

Investigation of the relationship between depth of overhang and amount of daylight indicators in office buildings of Kerman city

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Abstract

Background: The use of daylight in offices has become an effective strategy to improve the quality of indoor space and energy efficiency. There is enough potential to have daylight autonomy in Kerman as a city with more than 300 sunny days a year. Therefore, this study aimed to investigate the relationship between facades configuration and the amount of daylight in office buildings of Kerman.

Methods: This study was carried out based on the simulation in DesignBuilder software (DBS). In this study, 36 typical rooms, with the same physical characteristics (4 m×6 m×4 m), with window-to-wall ratio (WWR) between 10- 90% with four overhang depths (0, 0.5, 1 and 1.5 m) were modeled.

Results: Based on daylight utilization, the results indicate that an optimal WWR for a room with 1 m overhang depth ranged from 50% to 70%. Also, the room with 0.5 m overhang depth and without overhang, had suitable daylight while WWR was at least 50%, but the room with 1.5 m depth would not encounter glare problem even when WWR was 90%.

Conclusion: The results confirm that overhang depth and WWR have significant effect on daylight parameters such as daylight factor (DF), work plane illuminance (WPI), and WPI ratio. Hence, these insights can be useful for designers to design buildings with lower energy use and higher daylight quality, when enough light is provided in office rooms.

Keywords: Sunlight, Office, Kerman, Uniformity, Design software

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Introduction

In the primary steps of design process, prediction of building performance has an effective influence on the future performance of buildings and their energy consumption (1-4). It is essential to use these insights in the early design stages to improve the efficiency of buildings. However, in practice, designers use simulation tools in the later stages of design (5,6). In performance modeling, architects try to inform decisions about building envelope, façade configuration, shading device and environmental factors (7). In the face of projects, architects often try to apply device facades with large transition surface area to use free daylight provided by the sun.

Daylight is a useful and acceptable parameter for providing energy efficiency and visual comfort in a friendly building. However, it is an important factor to create delightful visible environment in modern architecture. Daylight makes indoor environment to be more attractive and pleasant for people who prefer to have a healthier livable

working space (8,9).

According to sustainability challenges such as renewable energy sources and environmental quality, natural light is a great resource to improve energy consumption by minimizing the lighting, heating and cooling load (10,11) (Figure 1).

More than 30% of lighting energy can be saved by two main solutions: increasing the naturally available indoor daylight and the use of efficient artificial lighting devices (12).

Window size, as one of the most effective factors, which is labeled as the window-to-wall ratio (WWR), influences the daylight quality and thermal performance (13-15).

In 1984, daylighting was studied in relation to windows without any movable shading devices in Washington DC with variable WWR (10%, 20% and 50%) and several orientations using daylight program (DALITE) (16). In a parametric study in the United Kingdom and Brazil, the results of scale and simulation models showed



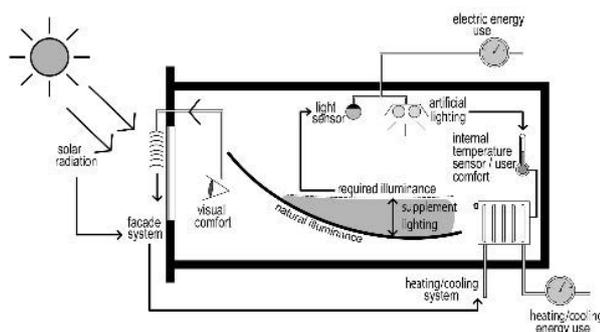


Figure 1. Influence of daylight on heating, cooling and artificial lighting systems.

the importance of window sizes and room features in improving electric lighting consumption and providing maximal view (17). A study in Sweden showed that daylight autonomy for 100% WWR with louvers was 50% and for the case of 60% WWR with louver systems, it decreased to 45% (18). In a city in saturation region such as Montréal, 30% WWR provides suitable daylight in office buildings (19). Energy simulation of an office in the tropical area has shown that 100% WWR can increase energy consumption by 15% more than 30% WWR in a building (20).

A simulation research based on daylight for different orientations indicated that an optimal WWR ranging from 20% for south orientation to 40% for north orientation was acceptable (21). In another research in Japan, as the WWR decreased, the CO₂ emissions also decreased and in 30%-50% WWR, the CO₂ emissions were minimized and with increasing the WWR, the CO₂ decreased (2).

