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Optimization of Window Dimensions Regarding Light and Heat Parameters in Residential Buildings of Cold Climate; Case Study: Ilam City*

Milad Heirani Pour[a]- Rima Fayaz[b]- Mojtaba Mahdavinia[c]**

[a] M.A. of Energy and Architecture, Faculty of Architecture and Urbanism, Tehran University of Art, Tehran, Iran.

[b] Associate Professor of Architecture, Department of Architecture, Faculty of Architecture and Urbanism, Tehran University of Art, Tehran, Iran (Corresponding Author).

[b] Assistant Professor of Architecture, Department of Architecture, Faculty of Architecture and Urbanism, Tehran University of Art, Tehran, Iran.

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ABSTRACT

One of the building elements having an essential impact on energy conservation is the external envelope of various facades. The building's external envelope consists of three parts: transparent, semi-transparent, and opaque. The main objective of this study is to design a parametric model to determine the optimal dimensions of the window to reduce energy consumption and maximize the use of daylighting in residential buildings of cold climate (Ilam). In this regard, first, the basic simulation model concerning the typology of residential buildings in Ilam was determined , and using weather statistics of Ilam's weather station, the weather file for simulation was validated. Then the modeling and simulation based on energy consumption parameters were performed and the optimization process was carried out using Rhino software, Honeybee & Ladybug plugins, and finally, the optimal window dimensions for various cases and south and north facades were introduced. The results show that the optimal window to wall ratio on the south façade without any shading devices is 24 % and with Code No. 19 suggested shadings it is 19%, while the value for the north façade is 4%.

Keywords: Optimal Window Area, Energy Conservation, Light, Heat.

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** E_mail: fayaz@art.ac.ir

1. INTRODUCTION

Nowadays energy conservation issue to maintain thermal comfort in buildings has become of particular importance and various countries have compiled codes to conserve energy. On the other hand, the incompatibility of architecture with climate results in increased consumption of heating and lighting energy in buildings and has negative effects both economically and environmentally.

Based on the statistics of the Ministry of Energy, more than 44 percent of the primary energy in the country is used for heating and cooling to maintain thermal comfort indoors of which about 10 to 30 percent is wasted through doors and windows (Kasmaei, Mohammadkari, & Nazari 2010). Meanwhile, 34 percent of electrical energy in Iran residential buildings is used for lighting (Heydari, 2012). Then, the use of natural light will significantly result in conserving this energy. The utilization of natural light as an important factor in thermal and visual comfort in architecture, not only meets the psychological and spiritual needs of people but also leads to a reduction in energy consumption. The simplest solution to benefit from solar energy in residential buildings is the use of a solar window; that is a single or double glazed window with special orientation to receive the maximum solar exposure during the cold period of the year.

As the need to determine the optimal window dimensions for all cities in the country is of high importance, it is necessary to study the characteristics of climate and architectural elements of each location and decide on the optimal dimensions accordingly. Regarding the specifications of the cold climate and the high energy consumption for heating in these regions, the need for energy conservation and heating load reduction in buildings should be considered foremost.

The purpose of this study is to design a parametric model for optimizing window dimensions concerning the two parameters of light and heat to minimize the annual energy consumption, for heating and lighting without increasing the cooling load of the building. As a result, determining the optimal length and width of the window, the optimal percentage of the transparent envelope in the building facade, the optimal shading depth on various facades, reduction of glare and discomfort near the window, the study of window and envelope materials on the energy consumption of the buildings in cold climate and reduction of buildings' energy consumption are aimed in this study. As there is no research on optimal window areas concerning light and heat in residential buildings of Ilam, the main purpose of this article is to provide these optimal dimensions.

2. METHODOLOGY

In this research, the characteristics of the design elements such as the constructional details of the walls and exterior envelope, thermal and lighting comfort ranges for individuals as well as other parameters required for simulation and optimization were determined based on library studies. Then, with regards to this information, the parametric model is developed using Grosshapper plugin version 0.0.0076 in Rhino s5sr7 64-bit software and Honeybee plugin version 0.0.63 and Ladybug version 0.0.066, in which the thermal energy is calculated with EnergyPlus engine and the lighting load with Open Studio. The reason for selecting Honeybee and Ladybug plugins is their ability to create a parametric model for future research and development and the use of validated engines such as Energy Plus and Open Studio. The amount of light intensity required for the space under consideration was adapted from the national building regulations, and based on this, the number of lamps was calculated using Dialox Light 12 software. After obtaining the data required for thermal and lighting calculations, climatic information of the last 30 years of Ilam city was obtained from the Meteorological Organization of the province and was compared with the climatic data file. The climatic data file of Ilam has been obtained using Meteonerm software version 7.1.3.18872. Using the weather information of several nearby cities, the software can calculate and provide the weather information of the studied city with acceptable accuracy.

