environment and communication with outdoor nature would be a crucial design priority [6].

Hospitals in general are stressful places for patients and visitors mainly due to fear of death, pain and noises. Therefore, providing better healing environment would help them relieve the stress and would also improve the outcome [18].

The recent studies have shown a strong relationship between daylight and human physical, psychological and mental health; it was found that daylighting has an impact on reducing depression [19], reducing the hospital length of stay [16,18], improving alertness and decreasing the consumption of killer pain drugs among hospitalized patients [5]. Whereas, the lack of exposure to natural daylight has a bad influence on the human health and may cause seasonal affective disorder [20], stress [21], delirium [22] and Vitamin D deficiency which is linked to many serious complications such as bone diseases, cancer, cardiovascular diseases, diabetes [23], autism, multiple sclerosis and schizophrenia [24]. Furthermore, the lack of daylight may affect the circadian rhythms badly, and therefore result in depression, sleep problems and immune deficiencies [25,26]. Furthermore, it was found that light therapy using both daylight and artificial light, has been shown to enhance sleep efficiency and rest/activity rhythm in patients with Alzheimer's disease, and manage as well their behavioral disturbances [27].

Having a natural view has also a positive impact on the patients as it reduces stress and decreases pain by distracting them from focusing on their suffering [15]. Furthermore, patients with nature view were found to have shorter recovery time after surgery and lower doses of pain drugs when compared to patients with wall-view [28]. Visual contact with the outside has also a great influence on reducing the feeling of isolation and strengthening patients' interest to the surrounding environment [29].

1.2. The impact of daylight and access to view on ICU patients and staff

There has been a good evidence on the impact of the ICU environment on patients' outcome and staff satisfaction; Jongerden, *et al.* (2013) found that physical environment such as noise, daylight and color has a significant influence on ICU patients' outcomes and family satisfaction [30]. Furthermore, it was found that the physical environment is one of the top three stressors patients experience in the ICU. This was also evident on the ICU doctors when one-third of them were found to suffer from high stress levels [31].

Daylight is one of the most important physical aspects affecting patients and medical staff in ICU. In addition to the positive effects mentioned earlier of the daylight on patients (i.e: reducing stress and depression, decreasing the request of pain drugs and reducing length of stay), natural lighting has a greater impact on critically ill patients who have a very high risk of delirium [9]. Delirium is defined as "a disturbance of consciousness with inattention, accompanied by a change in cognition or perceptual disturbance that develops over a short period (hours to days) and fluctuates over time" [32]. The prevalence of delirium in ICU patient can be as high as 80% [32,33] and it can be more in elderly patients [34]. It was found that ICU delirium maximizes risk of persistent cognitive impairment after discharge and increases ICU length of stay [32]; as patients with delirium may hospitalized twice as long as patients without [34]. It is responsible for 10% of dementia cases [34] and is highly correlated with poor patients' outcomes [6,35]. Moreover, ICU patients with delirium were found to have higher mortality than others without [33] and more likely to die in hospital [34].Delirium is also significantly correlated with substantial financial and social costs. Recent studies investigated a notable relationship between daylight and the occurrence of delirium. For example, Hashemighouchani, et al. (2020) found that isolation and absence of daylight are major risk factors of ICU delirium [36]. Vyveganathan, et al. (2019) found that visible day-light results in a reduction of incidence of delirium [22]. Chong, *et al.* (2013) have shown an evidence for the clinical benefits of bright light therapy of delirium and its impact on reducing the duration of delirium [35]. Simon (2018) found that delirium is more likely (2–3 times) to occur and the incidence of delusions and hallucinations is more than twice in a windowless unit compared to a unit with translucent window [32].

The positive effect of natural light is not limited to patients, but extends to medical staff as well. It was found that increasing daylight and window views have a positive impact on ICU staff absenteeism and reduces medical errors [31]. Physical aspects of ICU design (i.e: daylight and natural views) have significant impact on patients and staff outcomes. Access to daylight can significantly improve nurses' satisfaction and has a good impact on reducing job burnout [37]. A survey study was conducted in Hamad General Hospital in Doha, Qatar, emphasizes this positive effect of daylight on staff satisfaction, where 79% of the medical staff ensure their belief in the importance of daylight in patient's room to help them doing their job easily, including treating, diagnosing (i.e.: noticing the changing in patient's skin color) and monitoring patients [18]. The architectural design of healthcare rooms and ICU should be an evidence-based design that consider all functional and physical aspects to meet patients, staff, and visitors physical, psychological and mental requirements.

1.3. Parameters affecting daylight and access to view in ICU rooms

Designing a healthcare building should ensure appropriate daylight, as the average daylight factor in the ICU rooms should not be less than 3% [38,39], while at the same time minimizes the heating and cooling loads. In order to ensure the optimum daylight in a healthcare room, essential parameters should be taken into account:

1. The orientation of windows: the selection of the orientation is the first decision and the most important priority in the healthcare room design. It would affect other parameters such as the shape and the size of the window opening and the dimensions and placement of shading devices [40,41]. Access to a good view (i.e. natural view) is also a fundamental issue that should be considered in orientation selection. It was found that access to good view has therapeutic influences on patients and has a positive effect on their psychological, physical and mental statuses [42].
2. Window design: the design of windows has a direct impact on the amount of transmitted daylight and the thermal comfort for users [43], it would subsequently affect lighting, heating and cooling loads on one hand, and patients' satisfaction and health situation on the other [44]. Window designing determines the following parameters: window size[43,44]., window level height and the properties of glazing system (i.e. roughness, number of layers and color) that would affect the transmittance of glass [41,44].
3. Shading device: shading device plays a significant role in preventing uncomfortable glare, providing better light distribution and reducing energy demand for buildings [45].
4. Interior materials and painting colors: these factors have a significant influence on the reflectance value of interior surfaces (i.e. walls, ceiling, floor, partitions and furniture), which in turn would affect the internally reflected component of the daylight [46]. Light reflectance value is the percentage of visible light reflected by illuminated surface. It ranges from 0 to 1, as the value 0 represents a material that absorbs 100% of light while the value 1 represents a material that reflects 100%, which are theoretical values that cannot be reached in practice [47].
5. Beds layout: beds should be arranged near windows to achieve an access to the outdoor views [42].

