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Measuring Optimal Window-to-Wall Ratio in Hospitals Located in Mashhad City to Increase the Energy Efficiency of the Building*

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ABSTRACT

Many studies have shown that increased access to daylight through larger windows would improve the interior quality of hospital spaces; in terms of higher energy efficiency of the building, heat transmission through glasses is added when the size of windows becomes larger, which leads to less energy function of the building and more need for cooling load in summer. The smaller size of windows not only increases energy consumption in another way but also reduces the environmental quality of the hospital. In a climatic condition like Mashhad with a considerable temperature difference between interior and exterior spaces, windows' design is highly significant for increasing the energy efficiency of the building. This study aims to find those physical features of hospitals' windows in Mashhad that can create thermal comfort and increase energy efficiency in the building through optimal solar energy absorption. For this purpose, the conventional construction techniques for the design of hospitals, the methods resulting from the instructions of the 19th Topic of National Construction Regulations of Iran, and the proposed methods of this study for insulation increase were compared. The study is conducted using algorithmic simulation of building conditions within energy and light plugins (honeybee and ladybug) through Grasshopper software and data are described and analyzed through comparative method. As a result, the spaces shaped based on the instructions of Topic 19 provide more energy saving than the existing building; moreover, the methods proposed by this study can highly reduce energy consumption. The role of some considerations such as insulation is determining but limited in decreasing energy loss. Although the windows with 32-40% would bring useful light in all modes, it is necessary to consider the lower limit of this range to increase the energy efficiency of the building. The results of this study apply to the design of hospitals located in similar climates and this technique can be used in design of the spaces with similar time functions.

Keywords: Energy Efficiency of Building, Optimal Window-to-Wall Ratio, Hospital, Mashhad.

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1. INTRODUCTION

Windows are the weakest part of the building in terms of energy efficiency and function. They are responsible for the highest direct solar heat gain, thermal bridges, and heat transmission in buildings. The heat loss is estimated at around 10-51% depending on the external conditions and the window size (Alwetaishi and Benjeddou 2021). Hence, wide windows are mainly avoided in the design of hospitals because such windows reduce the daylight entering the space (Cesari et al. 2020). On the other hand, increased access to daylight in hospital rooms would dramatically decrease the healthcare costs of the hospital leading to positive effects on the economic stability of hospitals by reducing energy consumption related to illumination, improving the efficiency of healthcare presentation, and shortening the hospitalization duration (patient stay length). Some studies have concentrated on the positive effects of daylight on the recovery of patients in medical buildings (Choi, Beltran, and Kim 2012) (Lee and Song 2007) and few studies have optimized energy consumption in medical buildings by using energy simulations (Keighley 1973; Sherif et al. 2014). However, physical specifications of windows, including window-to-wall ratio (WWR) or optimal orientation of windows have been less examined, while the improper design of windows can have a negative effect on the energy consumption of the building. Therefore, consideration of window design techniques is a necessity in energy efficiency-based perspectives.

Many treatment centers have been constructed in Mashhad over recent years so that these centers try to achieve the highest patient satisfaction rate. This study aims to find the physical features of hospital windows in Mashhad to achieve thermal comfort in the interior space and also higher energy saving through optimal solar energy gain. The main purpose of this research is to optimize energy consumption in the hospital spaces of Mashhad City by designing external windows. To do this, an algorithmic tool and its corresponding design process have been employed.

2. LITERATURE REVIEW

Global health costs almost made up 10% of gross domestic production (GDP) in the recent decade. For instance, the USA has spent the highest cost (17.1%) on its healthcare system rather than other countries[1]. In this country, healthcare facilities make up 4.8% of the whole area of commercial buildings and are responsible for 10.3% of the whole energy consumption in this sector (CBECS 2019). This amount of energy is responsible for a considerable rate of environmental pollution and greenhouse gas emissions, including acid rain (12%), greenhouse gases (10%), and air pollution (10%) (González, García-Sanz-Calcedo, and Salgado 2018). Energy consumption in healthcare systems of the USA mainly occurs for heating or cooling spaces, producing steam, ventilation, illumination, using equipment, hot water, and cooking (Singer 2009). The large hospitals of the USA make up 47% of the whole area of medical centers, which are responsible for 64% of the whole energy consumption in this sector with an average energy intensity of 738.5kwh/m2. Also, hospitalization centers that account for 57% of the whole area of healthcare systems consume 76.5% of the total energy of this sector. According to a study conducted in hospitals in this country, ventilation, cooling, and illumination consume the highest amount of electricity (Bawaneh et al. 2019).