3. RESEARCH BACKGROUND

Due to the effect of window properties on the amount of energy consumption (heating, cooling, and lighting) of the building, many researchers have been looking for optimal window dimensions in terms of energy consumption and in this regard, several studies in various fields have been carried out, which are introduced in the following.

According to studies, the research on the effect of the window to wall ratio (WWR) on the energy consumption of the building has been started since 1980-1970. In the standards of different countries for the rule of thumb, the ratio of window to floor area (WFR) is introduced as a percentage. This ratio is determined according to the European standard and based on daylight, which is equal to 10% in southern Europe and 25% in northern regions. This percentage (WWR) varies according to different factors such as room depth, type of glass, and orientation and in general should not exceed 50% (Ghiabkloo, 2013). In the book entitled "Architecture and Lighting", in addition to other considerations, it is recommended that with regards to the Iranian Earthquake Regulations, the range of (WWR) remains 20% at maximum, which corresponds to the research and analysis on windows light and heat performance (Heydari, 2001). Ochoa et al. (Ochoa, Aries, Van Loenen, & Hensen, 2012) examined the appropriate ratio of window to wall surface from the visual comfort, light, heat, and energy conservation point of view in different façade orientations in office buildings in the Netherlands with an oceanic climate and obtained the optimal values for various façade orientations. In a study, Goia et al. (2013) examined the optimal ratio of the transparent envelope to the opaque wall in a unit of building facade in terms of thermal, cooling, and lighting energy savings in an office building in Sweden. According to this study, the proper WWR for the south wall is 35-45%. According to the research of Melendo et al. (Melendo & Roche, 2009), the appropriate WWR based on thermal energy loss and the use of daylight in an office building in Los Angeles, with a Mediterranean climate with dimensions of 4 x 4 x 3 meters, is 30% on the south wall. Scott et al. (2009) examined two types of single and double glazed windows of an office building, on the four main directions, in three cities with different latitudes in Australia and concluded that regardless of latitude and type of glass, the optimal WWR is 10% in terms of cooling and lighting energy. In a study, Fayaz (2013) proposed the optimal range of windows for residential buildings in Ardabil and Tehran to provide part of the building's heating needs. This study showed that it is possible to determine a suitable range for the south window of residential buildings in these two cities so that in the cold times of the year part of the space heating needs are met by solar radiation and at moderate times the indoor temperature remains at comfort level.

Montaser Koohsari, Fayaz and Mohammad Kari (2014) examined and determined the optimal dimensions of the window from the perspective of light and heat in Rasht. The optimal WWR for the southern façade was between 18-29% of the external envelope, while the horizontal shading with an angle of 60 degrees eliminated glare. In general, the dimensions of the optimal window affect the energy consumption by about 10% of the maximum. Bakhtiari and Kari (Bakhtiari & Kari, 2013) studied the effect of window location and determined the optimal position of the window in the building facade from the point of view of energy consumption and maximum use of natural light. Alwetaishi (Alwetaishi, 2017), studied various window-to-wall ratios in different climates, including hot and dry, hot and humid, and temperate ones in Saudi Arabia. The results show that the south and east facades are the worst for opening locations due to the high incident radiation. The best ratio is 10% of the external envelope for hot- dry and hot- humid climates and 20% for the temperate climate.

According to the research, the depth of light penetration in the buildings can be considered 1.5 to 2.5 times the height of the upper part of the window from the floor. It is also better to keep the difference between the maximum and minimum light as low as possible in a space. Therefore, horizontal windows and square windows under the ceiling, in addition to providing more moderate brightness on the work plane, create less light around the windows; and as result, they are considered as better options, which has been observed and proven in several researches. In long walls, it is recommended to use horizontal and continuous windows for lighting without creating contrast. Additionally, in window design considerations it is recommended that the minimum height of the window be 1.25 meters and its minimum width be half of the wall width. The area of the living room window should not be less than 7% of the room space (Ghiabkloo, 2013). In "Architecture and Lighting", for calculating the depth of the room based on its width, Equation 1 and for calculating the area of the window, Equation 2 is presented. In this regard, the height of the room is considered to be three meters. As a result, for a room with a width of five meters, the depth of the room to be able to use daylight should not be more than 6.25 meters (Heydari, 2012).

