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The Influence of Window Dimensions and Location on Residential Building Energy Consumption by Integrating Thermal and Lighting Analysis in a Mild and Humid Climate

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Abstract
It is essential in a sustainable architecture to design buildings with the lowest possible cost base and most efficient facilities. Solar energy, the most important free natural resource, is effective on thermal and lighting energy consumption which depends on building's enclosure characteristics. Choosing window characteristics is a key step on building design. The purpose of this paper is to determine the optimum window size and its position on building's façade that would provide the minimum energy consumption by integrating artificial lighting and air-conditioning analyze by a parametric approach. This paper presented a parametric methodology of thermal and lighting integration to simplify the design process which is utilized to develop a practical model of 450 window modes with different width, height and location of a residential building in a mild climate. First, the characteristics of the simulated model and all thermal and lighting parameters have been defined. Next, the thermal and lighting simulations have been integrated. Finally all the results of different width, height and window location are investigated. The results show that, the optimum solutions are the horizontal windows which are located at a higher sill level in the south oriented wall. In this range, day-lighting conditions are also satisfactory and these characteristics can therefore be considered as a good starting point in preliminary design phase for a south oriented window.

Keywords: window size; energy consumption; lighting analysis; thermal analysis.

1. Introduction

Iran is located on the world's Sun Belt, and is one of the countries that enjoy sunlight. This climatic characteristic has caused the architecture of this land to be formed constantly by taking sunlight into consideration, during many years. Iranian architects designed buildings in a way, that interior spaces take advantage of the sun heat in the cold periods of the year [1]. The utilization of free natural energies is one of the ways to reduce energy consumption and to reduce the use of fossil fuels, which reduces air pollution, environmental pollution and the greenhouse effect. Therefore, sustainable architecture has been established based on the application of the architecture which is based on climatic conditions, to reduce energy consumption and to preserve the environment. The design of the facade is one of the stages of architectural design, which could have a significant effect on the rate of energy loss from buildings. Among the primary points in sustainable architectural design are the window dimensions [2]. Many factors affect the type of thermal performance and daylight quality such as window size, glass materials and its frame, sunshade type and its dimensions, room dimensions and orientation of its view [3]. According to EN standard [4], windows and configuration of building facades affect the amount of energy required for heating, cooling, moisture and lighting, and does not directly affect the other energy requirements of a building, such as the amount of energy required

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for ventilation, hot water and other services. Also, it is necessary to be noted that 70% of electrical energy in residential buildings, in Iran, is consumed for lighting [5]. Therefore, use of natural light can largely save electrical energy, in residential buildings. The light intensity and the amount of radiation also affect energy consumption, because a large amount of solar radiation in summer increases cooling energy consumption, and also the glare rate of it, causes visual discomfort [6, 7].

In this article, the purpose of the modeling is to design a suitable procedure for calculating the impact of windows on the amount of energy consumption of a building, so that the building can reduce its exploitation costs, by a minimum initial cost. For this purpose, two important parameters, which are influenced by windows, are selected: 1. The building thermal and refrigeration parameter which affects the amount of electricity or gas consumption, in building installations. 2. The intended room lighting parameter which affects the amount of building electricity consumption. Therefore, in this article, the effect of window configuration on total energy consumption of buildings is investigated. Obviously, other factors such as the style of neighborhood, the materials of building elements, land use and other issues will affect the amount of consumption, that is why the parametric model is selected, so that in the future, and in other researches, their effectiveness can be evaluated.

2. Background

The characteristics of windows largely affect the amount of heating-cooling and electrical load of a building. So that many researchers, over the years, have sought and are still seeking to establish optimum conditions in terms of energy savings and the comfort of the occupants. Numerous researches have been conducted on various aspects of the subject. The investigation of the effect of the Window area to Wall area Ratio, WWR, on the energy consumption amount of a building, has begun since 1970-1980. Francisco et al. [8] in 1977, investigated the effect of WWR value and also the effect of the type of the selected algorithm for calculating the sky light, on the amount of energy saving. Also Marie et al. [9] in 2006, simulated a building with fully insulated elements and triple-glazed window, and concluded that in these conditions, in addition to the fact that window dimensions affect the lighting, it only results in cooling energy saving, and window area must not be less than 10% of the facade. In a research in 2013 by Greening et al. [10], windows have been discussed as a factor for energy losing or energy gaining. In this article, the optimal location and area of windows has been investigated in terms of thermal behavior. Also in 2010 Hasooneh et al [11], have investigated the window area based on the types of its transparency, according to the glass material, in different directions of Oman apartments, whose outcome shows that the greater transparent wall area is more economical, which indicates the importance of window dimensions in economic discussions. Disregarding the energy saving issues along with the art caused the free-form designs which have caused damage to the environment, over the years. Now, by limiting the designers to observe the principles and rules of reducing energy consumption, and determining a suitable, simple and low-cost structure for their design stages, the possibility of logic oriented designing is provided. In this case not only should the loss of heat resulting from heat transfer be considered, but also the beneficial effects resulting from solar radiation, and consequently reducing the demand for heating and artificial lighting is very important. Also, the air changes and attention to the lack of glare rate express other issue in relation to window dimensions and position. As can be seen in various articles in recent years, most researchers have ignored the investigation of window width and height and its location separately, and investigated the window area to wall area ratio by scientific-comparative method in the extent of office-use. Generally energy savings in residential buildings will be more cost-effective in relation to office buildings in urban savings.