1.4. Daylight, thermal comfort and energy consumption

As windows' design, position and orientation affect daylight accessibility, they also have considerable influences on indoor environment in terms of air temperature, which in turn affects the energy needed for heating and cooling. Despite large windows allow the access of more daylight; they may result in excessive heat gain that would lead to a sequential impact on users' thermal comfort as well as heating and cooling loads [44,48]. Since windows and glazed areas are the lowest performing parts of the building envelope in controlling heat gain and heat loss [49], it is important to maintain a balance between daylight availability, thermal comfort and energy consumption in the design process [43,48]. Particularly, because building's heating and cooling operations are responsible for the largest share of the energy consumption of buildings, which in turn are responsible for producing excessive emissions of CO2 [50]. Jiang, *et al.* (2012) have shown an evidence for that in hospitals, as the largest portion of the consumed energy goes for heating and cooling with a percentage of 48,9% [51]. Shading devices may be effective solutions for blocking solar radiation to reduce solar gain and overheating as well as preventing the access of direct daylight that may cause visual discomfort such as glare, while allowing the entry of reflected daylight to maintain the desirable indoor environment in terms of illuminance and air temperature [45,49].

2. Methodology

The study adopts a sequence of iterative computational simulations using a model of a 25 m2 square-shaped ICU room to investigate the impact of different parameters on daylighting and to determine the conditions that achieve the optimal daylighting and the minimal energy loads for heating and cooling as well. The model represents a single/isolated ICU room. Its dimensions were based on the standards of the ICU design that recommend an area of 25 m^2 for single rooms and isolation rooms [52]. The bed's layout was arranged in a way that achieves access to view as shown in Fig. 1. The studied room, which has a single window on its external wall, was modeled and simulated using DesignBuilder software. Table 1 shows the simulation input geometry parameters.

A Climate-Based Daylight Modelling approach (CBDM) was applied in this assessment process. CBDM uses Daylight Autonomy as its performance metric [53]. The optimization process examined

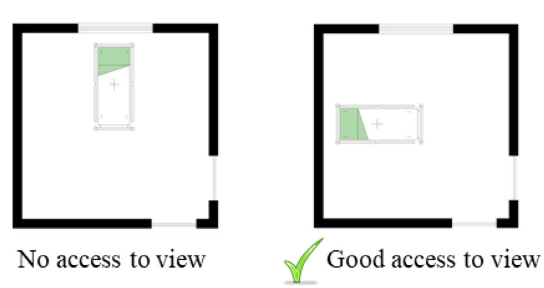

Fig. 1. Classification of beds' layout cases of the studied room according to access to view provision. The selected case is on the right.

Table 1
Simulation input geometry.

Parameters		Value
ICU room properties	length (m)	5
	width (m)	5
	floor to ceiling height (m)	3
	façade wall area (m^2)	15
	floor area (m^2)	25
	façade wall thickness (m)	0.29
	U-factor (W/m^2K)	0.35
	U-value of the slab (W/m^2K)	0.25
window properties	type	double clear glazing, low-E coating
	U-factor (W/m^2K)	2.429
	Visible transmittance (%)	0.745
	SHGC	0.569
systems	natural ventilation	inactive
	mechanical ventilation	active
	HVAC system	active
	heating system	natural Gas
	heating set point (℃)	22
	cooling system	electricity from the grid
	cooling set point (℃)	24
	air infiltration (ac/h)	0.7

sequentially three parameters (i.e. the window's lintel level height, WWR, and shading device's depth) in accordance with orientation. The optimum result obtained from the first parameter was used as a simulation input for the second and those from the first and second were used for the third; in order to consider the impact of each parameter on the others and pinpoint the optimum design scenario. The light reflectance value was investigated only in function to the optimum orientation. Fig. 2 shows the simulation based methodology used in this study.

Depending on Jerusalem meteorological datasets, the simulation process focussed on determining the average daylight factor (DF), Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE) and the annual heating and cooling loads of the room in parametric conditions.

The optimization proccess depends on finding conditions that achieve the lowest annual thermal loads (heating and cooling) as a first priority, then the best natural lighting indices (i.e. DF%≥ 3%, sDA greater than 75%, minimum $ASE_{(1000,\ 250h)}$). Thermal loads are estimated based on the following equation (Eq. (1)):

$TL_{(cooling/Heating)} = Q_{cond} + Q_{inf/vent} + Q_{SG} + Q_{IG}$ (1).

Where,

TL = thermal load (W) for heating and/or cooling.

Q_{cond} = heat gain/loss by conduction through building envelope.

$Q_{inf/vent}$ = heat gain/loss by infilitration and ventilation.

Q_{SG} = solar radiation gain through transparant surfaces in building envelope.

Q_{IG} = internal gains generated inside buildings by occupants, appliances and lights.

2.1. Climate-Based daylight modeling (CBDM)

CBDM is a daylight prediction model that defines various luminous quantities using sun and sky conditions derived from meteorological datasets.