$$\left(\frac{L}{W}\right) \times \left(\frac{L}{3}\right) < \left(\frac{20}{6}\right) \quad (1)$$

Where
L = Room Depth (m)
W= Room Width (m)

$$S_{window} = h \times w \times 20\% \quad (2)$$

Where
H= Floor Height Below the Upper Threshold of the Window (m)
W= Room Width (m)

4. STUDY AREA

The city of Ilam is located in southwestern Iran, at 46 degrees and 28 minutes east longitude and 33 degrees and 38 minutes north latitude. Its height from the sea level is 1363 meters (Fig. 1). This city is situated in mountainous valleys with an area of approximately 25 square kilometers in the Zagros Mountains (Akbari, Hosseinzadeh, & Shiri, 2016, p. 32). The city of Ilam is the center of Ilam province, which has mountainous terrain and forests with a temperate mountainous climate.

Fig. 1. The Geographical Location of Ilam Province in the Country
(https://fa.wikipedia.org/wiki)

5. SIMULATION

The aim of building modeling and simulation is to design a suitable process to calculate the effect of the window on reducing the energy consumption of the building. For this purpose, two important parameters that affect the window have been selected: heating and cooling parameters that affect the amount of electricity or gas consumption for building heating, along with the lighting parameter that affects the amount of electricity consumption and thus the effect of window construction on total energy consumption of the building is examined. Other parameters such as shading from neighboring buildings, building materials, ventilation, etc. will also affect energy consumption and as a result, the selected model is a parametric one, so that in the future the effect of other parameters may be studied.

The energy consumption modeling process in terms of light and heat has three main parts: input parameters, analytical calculations, and output results. Figure 2 shows the modeling and optimization process. This model is a combination of four main parts that are: defining the physical volume and the building under study and its conditions, lighting calculations and introducing the input parameters, thermal calculations, and its input parameters and the optimization process and the related algorithm. The ultimate goal of this study is to find a way to further reduce the energy consumption for heating, cooling, and lighting in the building. For this purpose, the fitness function is set in such a way that the energy consumption in all three parts is minimized (the numerical value of A is in the lowest state).

$A = \sum Ec + \sum Eh + \sum El$

Where

A= annual energy consumption (kWh)

Ec= annual energy consumption for cooling (kWh)

Eh= annual energy consumption for heating (kWh)

El= annual energy consumption for lighting (kWh)

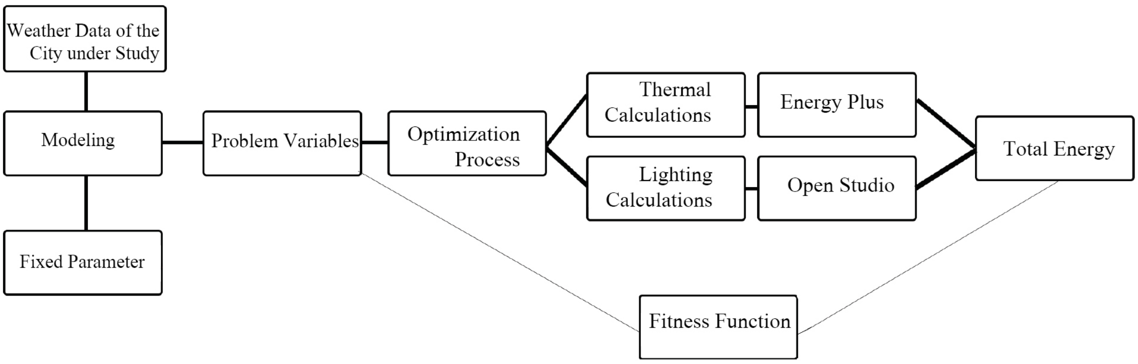

Fig. 2. The Process of Window Optimization and Light and Heat Calculations

5.1. Simulation Model

To determine the appropriate dimensions of the living room in Ilam city, the results of the research conducted by Kordjamshidi (2010) have been used, where the typology of residential buildings in Ilam from an energy perspective is introduced. The results of the study of residential types in Ilam show that the number of masonry buildings is more than buildings with skeletal structures (steel and concrete) (62.6% are masonry buildings) and the average area obtained for living space in building types is 38 square meters, while it is 50.25 square meters in the skeleton ones. Taking into account these values, the average area obtained for the living room in a residential building will be about 48 square meters. As a result, a space with dimensions of 7.3 x 6.6 meters and with a height of 2.80 meters with a window on the south wall was considered for the simulation. In this model, the floor is considered to be on the ground and the north and west walls are adiabatic, while the two other walls are adjacent to the exterior (Fig. 3).

