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Research Article

Optimizing Window Size and its Sunshade in Four Main Directions of Residential Buildings in Mild Climate by Integrating Thermal and Lighting Analysis

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ABSTRACT

As part of sustainable architecture principles and practices, designers need to define building's architectural requirements based on climatic conditions, environmental preservation and reduction in energy consumption. The natural energy sources such as solar radiation affect thermal and lighting performances of buildings depending on its facade characteristics. Traditionally, buildings thermal and lighting analyses are employed independently. As non-linear relationships are often disclosed, an integrated thermal and lighting approach is necessary to optimize the façade configuration.

This paper presents an integrated model of thermal and lighting energy simulation which investigates 1650 window configurations, and sunshade size in a residential building in a mild climate to find the optimum solution. The integrated thermal and daylight simulations are carried out using Energy PlusV8-1-0, Daysim 1.08 and Radiance 2.01 software. Calculations are performed on hourly basis for an entire year. First, climatic parameters are validated by on-site measurement. Then all thermal and lighting parameters of the simulated model are defined. Next, the optimal results of the window and sunshade characteristics in four main dimensions (South, North, East, and West) are presented by genetic algorithm approach.

The results show that, the window orientation affects up to 10% on energy saving, and horizontal windows with higher sill levels are more energy-efficient in south and east orientations. The optimal sunshade angel of the south orientation is 65-85 degree and its optimal range of Window Wall Ratio(WWR) is 15-25%.

1. INTRODUCTION

About 40.5% of total energy consumption in Iran pertains to building sector. Using artificial lighting electrical energy consumption to supplement total energy consumption has a recognized potential for energy saving. The use of the day lighting must be regulated in order to avoid excess illumination level, which may cause visual discomfort, overheating problems and an increase in cooling loads of buildings [1-2]. In addition, Natural gas is one of the products predominantly used for heating and maintaining thermal comfort inside buildings in Iran. Thus energy consumption, in large extent is related to heating and cooling demands as well as lighting demands [3]. The discrepancy between window's effect on thermal and lighting energy consumption is one of the research topics nowadays. The configuration of the façade can affect three terms of the annual energy demand of a building, as defined in EN 15603 [4]: energy needed for heating (EH), energy needed for cooling and dehumidification (EC), and energy needed for lighting (EL). However, other three ones, i.e. energy needed for ventilation and humidification, hot water and other services are not directly affected by it [5]. Significant and useful amounts of day-light maybe provided in buildings through well-designed and regularly cleaned skylights, windows, doors, and glass-block wall areas [6]. Therefore, choosing an appropriate window feature is a key step in building design [7]. Thermal and day-lighting performances are affected by many correlative factors

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such as glazing size and properties, shading properties and its control system, room aspect ratio and its orientation [8]. In spite of the numerous studies on energy efficiency in buildings through last decades, yet, most of new constructions are not designed properly with regard to the integration of day-lighting with the electric lighting and HVAC systems [9].
According to the advancement of computing and programming technology, analyzing and optimizing the architectural concept due to saving energy parameters is considered as a major step in the sustainable design process.
In this paper, the optimal Window Wall Ratio (WWR), window's Width to High Ratio (WHR), its sill level and the sun shade angel is presented by integrating thermal and lighting energy consumption and using UDI (useful day-light illumination) for glare analysis. For optimization process, a genetic algorithm is used.
The optimization is based on 1650 different window's configurations of a residential building in mild climate.

2. LITERATURE REVIEW

Optimizing architectural elements for utilizing natural energy sources and subsequently reducing building's energy consumption, is one of the important factors in sustainable design. The impact of windows area on buildings day-lighting and thermal performances has been investigated. However, because of the variety of designs and climate there couldn't be any standards to determine an optimum window for all designs. Therefore, scientists are investigating different cases and methods to find an appropriate window to wall ratio in different building programs and climates.
Fransisco [10], Goia et al [5], Peter and associates in a report to Australian Building Codes Board on optimal Window Size for energy efficiency [11], simulated office buildings and compared their cooling, heating and lighting energy consumptions for different WWR. Also Hassouneh et al. [12] presented influence of windows characteristics and area on the thermal energy balance of apartment buildings in Amman.
Shikder et al. [13] optimized window size and its location on a south wall in a patient's room.
The impact of window size on ventilation and visual comfort has also been investigated by Stavrakakis et al. [14] and Ochoa et al. [15].
In addition, a smart-window system influences on reducing energy consumption have been considered by Dussaul et al. [16] and Szymon et al. [17].
Some researchers studied the impact of the buildings material on lighting and thermal energy consumptions [18]. The impact of the shading devices on the office building's thermal and lighting energy consumptions have been investigated recently by Lee etal. [19]. The methodology of optimizing the window size and related parameters are really influential. Grynninga et al. [20] suggested three different rating methods and applied them to assess the energy performance of several window configurations.
It has been found that various rating methods give different energy saving potentials in terms of absolute figures. As seen in various articles in recent years, many researchers have not considered the glare influence on WWR optimization. Also, the best solution was obtained by comparing methods in official buildings, although the most energy consumption is for residential buildings.

3. METHOD

Due to variability of software and methods for analyzing thermal and lighting energy consumption, for lighting, cooling and heating analysis, Institute of Standards and Industrial Research of Iran (ISIRI) 14253 based on EN [21- 23] is considered.

In this study Dialux 4.11 for luminaire power calculation has been used. Also standby power and ballast loss factor are added as influential lighting parameters.
In addition Daysim software for lighting simulation is applied.
Szczepaniak et al. [24] investigated the accuracy of predictions of European Standard EN 15193, by comparing the standard's mathematical approach with computer predictions of Daysim.
They found that EN standard overestimates energy savings, especially in 'fully automatic' modes.
It is worth noting that analyzing software relate to ideally maintained and commissioned lighting systems, which is quite rare in real circumstances, so the possible savings are usually much smaller than the simulated results. The integrated thermal and daylight simulations are carried out using Energy Plus V8-1-0 [25], Daysim 1.08 [26] and Radiance 2.01 [27]. software. Calculations are performed on hourly basis for an entire year.
The integration process is designed by Rhinociros 5 software and its Grasshopper 0.9.0075, Honeybee 0.0.55, Ladybug 0.0.58 plugins. In addition, to consider Daylight Glare Probability (DGP), the range of Useful Daylight Illuminance (UDI) is employed [28]. In the modeling procedure, first the simulated buildings properties and its adjacent zones such as enclosure characteristics, thermal and lighting controlling systems, shading devices and other parameters are defined. Then the analysis period is mentioned and lighting parameters such as the sensor points, testing mesh, lighting power, ballast loss factor, standby factor, and delay times of the lamp are defined.
Afterwards, all thermal parameters like infiltration rate, number of people per area, ventilation, and equipment load and all lighting and air conditioning schedules are defined.
Then lighting and thermal set points are specified. Finally the results are integrated and optimized by genetic algorithm.

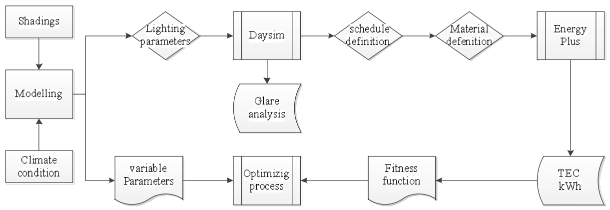

Figure 1. Process of modeling

The process of modeling is displayed in Fig. 1. It has four main steps: defining the building features and its requirements, validating input weather file data by on-site measurement, determining input parameters for the lighting and thermal analysis and clarifying variable parameters and fitness function for optimization algorithm.