Several studies have examined shading device as a daylight control device besides WWR. They investigated the relationship among critical variables such as energy consumption, air pollution and natural sources (22). The ratio between the amount of daylight in two conditions, with and without shading device, was used to evaluate the daylight efficiency of shading device. If the overhang depth is equal to the height of window, the amount of daylight will reduce by 60%, without considering the reflection and entering the light from sides (23). The amount of daylight factor (DF) can be minimized by 50% if the depth of shading device be appropriate. Furthermore, the amount of DF is between 2% and 6% in different positions with respect to the window under clear sky condition (24).

There is a relationship between shading device, daylighting and energy consumption. Shading devices also influence the amount of luminance, since they can provide luminance more than 500 cd/m². Shading device with dark color cannot provide acceptable work plane illuminance (WPI), even when the sky is clear and global illuminance is around 65 000 to 95 000 lux. The effect of different overhang ratios and light shelf configurations on the amount of daylight and uniformity of daylight in the room was investigated. The results demonstrated that the

amount of daylight at the rear of the room decreased by increasing the depth of shading device (25).

The daylight performance is assessed for hot and arid climates using specific shading devices. The effect of shading device depends on the surface reflectance. It has been revealed that 70% to 80% reduction in the illuminance level occurs when surface reflectance reduces by 50% (26). The average DF reduces 50% by using shading devices. Besides using shading devices, the problems of glare and contrast had been minimized (24). Ho et al showed that an appropriate use of solar shading not only improves the illuminance level, but also reduces energy consumption of lighting by 71.5% (27). Scale model was used to investigate the effect of shading device and window area on DF in sub-tropical climate (28,29). In addition, the impacts of external shading devices on the incident solar radiation and daylighting were investigated in office rooms under specific sky conditions (30). The best orientation for horizontal and vertical shading devices that provides acceptable illuminance was estimated when solar heat gain was in the minimum position (31).

Briefly, previous research consistently shows that increasing WWR is not always necessary to provide enough available daylighting and reduce electric lighting. The main objective of this parametric study was to determine the optimal WWR and overhang size, under different daylight indicators as a shading device in office buildings of Kerman located in a hot and dry arid climate, to improve the indoor daylight quality.

Methods

This paper proposed an analysis with scale model. This technique is called 'reference office' as a lighting assessment methodology (13,32-35).

Reference office description

The reference office model is used for comparative analysis of different studies on natural and artificial lighting to represent the characteristics of a simple typical office room. This method is commonly used for a standard concept design in any location. As a research method, "Shoebbox" model has been used as a default type of office room to assess daylight availability and lighting technology. Since its introduction in 1997, more than forty papers have used "Shoebbox" as a sample, by deploying various dimensions between 3 and 5 m width, 5 and 8 m length and 3 and 4 m height.

Using "Shoebbox" model allows us to conduct a comparative study on different results and also continue to develop achievement in actual model. Having access to a set of valid simulation and performing a comparative analysis with the same cases under various conditions, are the merits of the reference model methodology (32).

Lighting and energy simulation program

Computer simulations are suitable to improve building

optimization as well as indoor climate quality and energy efficiency. Evaluating both thermal and daylight evaluations by computer simulations is a reasonable idea for the prediction of physical features such as façade and window design strategies. This study was conducted by applying the validated dynamic daylight simulation software (DesignBuilder, DBS), which is a radiance-based one (36).

DBS version 1.8.1 (36) software evaluates the influence of configuration and physical characteristics of a building on energy efficiency and daylighting in several zones (37). This program is a dynamic daylighting and energy simulation software, which can demonstrate daylight performance in virtual space samples. DBS uses EnergyPlus as its simulation engine, which calculates the heating, cooling and lighting load of buildings according to ASHRAE standard method (38). First, the main question that comes to mind about the usage of any simulation software is related to its validation and calculation accuracy, in relation to the actual demands. Previous studies have shown that this software calculates the demands of energy and lighting with a high definitude (39). The difference between the amount of heating and cooling loads by EnergyPlus simulation with an experimental measurement during 24 hours was very significant (3%-5%) (40). In another research, this validation was about 13% in terms of energy and lighting consumption (41). In Iran, the results of a calibration study by DBS and Ecotect software based on an experimental test showed a difference of 23% in energy consumption and 14% in daylight estimation (42).

The present study adopted the indoor daylight quality of several glazed window types in four types of office room in Kerman using DBS.

The simulation models were carried out by lighting analysis and the date and location were set. Daylight indicators including DF, WPI, WPI Ratio, were calculated. Different analyses indicated the effect of shading devices and window size on daylight quality in office rooms. Microsoft (MS) Excel was used for drawing tables and charts and descriptive comparison analyses. Excel charts showed the behavior of light with window size and overhang depth in an office.