The studies conducted in other countries confirm the high energy consumption in hospitals. According to an energy audit in a hospital located in Malaysia, illumination and biomedicine equipment consume the highest amount of energy, 36% and 34%, respectively with an energy intensity of 234kwh/m2 (Saidur et al. 2010). In another study conducted on 210 hospitals in Thailand, electricity consumption accounts for 31.61% of the energy required for these hospitals (N. Thinate, Wongsapai, and Damrongsak 2017). According to the analysis of the energy consumption data in two hospitals in Korea, electricity intensity equaled 128kwh/m2 per year (Chung and Park 2015). Quantitative analysis of energy consumption in 20 hospitals in Spain indicates an energy intensity of 270kwh/m2 (González, García-Sanz-Calcedo, and Salgado 2018). Another study quantified the energy data of hospitals located in Germany. The authors found that 2100 hospitals in Germany consume around 6000kwh of electricity per bed in the year (González, García-Sanz-Calcedo, and Salgado 2018). Morgenstern and colleagues studied the electricity consumption data in 28 wards of 8 general acute hospitals (medium to large-sized) in the UK and confirmed that various wards have considerable nonhomogeneous electricity consumption (Morgenstern et al. 2016). Evaluation of 55 healthcare centers in Spain with a 500-3500m2 area indicated an average annual energy consumption of 86kwh/m2 (García-Sanz-Calcedo 2014).

A review of the mentioned figures indicates that hospitals have a high demand for illumination, pleasant ventilation, heating, and cooling especially in the electricity consumption sector. Therefore, the necessity of reducing hospital budgets and political pressure resulting from decreased healthcare costs requires energy-saving and cost-based predictions and evaluations. In Hospitals, patients' rooms that provide 24-hour healthcare services during the week have high energy consumption for heating and cooling due to high ventilation rate requirements and restrictive considerations for microclimate control. Therefore, the highest external area is provided for these rooms. This factor is one of the elements playing a role in their considerable energy consumption. On the other hand, low-consuming hospitals worsen the quality of interior space affecting desired comfort. The main problem in energy management and comfort in hospital automation and creating a balance between users' convenience and energy consumption (Gatea, Batcha, and Taweekun 2020). An indirect relationship has been found between achieving energy efficiency in buildings and the performance of interior space quality. In this case, interior space quality performance would lead to higher energy consumption in those buildings where thermal and illumination systems are a part of the parameters used by users to evaluate the hospital (Stephen Nimlyat, Kandar, and Sediadi 2015).

Many studies have considered the determination of WWR, particularly in the patients' stay room to achieve the highest energy efficiency while receiving the highest natural light or daylight in the desired daylight indicators range and no eye glare (Rose 2017; Shikder et al. 2010). These studies have simulated hospital buildings through illumination and energy stimulator software and suggested the optimal WWR by importing the required data, including meteorological information of each area.

Ahmed Sherif and colleagues focused on some strategies to make a balance between energy consumption reduction and achieving the suitable diffusion of daylight to identify the most efficient patient room designs in a hospital located in the desert climate of Cario, Egypt using simulation techniques. They recommended WWR=30-40% as the optimal range of window (Sherif et al. 2014). Shailaja Bhagwat and colleagues conducted a study with the same purpose and method in a hospital located in the city of Pune in India and found that WWR can vary between 30% and 70% based on the design conditions (Bhagwat et al. 2019). In the study conducted by Silvia Cesari based on the modeling and simulating hospital patient rooms in Bologna, Italy, the energy performance of a base window with WWR=25% was compared with a window with WWR=70% in the rooms facing all four geographical directions. The results showed that wider windows with suitable irradiation can considerably reduce the energy demand (Cesari et al. 2020). Chungloo and colleagues examined a similar condition in a hospital in Thailand by comparing the windows with the WWR=20-80% range and showed that WWR=50% results in more pleasant illumination and energy conditions (Chungloo et al. 2001). It is anticipated that a passive design strategy can increase the average annual energy performance of hospitals up to 184% up to 184% (Yuan et al. 2022).

3. METHOD

Modeling was done through Grasshopper parametric software, which is installed as a plugin on the Rhino. The analysis and simulation steps are pursued using energy simulation plugins in Grasshopper under the title honeybee and ladybug. Despite the diversity of simulation and energy optimization software, Grasshopper software has been used to use daylight measurement extensions in this software. In modeling Grasshopper software, the considered building can be simulated based on real climatic conditions to find how the building performs in real conditions; then, climatic and operating parameters are imported to the ladybug and honeybee energy plugins to examine the design elements on the considered parameters. The database library in these plugins is connected to data libraries through energy+ software, which performs data analysis within an algorithmic field using a data analysis engine. The input climatic data are based on the ASHRAE standards modified for the climate of Mashhad City.

3.1. Base Module

"Standard of Planning and Design of Safe Hospital, Tenth Volume" which is the reference providing general requirements of hospital design, considers the modular design a priority for the design of hospitals while introducing a module with a length and width of 7.2m as the optimum module. Accordingly, a module with a length and width of 7.2m and a height of 5m is chosen as the base shape for the simulation process.