3.1. Optimizing Criteria for Decision Making

In order to integrate optimization process with lighting and thermal energy analysis, genetic algorithm, which is an evolutionary type of algorithm, has been employed. It is noteworthy that evolutionary algorithms do not guarantee an exact solution but in this algorithm, newer answers are generally of a higher quality than older ones [29]. For this algorithm, a fitness function and some variable parameters is needed. The fitness function is defined as follows: Eq. 1.

$$TEC = \sum E_C + \sum E_H + \sum E_L \qquad (1)$$

Where, (TEC) is the Total Energy Consumption of a building (kWh), Cooling Energy Consumption is E_C (kWh), Heating Energy Consumption is E_H(kWh), and Lighting Energy Consumption is E_L(kWh).
TEC is the fitness function which should be minimized for optimization process. Furthermore variable and constant parameters for simulation process are defined as follows: Window height and width, sill and lintel level and its sunshade angel are variable parameters.
As a result WWR, WHR and the sunshade size are optimized.
The constant parameters are as follows: the number of zones which are analyzed, building program and occupancy, window pane specifications:
U factor value (Thermal conductance) and Solar Heat Gain Coefficient (SHGC). The other specifications of the building elements of the studied model are: roughness value, thickness, conductivity and density, specific heat, thermal absorption, solar absorption, visible- absorption, effective mass of partitions, heating and cooling set point temperatures, and HVAC system.

3.2. Model Characteristics

A living room in a residential building in mild climatic zone of Iran has been simulated. It is situated on the second floor. The room has a single skin facade and is 5 m (width) x 6 m (depth) x 3.2 m (height). Also the interior walls are considered as adiabatic. (Fig. 2. Left). These values are retrieved from an empirical research on Rasht's residential buildings in Iran [30, 31]. The appropriate area for window based on architectural design is displayed in Fig. 2. The Window is placed in the center of the wall. The minimum sill level is assumed to be 0.8 m, due to the standard height of a working plane. Also the maximum lintel level is 2.8 m.
Maximum window width is 4.4 m. The center of the window is one of the variable parameters shown in Fig. 2. Also the maximum size of the sunshade is 1.5 m.

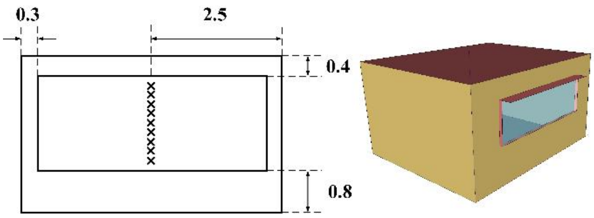

Figure 2. Left: The considered area for window design. Right: one of the simulated windows

According to Fig. 2, there are many different configurations of window size and position. Therefore the range of the parameters should be restricted. Window height is increased at 0.4m intervals, which consist of six different values (0, 0.4, 0.8, 1.2, 1.6, 2 meter).
Window width is increased at 0.44 m intervals. It consists of eleven different values, as follows: 0, 0.44, 0.88, 1.32, 1.76, 2.2, 2.64, 3.08, 3.52, 3.96, 4.4 meter.
In addition 9 points at 0.2 m intervals are selected for the center of the window.
Also the horizontal sunshade width is increased at 0.1 m intervals. It consists of 15 different values. Therefore 1650 cases have been considered for optimization procedure in 4 main orientations of the simulated building in Rasht. The Specifications of the building components are those which are recommended for 4A climate zone in ASHRAE [32] and by the national building code part 19 [33]. PVC double glazed window with total U value of 2.9 W/m^2 K is selected.
The U values of components are listed in Table 1. The RGB reflectance for the Walls, Window, Floor and Roof is 0.5, 0.654, 0.2, and 0.35 respectively.

The occupancy schedule is presented in Table. 2. Internal loads which are dependent on the number of people per area, lighting density, infiltration rate per area, ventilation rate per person, equipment load per area are shown in Table 3.

TABLE 1. U values of simulated living room's components

Room's components	Window	Internal walls	Floor	Roof	External wall
U values (W/ m²K)	2.9	2.5-adiabatic	1.4	0.6	1

TABLE 2. Occupancy schedule (%)

Hour	22-24	19-21	18	17	10-16	9	8	1-7
Occupancy %	100	90	50	30	25	40	85	100

TABLE 3. Internal loads

Ventilation rate (CFM/ person)	Infiltration rate per area (%)	Number of people per area(people/m²)	Lighting density (W/m²)	Equipment load (W/m²)
7.5	0.0003	0.03	2.45	1

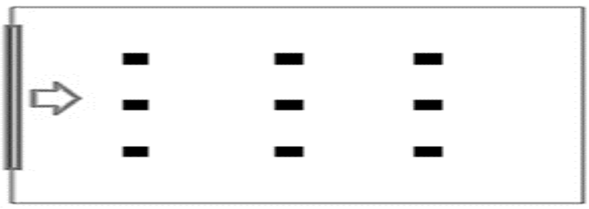

Figure 3. Arrangement of daylight sensors in the room

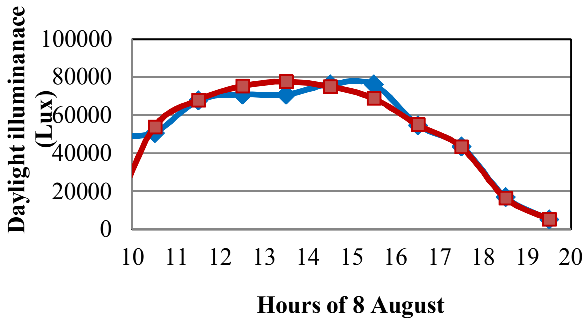

Figure 4. The comparison between monthly average temperature data used in the simulation and averages of 5-Year meteorological data

The amount of the simulated lighting power using Dialux software is 184 W. Also the standby power is 3W and the ballast loss factor is 20%. The ideal HVAC system considered in the design has a heating set point of 20°C, while the cooling set point is 25°C and lighting set point is 135 lux [34]. The lighting control system is assumed by auto dimming and occupancy scenarios. Fig. 3 the arrangement of daylight sensors over a working plane with 0.8 meters height is shown. To define an accurate and complete weather data for the simulated model, the EnergyPlus Weather (EPW) file which is obtained from Meteonorm software has been measured empirically. A luxmeter logger LX-1128SD, placed on the 7 th floor of an apartment building on 8th August 2015, for lighting measurement. And 5-Year meteorological data from Rasht meteorological organization was used. The information is compared to EPW file's data used in the simulation. In Fig. 4 the comparison between the 5-year average temperature and the simulated data is displayed. As shown, the correlation coefficient is 0.99 also the simulation error is equal to 4.7%. In addition in Fig. 5, the comparison between the measured daylight illuminance and those simulated is displayed. As shown, the correlation coefficient is 0.99 also the simulation error is equal to 3.7% which presumably relates to the difference in sky cloud coefficients

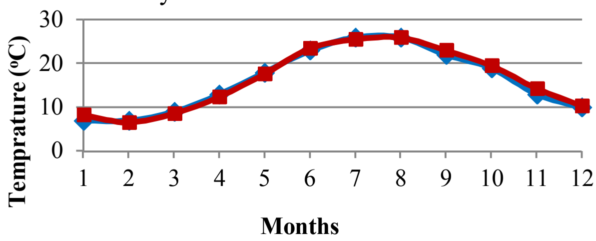

Figure 5. The comparison of daylight illuminance values on 8th August between the measured and the simulated data

3.3. Evaluating the Quantity of Lighting

The metric used to evaluate the day-lighting provision was the useful day-light illuminance (UDI) scheme. UDI is defined as the annual occurrence of illuminances across the work plane where all the illuminances are within the range of 100-2000 lux. Illuminances exceed the upper limit is indicative of the potential for occupant discomfort [28].

