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Analysis of energy and daylight performance of adjustable shading devices in region with hot summer and cold winter

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Abstract. Large glazed surfaces and windows become common features in modern buildings. The spread of these features was influenced by the dependence of designers on mechanical and artificial systems to provide occupants with thermal and visual comfort. Countries with hot summer and cold winter conditions, like Jordan, require maximum shading from solar radiation in summer, and maximum exposure in winter to reduce cooling and heating loads respectively.

The current research aims at designing optimized double-positioned external shading device systems that help to reduce energy consumption in buildings and provide thermal and visual comfort during both hot and cold seasons. Using energy plus, a whole building energy simulation program, and radiance, Lighting Simulation Tool, with DesignBuilder interface, a series of computer simulations for energy consumption and daylighting performance were conducted for offices with south, east, or west windows.

The research was based on comparison to determine the best fit characteristics for two positions of adjustable horizontal louvers on south facade or vertical fins on east and west facades for summer and winter conditions. The adjustable shading systems can be applied for new or retrofitted office or housing buildings. The optimized shading devices for summer and winter positions helped to reduce the net annual energy consumption compared to a base case space with no shading device or with curtains and compared to fix shading devices.

Keywords: exterior shading system; glazed surfaces; cooling loads; heating loads; lighting loads; indoor comfort; adjustable shading devices; greenhouse gas (GHG); window wall ratio (WWR)

1. Introduction

Buildings consume up to 40%, for heating and cooling only, of global annual energy, and responsible for 30% of global annual greenhouse gas (GHG) emissions (UNEP-SBCI 2009, Aldossary *et al.* 2014). In Jordan, buildings sector accounted for 60% of the total electrical energy consumption (MEMR 2015). Therefore, it is essential to address energy-related issues in buildings, in order to reduce fossil fuels burning and GHG emissions. Therefore, buildings design should take into account the prevailing climatic conditions and the potentials of using natural sources to provide indoor comfort (Bauer *et al.* 2009).

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Large glazed surfaces, of more than 50% window to wall ratio, have major impacts on indoor cooling, heating and lighting quality, as they provide spaces with natural daylighting, solar heating, and connection with exterior environment (LEED 2009). Designing of large glazed areas requires taking into consideration heat gains, heat losses, daylighting quality and quantity by considering solar angles in different locations, orientations and seasons. Therefore, it is important to provide protection from direct solar radiation in summer by using; self-shading forms, orientation, using glass with specific features, or using shading systems (Nasrollahi 2009, Hyde 2013). Shading devices have a significant impact on cooling, heating and lighting energy consumption of a building as they regulate and control daylight and heat gain (Yao 2014). Shading devices could be adjustable, fixed, external or internal that depends on design requirements, functions and building types. There are many types of shading devices that exist in literatures and developed throughout the history. These include, overhangs, horizontal and inclined louvers, vertical and rotated fins, canopies, lightshelf, and many innovative devices like, smart and coated glazing, laser cut panels and prismatic panels. Shading devices could significantly control heat gain and reduce cooling requirements and improve the quality of the natural lighting. well-designed shading devices depend on many variables like solar angles, orientation, windows size and location, materials and building forms (Kirimtat *et al.* 2016).

Hernández *et al.* (2017) evaluated energy demands and visual comfort of a real case office building with high WWR in a Mediterranean city by using vertical and horizontal louvers. They used DAYSIM simulation software for daylight analysis and TRNSYS 17 for thermal analysis and found that shading devices could reduce cooling demands with high rates on south, east and west offices. Evola *et al.* (2017) used Energy Plus simulations to study thermal comfort with a series of shading devices and found that external shading perform better than internal shading and reduced energy consumption with more than 50%. Bellia *et al.* (2013) and Cho *et al.* (2014) studied the effect of external shading devices on the indoor environment in buildings and energy demands during summer.

Yun *et al.* (2014) evaluated the effect of shading control strategies on the daylighting, visual comfort, and energy performance in buildings. Freewan (2014) examined the effect of fixed external shading devices on air temperature and visual comfort in offices with specific orientation, focusing on finding the most efficient devices that reduce air temperature and control daylighting. Palmero-Marrero and Oliveira (2010) studied the effect of static external shading devices on energy demands during summer and winter in various regions around the world. The results showed that total annual energy reduction was achieved in regions with hot dominant seasons; however the annual energy increased in regions with low temperatures.

Previous researches on movable and adjustable shading devices showed their potential to save energy compare to fixed shading devices or non shaded glazing. These researches were based on user behavior which almost stochastic and unpredictable or based on automatic adjusting role up shading devices (Foster and Oreszczyn 2001, Olbina and Hu 2012, Van Den Wymelenberg 2012, Yao 2014, Yousefi *et al.* 2017). In addition, many previous studies focused on the performance of fixed shading devices in controlling over heating in summer time and improving daylighting. Moreover, the previous research by the author showed that fixed egg crate was the best option to reduce air temperature in hot climate without consideration heating requirements which required less horizontal and vertical slats. The results fit better for simple academic offices buildings while there is a need for more studies for housing buildings and large offices buildings. Yao (2014) research showed that manually adjusted shading devices reduced energy consumption in buildings than building with clear-pane windows. Moreover the study showed that manually

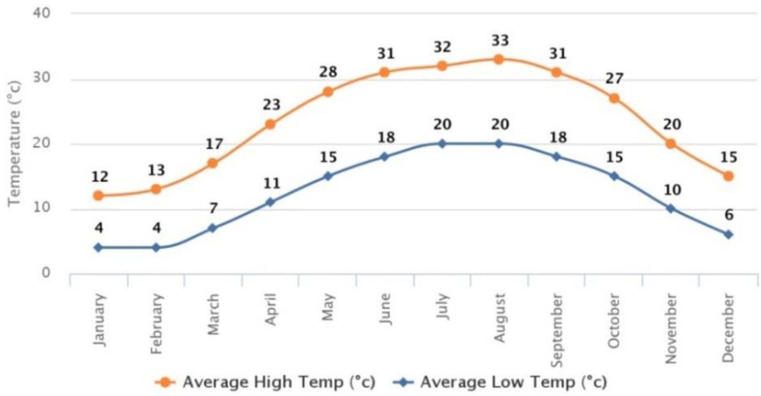

Fig. 1 Air temperature in Irbid-Jordan (Worldweatheronline 2016)

adjusted external shading devices performed better than LOW-E windows and internally adjusted shading devices and they widely used in buildings because of low cost.