3.2. Procedure

Three different modes were determined for simulation: the first mode is the current and common mode of design of hospitals in Mashhad based on the type of construction materials and techniques. In this mode, walls and roofs do not require forced insulation, and the canopy is not considered. Because the Engineering Organization of Iran has some guidelines for reducing energy consumption in the Topic 19 edition 2019, the second mode is formed based on the design and construction of the base module considering the guidelines of Topic 19. In the proposed status of Topic 19, all fronts such as the ceiling and floor are adiabatic (without thermal transfer) except for the external wall. A 3cm insulation was considered for the ceiling and an industrial block without insulation was used for the wall. The third mode includes the design and construction of a base module based on the proposed techniques of this study. All presumptions of the proposed mode are similar to Topic 19 of the National Construction Regulation just by changing the materials. In this mode, insulation is increased, and thermal conductivity transmission of all materials is decreased. Wall and floor are selected based on the sand-base expandable block and concrete ceiling, respectively both with cm insulation. Topic 19 and the proposed modes have canopies with the canopy specifications for Mashhad City as reported in Appendix 10. The UPVC single, double, and triple glazing glasses are materials used for windows.

Considering the 40cm thickness of the ceiling, 130cm thickness of the false ceiling, 45 and 90cm upper and lower limits of the window from floor and ceiling, and 10cm thickness of frames around the window, 185cm finally remains for deploying the window; therefore, the window can vary within the 4%-56% range of wall surface.

4. EXPLAINING AND ANALYZING SIMULATION DATA

Tables and Figures 1-4 indicate the result of the simulated studied module within four geographical directions and three considered modes. In Tables, EUI indicates energy usage; UDI less than 100 represents dark space percentage; UDI>2000 shows values with excessive illuminance with glaring, and UDI between 100 and 2000 shows the most optimal light range. According to the standard, the sDA of daylight adequacy in the space must be greater than 55%.

Table 1. Illuminance and Energy Consumption Indicators in Different WWR Ratios of North-Facing Windows in three Studied Modes

sDA	UDA≥2000	UDI: 100-2000	UDA≤100	Proposed EUI	EUI Topic 19	EUI of the Current Status	WWR
2.04	0.02	9.24	90.76	84.12	138.31	244.48	0.04
4.08	0.41	21.67	77.94	85.50	139.25	245.09	0.08
12.24	0.76	32.78	66.47	87.04	140.26	245.70	0.12
14.29	1.02	44.78	54.29	88.65	141.24	246.27	0.16
18.37	1.65	59.18	39.18	90.34	142.29	246.89	0.20
22.45	2.39	71.98	25.67	92.02	143.36	247.53	0.24
28.57	2.86	79.47	17.73	93.71	144.40	248.21	0.28
34.69	3.29	83.94	12.80	95.45	145.50	248.96	0.32
42.86	3.84	86.37	9.80	97.26	146.65	249.68	0.36
48.98	4.55	87.80	7.63	99.14	147.82	250.34	0.40
48.98	5.47	87.98	6.59	100.96	149.03	250.99	0.44
57.14	6.02	88.08	5.92	102.78	150.18	251.70	0.48
57.14	6.49	88.08	5.41	104.62	151.41	252.39	0.52
63.27	7.20	87.80	4.98	106.54	152.66	253.00	0.56

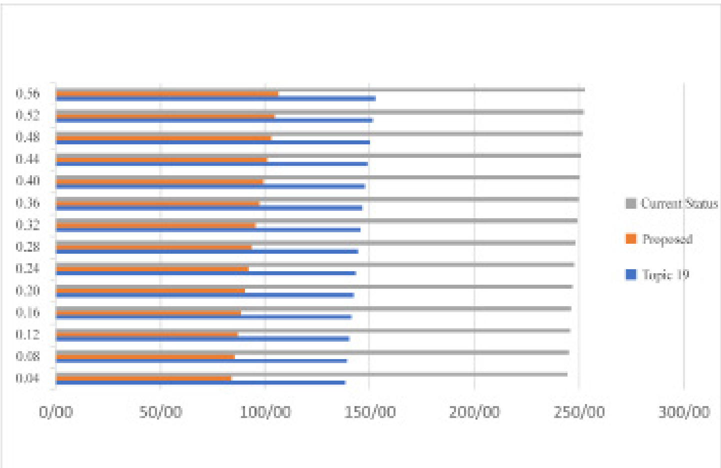

Fig. 1. Comparison of Energy Consumption in Different WWR Ratios of North-Facing Window in three Studied Modes

Table 2. Illuminance and Energy Consumption Indicators in Different WWR Ratios of South-Facing Windows in three Studied Modes

sDA	UDA≥2000	UDI: 100-2000	UDA≤100	Proposed EUI	EUI Topic 19	EUI of the Current Status	WWR
2.04	1.65	18.20	80.20	84.10	136.40	242.98	0.04
12.24	2.86	35.02	62.22	84.14	135.33	241.57	0.08
14.29	4.08	48.12	47.90	84.42	134.40	240.98	0.12
18.37	4.98	59.24	35.82	85.29	133.57	240.49	0.16
24.49	6.69	67.86	25.43	86.31	132.88	240.15	0.20
32.65	7.94	74.04	18.00	87.66	132.29	239.77	0.24
36.73	9.49	77.35	13.20	89.32	131.82	239.44	0.28
46.94	10.61	79.24	10.24	91.24	131.48	239.22	0.32
48.98	11.86	80.06	8.08	93.51	131.17	239.09	0.36
59.18	13.39	79.88	6.78	95.95	131.06	238.95	0.40
65.31	14.92	79.22	5.88	98.71	130.97	239.00	0.44
67.35	16.22	78.39	5.47	101.39	131.14	239.06	0.48
71.43	17.29	77.65	5.04	104.23	131.44	239.23	0.52
77.55	18.51	76.55	4.90	110.59	132.05	238.06	0.56