4. RESUITS

In this section, the heating, cooling and lighting energy consumptions of the building in all 1650 modes of the window size, location and its sunshade in four main orientations (South, North, East and West) are analyzed separately. Subsequently the UDI parameter is investigated as the glare analysis in the optimal windows and sunshades lighting performance. In order to integrate optimization process of window size with thermal and lighting energy analysis, a genetic algorithm has been selected. This process, is applied by Galapagos plug in of Grasshopper in Rhinoceros software. Window height and width, window center, its sill and lintel level and its sunshade width are defined as the variable parameters or genomes. Also the value of the algorithm population and stagnant is considered constant and equal to 10 which means after finding the optimal solutions, optimization process will be continued with 10 other populations to validate the answer.

4.1. Optimizing Window and its Sunshade Size

Heating, cooling and lighting energy consumptions of the building in all 1650 modes in four main orientations (South, North, East and West) are analyzed separately.

4.1.1. Optimizing WWR and the Horizontal Sunshade Size in South Orientation.

In south orientation, the optimal TEC is 1512.5 kWh when the optimal window width is 3 m, its height is 1.2 m and its sill level is 1.6 m.
In addition, the optimal horizontal sunshade angel in this mode is 75 degree which saves annual total energy up to 0.6 % per year.
Also the optimal configurations generally are the horizontal windows with higher sill levels (Table. 4).

TABLE 4. Comparing the annual TEC among 6 configurations of the south oriented wall's window with and without sunshade

TEC (kWh) (with shading device)	Horizontal shading angel	TEC (kWh)(without shading device)	Window sill level (m)	Window width (m)	Window height (m)
1513.8	75	1522.2	1.6	3	1.2
1519.6	80	1521.7	1.72	3	0.96
1520.2	80	1522.2	1.6	3	2
1521.3	70	1528.7	1.2	2.6	1
1526.6	85	1532.8	2	2.6	0.8
1526.7	85	1527.5	1.6	3.52	1.2

Since a range of optimal WWR is desired in architectural design, the WWR of the 50 Premier modes of optimal windows are analyzed. As in Fig. 7 is displayd building's TEC reached minimum when WWR is 15–25%. In addition, the optimal range of the angel of the south oriented horizontal sunshade is between 70 and 85 degree (Fig. 8).

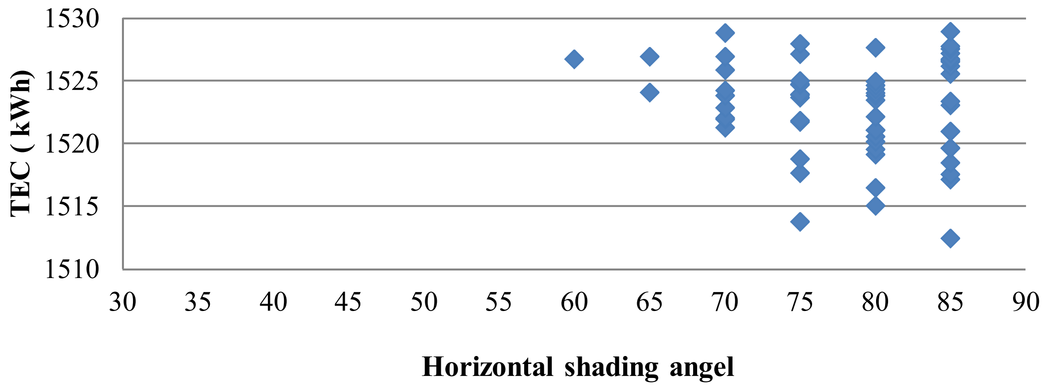

Figure 6. The optimal range of WWR in south oriented wall

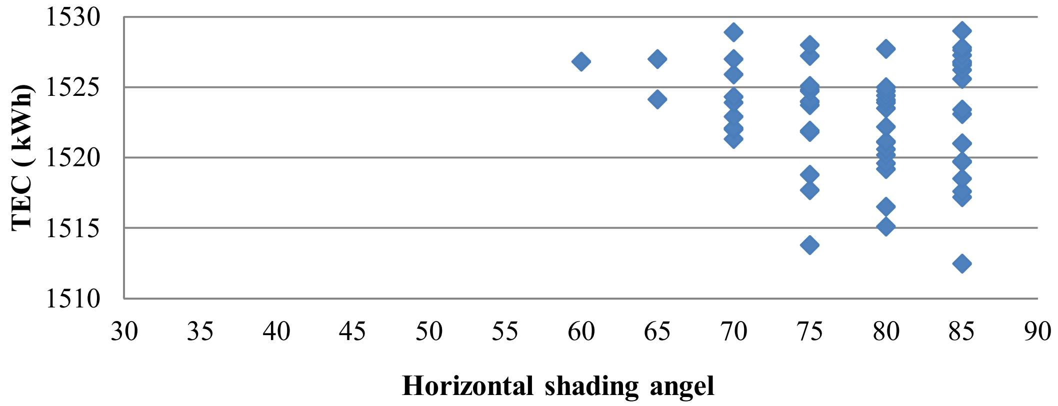

Figure 7. The optimal range of the angel of the south oriented horizontal sunshade

In Fig. 9 the distribution rate of above 100 lux illumination, on the 0.8 m height working plane during the year in the optimal configuration of window characteristics with and without sunshade is compared. The optimal window with or without sunshade provides 40-65% of interior lighting demand throughout the living room. The glare rate is displayed in Fig. 12. The visual comfort has not been provided in 0-24% hours of a year (Fig. 10. right). And it is not provided in 0-20% hours of a year by the optimal window with sunshade (Fig. 10. Left). Thus it is obvious that an appropriate sunshade should be chosen besides the proper WWR to reduce inside glare rate.

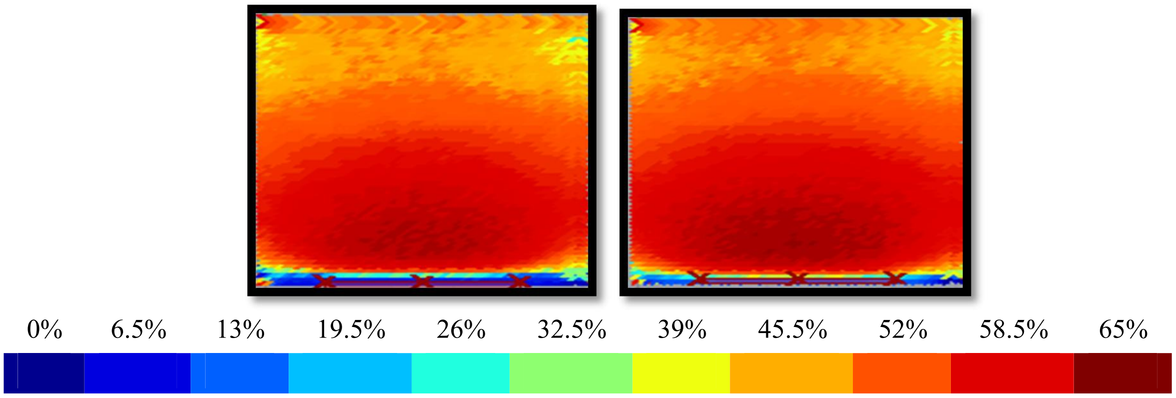

Figure 8. Distribution rate of above 2000 lux illumination, on the working plane during the year. Right: the window with minimum TEC (without sunshade), Left: the window with minimum TEC (with sunshade)