Measurement indicators

The metrics used for daylighting analysis, were DF, WPI and WPI Ratio. These metrics were proposed by the Illuminating Engineering Society (IESNA) and International Commission of Illuminance (CIE) to assess the sufficiency of daylighting quality in an interior working environment (14,25,43-45).

Maximum and minimum set points of daylight indicators were defined according to several standards, which propose the indoor conditions of buildings based on visual comfort and user satisfaction. DF, WPI and WPI Ratio are the output parameters of lighting computations

in DBS.

The basic model in this research represented a south-facing side office room, located in Kerman city (30.2839° N, 57.0834° E), with a hot and dry climate. The room was not adjoined with other rooms. The dimensions of the space were 6 m width, 4 m length and 4 m height, which represents the common height of the majority of office rooms in Kerman. The reflectance amounts of the ceiling, walls, floor and window were assumed to be 70, 30, 90 and 80 as the reflectance of general materials in an actual model (Table 1). The window sizes were in a variable range between 10% and 90% WWR with four types of overhangs (0, 0.5, 1, 1.5 m).

In total, four office rooms with 6 m length, 4 m width and 4 m overhang height were modeled. One of the rooms has no overhang. An overhang with 0.5 m depth was modeled in one of the rooms. In another one, the depth of overhang was considered 1 m. Finally, the last model had an overhang with 1.5 m depth. Furthermore, different sizes of south-facing window, from 10% to 90% (WWR), were modeled in all four models. Therefore, 36 different models with different window areas and different overhang depths were simulated in DBS software (Figure 2).

In the construction section of DBS program, materials and different layers of external walls and roofs were specified. In the opening section of DBS, window materials and layers were specified: windows had 2 layers with 6 mm thickness and 13 mm argon gas between the layers. Finally, in daylighting section, all 30 models were analyzed and different indicators of daylight such as DF, average WPI and uniformity ratio were recorded for each model.

Results

The results obtained from 36 models were calculated and analyzed by MS Excel program. Data were classified into three categories in terms of daylight performance indicators (DF, WPI and WPI Ratio).

Table 1. The parameters of a typical office used for computer simulation

Office Parameter	Average Reflectance (%)
Walls	70
Floor	30
Ceiling	90
Window	80

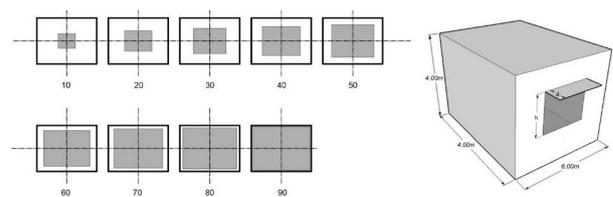


Figure 2. Window size variations of office rooms with different overhang depths.

Evaluation of office rooms with different WWRs and overhang depths in terms of DF

The amount of DF [(internal/external illuminance) ×100] and different depths of overhang and WWRs of an office room model were simulated, assuming that the models were south-facing. The data are presented in Table 2.

As shown in Table 2, for different overhang depths and WWRs, the maximum amount of DF was 7.71 for 90% WWR, when the room was without overhang and was under overcast sky condition. However, almost for all positions of overhang depth in the case of 10% WWR, the minimum amount of DF was obtained. The DF monotonically increases by increasing WWR in all depths of overhang. According to the Dubois recommendation, DF should be between 2% and 5% (45). It means that the acceptable range of DF is between 50% and 60% WWR, when the model has the best daylight quality. The space between two bold lines in Figure 3 shows the acceptable range of DF for the research model. However, the DF trend shows that in a hot and dry climate, using larger windows over 60% WWR without overhang becomes a steely glare and to provide the minimum available daylighting with or without overhang, WWR should be at least 50%.

Evaluation of office rooms with different WWRs and overhang depths in terms of WPI

The amount of WPI in different models with different WWRs and overhang depths are summarized in Table 3. The acceptable rate for WPI was set according to Dubois standard. Although WPI more than 300 lux for both paper work and computer work was ideal, but it did not enhance more than 500 lux (45). Furthermore, it was revealed that an office room without overhang could not achieve the

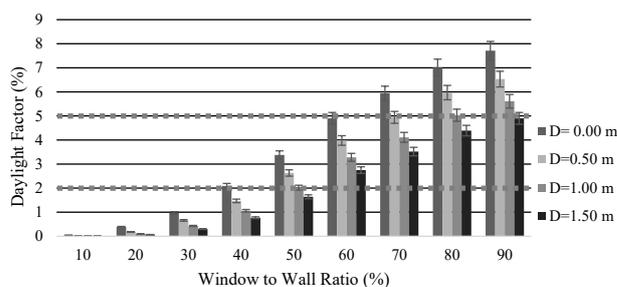


Figure 3. Amount of daylight factor in different models with different WWR according to the depth of overhang

ideal condition in terms of WPI at all (Table 3). Because the room without overhang and with 30% WWR had a WPI less than 300 lux but in cases with 40% WWR, WPI was more than 500 lux. If the office room had overhang with 0.5 m depth, the ideal condition of daylight would be provided when 40% WWR was applied. In addition, when overhang depth was considered 1 m, the office room with 50% WWR could provide 505 lux WPI and the amount of WPI in an office room with an overhang with 1.5 m depth was 384 lux.