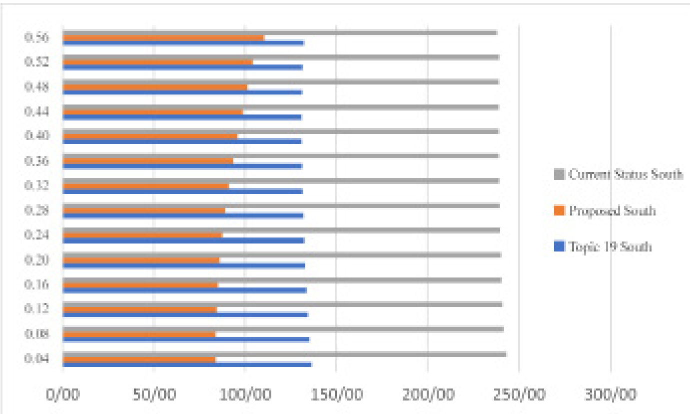

Fig. 2. Comparison of Energy Consumption in Different WWR Ratios of South-Facing Window in three Studied Modes

Table 3. Illuminance and Energy Consumption Indicators in Different WWR Ratios of East-Facing Windows in three Studied Modes

sDA	UDA≥2000	UDI: 100-2000	UDA≤100	Proposed EUI	EUI Topic 19	EUI of the Current Status	WWR
2.04	1.49	16.65	81.90	85.55	139.20	243.95	0.04
8.16	2.78	32.55	64.69	88.52	140.62	244.17	0.08
16.33	3.78	45.45	50.78	92.06	142.14	244.49	0.12
20.41	5.04	56.86	38.08	96.12	144.07	244.78	0.16
22.45	7.06	65.27	27.65	100.36	146.11	245.17	0.20

sDA	UDA≥2000	UDI: 100-2000	UDA≤100	Proposed EUI	EUI Topic 19	EUI of the Current Status	WWR
32.65	8.78	72.61	18.69	104.79	148.39	245.65	0.24
42.86	10.14	76.02	13.90	109.79	150.83	246.11	0.28
42.86	11.22	78.16	10.51	114.78	153.43	246.65	0.32
51.02	13.00	78.61	8.51	119.85	156.05	247.23	0.36
55.10	15.06	78.35	6.59	125.15	158.95	247.87	0.40
63.27	16.55	77.57	5.88	130.66	162.00	248.58	0.44
69.39	18.00	76.63	5.31	136.18	165.36	249.27	0.48
69.39	19.14	75.98	4.98	141.68	168.78	250.07	0.52
69.39	21.14	74.24	4.63	147.34	172.14	250.84	0.56

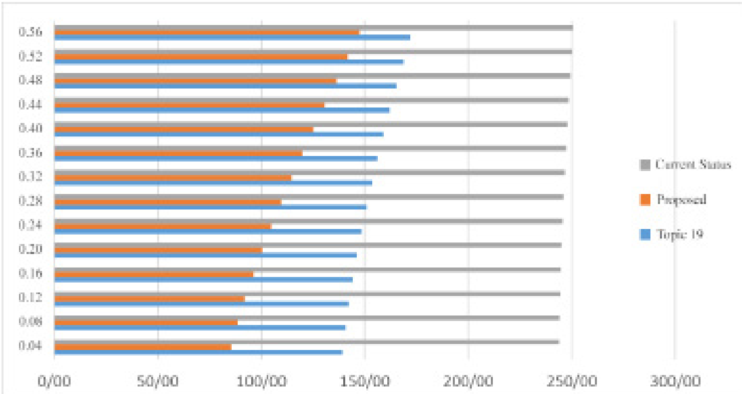

Fig. 3. Comparison of Energy Consumption in Different WWR Ratios of the East-Facing Window in three Studied Modes

Table 4. Illuminance and Energy Consumption Indicators in Different WWR Ratios of West-Facing Windows in three Studied Modes

sDA	UDA≥2000	UDI: 100-2000	UDA≤100	Proposed EUI	EUI Topic 19	EUI of the Current Status	WWR
2.04	0.88	13.31	85.88	85.23	138.77	244.99	0.04
8.16	1.94	26.86	71.29	88.30	140.42	246.21	0.08
12.24	2.63	38.33	59.06	92.07	142.20	247.53	0.12
14.29	3.20	48.47	48.39	96.19	144.18	248.91	0.16
20.41	4.16	58.18	37.69	100.63	146.51	250.41	0.20
20.41	5.24	68.14	26.61	105.24	149.11	251.94	0.24
28.57	6.20	74.92	18.84	110.00	151.97	253.47	0.28
34.69	6.78	78.69	14.51	115.13	155.04	254.99	0.32
40.82	7.84	81.04	11.16	120.36	158.20	256.71	0.36
44.90	8.86	82.55	8.63	125.64	161.28	258.46	0.40
51.02	9.94	82.90	7.12	131.15	164.55	260.24	0.44

sDA	UDA≥2000	UDI: 100-2000	UDA≤100	Proposed EUI	EUI Topic 19	EUI of the Current Status	WWR
55.10	10.80	82.86	6.39	136.87	167.92	262.12	0.48
57.14	11.39	82.65	5.90	142.65	171.51	264.01	0.52
61.22	12.55	82.02	5.47	148.49	175.05	265.79	0.56