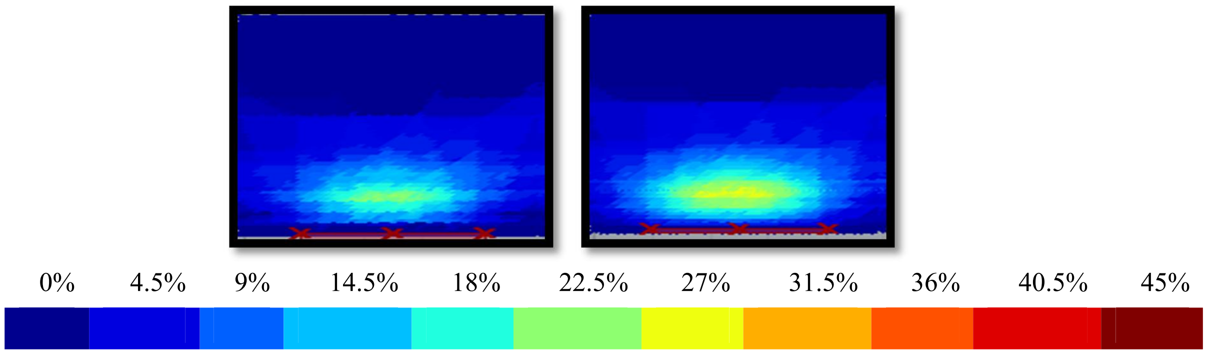

Figure 9. Distribution rate of above 100 lux illumination, on the working plane during the year. Right: the window with minimum TEC (without sunshade), Left: the window with minimum TEC (with sunshade)

4.1.2. Optimizing WWR and the Vertical Sunshade Size in North Orientation.

Based on [35] the north oriented window just needs the vertical sunshades. Therefore in this paper the vertical sunshade is optimized.

As a result of the optimization process of the north oriented window size and its vertical sunshade, the optimal annual TEC is 1765 kWh which occurs when there is not any window, so the optimal WWR is 0% (Fig. 11). Thus if the only external wall is the north oriented one, it would be better to use artificial lighting than natural lighting from the point of view of the sustainable design. In addition, as in Fig. 15 is displayed, the optimal range of the angel of the north oriented vertical sunshade will be 60-80 degree if there is a window in north oriented wall design.

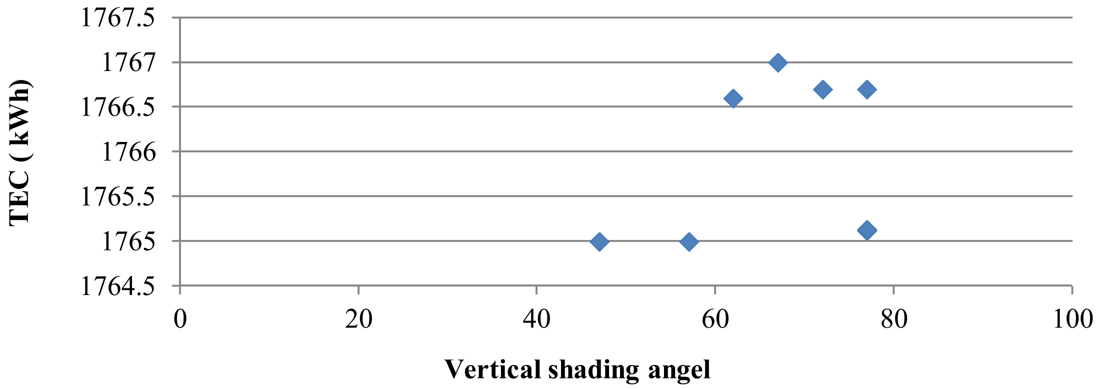

Figure 10. The optimal range of the angel of the north oriented vertical sunshade

4.1.3. Optimizing WWR and the Horizontal and Vertical Sunshades Sizes in East Orientation.

The minimum annual TEC is 1740.7 kWh by optimizing 1650 modes of window, which occurs when the east oriented WWR is 13% and the optimal window width is 3 m, its height is 0.72 m and its sill level is 1.84 m, in addition, the optimal sunshade angel is 77 degree.

Heating, cooling and lighting energy consumptions in 6 optimal configurations of the east oriented wall's windows and sunshades are displayed in Table 5. As shown, the optimal configurations are the horizontal windows with higher sill level. And the optimal shadings most effect the cooling and lighting energy consumption in which there are not any linear relationships between them. Thus the optimization process provides a balance to them.

TABLE 5. The 6 optimal configurations of the east oriented wall's window with horizontal sunshade

E_C(kWh)	EH (kWh)	E_L(KWh)	Window width (m)	Window height (m)	Window sill level (m)	Horizontal shading angel	WWR	TEC (kWh)
534.7	888.5	317.5	3.08	0.72	1.84	77	13	1740.7
541.4	886.7	314.5	3.08	0.72	1.84	82	14	1742.7
530.7	886	328.5	3.08	0.72	1.84	72	14	1745.7
539.1	886.8	320.2	3.5	0.64	2	77	14	1746.2
539.3	870.6	336.3	2.64	0.72	1.84	82	12	1746.3
537.6	876.6	332.5	2.64	0.8	2	77	13	1746.8

In Fig. 12 the range of the optimal WWR is displayed. As seen, building's TEC reached minimum when WWR is 12-16%. In addition, as in Fig. 13 is shown, the optimal range of the angel of the east oriented horizontal sunshade is 65-85 degree.