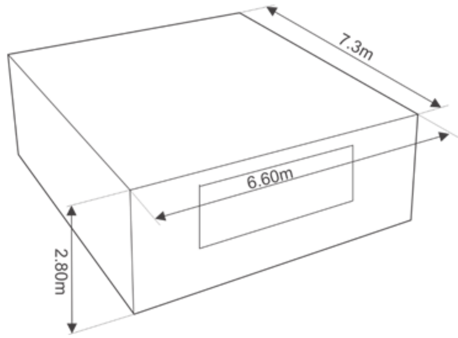

Fig. 3. The Dimensions of the Living Space Understudy

5.2. Materials of the Building Elements

One of the main problems of buildings in Ilam is the high heat exchange between indoors and outdoors due to the lack of proper sealing around the openings and lack of thermal insulation in the exterior envelope, including walls and roofs (Kordjamshidi, 2010). In this section, due to the unsuitable thermal condition of the existing walls, the prescription method proposed in Code No. 19 of the National Building Regulations is used to determine the minimum thermal resistance for building envelopes. Resultantly, the thermal resistance of the building envelopes is determined as described in Table 1.

Table 1. Thermal Resistance of Building Envelope in the Simulated Model

Window m^2K/W	Floor m^2K/W	Roof m^2K/W	Wall m^2K/W
0.34	0.3	1.7	1.2

5.3. Determining the Schedule of People's Presence and other Required Parameters

Among the effective parameters on the heating and cooling energy consumption in each thermal zone, the schedule of people's presence in the room, the amount of thermal energy produced inside, including heat generated by lamps, occupants, indoor appliances, unwanted air infiltration are of importance (Table 2). The utility system in this research is considered ideal. According to publication No. 1-110 (General Technical and Construction Specifications of Building's Electrical Utilities), the proposed lighting intensity for a living space is 200 lux.

Table 2. Constant Parameters for Simulation According to ASHRAE Standard

Ventilation Rate Per Person (m^3/s)	Infiltration Rate for Each Square Meter	The Number of People Per sq.m.	Thermal Load of Lamps Per Square Meter (W/m^2)	Thermal Load of Equipment Per Square Meter (W/m^2)
0.0075	0.0003	0.03	2.45	1

5.4. Determining the Power Consumption of the Lamps

To determine the required number of lamps as well as the light intensity, the living space was modeled and studied in Dialox software, the results of which are shown in the following Figure. For the studied space, six 60 W lamps were selected from Mazi Noor Company (Fig. 4). As a result, the light intensity inside the space is equal to 7.63 W / m^2.