Therefore, the current study focused on simple and manually rotatable horizontal or vertical fins for southern, eastern, or western elevations in Jordan. It is to compromise between summer and winter requirements, fixed and movable shading device, cost and maintenance, stochastic behavior of user, and applicability on new and existing buildings and maintain connection with outside. It can be used for housing and offices building or retrofit scenarios and do not required sophisticated controlled technologies which depend on complicated algorithms. The systems can be adjusted into two positions, to provide maximum shading from sunrays or maximum exposure to sunrays.

The current research used the EnergyPlus and radiance calculation engine. EnergyPlus is a dynamic thermal simulation developed by Lawrence Berkeley Laboratory (USA). Energy Plus calculates both heating and cooling loads in buildings using heat balance method developed by the ASHRAE. The ASHRAE method ensures the balance of all energy flows in each zone. Design Builder software used as interface for energy plus. It is a dynamic simulation software and can be used to determine the monthly and yearly heating and cooling in buildings. Radiance is a professional light visualizing tool used in virtual environments. It is an advanced light calculation, visualization and analyzing program developed by the Lawrence Berkeley Laboratory. It depends on back ward ray tracing. Design builder has been validated with many researches compare to many tools like matlab calculation (Blanco *et al.* 2016), compare to experimental results (Elshafei *et al.* 2017) and compare to real measurements (Campano *et al.* 2017). DesignBuilder rests were used to perform comparison between different variables, thus to find characteristics of shading device for summer and winter conditions during cooling and heating seasons in Jordan.

1.1 Case of Jordan

Jordan climate is characterized by variation in temperatures from hot-dry seasons during summer, and cold seasons during winter (JEM 2009). Irbid-Jordan, with latitude 31.9°N, and longitude 35.9°E was selected as the location for simulation. Based on air temperature measurements in Irbid, the cooling period was determined between (1st of April-31st of October), and heating period (1st of November-31st of March) as shown in Fig. 1 (Worldweatheronline 2016), and therefore all simulations of in the research were based on these two periods.

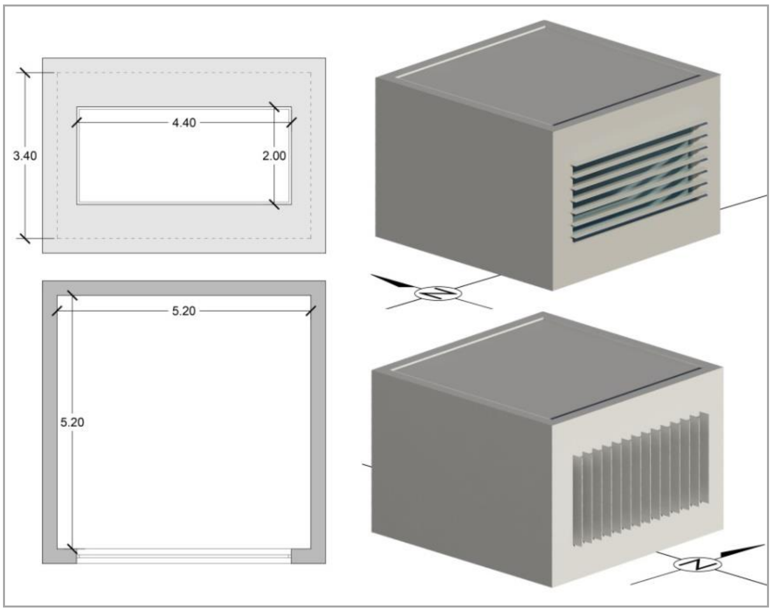

Fig. 2 (Left) Plan and elevation of the base case. (Right) 3D model of the vertical fins and horizontal louvers (Freewan and Shqra 2017)

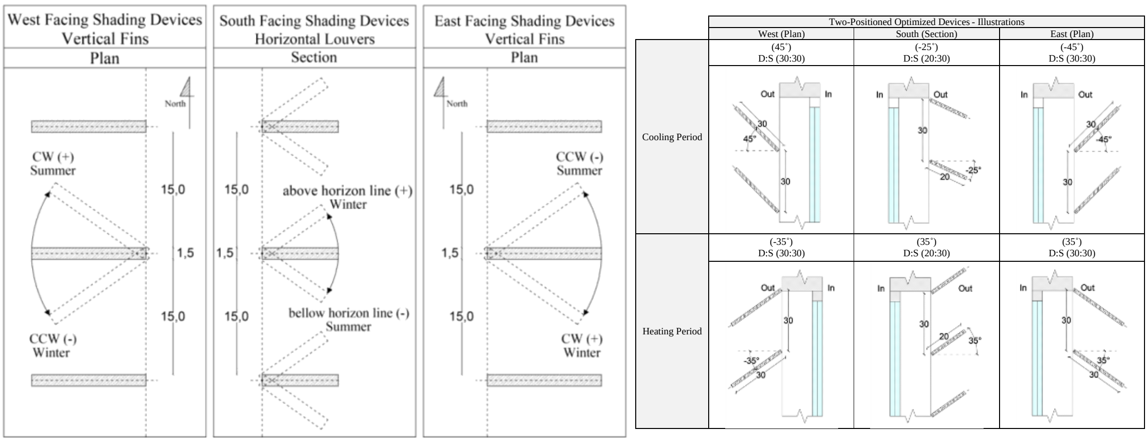

Fig. 3 Inclinational and rotational angles of the shading devices for summer and winter conditions (Freewan and Shqra 2017)