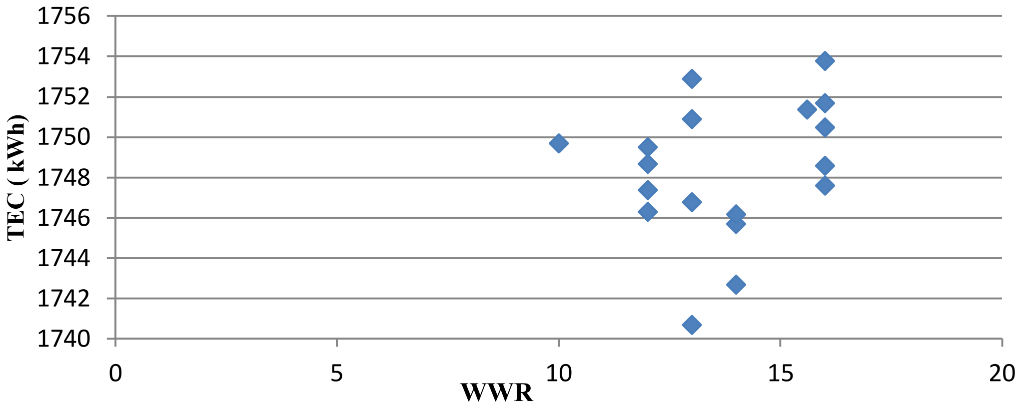

Figure 11. The optimal range of WWR in the east oriented wall

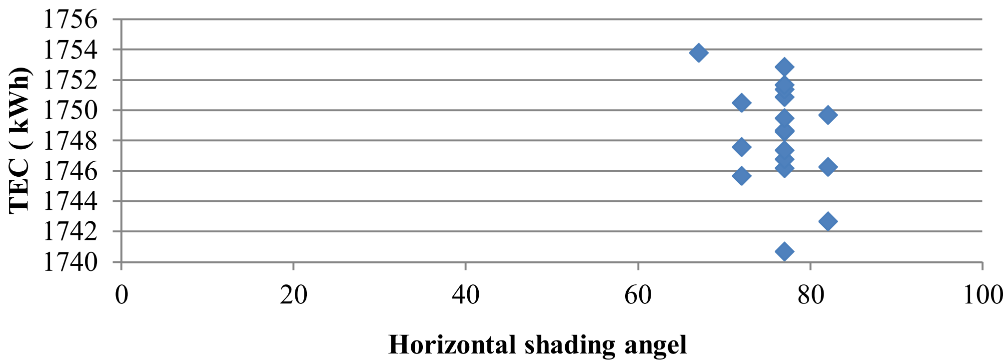

Figure 12. The optimal range of the angel of the east oriented horizontal sunshade

In Fig. 20 the distribution rate of above 100 lux illumination on the 0.8m height working plane during the year in the optimal window (Fig. 13) with and without sunshade is compared.

In this case, window is located in the length of the room which could be more suitable especially for a room with just a window in east oriented wall.

The optimal window with or without sunshade provides 45-65% of interior lighting demand throughout the living room (Fig. 14). The glare rate is displayed in Fig. 16.

The visual comfort has not been provided in 0-20% hours of a year (Fig. 16. right). And the lighting comfort is not provided in 0-14% hours of a year by the optimal window with sunshade (Fig. 15. Left). Therefore, an appropriate sunshade reduces the inside glare rate up to 6%.

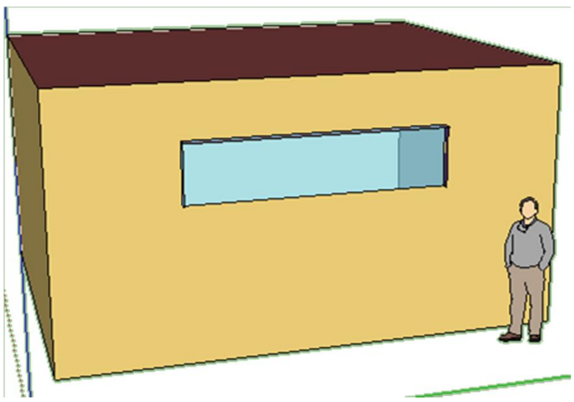

Figure 13. The optimal east oriented window

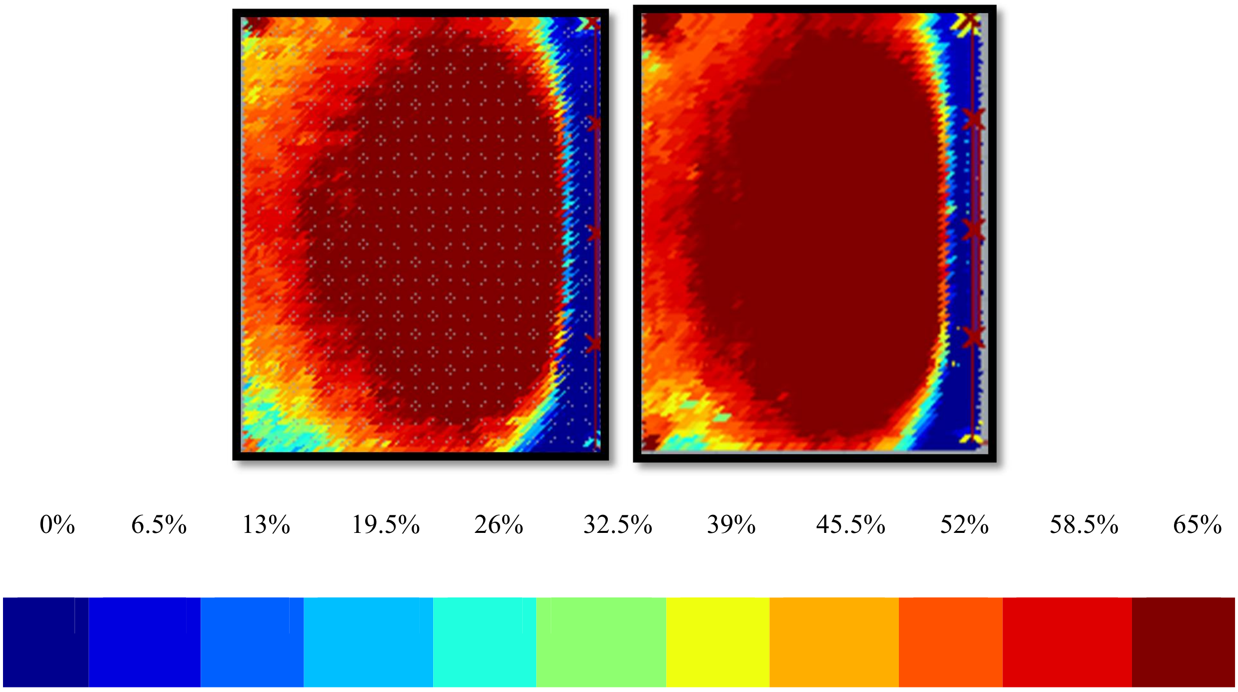

Figure 14. Distribution rate of above 100 lux illumination, on the working plane during the year. Right: the window with minimum TEC (without sunshade), Left: the window with minimum TEC (with sunshade)

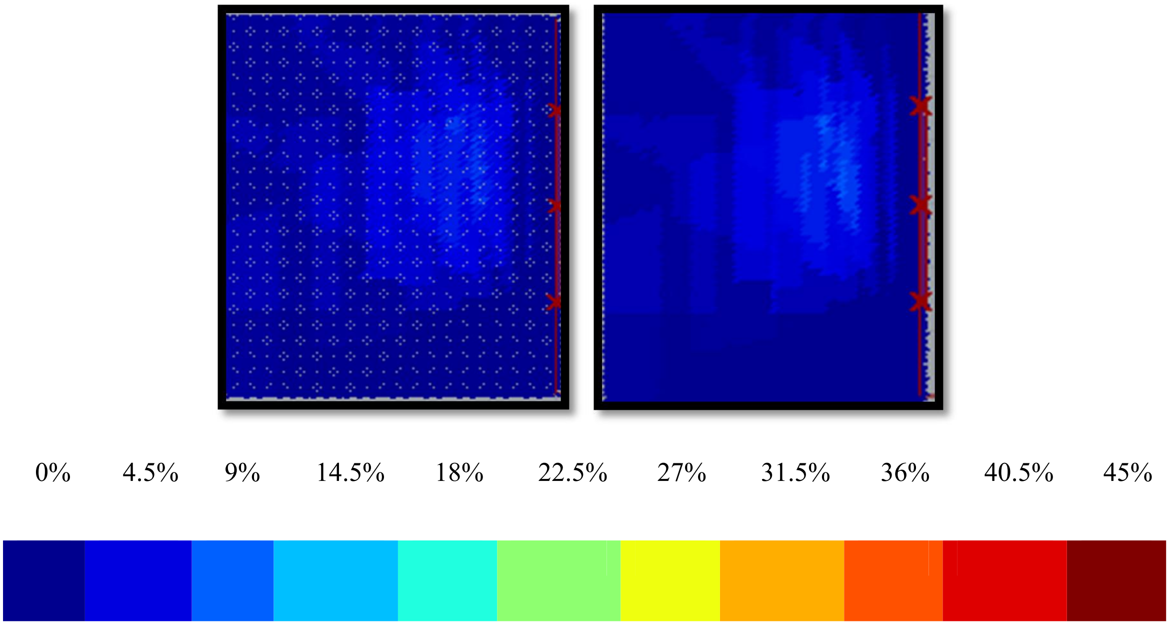

Figure 15. Distribution rate of above 2000 lux illumination, on the working plane during the year. Right: the window with minimum TEC (without sunshade), Left: the window with minimum TEC (with sunshade)

4.1.3.1. Optimizing Window and its Vertical Sunshade

As in Table 6 is displayed, the minimum TEC is 1751.9 kWh which occurs when the WWR is 14% and the optimal window width is 3.5 m, its height is 0.64 m and its sill level is 2 m. In addition, the optimal sunshade angel is 56 degree.