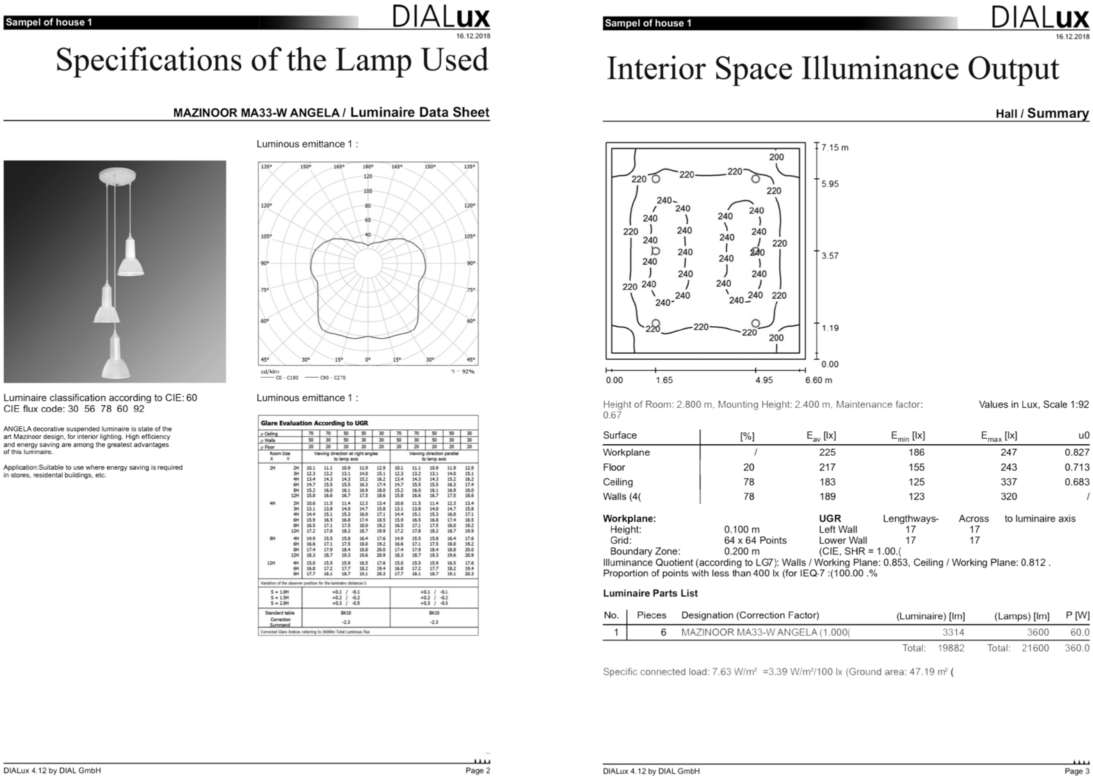

Fig. 4. Type and Intensity of the Selected Lamps in the Area under Study and the Produced Light Intensity (Dialux)

5.5. Validation of Weather Data

For energy simulation, complete climatic information of the city is required, which includes dry bulb temperature, wet bulb temperature, wind direction and speed, relative humidity, number of frost days, sunshine hours, percentage of cloud cover, direction and intensity of solar radiation, etc. This information has been obtained using a meteorological information simulator software such as Meteonerm and has been validated using 30-year statistics of the General Meteorological Organization of Ilam. The root means square error between the two data sets is about 6%, which is acceptable (Fig. 5).

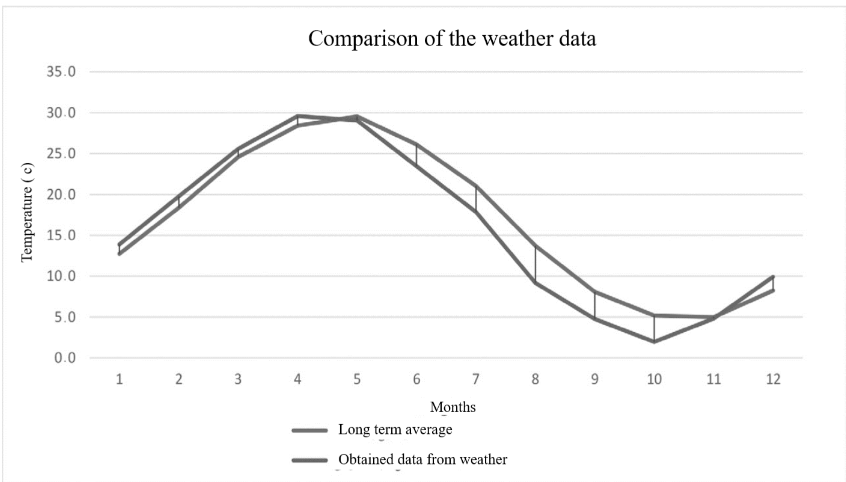

Fig. 5. Comparison and Validation of the Weather Data

5.6. Limitations for Window Dimensions

In this study, some limitations are considered for window location. The distance of the window from the ceiling due to the thickness of the ceiling is equal to 40 cm, from the side walls it equals 30 cm and 80 cm from the floor due to the height of the desk and the radiators, etc., also, the center of the window is in the middle of the wall. The optimization process takes place in this range (Fig. 6). The variable parameters for finding the best optimization result for the dimensions of the simulated window are as follows:

A. Window width
B. Window height

Due to the change of these parameters, all possible situations for the location of the window have been calculated by considering the change domain of 10 cm for the dimensions, and thus the dimensions of the window will change from zero to 3 m width and 1.6 m length.