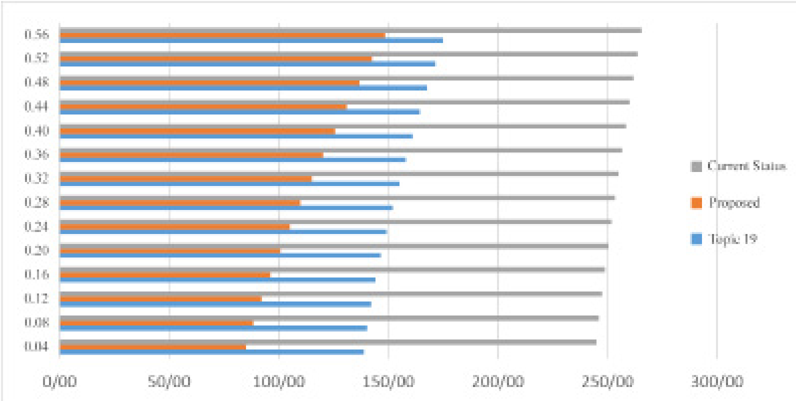

Fig. 4. Comparison of Energy Consumption in Different WWR Ratios of the West-Facing Window in three Studied Modes

4.1. Analysis of Simulation Results in Current Status Mode

According to the results obtained from the current status, energy consumption in the north front varies between 244 and 253, so energy consumption increases when the window size becomes larger. The light rate is increased in the same way. The sDA rate reaches its optimal value in WWR=40%. Moreover, the UDI index 100-2000 is at a maximum rate in the range of 40-56 indicating that optimal illuminance is at best mode. Therefore, the light is at the optimal level and energy consumption is lower in WWR=40%. However, the window size can be decreased in case of higher importance of energy consumption.

In the east-facing window mode, energy consumption varies between 244 and 250 which has a better status compared to the north-facing window. In this case, optimal illuminance varies between 32 and 36. Since energy consumption is less in the mode of 32%, this WWR is suggested.

In south-facing windows, energy consumption varies between 239 and 242. In this front with widened window size, the higher direct solar gain and uninsulated materials result in more heat entering the space during summer and less heating energy consumption; therefore, EUI is reduced when window size increases in this mode. However, this decline occurs up to 44%. Larger windows would lead to higher energy consumption although at a minor rate. The useful light rate and lack of glaring occur at the 32-36 interval. Since the optimal sDA index is at 36% and the energy consumption is less in this mode, the WWR=36% is suggested for the south front.

The west-facing window with an energy consumption rate of 244-266 leads to higher energy loss compared to other modes. The optimal illuminance occurs between 40 and 48%, and because less energy consumption occurs in small windows, the WWR=40% is recommended.

In the current status mode, energy consumption varies between 239 and 266. According to the comparison of energy consumption on all fronts in this mode, the west-facing and south-facing windows have the least energy loss. The north and east diagram is in the middle part and behaves relatively similarly. Although the widened size of windows on all fronts increases space lighting and energy consumption, the energy consumption is decreased only in the south direction especially when window size and lighting are increased. However, this reduction is seen up to 44%, and energy consumption a little increase in larger windows.

4.2. Analysis of Simulation Results in the Mode of Topic 19 of National Construction Regulations of Iran

In the north front, energy consumption varies between 138 and 152, which is around 100kw less than the same mode of current status. Also, energy consumption increases when windows get wider. The light rate increases when the dimensions of the window become larger so that optimal illuminance is seen in the space in the windows larger than 40%. The light is optimal in the WWR=40%, and the energy consumption is somewhat lower. In the east-facing window mode, energy consumption varies between 139 and 172 indicating the loss of energy performance compared to the north-facing window. The optimal illuminance varies between 32 and 36 and less energy consumption at the lower limit of this interval result in WWR=32%.

In the model with a south-facing window, energy consumption varies between 130 and 136. In this front, when window size increases then the heat gain gets higher and heating energy becomes less due to direct solar gain and used materials; therefore, EUI decreases when window size becomes wider in this mode. However, this reduction occurs up to WWR=44%, and windows greater than this rate would result in higher energy loss and finally greater energy consumption. The useful light rate and lack of glaring occur in the 32-44 range. Because the optimal sDA index is at 36% and the energy consumption is less in this mode, the WWR=36% is suggested for the south front.

In the mode of the west-facing window, energy consumption varies between 138 and 175 which has higher energy loss than the east-facing window. The optimal illuminance occurs in the range of 40-48%; hence, WWR=40% is recommended.