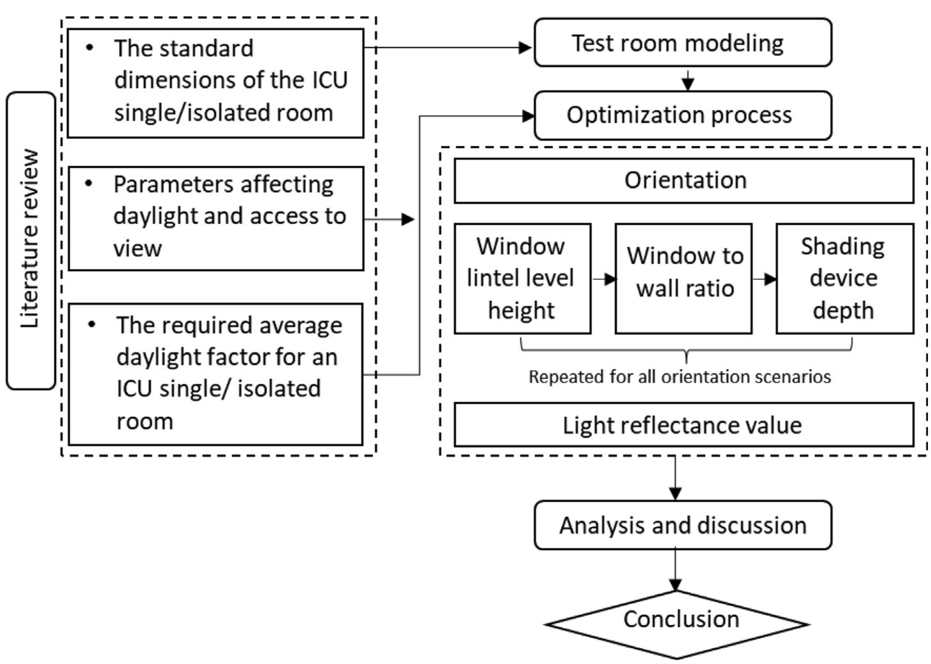

Fig. 2. The research methodology flowchart.

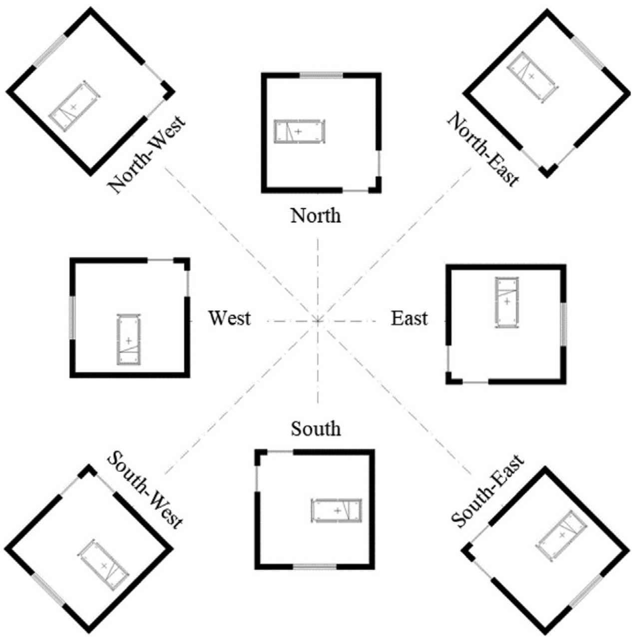

Fig. 3. Simulation cases of the studied room with orientation change.

- Daylight factor (DF) is defined as the ratio of the indoor daylight illuminance (E_i) at a point within the enclosure to the outdoor illuminance (E_o) at that point under the same unobstructed overcast sky, expressed in percentage (Eq. (2)).

$$DF = (E_i/E_o)*100\% \quad (2).$$

- Spatial Daylight Autonomy (sDA) has been developed to test the sufficiency of daylight illuminance, using the percentage of the floor area that meets certain illuminance level for a specified amount of annual hours. For example, sDA(300, 50%) represents the percentage of space, in which the illuminance level is greater than 300 lx for 50% of the occupied hours [54]. The IES guideline suggests two different quality levels for Spatial Daylight Autonomy, the first being 'preferred daylight sufficiency', in case 75% or more of the analysis area meet the above mentioned criteria. The second being the 'nominally accepted daylight sufficiency', if 55% or more of the analysis area meet the above criteria.
- Annual Sunlight Exposure (ASE) is a metric describing potential for excessive sunlight exposure by calculating the percent of the space that exceeds a certain illuminance level more than a specified number of annual hours [54]. For example, $ASE_{(1000,\ 250h)}$ represents the percentage of space, where the illuminance level is more than 1000 lx for 250 annual occupied hours.

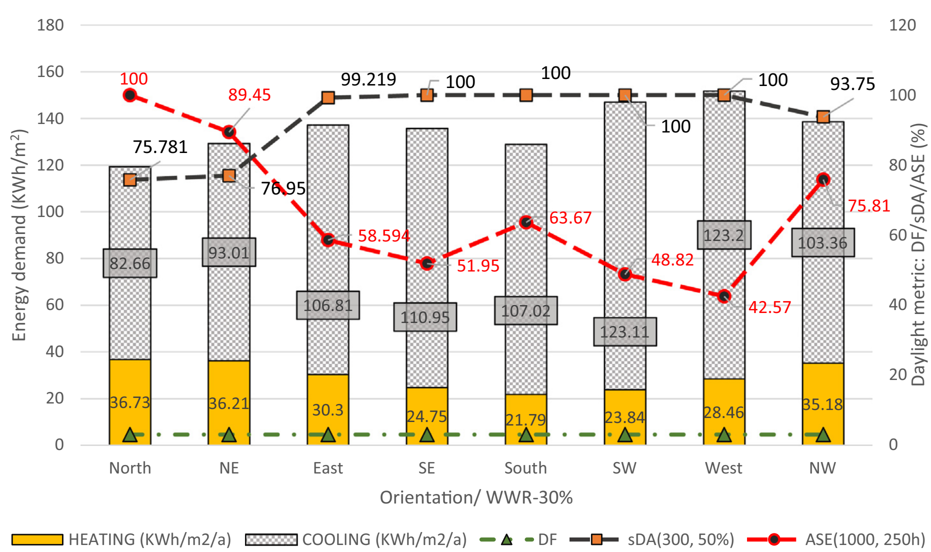

Fig. 4. Simulation results of average daylight factor and the annual heating and cooling loads of the studied room according to the orientation change with WWR 30%.