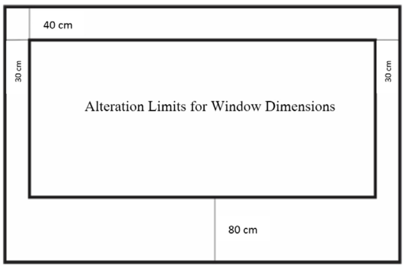

Fig. 6. The Considered Limitations for the Optimization Process

6. SIMULATION RESULTS

Here, the results of total energy consumption for cooling, heating, and lighting for 480 cases of window dimensions in two conditions without and with shading devices based on Code No. 19 on south and north walls are calculated and compared. This process is optimized using the Galapagos Optimization Plugin, which works with a genetic algorithm. The optimization process can continue indefinitely, and it is the user who, according to his desired accuracy, ends the operation when the desired results are achieved. To be ensured that the obtained results are appropriate, it is necessary to try to discover the optimal conditions by using techniques such as genetic mutation (in the genetic algorithm) and repetition of operations (in both genetic algorithm and simulated refrigeration algorithm) to find out the answers that may not have been discovered in the initial optimization. Here, the process of repeating the optimization operation continues until the results obtained are similar to the previous ones, and each optimization cycle is analyzed between 400 and 4000 cases, depending on the number of variables studied. Furthermore, given that the range of differences between the best answers in all cycles examined is a small number (less than 1%), the probability of optimal response or undiscovered answers can be considered very low and negligible. The calculations in this research are carried out for each month of the year and a whole year. As previously mentioned, due to the considered limitations, the maximum dimensions of the window will be 6 meters wide and 1.6 meters high, which according to the wall under consideration, the maximum WWR is equal to 52 percent.

6.1. Optimization of South Window Dimensions with No Shading

The variables of length, width, and location of the window in the no shade case were analyzed and optimized in 480 modes, resulting in a window with dimensions of 2.8 meters wide, 1.6 meters high, and 0.8 meters high from the floor (Fig. 7). The amount of WWR, in this case, is equal to 24% and the amount of energy consumption is equal to 136 kWh per square meter per year, of which 19 kWh per square meter is related to the lighting and 117 kWh per square meter is allocated to the heating.

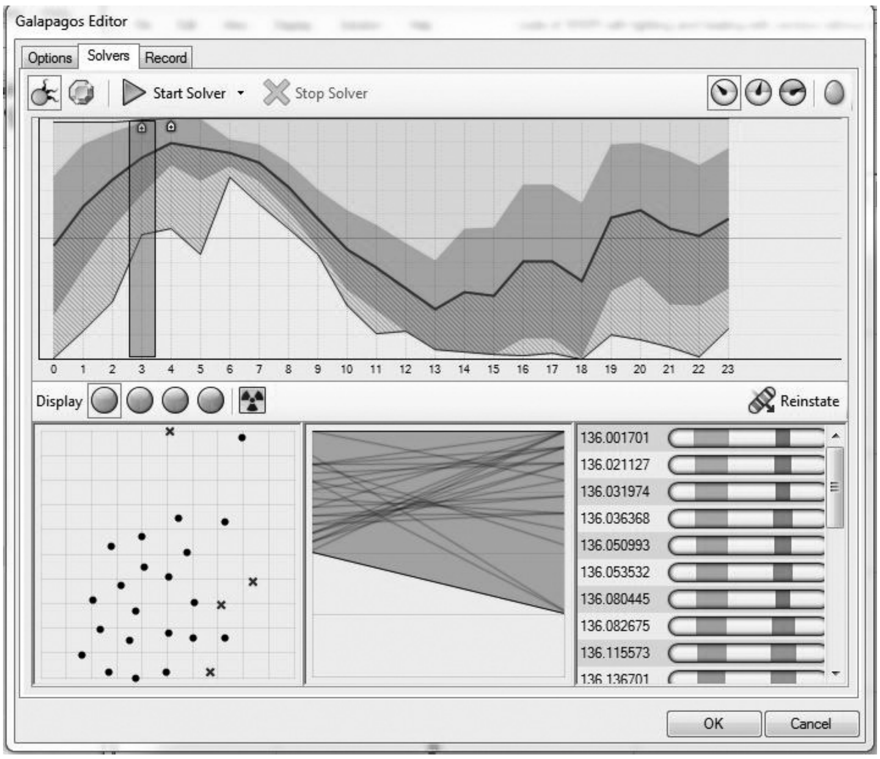

Fig. 7. Optimization of Dimensions and Location of the South Window without Any Shading Devices in Galapagos Component

6.2. Optimization of the South Window with Shading Devices

Here, too, the variables of length, width, and location of the window have been analyzed and optimized in 480 different modes. In this algorithm, the number of each data generation is considered to be 50. After finding the closest answer to the optimal state, the plugin generates another 50 data generations to make sure of the obtained results. As shown in Figure 8, the optimal case is 2.4 meters wide and 1.5 meters high, and 0.8 meters above the floor. The amount of WWR, in this case, is equal to 19% and the amount of energy consumption is equal to 137 kWh per square meter per year, of which 20 kWh per square meter is related to the lighting sector and 117 kWh per square meter is related to the heating sector.