2. Base case

The base case room is of 5.20 m × 5.20 m × 3.40 m for length, width, and height respectively. The external walls were assigned with a total overall heat transfer (U-Value) of 0.306 W/m^2-k with the following layers: Concrete plaster 0.04 m, brickwork 0.10 m, thermal insulation 0.05 m, and brickwork 0.10 m. Flat roof and floor of the room were assigned with a U-Value of 0.30 W/m^2-k as a concrete slab. The room has a window with a height of 2 meter and window to wall ratio (WWR) of 50%, and the glass was double-paned with an approximate the overall heat

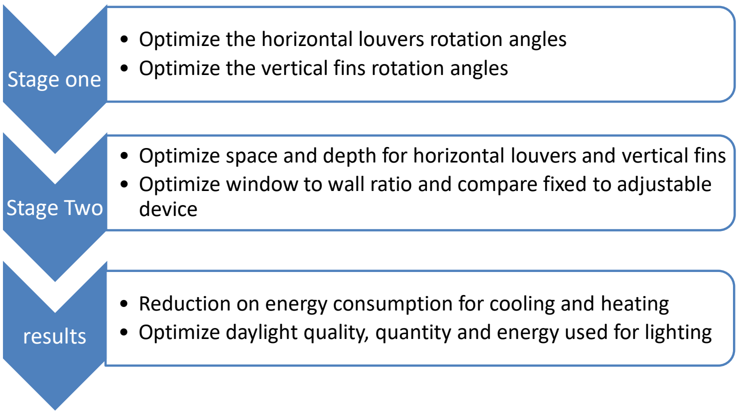

Fig. 4 The study flow and stages (Freewan and Shqra 2017)

transfer (U-Value) of 2 W/m²-k. The working plan inside the room is set to a height of 0.75 m. Fig. 2 shows an illustration of the base case plan, elevation, and 3D models for the vertical and horizontal louvers.

The window side was directed towards east, west, or south, as variation in the research variables. The building type was specified as an enclosed office with occupancy density of 0.111 person/m^2. The schedule of the office was set to five working dates weekly from 07:00-17:00. The set point temperatures for heating and cooling the office were 22℃ for heating with 12℃ heating setback and 24℃ for cooling with 30℃ cooling setback. Lighting requirements were specified with 300Lux illumination target, as the Illuminating Engineering Society of North America (IESNA) recommends 300-500 lux on the working plane for offices with computer based task (Veitch and Newsham 2000).

Horizontal louvers and the vertical fins were simulated, with different variables like; spacing between blades, depth, number, and inclinational angles of the blades. The results of the simulated cases were evaluated in term of energy consumptions (*kWh)* for cooling, heating, and lighting. The cooling and heating loads are associated with the indoor thermal comfort during summer and winter, and the artificial lighting load is associated with the daylighting performance in the indoor environment.

Spacing between blades (S) and depth of blades (D) were fixed in the first stage with a value of 15 cm (S) and 15 cm (D) for east and west shading devices, and for south shading devices the values were fixed to (S=15 cm) (D=10 cm). The rotation angles of the horizontal louvers and the vertical fins were changed and simulated using simple rotation angles of ±(0° 15° 25° 35°, and 45°), all of which were taken with a positive and negative rotations (Above (+) and below (-) horizon line) for horizontal louvers on south facade , and (clockwise CW (-) and counterclockwise CCW (+)) for vertical fins on, east and west facade. Fig. 3 shows an illustration of the shading devices and their inclination and rotational angles for summer and winter conditions.

Two main stages were used in the current research, as seen in Fig. 4, to optimize the performance of shading devices these are: first stage focused on optimizing the position and rotation angles for summer and winter conditions. The second stage focused on studying of the best positions with other variables like depth and space dimensions, windows to wall ratio and dynamic to fixed shading devices.

Table 1 Energy consumptions for South-facing office window during the cooling period (Freewan and Shqra 2017)

Angle˚	No Shading	Curtains	00˚	-15˚	-25˚	-35˚	-45˚
Windows gains (kwh)	2089.6	2089.6	1202.8	1065.2	992.3	937.6	903.7
Lighting (kwh)	6.7	76.95	14.8	15.56	15.4	40.4	41.9
Cooling loads (kwh)	1408.3	1473.2	849.2	780.3	746.9	737.0	723.1
Total Energy (kwh)	1415.0	1550.1	864.0	795.8	762.3	777.4	765.1

(Fixed variables: spacing 15 cm thickness 1.5 cm depth 10 cm)

(Tested variable: Rotation angle 0 15 25 35 45 degrees (bellow horizon line -) (above, horizon line +))

Table 2 Energy consumptions for South-facing office window during the heating period (Freewan and Shqra 2017)

Angle˚	No Shading	Curtains	00˚	15˚	25˚	35˚	45˚
Windows gains (kwh)	2339.66	2339.66	1380.39	1715.24	1924.53	2082.02	2006.27
Lighting (kwh)	19.05	46.5	25.2	19.66	19.3	19.4	21.1
Heating loads (kwh)	492.0	844.1	698.0	613.291	552.5	573.6	1162.4
Total Energy (kwh)	511.1	868.1	716.6	631.6	571.0	593.788	1162.43

(Fixed variables: spacing 15 cm thickness 1.5 cm depth 10 cm)

(Tested variable: Rotation angle 0 15 25 35 45 degree (bellow horizon line -) (above horizon line +))