Heating, cooling and lighting energy consumptions in 6 optimal configurations of the east oriented wall's windows and sunshades are presented in Table 6. The optimal shadings most effect the lighting energy consumption.

TABLE 6. The 6 optimal configurations of the east oriented wall's window with vertical sunshade

E_C (kWh)	EH (kWh)	E_L (kWh)	Window width (m)	Window height (m)	Window sill level (m)	Vertical shading angel	WWR	TEC (KWh)
538.2	894.9	318.7	3.5	0.64	2	56	14	1751.9
532.4	882.7	336.9	3	0.64	2	56	12	1752
528.9	870.3	353.7	3.5	0.48	2.16	56	10.5	1753
534.9	878.9	339.7	3	0.64	2	71	12	1753.6
527.7	859.7	366.3	3	0.48	2.16	81	9	1753.8
540.7	905.3	308.6	3.08	0.8	2	51	15	1754.7

In Fig. 16 the range of the optimal WWR in the east oriented wall with vertical shading is displayed. As seen, building's TEC reached minimum when WWR is 11-15%. In addition, the optimal range of the angel of the east oriented vertical sunshade is 50-60 degree (Fig. 17). In Fig. 19 the optimal window and sunshade is presented.

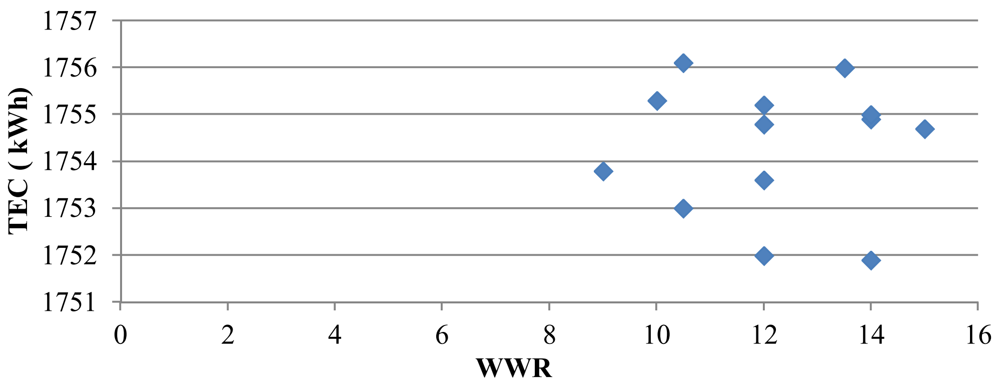

Figure 16. The optimal range of WWR in the east oriented wall

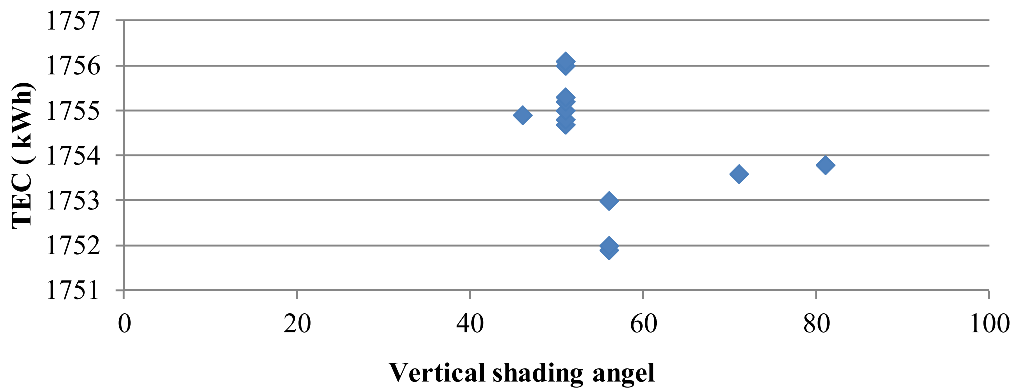

Figure 17. The optimal range of the angel of the east oriented vertical sunshade

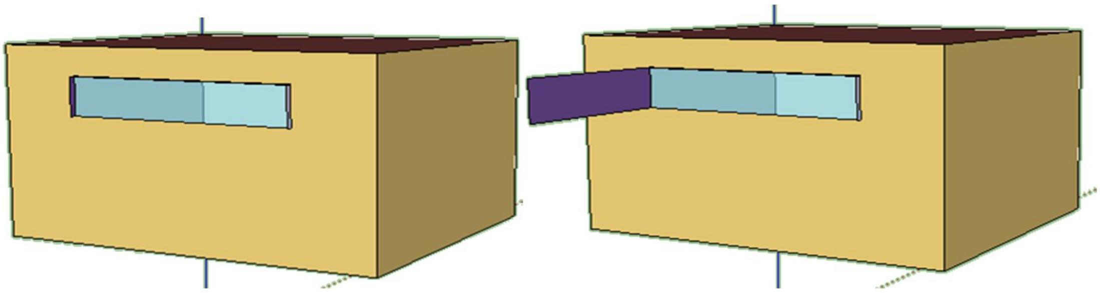

Figure 18. The optimal east oriented window and its vertical sunshade

In Fig. 20 the distribution rate above 100 lux illumination on the 0.8 m height working plane during the year in the optimal window (Fig. 18) with and without sunshade is compared. The optimal window with or without sunshade provides 45-65% of interior lighting demand throughout the living room. The glare rate is displayed in Fig. 21. The visual comfort has not been provided in 4.5-20% hours of a year (Fig. 21-right). And the lighting comfort is not provided in 0-14% hours of a year by the optimal window with sunshade (Fig.21–Left). Therefore, an appropriate sunshade reduces the inside glare rate up to 6%.