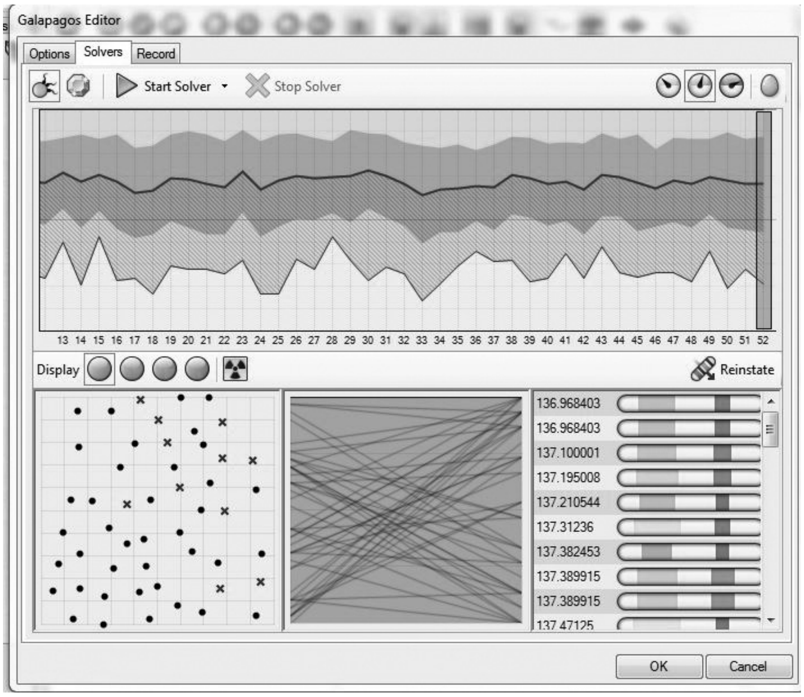

Fig. 8. Optimization of Dimensions and Location of the South Window with Standard Shading

6.3. Evaluation of the Lighting Quality of the Optimal South Windows

One of the parameters that can be used to check the annual amount of light and its quality in the room is the UDI index. The range of this parameter is considered to be 100 to 2000 lux. So that the lighting in this range will be tolerable and more than 2000 lux the glare occurs and less than 100 lux is not enough light and the environment would be unpleasant. The level of the study is equal to the height of the table, i.e. 0.80 meters above the floor.

The optimal south window was examined in terms of the UDI index. In the first case, the south window was examined without any shading devices. As shown in the figure below, glare is created in the areas near the window, but most of the room benefits from adequate light, which is within the visual comfort limit (Fig. 9). Using the shading suggested in Code No. 19 the glare near the window is reduced and more balanced conditions are created indoors, but the penetration depth of light inside is reduced (Fig. 10). However, with the use of shadings, the amount of energy consumed is more than that of the window without any shading (1 kWh per square meter per year) (Table 3); and in this case, less glare is observed near the window (Fig. 10).

Fig. 9. UDI Index for the South Window without Shading

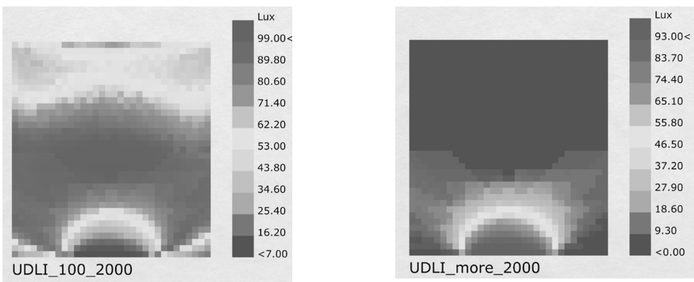

Fig. 10. UDI Index for the South Window with Shading

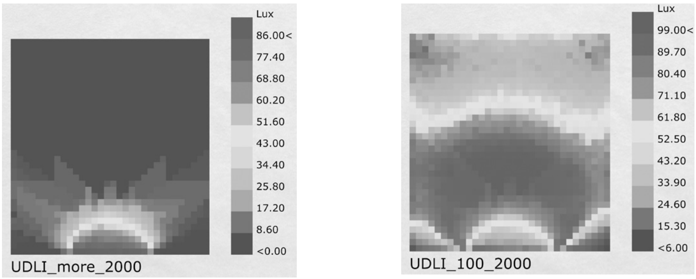

Table 3. Comparison of Consumed Energy in Various Cases of the South Window

Energy Consumption (kwh)	Thermal	Lighting	Total Annual
No Shading	**117**	**19**	**136**
With Code No. 19 Shading	**117**	**20**	**137**