The energy consumption range in the Topic 19 mode varies between 130 and 175. According to the comparison between energy consumption rates of all fronts in the Topic 19 mode, west-facing and east-facing windows have the highest energy loss, while south-facing window results in the least energy loss which is around 100kw less than the similar mode of current status.

4.3. Analysis of Simulation Results in the Proposed Mode

In the case of the north-facing window, the proposed mode of energy consumption varies between 84 and 106. Regarding illuminance indicators, the suitable ratio for this module varies between 40% and 44%. According to the ascending trend of energy consumption, the lowest percentage reaching illuminance (40%) is preferably recommended.

Figure 5 depicts the monthly energy consumption of this window from January to December. Almost equal energy is required for both cooling and heating.

According to Figure 6, the optimal light index equals 100% in all areas of the room indicating a highly suitable optical quality. The DLA index that depicts the illuminance higher than 300 lux has encompassed half of the space. According to the comparison between this figure and the figure for the UDI index, half of the room receives more than 300 lux illuminances while the other half receives 100-300 lux light. The mentioned light rate is highly suitable regarding the north orientation and lack of direct sunlight irradiation to this front.

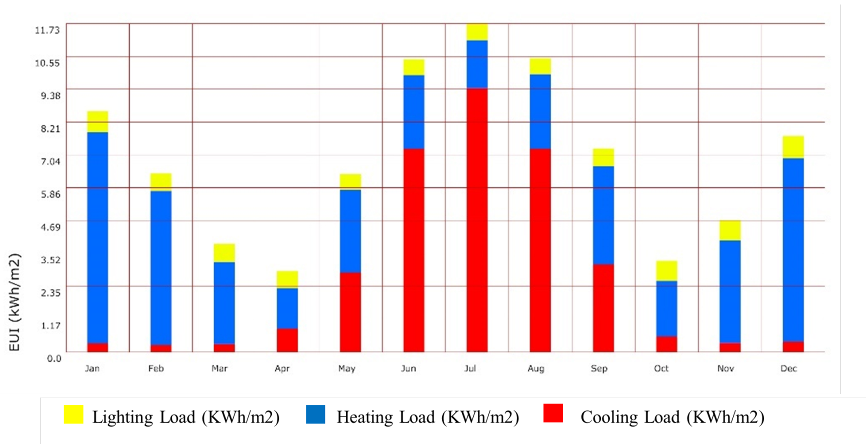

Fig. 5. Monthly Energy Consumption for Illuminance, Cooling, and Heating in the Optimal North-Facing Window

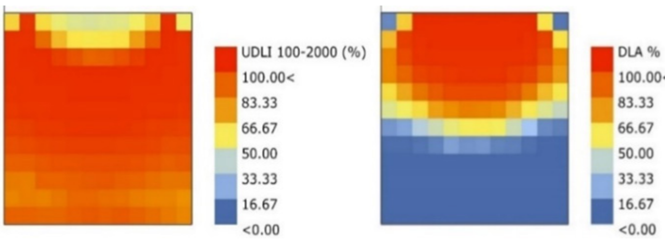

Fig. 6. DLA (Right) and UDI 100-2000 (Left) in the Optimal North-Facing Window

Energy consumption in the east-facing window mode varied between 85 and 147 indicating the exponential increase in energy consumption along with the window percent increase. The optimal light is in the range of 36-40%, and a lower ratio (36%) is suggested for this front.

The monthly diagram of energy consumption in the optimal model of the east-facing window indicates the higher energy consumption for heating in summer and its lower amount in winter compared to the north-facing window. According to Figure 8, almost 80% of the space has useful light, and an illuminance of a little greater than 2000 lux is seen near the window. According to the comparison between the mentioned illuminance indicators, less than half of the room has 100-300lux illuminance most of the room space has 300-2000 illuminance, and only 10% of the space has more than 2000-lux illuminance.

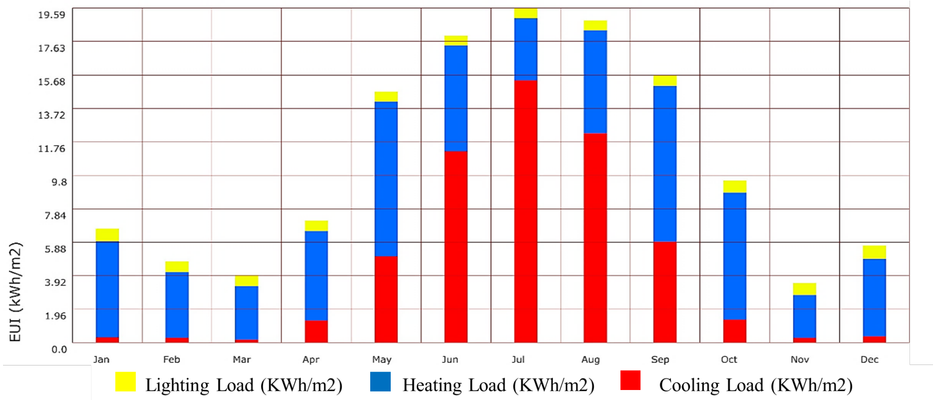

Fig. 7. Monthly Energy Consumption for Lighting, Cooling, and Heating in an Optimal East-Facing Window