3. Results and discussion of the first stage

3.1 Energy consumption in a space with a south facing window

Cooling and lighting simulations were conducted for the summer period for the base case offices; one with no shading, and one with indoor fabric curtains. The curtain case is widely used in Jordan by users to prevent direct sunrays, glare and overheating and so daylight levels were decreased to minimum level, although of abundant daylight outside, and thus the offices depend mainly on artificial light. Thereafter, the simulations were conducted for the office with external horizontal louvers with five different angles (00˚,-15˚,-25˚,-35˚,-45˚) as seen in Fig. 3. Table 1 presents the results of energy consumptions for all cases. The comparison of results of spaces with shading devices to the two base cases, showed that the louvers with inclination angle of -25˚ had the lowest energy consumption with a reduction of an average of -46% compared to the base case with no shading, and -51% compared to the base case with curtains for both cooling and lighting. During the winter period, the same process was conducted for heating and lighting demands, and with positive values for the angles (00, 15, 25, 35, 45). The results showed that the louvers with inclination angle of 35˚ caused the least increase compare to the base cases, with a value of +10% compared to the base case with no shading, and +9% compared to the base case with curtains, as shown in Table 2.

Therefore, the annual total energy reductions for the adjustable with two-positioned horizontal louvers are -37 % compared to the first base case, and -42% compared to the second base case for cooling, heating and lighting as well.

The two base cases have high heat gains through windows and glazed surfaces due to the fact

Table 3 Results for daylighting performance of South-facing window for base cases and tested devices during cooling period (Freewan and Shqra 2017)

South-Summer-(1st Of April-31st Of October)							
Angle˚	No Shading	Curtains	00˚	-15˚	-25˚	-35˚	-45˚
Illuminated Area% >300Lux	100.0	00.00	98.817	96.450	94.6	85.2	71.598
Illuminated Area% >1000Lux	40.2	00.00	0.592	00.00	00.0	00.0	00.00
Illuminated Area% >2000Lux	13.6	00.00	00.00	00.00	00.0	00.0	00.00
Average DF (%)	9.8	0.126	5.2	4.6	4.2	3.8	3.4
Minimum DF (%)	3.6	0.012	2.0	1.979	1.9	1.8	1.7
Maximum DF (%)	23.7	2.2	9.1	7.6	6.8	6.2	5.6
DF Uniformity Min DF/Avg DF (%)	0.3	0.09	0.37	0.42	0.45	0.4	0.4
DF Uniformity Min DF/Max DF (%)	0.1	0.005	0.21	0.258	0.28	0.3	0.3
Average Illuminance (Lux)	1502.0	126.1	610.8	528	481.1	442.5	402.5
Minimum Illuminance (Lux)	402.2	1.30	218.8	216.3	214.1	205.5	186.4
Maximum Illuminance (Lux)	2603.1	250.9	1002.8	839.7	748.1	679.5	618.7
Illum. Uniformity Min/Avg Lux (%)	0.26	0.01	0.35	0.44	0.44	0.4	0.4
Illum. Uniformity Min/Max Lux (%)	0.15	0.01	0.218	0.25	0.28	0.3	0.3

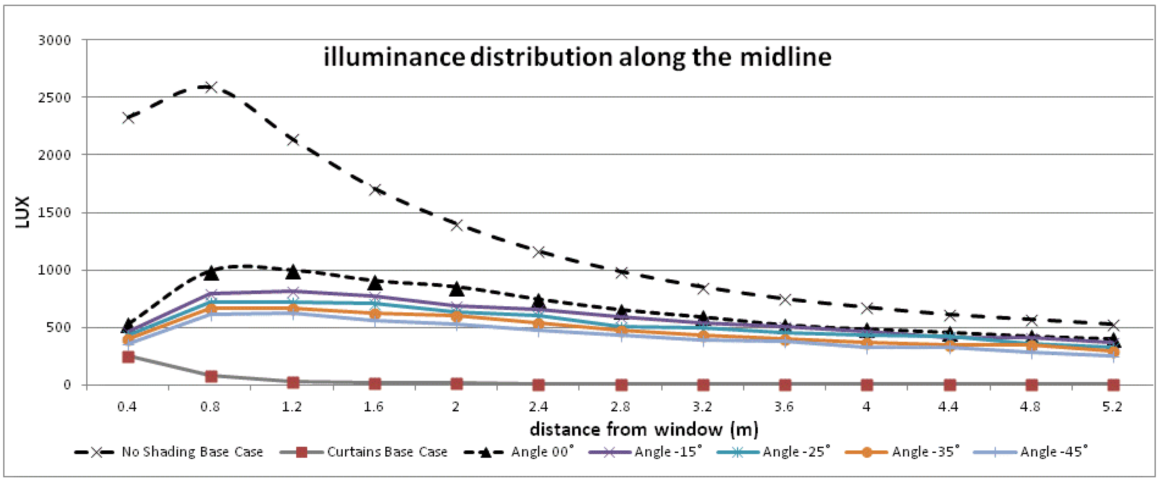

Fig. 5 Distribution Curves for the South-facing window for the base cases and the tested devices with a sky model CIE Clear day during summer (Freewan and Shqra 2017)

that internal curtains did not reduce heat gains, as they only block direct solar radiation from reaching inner spaces directly and slightly reduce heat gain by reflection part of sunrays. Summer heat gains through south facing window with shading devices had lower values compared to the two base cases. Shading devices are blocking sunrays before reaching the glazed surfaces and inner spaces and thus reduce direct heat gain. It has been noticed that lower angles of the devices results in lower solar gains, and improving in shading performance. However, it has been noticed

Table 4 Results for daylighting performance of South-facing window for base cases and tested devices during heating period (Freewan and Shqra 2017)