ICU orientation	no window	S	SE	E	N	NW	W
daylight satisfaction	1	4	3	3	3	1	2
#i nvestigated rooms	3	4	3	1	2	1	1

scale	1	2	3	4	5
	strong dissatisfaction				strong satisfaction

Fig. 5. Users' satisfaction about daylight quality in different ICU rooms in Palestinian hospitals.

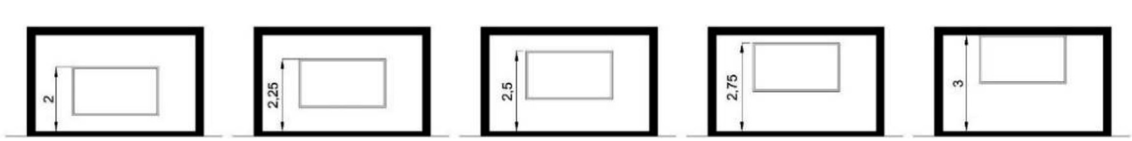

Fig. 6. Simulation cases of the studied room with the change of lintel level height.

3. Analysis and discussion

3.1. Orientation

Eight simulation trials of the ICU room were tested with an orientation change of 45° each time, as presented in Fig. 3. While other parameters were kept constant; window to wall ratio was 30%, window height was 1.5 m, window lentil level height was 2,3m, light reflectance value of the interior surfaces was 0.5 and no shading device was used.

Simulation results, presented in Fig. 4, show that all orientations have DF higher than minimum threshould of 3% [38,39]. In addition, south-east and south are the best orientations in terms of the provision of the best $sDA_{(300,\ 50\%)}$ and $ASE_{(1000,\ 250h)}$ associated with the minimum heating and cooling energy demand. West and south-west orientations are associated with the highest cooling load [62], which might probably be due to the low altitude sun angle in this direction [55,56], which in turn results in increasing heat gain. Whereas, the minimum total energy demand values were recorded in south and north orientations as shown in Fig. 4. Therefore, south orientation is considered the optimal orientation in terms of daylighting and energy demand in Palestinian climate, which scored a daylight factor of 3.05%. This result is consistent with those obtained in several previous studies [58,63,68] intereseted by residential and non residential buildings located in Mediterranean climate areas as like palestine. In case of ICU multibed ward, south-north orientation is probably the best orientation of the longer and glazed sides of the ward that would

Table 2
Simulation results of average daylight factor and the annual heating and cooling loads of the studied room at all orientation scenarios according to the change of window lintel level height.*

Orientation	lintel level height (m)	DF	$sDA_{(300,\ 50\%)}$	$ASE_{(1000,\ 250h)}$	Heating (kWh/m^2)	Cooling (kWh/m^2)
North	2	2.48	58.594	100	36.7	82.7
	2.25	3.05	75.781	100	32.86	101.14
	2.5	3.35	93.75	100	36.74	82.65
	2.75	3.27	98.047	100	36.76	82.63
	3	3.13	98.828	100	36.73	82.55
NE	2	2.48	58.984	90.625	36.19	93.04
	2.25	3.05	76.95	89.45	36.21	93.01
	2.5	3.35	94.922	86.328	36.22	92.99
	2.75	3.27	99.609	84.766	36.24	92.96
	3	3.13	99.219	87.5	36.25	92.85
East	2	2.48	75.391	66.797	30.27	106.86
	2.25	3.05	99.219	58.594	30.3	106.81
	2.5	3.35	100	53.516	30.31	106.78
	2.75	3.27	100	48.437	30.33	106.74
	3	3.13	100	45.312	30.36	106.55
SE	2	2.48	98.828	63.281	24.75	111.01
	2.25	3.05	100	51.95	24.75	110.95
	2.5	3.35	100	42.578	24.8	110.9
	2.75	3.27	100	33.594	24.82	110.86
	3	3.13	100	29.297	24.87	110.63
South	2	2.48	100	70.313	21.76	107.1
	2.25	3.05	100	63.67	21.79	107.02
	2.5	3.35	100	50.078	21.83	106.95
	2.75	3.27	100	50.391	21.85	106.9
	3	3.13	100	51.953	21.9	106.66
SW	2	2.48	100	59.766	23.8	123.21
	2.25	3.05	100	48.82	23.84	123.11
	2.5	3.35	100	38.281	23.87	123.01
	2.75	3.27	100	31.641	23.89	122.93
	3	3.13	100	31.641	23.94	122.62
West	2	2.48	24.707	52.734	28.43	123.3
	2.25	3.05	100	42.57	28.46	123.2
	2.5	3.35	100	33.984	28.49	123.11
	2.75	3.27	100	30.859	28.51	123.03
	3	3.13	100	29.297	28.55	122.73
NW	2	2.48	68.359	78.516	35.15	103.42
	2.25	3.05	93.75	75.81	35.18	103.36
	2.5	3.35	98.828	75.391	35.2	103.3
	2.75	3.27	99.219	75.391	35.22	103.25
	3	3.13	99.609	80.078	35.23	103.06

* Window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 30%, 0.5 and 1,5 m respectively and no shading device was used for all orientations.