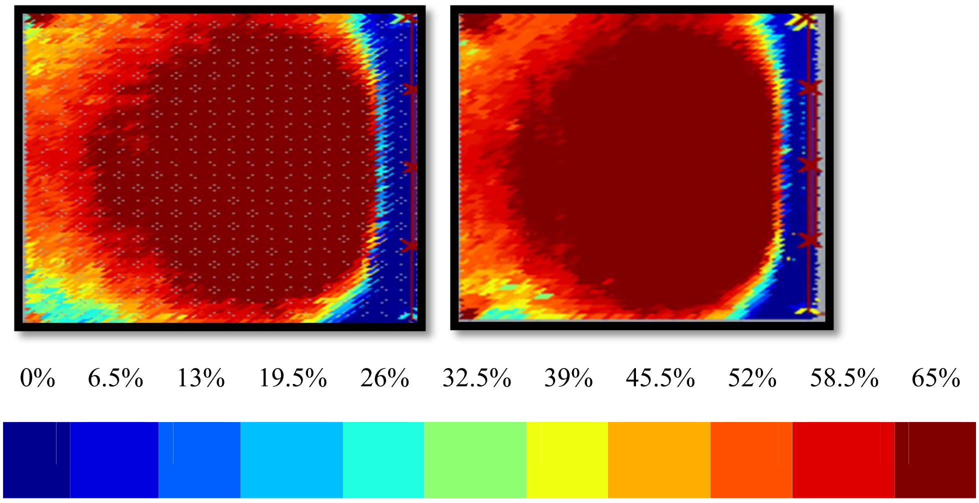

Figure 19. Distribution rate of above 100 lux illumination, on the working plane during the year. Right: the window with minimum TEC (without sunshade), Left: the window with minimum TEC (with sunshade)

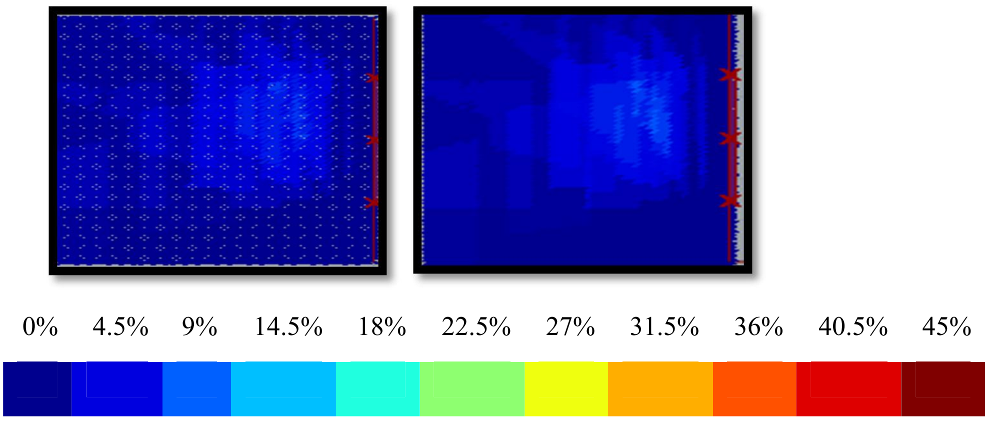

Figure 20. Distribution rate of above 2000 lux illumination, on the working plane during the year. Right: the window with minimum TEC (without sunshade), Left: the window with minimum TEC (with sunshade)

4.1.4. Optimizing WWR and the Horizontal Sunshade Size in West Orientation

As shown in Table 7, the optimal TEC is 1772.5 kWh which occurs when WWR is 19.5% and window width is 3.9 m, its height is 0.8 m and its sill level is 1.4 m in addition the optimal sunshade angel is 47 degree. Considering previous results, it is better not to choose west oriented wall as an external wall, because the TEC will be increased.

TABLE 7. The 6 optimal configurations of the west oriented wall's window with horizontal sunshade

E_C (kWh)	EH (kWh)	E_L (kWh)	Window width (m)	Window height (m)	Window sill level (m)	Horizontal shading angel	WWR	TEC (kWh)
511.8	926.6	333.5	3.9	0.8	1.4	47	19.5	1771.9
512.3	880.1	380	1.3	2	0.8	17	16	1772.5
505.9	909	358.5	1.7	2	0.8	17	21	1773.4
502.5	892.2	379.9	1.7	1.6	1	17	17	1775.4
513.9	939.1	324.3	4.4	0.8	1.4	47	22	1777.3
514.9	900.1	363.2	3.9	0.64	1.28	47	15.6	1778.4

If designers have no choice and they should design a window in the west oriented wall then as in Fig. 21 is displayed, the minimum TEC is achieved when WWR is between 14-22%, buildings. In addition as in Fig. 22 is shown the optimal range of the angel of the east oriented horizontal sunshade is 17 0r 47 degree.

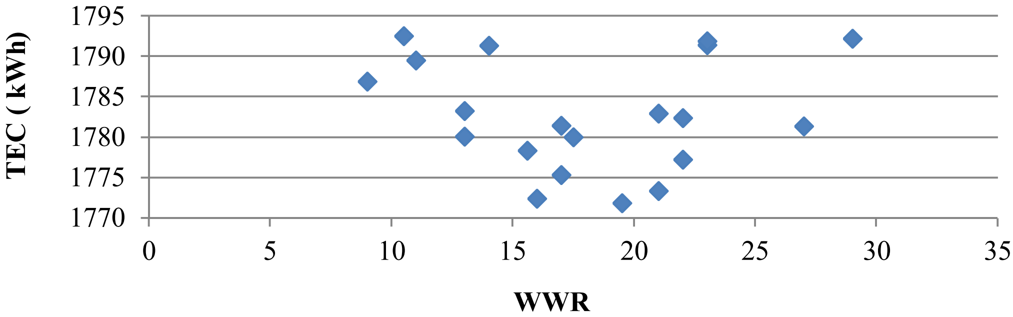

Figure 21. The optimal range of WWR in the west oriented wall

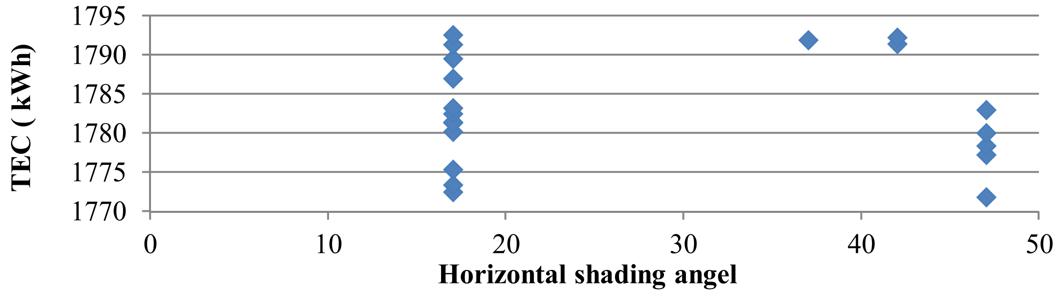

Figure 22. The optimal range of the angel of the west oriented horizontal sunshade

5. CONCLUSION

The purpose of this paper is to determine the approximate window area to wall area ratio (WWR), sunshade angel, window width, height and position on building's façade, that would provide the minimum energy consumption by integrating artificial lighting and air-conditioning analysis, whilst maintaining internal comfort conditions, which is utilized to develop a model of 1650 window configurations with different WWR, WHR (window width to height ration), sunshade and window locations of a residential building in a mild climate of Iran. The proposed methodology presents an integrated Energy plus and Daysim analysis with optimizing genetic algorithm approach in order to identify buildings windows design to achieve thermal comfort and indoor daylight quality. The results show that the proper window configurations of a living room have an influence of 0-5.5 % per year on the total energy demand of the building. And an appropriate sunshade will reduce 0.6% of total annual energy consumption and 6-12% of glare effect in the living room. In addition, the south oriented wall is the best solution for buildings frontages. After that the north and east oriented walls are appropriate. The minimum building's TEC is reached when WWR parameter in south orientation is 15–25%, in north orientation is 0%, in east orientation is 11-16%, and in west orientation is 14-22%. The horizontal sunshade angel is 65-85 degree for south, 65-80 degree for east and 17 or 47 degree for west oriented windows. And the optimal vertical sunshades angels in east orientation windows are 45-60 degree. Also the optimal configurations are the horizontal windows with higher sill level. In this range, day-lighting conditions are also satisfactory and these characteristics can therefore be considered in preliminary design phase of windows. The proposed method applied to a residential building located in mild climate of Iran and results are therefore significant for this climate only. In the future, the method can be implemented in various locations in order to highlight the influence of each climate on the optimal WWR for designing windows of low-energy buildings in different climates. In addition, the ventilation and view comfort parameters can be add in to the parametric model process to optimize WWR by integrating all 4 main parameters; (lighting, thermal, ventilation and view comfort).