South-winter-(1st of November-31st of March)							
Angle°	No Shading	Curtains	00°	15°	25°	35°	45°
Illuminated Area% >300Lux	100.0	00.0	98.8	98.8	98.8	98.8	98.2
Illuminated Area% >1000Lux	61.5	00.0	31.3	40.2	40.2	38.4	39.6
Illuminated Area% >2000Lux	21.8	00.0	00.0	00.0	5.9	12.4	10.0
Average DF (%)	18.2	0.2	10.3	12.4	13.3	13.2	12.4
Minimum DF (%)	5.2	0.1	2.2	2.4	2.5	2.6	2.8
Maximum DF (%)	39.3	2.6	18.4	24.0	27.1	29.4	29.5
DF Uniformity Min DF/Avg DF (%)	0.28	0.07	0.2	0.1	0.1	0.2	0.2
DF Uniformity Min DF/Max DF (%)	0.1	0.01	0.12	0.10	0.09	0.09	0.09
Average Illuminance (Lux)	1758	105.15	814.7	1041.7	1168.9	1264.0	1272.0
Minimum Illuminance (Lux)	416.3	1.40	178.8	190.1	198.1	210.5	221.5
Maximum Illuminance (Lux)	3099.7	208.9	1450.6	1893.3	2139.8	2317.6	2324.1
Illum. Uniformity Min/Avg Lux (%)	0.23	0.01	0.41	0.35	0.36	0.35	0.47
Illum. Uniformity Min/Max Lux (%)	0.13	0.01	0.12	0.32	0.29	0.24	0.25

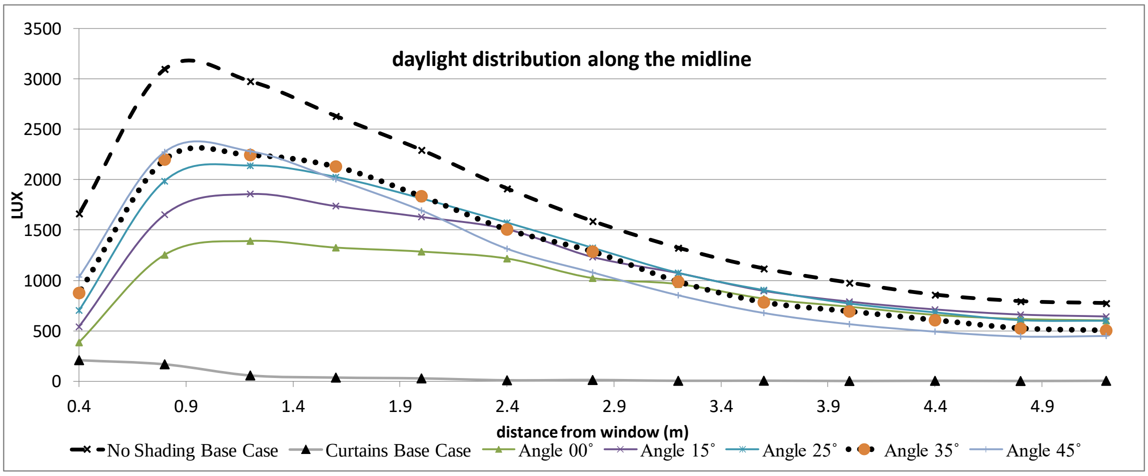

Fig. 6 Daylighting distribution for South-facing window with shading device of 35° inclinational angle with a sky model CIE Clear day at 21st of Jan at 12:00 PM (Freewan and Shqra 2017)

that increasing shading performance will result in reducing daylighting performance, which increased the dependence on electrical lighting and the cooling loads associated with the heat gains from these lighting. It is therefore necessary to consider balancing all variables like window gains, daylighting, cooling loads, and lighting loads in order to achieve an optimized summer devices design. On the other hand, the best winter device that has less impact on the heating loads was the one with the highest window gains with an angle of (35˚).

Daylighting analyses

Simulations for daylighting performance were conducted along with the energy consumption for the south-facing office. The chosen date for summer was 21st of June at 12:00PM, with sky model of CIE Clear Day. The results showed that all shading devices improved the daylighting performance compared to the first base case. Tables 3 and 4 present the results of the daylighting analysis in summer and winter periods and Figs. 5 and 6 show the daylighting distribution along the midline in June and January. It is clear that both daylight quality and quantity have improved. The quality has been improved in term of uniformity by minimizing the difference between the maximum value compare to minimum or average value. Moreover the quantity of daylight has been improved by reducing the daylight in the area near windows to the required level and preventing high level of more than 1000 Lux which causing glare. It can inferred from the tables and figures that assigned shading devices for summer to maximize the shading effect and that for winter to maximize the exposure to sun rays for heating purpose have a great and positive impact on daylight quality and quantity in both seasons.

The daylighting results showed that shading devices provided improvements in the ranges of daylighting factors. The DF range of the first base case was (3.6-23.7%), and the optimized shading with angle (-25˚) provided a range of (1.9-6.8%). The second base case showed the lowest DF due to the blocking of the solar radiation associated by using curtains. It must also be noted that lower in angle of shading devices will result in lower the DF values.

The distribution curves show that the shading devices decreased daylighting levels near the window compared to the first base case office. However daylighting levels at the back of the room were slightly affected by the devices. This indicated that the shading devices blocked the direct solar radiation and reduced daylighting levels near the window, more than that at the back of the room in the same base case. Also, the difference between the daylighting levels of the first base case and that of the shading devices was more in summer, compared to that in winter as seen in Fig. 9 due to the exposure performance positions of the shading devices that designed for the winter.

South-facing devices during winter provided high values of daylighting levels compared to summer devices, as seen in Table 4 and Figs. 9 and 10. The maximum illuminance reached above 2000 lux and DF for best winter position of the shading device (35˚) is between (2.6-2.95%). The daylight uniformity is better in summer as a result of controlling the direct sun rays. On the other hand, the illuminance level in winter is more than that in summer due to direct exposure to sun for heating purpose.