Finally, the least useful daylight illuminance, without artificial lighting, was observed at 40% WWR, when the maximum overhang depth was 0.5 m. Against that, designing windows over than 50% WWR is not suitable for all conditions.

Evaluation of office rooms with different WWRs and depths of overhang in terms of uniformity ratio

The input parameters used in this study for WPI Ratio analysis are summarized in Table 4, which shows the

Table 2. Amount of daylight factor in different models with different WWRs according to the depth of overhang

Overhang Depth	WWR								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
D = 0.0 m	0.04	0.39	0.97	2.09	3.38	4.90	5.94	7.01	7.71
D = 0.5 m	0.01	0.18	0.66	1.47	2.63	3.98	4.94	5.97	6.53
D = 1.0 m	0.01	0.09	0.43	1.06	2.02	3.28	4.11	5.03	5.61
D = 1.5 m	0.01	0.07	0.30	0.77	1.64	2.75	3.52	4.39	4.90

Table 3. Amount of work plane illuminance in different models with different WWRs according to the depth of overhang

Overhang Depth	WWR								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
D = 0.0 m	14.9	105.7	273.4	555.3	841.8	1228.6	1270.4	1310.2	1332.5
D = 0.5 m	2.03	37.2	166.6	398.8	649.3	1045.3	1144.4	1186.6	1201.8
D = 1.0 m	1.9	13.0	88.6	250.5	505.4	876.7	962.9	1028.0	1061.0
D = 1.5 m	1.7	10.8	50.63	163.1	384.0	744.3	820.5	901.3	932.6

Table 4. Amount of uniformity ratio in different models with different WWRs according to the depth of overhang

Overhang Depth	WWR								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
D = 0.0 m	0.00	0.08	0.12	0.28	0.44	0.64	0.64	0.72	0.76
D = 0.5 m	0.04	0.16	0.16	0.28	0.48	0.68	0.72	0.76	0.76
D = 1.0 m	0.08	0.20	0.24	0.32	0.56	0.72	0.76	0.80	0.80
D = 1.5 m	0.12	0.32	0.32	0.40	0.60	0.76	0.84	0.84	0.88

effect of overhang depth on the amount of WPI Ratio and uniformity ratio when various WWRs (10%-90%) were applied. WPI uniformity is important to keep away places from contrast and better lighting quality. The acceptable illuminance uniformity (minimum/average) over any task area should be lower than 0.8 CIE (1986) and CIBSE (1994) (44,46). Many lighting standards require a uniformity ratio of 0.8 (minimum/average) or 0.7 (minimum/maximum). However, some research indicated that a ratio of 0.5 (minimum/maximum) may be even acceptable (45).

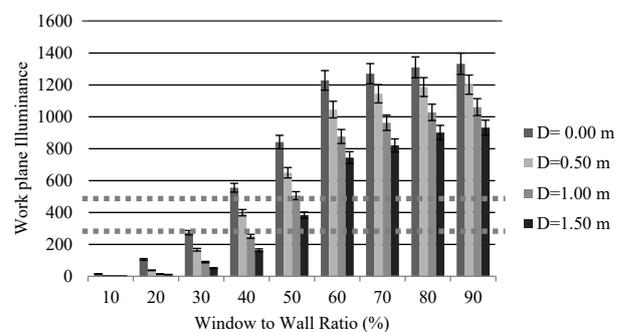
Table 4 shows that for a window with WWR more than 60%, uniformity was around 0.7-0.8, which is acceptable for excellent daylight uniformity, according to daylight standards. Moreover, Table 3 shows that WPI Ratio or uniformity ratio below 0.5 was obtained for 50% WWR or less. WPI Ratios show the urgency to use solar shading devices for 50%, 60% and 70% WWR. If the office room had no overhang depth, the ideal daylight uniformity would be provided when 80%-90% WWR was applied. In addition, when overhang depth was considered between 0.5 m and 1.5 m, the office room with a WWR more than 50% could provide acceptable uniformity. The optimal WPI Ratios without overhang in this section, also were proposed by 70% and 80% glazing type.