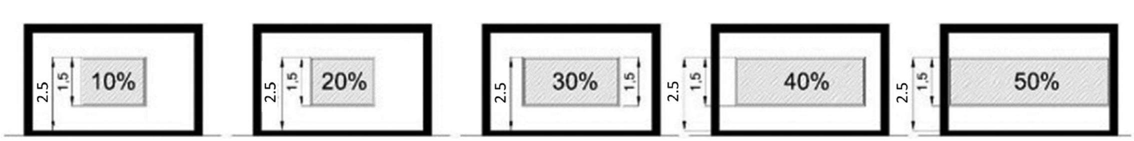

Fig. 7. Simulation cases of the studied room with the change of window wall ratio.

Table 3
Simulation results of average daylight factor and the annual heating and cooling loads of the studied room at all orientation scenarios according to the change of window to wall ratio.

	WWR	DF %	$sDA_{(300,\ 50\%)}$	$ASE_{(1000,\ 250h)}$	Heating ($kWh/m^2/a$)	Cooling ($kWh/m^2/a$)
North	10%	0.957	12.1	100	34.47	73.46
	20%	2.186	49.609	100	35.37	78.11
	30%	3.35	93.75	100	36.74	82.65
	40%	4.66	100	100	37.8	87.2
	50%	5.3	100	100	38.84	91.64
NE	10%	0.957	14.1	97.266	34.77	77.3
	20%	2.186	53.516	90.625	35.49	85.21
	30%	3.35	94.922	86.328	36.22	92.99
	40%	4.66	100	82.8	37	100.83
	50%	5.3	100	81.25	37.8	108.46
East	10%	0.957	17.969	84.375	32.52	80.74
	20%	2.186	64.84	65.63	31.29	93.79
	30%	3.35	100	53.516	30.31	106.78
	40%	4.66	100	39.844	29.55	120.1
	50%	5.3	100	31.25	28.96	133.1
SE	10%	0.957	22.26	19.23	30.86	82.4
	20%	2.186	81.25	58.59	27.95	96.65
	30%	3.35	100	42.578	24.8	110.9
	40%	4.66	100	25.39	24	126.65
	50%	5.3	100	18.75	22.9	142.1
South	10%	0.957	26.56	80.86	28.84	79.68
	20%	2.186	89.06	61.33	24.7	92.7
	30%	3.35	100	50.078	21.83	106.95
	40%	4.66	100	52.73	19.79	122.6
	50%	5.3	100	50.78	18.5	138.85
SW	10%	0.957	29.297	76.562	29.85	85.46
	20%	2.186	93.359	57.031	26.32	103.75
	30%	3.35	100	38.281	23.87	123.01
	40%	4.66	100	25	22.19	143.53
	50%	5.3	100	19.531	21.04	164.26
West	10%	0.957	21.875	19.238	31.68	85.56
	20%	2.186	76.953	56.641	29.83	107.24
	30%	3.35	100	33.984	28.49	123.11
	40%	4.66	100	17.578	27.53	142.65
	50%	5.3	100	7.03	26.9	181.87
NW	10%	0.957	16	94.53	34.41	80.49
	20%	2.186	58.59	83.2	34.77	92
	30%	3.35	98.828	75.391	35.2	103.3
	40%	4.66	100	66.797	35.72	114.68
	50%	5.3	100	60.156	36.29	125.75

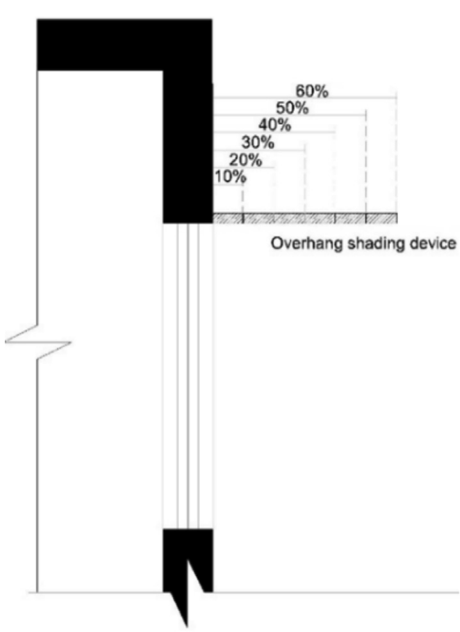

Fig. 8. Simulation cases of the studied room with the change of horizontal shading device depth.

provide acceptable daylighting without increasing heat gains or causing glare.

Moreover, in this study, which is part of field research about the healing environment in the intensive care units of Palestinian hospitals, the ICU users' comfort satisfaction was investigated via a field survey. Medical staff at six hospitals located in different Palestinian cities were interviewed to evaluate the visual and thermal comfort inside their ICU rooms. Most of the interviewees showed dissatisfaction in regards to daylight quality in their investigated ICU rooms (15 rooms) regardless their orientation. However, the south-facing rooms were most satisfactory, see Fig. 5. In addition, this result is similar to what was found by Haj Hussein [69] when he investigated quantitatively and qualitatively the thermal and luminous comfort in Palestinian residential buildings in two different climatic zones. He noticed that the south-facing rooms were more comfortable.

3.2. Window's lintel level height

The window's lentil level height was optimized by conducting simulation trials of different heights, with a height change of 25 cm for each trial (the typical height of cladding stone used in Palestine) as shown in Fig. 6. Other parameters were kept constant; window to wall ratio was 30%, window height was 1.5 m, light reflectance value of the interior surfaces was 0.5 and no shading device was used.