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REFERENCES

1. Raphaela, W.F., Fernando, O.R.P., Fernando, S. W., Carolina, R.D.S., Priscila, B., "Development of a daylighting index for window energy labelling and rating system for residential buildings in brazil", 13th Conference of International Building Performance Simulation Association, Chambery, France, August, (2013), 26-28.
2. Mardaljevic, J., Andersen, M., Roy, N., "Daylighting Metrics for Residential Buildings", the 27th Session of the CTE, Sun City, South Africa, July, (20ll), ll-l5.
3. Grynninga, S., Gustavsena, A., Time, B., Jelle, B.P., "Windows in the buildings of tomorrow: Energy losers or energy gainers?", ***Energy and Buildings***, Vol. 61, (2013), 185–192.
4. BSEN 15603: "Energy performance of buildings – overall energy use and definition of energy ratings", (2008).
5. Goia, F., Haase, M., Perino, M., "Optimizing the configuration of a façade module for office buildings by means of integrated thermal and lighting simulations in a total energy perspective", ***Applied Energy***, Vol. 108, (2013), 515–527.
6. Kamila, M.L., Rosana, M.C, "The Influence of Window-Related Design Variables On Thermal, Daylight and Energy Performance of Offices", Instituto de Arquitetura e Urbanismo, Universidade de São Paulo, São Carlos, Brazil, (2013).
7. Shen, H., Tzempelikos, A., "Sensitivity Analysis on Daylighting and Energy Performance of Perimeter Office Spaces", International High Performance Buildings Conference, Paper 67, (2012).
8. Jose, M.A.M., Pablo, R., "Effects of window size in daylighting and energy performance in buildings", PLEA 2009, 26th Conference on Passive and Low Energy Architecture, Quebec City, Canada, June (2009).
9. Francisco, A., "Day Lighting as a Factor in Optimizing the Energy Performance of Buildings", ***Energy and Building***, Vol. 1, (1977), 175-182.
10. Peter, L., "report to Australian Building Codes Board on Optimum Window Size for Energy Efficiency", BCA, Vol. 1, December, (2008).
11. Hassouneh, K., Alshbou, A., Salaymeh, A.Al., "Influence of windows on the energy balance of apartment buildings in Amman", ***Energy Conversion and Management***, Vol. 51, (2010), 1583-1591.
12. Shikder, S.H., Mourshed, M., Price, A.D.F., "Optimization of a daylight-window: Hospital patient room as a test case", Proceedings of the international conference on computing in civil and building engineering, Tizani, W. (Editor), Nottingham University Press, (2010).
13. Stavrakakis, G.M., Karadimou, D.P., Zervas, P.L., Sarrimveis, H., Markatos, N.C., "Selection of window sizes for optimizing occupational comfort and hygiene based on computational fluid dynamics and neural networks", ***Building and Environment***, Vol. 46, (2011), 298-314.
14. Ochoa, C.E., Aries, M.B.C., Loenen, E.J., Hensen, J.L.M., "Considerations on design optimization criteria for

windows providing low energy consumption and high visual comfort", ***Applied Energy***, Vol. 95, (2012), 238–245.
15. Dussaul, J., Gosseli, L., Galstian, T., "Integration of smart windows into building design for reduction of yearly overall energy consumption and peak loads", ***Solar Energy,*** Vol. 86, (2012), 3405–3416.
16. Szymon, F., Mehrangiz, Y., Charlie, C., Christian, K., Simon, V., Robert, H., Stephen, C., "Control algorithms for dynamic windows for residential buildings", ***Energy and Buildings***, Vol. 109, (2015), 157–173.
17. Mari, L.P., Arne, R., Maria, W., "Influence of window size on the energy balance of low energy houses", ***Energy and Building***, Vol. 38, (2006), 181-188.
18. Lee, E.S., Dibartolomeo, D.L., Selkowitz, S.E., "Thermal and daylighting performance of an automated venetian blind and lighting system in a full-scale private office", ***Energy and Building***, Vol. 29, (1998), 47-63.
19. Grynninga, S., Gustavsena, A., Time, B., Jelle, B.P., "Windows in the buildings of tomorrow: Energy losers or energy gainers?", ***Energy and Buildings***, Vol. 61, (2013), 185–192.
20. BS EN ISO 13790: "Energy performance of buildings - Calculation of energy use for space heating and cooling", (2008).
21. BS EN 15193: "Energy performance of buildings, Energy requirements for lighting", (2007).
22. ISIRI 14253, (Institute of Standards and Industrial Research of Iran), "Residential Building Criteria for Energy Consumption and Energy Labeling Instruction", (2011).
23. Szczepaniak, R., Wilson, M., "Investigating Energy Requirements for Lighting: A Critical Approach to EN15193", Low Energy Architecture Research Unit, Department of Architecture and Spatial Design, London Metropolitan University, The International Conference Adapting to Change: New Thinking on Comfort Cumberland Lodge, Windsor, UK, 9-11. London: Network for Comfort and Energy Use in Buildings, http:/ /nceub.org.uk, April, (2010).
24. Energyplus engineering reference, http://apps1 .eere .energy .gov/ buildings/ energyplus/ pdfs/ engineering reference .pdf, October, (2011).
25. Http://daysim.ning.com/, DAYSIM is validated, RADIANCE-based daylighting analysis software that models the annual amount of daylight in and around buildings.
26. RADIANCE, the Radiance 4.0 Synthetic Imaging System, Lawrence Berkeley, National Laboratory, (2010).
27. Mardaljevic, J., Nabil, A., "The useful daylight illuminance paradigm: A replacement for daylight factors. ", Lux Europa, Berlin, (2005), 169–174.
28. David R., "Evolutionary Principles applied to Problem Solving", Proceedings of the international conference AAG10, conference in Vienna on September 25st, http://www.grasshopper3d.com/profiles/blogs/evolutionary-principles., (2010).
29. Kari, B.M, "Energy auditing prevalent buildings in Iran", In persian, Building Physics, Building and Housing Research Center, (2006).
30. Fayaz, R., "Determining the optimum area for glazed openings of residential buildings in various climatic zones of Iran", Research project, Department of architecture, Faculty of architecture and urban planning, Jan, (2009).
31. ANSI/ASHRAE/IESNA Standard 90.1-Normative Appendix B – "Building Envelope Climate Criteria"., The information below is from Tables B-2, B-3, and B-4 in that appendix, (2007).
32. National building code, part 19, "saving energy", Iran Building and Housing Research Center, (1389).
33. National building code, part 13, "Design and implementation of electrical installations for buildings", Iran Building and Housing Research Center, in Persian, (2009).
34. Fayaz, R., Kasmaiee, M., "Fundamentals of designing fixed shading devices for various climatic regions of Iran", building and housing research center, No. R-577, (2009).