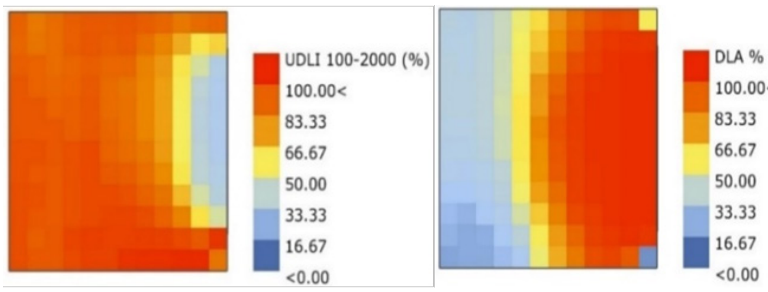

Fig. 8. DLA (Right) and UDI 100-2000 (Left) in the Optimal East-Facing Window

Unlike the two previous modules, energy consumption has not been reduced in the proposed mode and south-facing window due to the high use of insulation; however, the highest energy usage intensity in this mode outperforms the best mode of current status (with 130 kw rate) and the best mode of Topic 19 (with 38 kw rate).

The optimal model of window percentage varies between 32 and 40% regarding the light conditions, and a rate between these two percentages (36%) is recommended considering the energy consumption. The optimal mode of energy usage intensity indicates the reduction in energy required for heating in cold seasons towards the north front, which occurs due to the positive effect of sunlight but this insulation rate leads to higher heating usage from September to November.

In terms of illuminance, more than half of the space receives optimal illumination greater than 300. The UDI index indicates that around 80% of space has optimal light. The light intensity of the remaining 10% is greater than 2000, while the light intensity of another 10% is less than 2000.

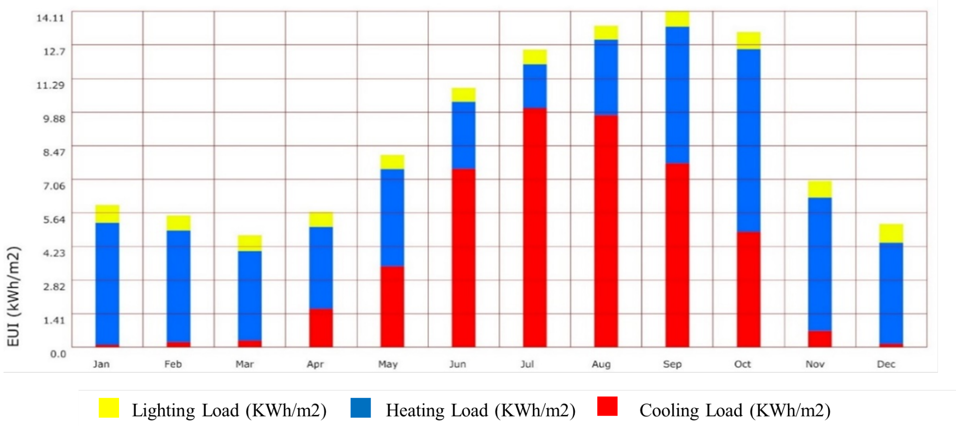

Fig. 9. Monthly Energy Consumption for Lighting, Cooling, and Heating in an Optimal South-Facing Window

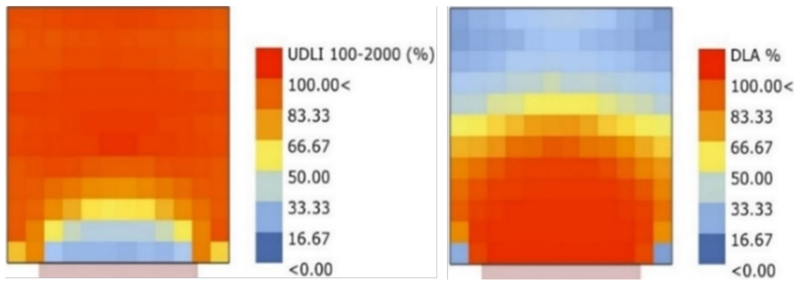

Fig. 10. DLA (Right) and UDI 100-2000 (Left) in the Optimal South-Facing Window

The energy usage intensity of a west-facing window varies between 85 and 148 kw and almost performs like an east-facing window. The optimal illuminance varies between 32% and 44%, and since the energy usage is better when WWR is less, the rate of 36% is suggested for this front. The energy usage intensity in the optimal mode of the west-facing window equals 12 kw, which is 25 kwh greater than this rate for the south-facing window with the same WWR. Like other modules, optimal illuminance encompasses almost 80% of the space.