Simulation results show that there is a significant impact of the window level on the average daylight factor, sDA and ASE of the space, unlike the energy demand, where no noticeable variation resulted from the change of window's lintel level recorded, see Table 2.

The height of 2.5 scored the highest average daylight factor, preferred sDA and ASE for all orientation scenarios, as shown in Table 2. Implementing the optimum orientation and window level height together raised the daylight factor from 3.05% to 3.35%.

3.3. Window wall ratio (WWR)

Window to wall ratio was tested for the studied room such that five simulation trials were conducted with a change of 10% of window wall ratio for each one, taking (10%, 20%, 30%, 40% and 50%) as simulation cases, as shown in Fig. 7 below. Window height was constant, while window width varied as per the required ratio. Other parameters were constant; window height was 1,5m, light reflectance value of the interior surfaces was 0.5, no shading device was used and window lintel level height was 2,5m for all orientations.

Table 4
The proposed shading device types for different orientation scenarios.

	North	NE	East	SE	South	SW	West	NW
Overhang shading device				✓	✓	✓		
Vertical shading device		✓	✓	✓		✓	✓	✓

Table 5
Simulation results of average daylight factor and the annual heating and cooling loads of the studied room according to the change of overhang shading device depth of the south oriented window *.

	Horizontal shading device depth (as a percentage of window height)	DF %	$sDA_{(300,\ 50\%)}$	$ASE_{(1000,\ 250h)}$	Heating (kWh/m^2)	Cooling (kWh/m^2)
South	10%	3.11	100	60.547	22.59	102.05
	20%	2.836	100	60.547	23.73	96.91
	30%	2.605	100	65.652	24.91	92.91
	40%	2.406	100	66.406	26.1	89.92
	50%	2.235	100	70.313	27.27	87.56
	60%	2.076	100	70.313	28.31	85.67

* Light reflectance value of inner surfaces of walls, window height, and window to wall ratio were assumed 0.5, 1,5m and 30% respectively and no shading device was used. The value of the window lintel level height was taken from the results in Table 3.

Table 6
Simulation results of average daylight factor and the annual heating and cooling loads of the studied room at all North-East, East, West and North-West orientations according to the change of the vertical shading device's depth.*.

Window orientation	Vertical shading device depth	DF %	$sDA_{(300,\ 50\%)}$	$ASE_{(1000,\ 250h)}$	Heating (kWh/m^2)	Cooling (kWh/m^2)
North-East	10%	3.25	94.14	87.5	36.58	91.18
	20%	3.16	88.67	87.89	36.85	89.81
	30%	3.08	89.84	89.06	37.03	88.86
	40%	3.04	88.28	89.45	37.16	88.2
	50%	3.02	84.37	89.84	37.27	87.68
	60%	3	85.55	89.84	37.35	87.28
East	10%	3.25	100	53.9	31.04	105.33
	20%	3.16	99.6	54.68	31.63	104.17
	30%	3.08	99.6	55.08	32.04	103.34
	40%	3.04	98.83	55.47	32.33	102.74
	50%	3.02	98.83	55.86	32.56	102.26
	60%	3	98.44	56.25	32.74	101.88
west	10%	3.25	100	37.76	29.12	121.31
	20%	3.16	100	36.33	29.7	119.63
	30%	3.08	100	37.9	30.18	118.34
	40%	3.04	100	38.67	30.55	117.34
	50%	3.02	100	39.45	30.87	116.5
	60%	3	100	40.23	31.14	115.79
North-West	10%	3.25	98.44	78.9	35.78	100.82
	20%	3.16	97.27	82	36.27	98.6
	30%	3.08	96.88	83.2	36.6	96.9
	40%	3.04	97.26	84.76	36.9	95.66
	50%	3.02	96.87	85.5	37	94.6
	60%	3	94.5	86.7	37.2	93.78

* Light reflectance value of inner surfaces of walls, window height, and window to wall ratio were assumed 0.5, 1,5m and 30% respectively and no shading device was used. The value of the window lintel level height was taken from the results in Table 3.

Simulation results show that the more window to wall ratio, the higher daylight factor and the higher energy loads. Ratio values below 30% leads to unacceptable daylight factor (less than 3%), while values more than 30% resulted in more energy loads.

Window to wall ratio of 30% achieved the optimum situation for all orientation scenarios that provides the minimum heating and cooling load when the daylight factor is more than the minimum acceptable value of 3%. This can be noticed in Table 3.

This result is consistent with that obtained in Goia *et al.* and Sayadi *et al.* studies who searched for the optimal WWR in office buildings in different European climates and their implications on total energy saving [66,67].

3.4. Shading device

Overhang shading device was proposed to south orientation, since it is the appropriate solution for south oriented facades in the Mediterranean climate [59]. While side fins were used as vertical shading devices for the north-east, east, west and north-west elevations [60]. Hence, simulation trials were done to investigate the influence of the shading device's depth on the average daylight factor as well as the heating and cooling loads. The investigations starting with a depth of 10% to 60% of window width for vertical shading device and window height for horizontal shading device with an increment of 10% for each trial as shown in Fig. 8.

Combined shading device (both overhang and vertical) was proposed for south-east and south-west oriented windows. Two different options were proposed: at the first, the vertical device was used and investigated to identify the optimum depth, which used as a simulation input for optimizing the horizontal device, which was tested five times with different depths ranging from 10% to 50% of window height, in order to determine the optimum values of both shading devices together. While at the second option, the horizontal shading device's depth was tested first, then the result of the optimum depth was used as an input in the optimization process of the vertical one's depth. On the other hand, no

Table 7
Simulation results of average daylight factor and the annual heating and cooling loads of the studied room at south-east and south-west orientations according to the change of combined shading devices' depth.[1,2.]