6.4. Optimization of the North Window with No Shading

According to the typologies determined for the city of Ilam, the living space may be located on two northern or southern fronts. As a result, the optimization has been done for the northern facade, as well. The optimal dimensions for this façade are 1meter wide and 0.80 meters high and 0.8 meters high from the floor. The amount of WWR, in this case, is equal to 4% and the amount of energy consumption is equal to 145 kWh per square meter per year of which 21 kWh / m^2 is related to the lighting sector and 124 kWh / m^2 is related to the heating sector (Fig. 11).

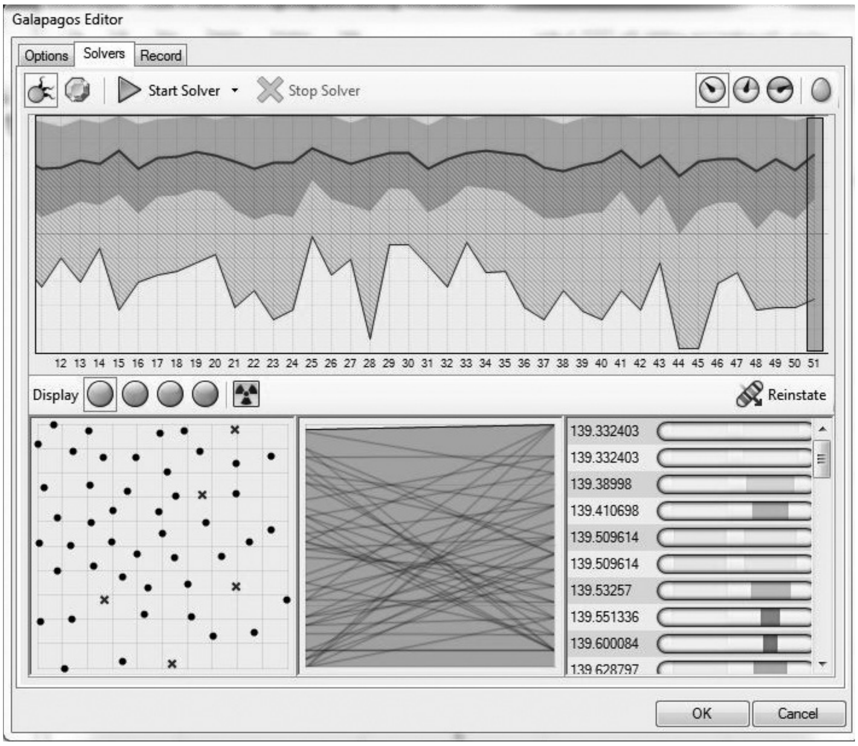

Fig. 11. Optimization of Dimensions and Location of the North Window Without Any Shading Devices

7. CONCLUSION

In this paper, the optimal dimensions of the window on the north and south facades of a common living room in a residential building in Ilam, from two perspectives of lighting and heating were obtained. In this process, two parameters of daylight and the energy consumption of occupants were studied simultaneously to optimize the dimensions of the window and minimize the annual energy consumption.

In general, the analysis shows that in a typical living room in the city of Ilam with a width of 6.60 meters and a length of 7.15 meters and a height of 2.80 meters, with exterior south and east facades and two other adiabatic sides, among the four main directions for window position, the south one is the best. In this facade, WWR for the case with no shading is equal to 24% and the amount of energy consumption is equal to 136 kWh per square meter per year, of which 19 kWh per square meter is related to the lighting and 117 kWh per square meter is allocated to the heating. And WWR in the case with shading according to Code No. 19 is 19%, while the amount of energy consumption is equal to 137 kWh per square meter per year, of which 20 kWh per square meter is related to the lighting and 117 kWh per square meter is related to the heating. In this case, the glare phenomenon can be prevented. On the northern facade, the WWR is 4% and the energy consumption is 145 kWh / m^2 per year, of which 21 kWh / m^2 is related to the lighting and 124 kWh / m^2 is allocated to the heating.

It is important to note that in future studies the results of the optimal range, can be considered with other parameters such as ventilation, humidity, visual comfort, etc. along with the two lighting and thermal parameters simultaneously, to find the exact optimal window area in Ilam.

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