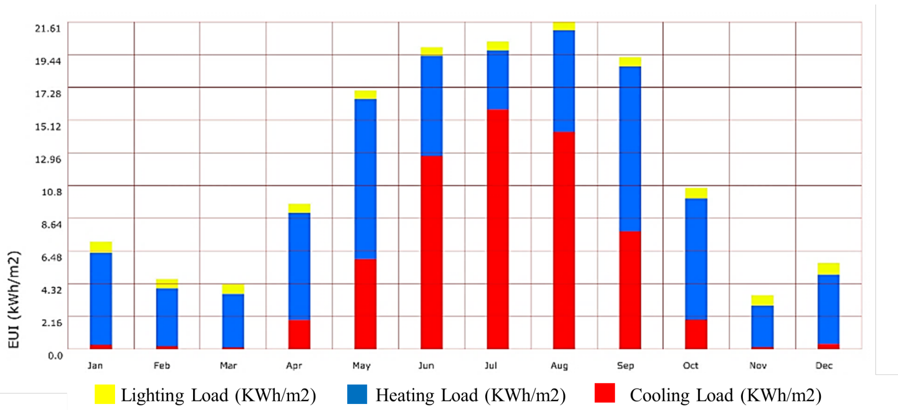

Fig. 11. Monthly Energy Consumption for Lighting, Cooling, and Heating in an Optimal West-Facing Window

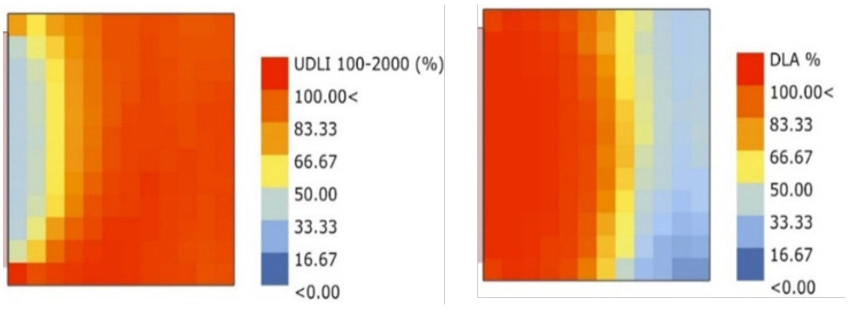

Fig. 12. DLA (Right) and UDI 100-2000 (Left) in the Optimal West-Facing Window

The energy usage interval in the proposed mode varies between 84 and 148. In the proposed module, the least energy loss occurs through north-facing and south-facing windows, while the highest energy loss occurs through east-facing and west-facing windows. Smallest windows in all directions with almost similar conditions have very low energy usage, while energy usage indicates a considerable difference of up to 60% when window size in all directions, particularly east and wet, is increased.

5. CONCLUSIONS

This study aims to find the physical features of the windows on the external walls of hospitals located in Mashhad City to achieve thermal comfort in the interior space but also higher energy usage saving through optimal solar energy adsorption. Hence, suitable window direction and WWR were tested within 12 different modes of windows in combination with three techniques of current status, Topic 19 and proposed by the authors.

The results show that those windows shaped based on the instructions contained in Topic 19 of National Construction Regulations provide 45% energy savings greater than the common windows used in these hospitals, while the saving rate would be 65% higher if those insulation techniques with better performance are used. The windows in the proposed mode outperformed their counterparts available in the Topic 19 module. The same relationship exists between windows in the Topic 19 module and windows available in current status.

The south direction is the best lighting orientation. In all three studied modes, the west-facing window had the worst performance. The highest energy usage of the improved south-facing window outperformed the most energy-efficient south-facing window of current status (129 kw) and the most energy-efficient south-facing window of Topic 19 (20 kw).

In small windows, the effect of improper orientation on energy usage is highly low, while orientation has a considerable effect on energy usage in larger windows. The large windows in the east and west directions of the hospital underperform the windows on two other fronts.

Although energy usage increases when the window becomes larger in all modules, energy usage decreases in the south-facing window in current status and Topic 19 modules when the window becomes larger up to WWR=44%. The possibility of higher solar gain through a larger south window reduces the need for heating energy in cold seasons leading to less energy usage. In large window modules, increased heat loss would raise energy usage again.

According to the slope of energy usage curves in all modules and directions, the energy usage of larger windows in the proposed module approaches the energy usage of windows of the same size in two other modes. It means that the role of some considerations such as insulation in reducing energy loss is determining but not restricting. Although this study indicated that the windows with around 32-40% ratio can reach the highest illuminance level in all modules, the lower limit of this range must be considered to reduce energy loss.

Considerations for optimizing the design of windows are more substantial when large windows are used. Large windows are preferred in hospitals to increase environmental quality. Accordingly, the techniques proposed in this study based on the higher insulation of external walls and using a canopy, as well as using large windows and improving the environmental quality of the hospital would increase energy efficiency.

The algorithms used in the software simulation space can be examined as a design technique regarding the algorithmic process of optimization that can receive diverse inputs for various objective functions in the output part of the optimization algorithm.

These types of studies can be developed and enhanced from theoretical scale to real scale of architecture due to simulation techniques in their processes, so they can be used as an effective strategy for the design of medical and healthcare buildings. In addition to medical buildings, the results of this study can be generalized to all full-time uses (7 days a week and 24 hours a day) in similar climatic conditions like Mashhad.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

ENDNOTE

1. www.worldbank.org

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