Orientation	Vertical shading depth	Horizontal shading depth	DF %	sDA(300, 50%)	ASE(1000, 250 h)	Heating (kWh/m^2)	Cooling (kWh/m^2)
South-East	10%	0	3.25	100	42.6	25.93	108.6
	20%		3.16	100	43.35	25.85	106.7
	30%		3.1	100	43.75	26.17	105.36
	40%		3.05	100	44.5	26.4	104.48
	50%		3.01	100	44.5	26.55	103.84
	60%		2.97	100	44.5	26.7	103.34
	30%	10%	2.87	100	45.3	26.89	101.28
		20%	2.55	100	50.8	27.93	96.72
		30%	2.3	100	52.3	28.98	92.72
		40%	2.08	99.6	58.6	30.02	89.37
		50%	1.88	99.2	59.76	31.02	86.54
		60%	1.73	98	65.2	31.96	84.3
	0	10%	3.1	100	44.1	25.5	106.84
		20%	2.85	100	48.8	26.5	102.03
		30%	2.6	100	50.39	27.5	97.77
		40%	2.4	100	55.47	28.5	94.3
		50%	2.22	100	56.64	29.4	91.43
		60%	2.07	100	61.7	30.33	89.11
	20%	10%	2.94	100	44.9	26.5	102.6
		20%	2.64	100	50	27.59	97.98
		30%	2.36	99.6	51.5	28.65	93.85
		40%	2.1	99.6	57.4	29.68	90.45
		50%	1.96	99.2	58.6	30.65	87.67
		60%	1.8	98.8	64.4	31.55	85.46
South-West	10%	0	3.25	100	40.23	24.47	119.45
	20%		3.16	100	41.79	24.98	116.44
	30%		3.1	100	42.99	25.35	114.18
	40%		3.05	100	43.6	25.63	112.5
	50%		3.01	100	43.35	25.86	111.3
	60%		2.97	100	43.36	26.05	110.4
	50%	10%	2.8	100	51.95	26.13	101.2
		20%	2.5	100	55	27.3	95.77
		30%	2.26	100	60.9	28.39	91.3
		40%	2.04	100	63.67	29.47	87.7
		50%	1.86	100	67.96	30.55	84.83
		60%	1.65	99.6	70.3	31.55	82.74
	0	10%	3.1	100	47.65	23.37	112
		20%	2.85	100	50.4	24.35	106.39
		30%	2.6	100	54.7	25.35	101.47
		40%	2.4	100	56.6	26.33	97.5
		50%	2.22	100	59.4	27.28	94.95
		60%	2.07	100	60.5	28.2	92
	20%	10%	2.94	100	50.39	24.85	105.38
		20%	2.64	100	53.5	25.9	99.9
		30%	2.36	100	58.6	27	95.18
		40%	2.1	100	60.9	28.05	91.3
		50%	1.96	100	60.9	29.06	90.24
		60%	1.8	100	66	30	86.2

[1] Light reflectance value of inner surfaces of walls and window height were assumed 0.5 and 1,5m respectively and no shading device was used. The value of the window's lintel level height was taken from the results in Table 3.

[2] The depth of the vertical shading device is as a percentage of window width, while the depth of the horizontal is as a percentage of window height.

shading devices were proposed to north elevation, since sun penetration does not occur at north windows (in the northern hemisphere) except in early morning and late evening in very low angles in summer and no significant heat gains result. Therefore, no shading device is required [57]. Table 4 shows the types of shading devices that are proposed in different orientation scenarios. The selection of side fins as vertical shading devices and overhangs as horizontal shading devices is based on the fact that they do not obstruct the access to the outside view compared with other shading devices' types such as multiple vertical fins and egg-crate [6,61].

The results of the depths of the horizontal shading device, the vertical shading devices and the two options of the combined shading device are shown in Tables 5, 6, 7 respectively. It was found that the optimum depth of the horizontal shading device for south oriented windows is 30% of window height, while the optimum one for the vertical shading devices for north-east and north-west orientations are 20% and 60% respectively. However, side fins were found to be ineffective in east and west orientations; this probably is due to the loss of sun penetration potentials in winter, which in turn would increase the heating loads in cold days. Moreover, the use of side-fin shading device may not be significant in east orientation compared to multiple vertical fins or egg-crate [57]. Vegetative Shading can be used as an alternative solution for window shading, if the ICU is located in low level floors [57]. Treated glass can be used in these orientations as well; reflective glass, glass treated with nanotechnology, tinted glass, multipane glazing, gasfilled cavities and vacuum-glazing are examples for it [62–64]. The combination between the two shading system on the south-east and south-west shows ineffectivity in terms of daylighting and energy demands. However, the most suitable achieved values (natural lighting and energy demands) were recorded when using horizontal shading depth of 20% of window height and vertical fins of 20% of window width respectively for south-east orientation, and 50% and 10% respectively for south-west orientation.

Based on the previouse analysis, the optimum values of window lintel level height, window to wall ratio and shading device depth that related to north, north-east, east, south-east, south, south-west, west and north-west orientation scenarios are in Fig. 9.