3.2 Spaces with windows facing east or west energy consumption

Tables 5 and 6 describe the results of summer energy consumption for East-facing and West-facing offices respectively. The rotational angles of the vertical louvers were assigned a positive value when taken CW, and a negative value when taken CCW as seen in Fig. 3. The East-facing space with shading devices that marked the highest energy reduction in summer was the one with a rotation angle of -45, and the west-facing one with angle of +45. Energy consumption for cooling in summer in the east-facing cases has been reduced by an average of -53% compared to first base case, and -56% compared to the second base case. As for the west-facing space the energy consumption has been reduced by an average of were -49% compared to the first base case, and -

52% compared to the second case.

Table 5 Energy consumptions for East-facing office window during the cooling period (Freewan and Shqra 2017)

Angle°	No Shading	Curtains	00°	-15°	-25°	-35°	-45°
Windows gains (kwh)	2764.1	2764.1	2883.1	2657.6	2323.1	2030.0	1255.4
Lighting (kwh)	7.60	99.1	12.3	13.1	13.1	32.6	52.6
Cooling loads (kwh)	2173.7	2243.7	1908.7	1768.3	1557.0	1382.2	979.5
Total Energy (kwh)	2181.3	2342.8	1921.0	1781.5	1570.2	1414.8	1032.2

(Fixed variables: spacing 15 cm thickness 1.5 cm depth 10 cm)
(Tested variable: Rotation angle 0º, -15 º, -25 º, -35 º, -45º, degrees (From North axis CW+ CCW-))

Table 6 Energy consumptions for East-facing office window during the heating period (Freewan and Shqra 2017)

Angle°	No Shading	Curtains	00°	15°	25°	35°	45°
Windows gains (kwh)	1040.93	1040.9	507.12	601.06	657.8	710.7	701.6
Lighting (kwh)	22.1	112.6	27.5	32.8	31.2	33.7	28.0
Heating loads (kwh)	1053.33	944.376	1285.8	1225.2	1189.9	1149.0	1162.4
Total Energy (kwh)	1075.4	1051.4	1311.9	1256.4	1219.6	1181.1	1189.0

(Fixed variables: spacing 15 cm thickness 1.5 cm depth 10 cm)
(Tested variable: Rotation angle 0º, 15 º, 25 º, 35 º, 45º degrees (From North axis CW+ CCW-))

Table 7 Energy consumptions for West-facing office window during the cooling period (Freewan and Shqra 2017)

Angle°	No Shading	Curtains	00°	15°	25°	35°	45°
Windows gains (Kwh)	3802.05	3802.05	2883.16	2657.64	2323.17	2030.03	1729.42
Lighting (kwh)	8.25	107.61	12.36	13.18	13.18	32.64	52.62
Cooling loads (kwh)	2525.73	2607.06	1908.7	1768.36	1557.06	1382.24	1243.99
Total Energy (kwh)	2533.98	2714.67	1921.06	1781.54	1570.24	1414.88	1296.61

(Fixed variables: spacing 15 cm thickness 1.5 cm depth 10 cm)
(Tested variable: Rotation angle 0 15 25 35 45 degrees (From North axis CW+ CCW-))

Table 8 Energy consumptions for West-facing office window during the heating period (Freewan and Shqra 2017)

Angle°	No Shading	Curtains	00°	-15°	-25°	-35°	-45°
Windows gains (kwh)	1431.8	1431.8	728.9	899.8	987.8	1018.2	963.5
Lighting (kwh)	24.0	71.15	28.7	29.0	29.8	34.9	54.17
Heating loads (kwh)	906.5	830.7	1187.0	1099.5	1051.5	1027.4	1035.0
Total Energy (kwh)	930.5	898.3	1214.3	1127.1	1079.8	1060.6	1086.5

(Fixed variables: spacing 15 cm thickness 1.5 cm depth10 cm)
(Tested variable: Rotation angle 0 15 25 35 45 degrees (From North axis CW+ CCW-))

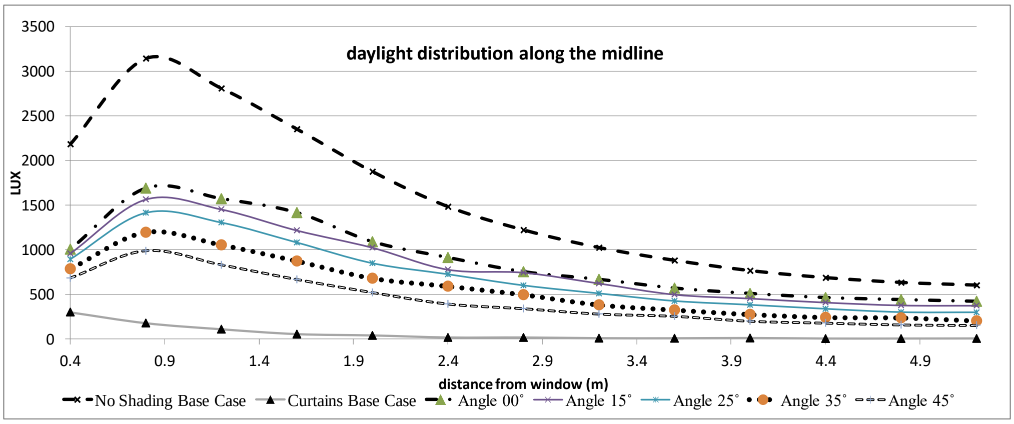

Fig. 7 Distribution curves for the East-facing window for the base cases and the tested devices with a sky model CIE clear day during summer (Freewan and Shqra 2017)