Discussion

In this study, simulation technique by DBS was used to carry out daylight analyses and characterize the façade configuration such as WWR and overhang depth. Optimizing daylight parameter is important as it influences energy consumption through supplementary artificial lighting, heating and cooling demand besides providing the visual comfort (47). The results show that, office rooms with overhang depth of 0.5 m and 1 m had enough potential for daylight utilization, when they had at least 50% WWR. Furthermore, these two office rooms with 80% and more than 80% WWR, probably encountered glare problems because they had an average of DF more than 5%. According to Figure 3, office room with overhang depth of 1.5 m, will not encounter glare problem even though 90% WWR is applied. The office room without overhang, will have acceptable potential for daylight utilization when WWR is considered 40%,

50% or 60%. Based on CIE and CIBSE standards, DF had an acceptable range between 0.2 and 0.5 in rooms with different WWRs and overhang depths (44,46).

As shown in Figure 4, the amount of WPI in different models with different WWRs and depths of overhang, could be increased by increasing WWR. Against, it can be concluded that with increasing the depth of overhang, WPI decreases in all ranges of WWR. Therefore, an ideal condition can be provided with larger window area while a greater depth of overhang is applied. The license predicts that the optimum daylight illuminance is in the range 300-500 lux, which is specified by the space between bold lines in the graph. The results show that for 40% WWR on a south orientation with no overhang, daylight supported the model with 500 lux, which is equal to a same case in Montreal by 30% WWR in the cold region (14). As shown in the chart analysis, the maximum acceptable WWR with overhang was 50% whenever the available daylight was approximately 500 lux. With the same research in Sweden, the results indicated that an office glazed to 100% does not provide significantly more daylight on the office desk than a 60% glazed office both with and without shading system (18). Large transparent surface causes glare problem by entering a highly amount of daylight in office spaces (21). Thus, shading devices should be prevented discomfort glare and energy waste besides allowing complain view. According to Figure 5, window to façade ratios between 10% - 90% were considered for uniformity ratio analysis. However, with increasing depth of overhang, WPI and uniformity ratios were also increased, but in this case, the amount of uniformity ratio does not reach the acceptable

**Figure 4.** Amount of work plane illuminance in different models with different WWRs according to the depth of overhang

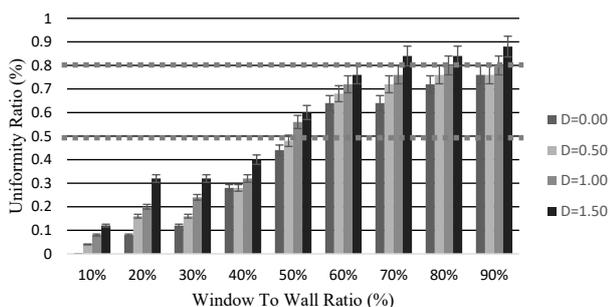


Figure 5. Amount of uniformity ratio in different models with different WWRs according to the depth of overhang.

condition. As the result shown, 50%-90% WWR has satisfying goals in the case of uniformity ratio for offices in Kerman with clear sky condition.

Conclusion

According to the results, increasing depth of overhang as a shading device can influence different daylight indicators such as DF, WPI and WPI Ratio. Depth of overhang has a direct relationship between with uniformity ratio but it has a reverse relationship with WPI and DF. Using overhang has a significant effect on daylight quality and it can provide enough daylight inside rooms when larger window area is applied. So it can influence the design of façade and provide wide view for occupants. Providing enough daylight potential in office room, not only causes more energy saving but also reduces air pollution caused by energy consumption. Furthermore, overhang can enhance the amount of uniformity ratio but it is not sufficient. Thus, shading devices are used more repeatedly in glazed buildings to preserve the same quality of daylight as in a building with a general facade.

The increase of WWR not only could not provide satisfying condition for indoor daylight quality, but also caused glare problem or increased energy consumption. However, findings of this research can be used in energy efficiency and specifically, daylight quality in office buildings of Kerman with a hot and arid climate in Iran. Therefore, enough daylight potential reduces the electricity consumption with lighting devices. Thus, the result of this research can help designer to design office rooms with suitable WWR and overhang depth for providing sufficient daylight without energy consumption.

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Ethical issues

The authors certify that all data collected during the study are as stated in the manuscript, and no data from the study

has been or will be published separately elsewhere.

Competing interests

The author declare that he has no competing interests.

Authors' contributions

All authors participated in the data collection, analysis, and interpretation. All authors critically reviewed, refined, and approved the manuscript.

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