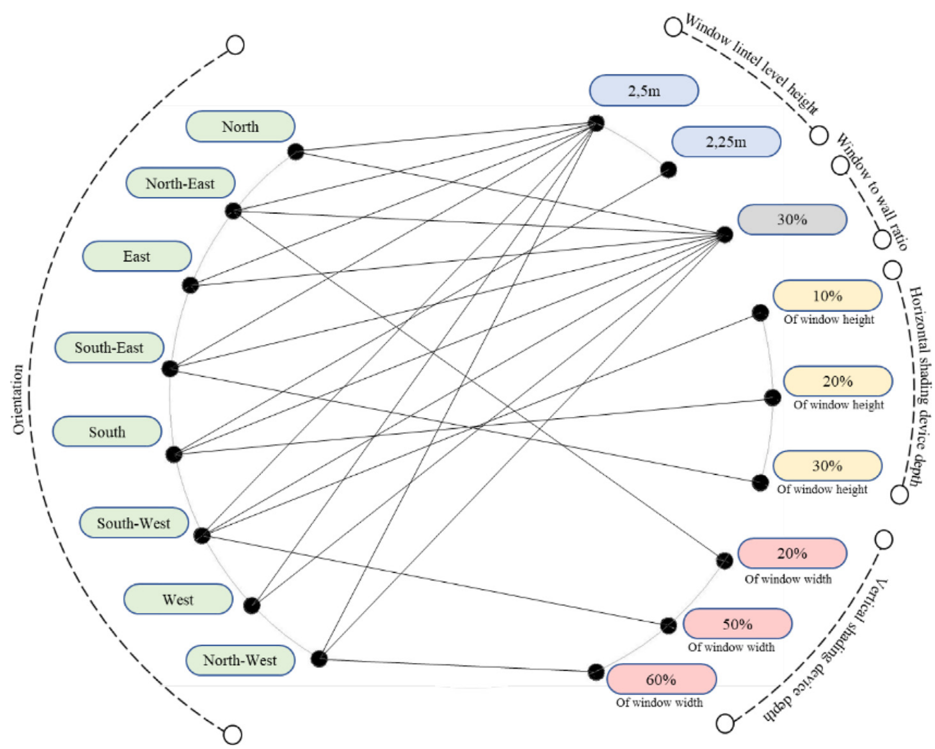

Fig. 9. The optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for the ICU single/isolated room.

Table 8
Simulation results of average daylight factor, sDA, ASEand the annual heating and cooling loads of the studied room according to the change of light reflectance value.

	Light reflectance value	DF %	$sDA_{(300,\ 50\%)}$	$ASE_{(1000,\ 250h)}$	Heating (KWh/m^2)	Cooling (KWh/m^2)
South	10%	2.91	75.39	55.08	21.83	106.95
	20%	2.99	82.4	55.07	21.83	106.95
	30%	3.09	96.09	55.08	21.83	106.95
	40%	3.2	99.6	55.08	21.83	106.95
	50%	3.35	100	55.08	21.83	106.95
	60%	3.47	100	55.08	21.83	106.95
	70%	3.62	100	55.08	21.83	106.95
	80%	3.78	100	55.08	21.83	106.95
	90%	4	100	55.08	21.83	106.95

3.5. Walls' inner surfaces material and color

The relationships between the light reflectance value of the inner surfaces of the walls and the daylight factor, heating and cooling loads and the uniformity ratio were investigated by conducting simulation trials with a variation of 0,1 of light reflectance value, without changing the thermal properties. Input range of the light reflectance value was from 0,1 as a minimum value to 0,9 as a maximum value, while window height, window to wall ratio and window lintel level height were assumed 1,5m, 30% and 2,5m respectively, window orientation was assumed toward south and no shading device was used.

Simulation results show a significant relationship between light reflectance value and the average daylight factor of the room as well as the uniformity ratio; the higher light reflectance value, the higher average daylight factor. However, heating and cooling loads remained constant while the variation of light reflectance value as shown in Table 8.

A high reflectance value can be achieved through using smooth and light color paints of walls, for example, the light reflectance value of the white paint ranges from 0.75 to 0.85. However, the most common paint color of the walls of hospital rooms is light green, which has a reflectance value of 0.45 to 0.55 [65].

4. Conclusion

This study identified the conditions of the ICU single room that can enhance the average daylight factor and reduce the heating and cooling loads, with keeping patient ability of accessing the outside view. Using CBDM appraoch to determine the best optimization results for the different scenarios was indisponsable as in many cases the defirances in DF% and energy loads results were unnoticiable.

- Optimization results show a significant relationship between the studied parameters and natural lighting indices (i.e. DF, sDA, ASE) as well as the energy laods for heating and cooling, while light reflectance value has no significant impact on the heating and cooling loads.
- The optimal natural lighting indices as well as the minimal energy loads were recorded at south orientation.
- The results of the optimum values of window lintel level height, window to wall ratio and light reflectance value of the orientation scenarios (north, north-east, east, south-east, south, south-west, west and north west) were the same and equal 2,5m, 30% and 0,9 respectively. However, they differ in terms of the shading device type and depth.
- A high light reflectance value can be achieved by using white paint instead of light green in the ICU room; this would raise the daylight factor and enhance light uniformity.The proposed shading device has no significant impact on the energy load of east and west orientations, while other types of shading may negatively affect patient access to view. Therefore, treated glass such as reflective glass, glass treated with nanotechnology, tinted glass, multi-pane glazing, gas-filled cavities and vacuum-glazing are recommended in these orientations. Furthermore, if the ICU located in low-level floors, vegetative shading is recommended as well. In addition to the use of the appropriate values of the studied parameters, some strategies can be used to further enhance daylighting without negatively affecting heating and cooling loads. For example, window to wall ratio can be raised when using effective shading devices to maintain a balance between the daylight factor and the energy load.

The resulted optimum values of window orientation, window's lintel level height, reflectance value and the used shading devices' depth can be followed when designing an ICU in Palestine. On one hand, this would enhance the healing environment for patients, hence reduce the incidence of delirium and other health consequences resulted from the lack of daylight and access to view and improve the productivity of health providers and reduce medical errors on the other hand.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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