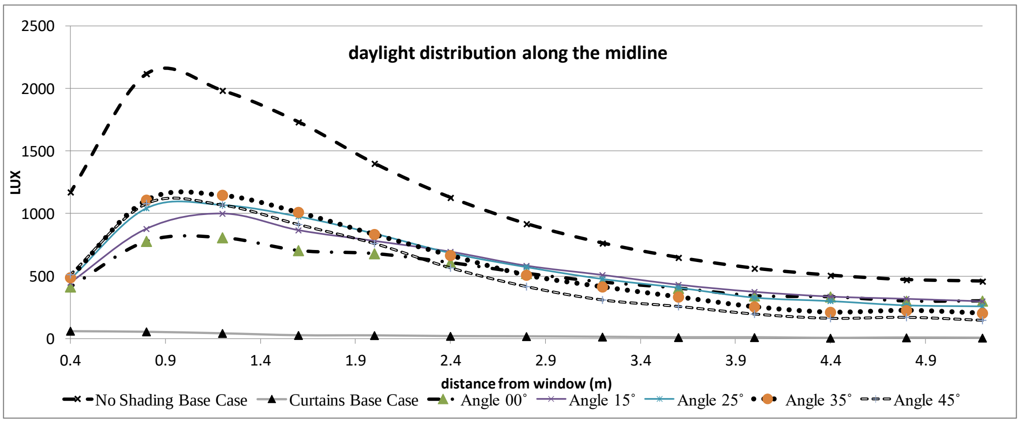

Fig. 8 Distribution curves for the East-facing window for the base cases and the tested devices with a sky model CIE clear day during winter (Freewan and Shqra 2017)

Energy consumption for heating due to using shading devices compare to base cases showed that the angles that caused the least increase in heating and lighting loads were; for East-facing devices; a value of 35, with 13% increase compared to first base case and 10% increase compared to the second. On the other hand, west-facing devices shading devices with rotation angle of -35 had 11% increase compared to first base case and 9% increase compared to the second. Table 5 and table 6 describe the results of winter energy consumptions for east-facing and west-facing offices respectively.

The annual energy reduction for the two-positioned shading devices for the east-facing device was -41% compared to first base case, and -47% compared to the second due to save for lighting energy. Energy saving in west-facing space with adjustable shading devices was -35% compared to first base case, and -40% compared to the second base case.

Summer shading devices were designed to reduce exposure to solar radiation, therefore reduce heat gain through windows as a result of preventing direct sunrays from reaching the glazed surfaces, while winter devices were designed to maximize exposure to sunrays. Designing of shading for both periods will need to bring into balance all variables like shade and cooling loads, heating load and solar exposure, daylighting and artificial light utilization to minimize energy consumption.

Simulations for daylighting analysis were conducted for east and west-facing offices. For summer conditions the date chosen was 21st of June, 09:00am for east and 03:00pm for west, and both with a CIE clear sky model day. The results of east-facing office showed that about 5%-27% of floor area was illuminated naturally with level of 800lux, with the lowest range with shading devices at angle -45˚. Figs. 7 and 8 show the daylight distribution along midline of the space in summer and winter respectively. It is clear that all tested devices improved daylighting performance in the tested spaces compared to the base cases.

On the other hand, results of west-facing office show that a range of 5%-28% of floor area was illuminated naturally of daylight level of 800lux, with the lowest performance with shading devices of 45 angle as seen in Figs. 9 and 10.

The base cases include an office with no shading device and an office with closed interior fabric curtains as the common response of the users to direct sunrays, over heat and glare during the working hours. Simulation results showed the solar heat gains from the windows were high in both base cases; this was due to the fact that interior shading devices like curtains do not, in fact, reduce heat gains from window, but it only prevents direct sunrays from reaching users and so the same heat gains flow to interior. Therefore, the comparison of the tested shading devices with the curtains base case was closer to the real life situation than that of the base case with no shading devices.

The results showed that shading devices in general improved the uniformity of the illuminance levels by reducing daylighting near the window in summer. Winter shading devices were designed to maximize the exposure to solar radiation; therefore the effect of the devices on the illuminance peaks near the window was less than that in the summer.

4. Optimization process/ second stage

4.1 Louvers depth and space between louvers

The simulations in the first stage were conducted with fixed basic variables for south devices (Depth =10 cm and space =15 cm), for east and west devices (Depth and Space=15 cm). Therefore the results focused to find the optimized inclination and rotational angles for the three elevations in summer and winter conditions. The current stage presents the results of simulation aimed to find the best depth and spacing dimensions for each device, by fixing the optimized angles for all orientations. The chosen depth and space dimensions are (10:15 20:30 30:45) for south facade and (10:10 15:15 20:20 30:30) for east and west facades. Dimensions were determined to block high sunrays angles by horizontal louvers on south facade and to block low angles and horizontal sunrays by vertical fins on east and west facades. The best space and depth are these would produce the maximum net energy reduction during both seasons, in addition to best daylighting performance in term of uniformity and controlled illuminance levels. The south-facing devices, louvers of 20 cm depth and 30 cm spacing caused the highest total annual energy reduction with -34% reduction compared to first base case, and -41% reduction compared to second base case.

For east and west-facing devices, fins of 30cm depth and 30 cm spacing caused the highest total annual energy reduction with the following values; for east, a reduction of -43% compared to the first base case, and -48 % compared to the second one. For the west ordination, the reduction was of -38 % compared to the first base case, and -42% compared to the second.

Table 9 Total annual energy reduction for each of the tested WWR and three elevations (Freewan and Shqra 2017)

WWR%	South		East		West	
	Summer	Winter	Summer	Winter	Summer	Winter
30%	-36.6	8.9	-43.5	8.5	-45.5	10.1
40%	-43.9	12.4	-41.0	11.6	-49.2	13.7
50%	-47.4	15.7	-56.7	14.1	-52.9	16.8
60%	-51.0	20.6	-50.8	17.2	-54.7	21.0
70%	-54.0	25.0	-55.3	20.2	-58.2	23.8

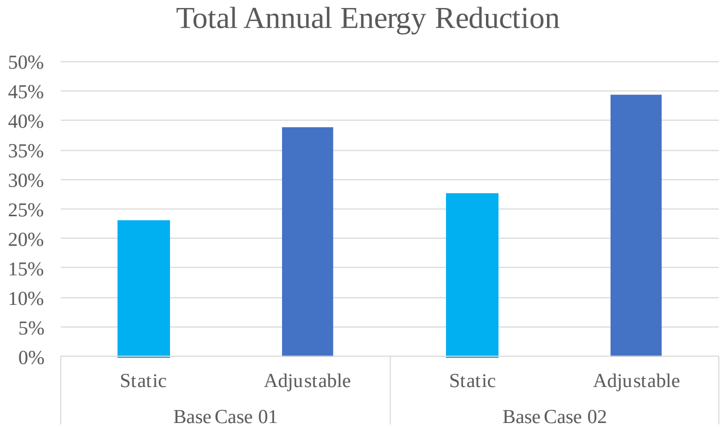

Fig. 11 Energy consumption saving as results of using different shading devices on south facing windows (Freewan and Shqra 2017)

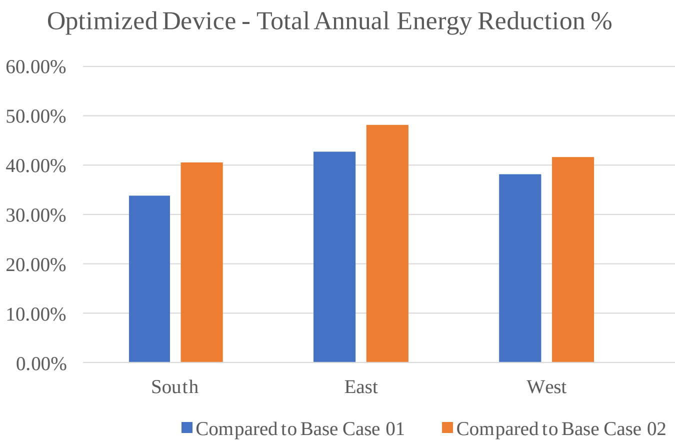

Fig. 12 Percentage of energy saving as results of using shading devices on different orientations compare to the two base cases (Freewan and Shqra 2017)

4.2 Windows to wall ratio

The results of shading devices with the best inclinational, rotational angles and best depth and spacing were used in simulations for cases with different Window-to-Wall ratios. These ratios are of: 30%, 40%, 50%, 60%, and 70%. The total energy reductions produced by the tested WWR compared to the first base case are summarized in Table 9. The results showed that the total energy reductions in summer increased with the increase of the WWR, due to the increase of the glazed surfaces size and the shading devices will be more efficient tool compared to a base case with no shading. The results also showed that total energy consumption is increased during winter as WWR is increased. The results WWR 50%, ratio produced the best balance between summer reductions and winter increase, and therefore the highest total annual energy reductions.

4.3 Adjustable to fixed shading devices

The results of the fixed devices of 0° angle on south windows that design with balance for hot period and cold together as seen in tables (1-2) showed a total annual reduction of -22% compared to the first base case, and -26% compared to the second base case. These results produced 16% and 19% less saving compared to the two-positioned systems for the two base cases respectively, which proved the efficiency of the adjustable of two-positioned shading system in the current research as seen in Fig. 11.

Compared to the second base case, the fixed shading devices with 0° (perpendicular to window) on east orientation for both seasons produced total energy reduction of -31% compared to the first base case, and -19.70% compared to the second. These reductions were around 21% less than the adjustable of two-positioned systems. On the hand, the fixed shading devices with 0° (perpendicular to window) on west orientation for both seasons produced total energy reduction of -19% compared to the first base case, and -22% compared to the second. These reductions were around 23% less than the adjustable of two-positioned systems.

The total energy saving for optimized variables are presented in Fig. 12. It is clear that adjustable shading devices helped to save energy and thus help to improve human comforts.

5. Conclusions

The current research presented the performance of adjustable double-positioned external shading systems in term of energy consumption and daylight performance. The aim was to reduce net energy consumption for cooling and heating and improve both daylight quality and quantity in office buildings in regions with cold winter and hot summer conditions. The research used energy plus and radiance engines within DesignBuilder software to determine the best shading devices positions on south, east, and west facing windows, for cooling, heating and daylight.

The results of the south facing shading device showed that for the summer condition the best variables are louvers with rotation angle of -25°(downward from inside) for shading devices with 20cm depth and spacing between louvers is 30 cm. On other hand, the best rotation positions for winter condition was 35°(upward from inside) for louvers with width of 20 cm depth and spacing between louvers of 30cm with energy saving of more 33% compare to the base case one and around 40% compare to the second base case.

The results of the east facing shading device showed that for the summer condition the best variables are vertical fins with rotation angle of -45° (to north direction from inside) with width of fins is 30 cm depth and spacing between fins of 30 cm spacing with energy saving more than 35% . In addition, the winter rotation angle of fins was 35° (to south direction from inside) with 30 cm fins and depth and spacing between them of 30 cm. The results of the west facing shading device showed that for the summer condition the best variables are fins with rotation angle of -45° (to north direction from inside) for 30 cm depth fins and spacing between them of 30 cm. On the other hand, winter position for the fins 30 cm depth was rotation angel of 35° (to south direction from inside) with spacing between them is 30 cm with energy saving of more 38%. Compared to fixed shading, adjustable shading devices are more efficient as they reduce direct solar gain in summer and allow sunrays to inter indoor spaces in winter by controlling angle or position.

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