3. Method

The building window modeling process based on thermal and lighting energy consumptions, has three main sections: input parameters, thermal and lighting analyses, and outcomes. This process is illustrated in Figure 1.

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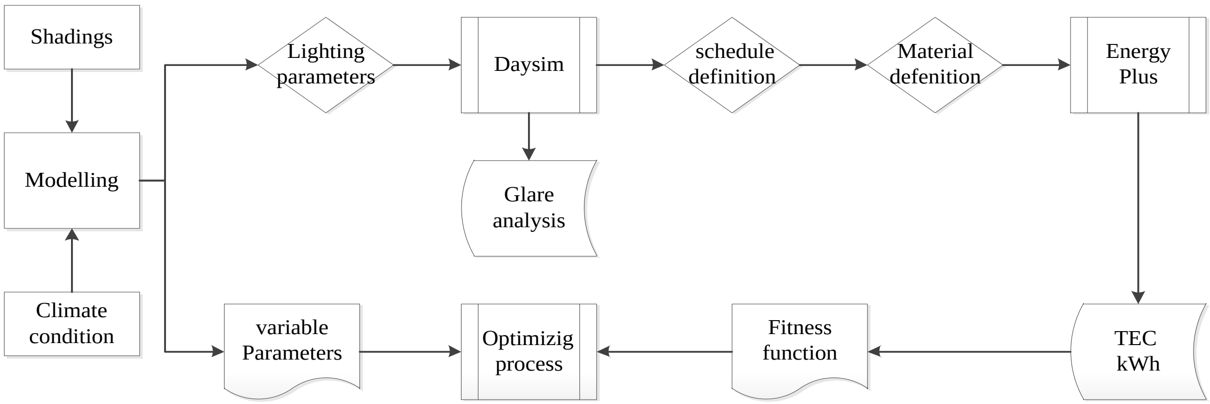

Fig.1. Window modeling process, and lighting and heating calculations (Reference: The authors)

The designed model is a combination of four main sections: 1.Definition of the investigated building characteristics and its conditions, 2.Lighting calculations and defining its input parameters, 3.Heating calculations and defining its input parameters, 4.Optimization process and defining the objective function and its variable parameters. The results obtained from the model are categorized into three sections: consumed total energy, the rate of useful natural lighting illuminance and the range of optimized answers of window configurations, so that the set of the results can provide the audience with a general schema of optimal window configurations for the designed building.

In the present article, considering the mild and humid climate conditions, the optimal dimensions of windows have been determined separately in the main direction (south) of residential buildings, so that designers can ensure the suitable heating and desirable lighting throughout the year, along with the savings in energy consumption, using the defined range. For this purpose, thermal energy is calculated by Energy Plus 8.1.0 software, and lighting by Radiance 2.01 and Daysim 1.08 software.

3-1. Characterization of the sample being investigated and limitations determined in the simulation process.

Process of the simulation has been performed in a sample of typical living room in residential buildings of Rasht city located in Giulan province. It is situated on the second floor and is of a single skin facade being 5m (width) x 6 m (depth) x 3.2 m (height). The dimensions of the specified living room are based on the average dimensions of Rasht City common living rooms, which are shown in Table 1. To determine the appropriate dimensions of the living room, various research works conducted by Kari et al. [12] and Fayaz [1] concerning the interpretation and analysis of eleven traditional houses of Rasht City.

The range of the designed window configurations is shown in Figure 2. The window distance from both sides of the wall is considered one and a half brick or 30 cm, the thickness of the ceiling is considered 40 cm, and the minimum height from the floor to the window is considered equal to the working plane (0.8 m).

Table1. The dimensions of the living room which is common in Rasht (meter) (Reference: The authors)

Cases	1	2	3	4	5	6	7	8	9	10
Room's width	3.5	7.3	3.7	6.4	5.6	4.9	3.9	3.4	5.1	6.4
Room's height	3.6	8.6	6	8.4	6.4	5.3	7.1	4.4	5.9	7.4
Average	Room's width =5m					Room's height = 6.3m				

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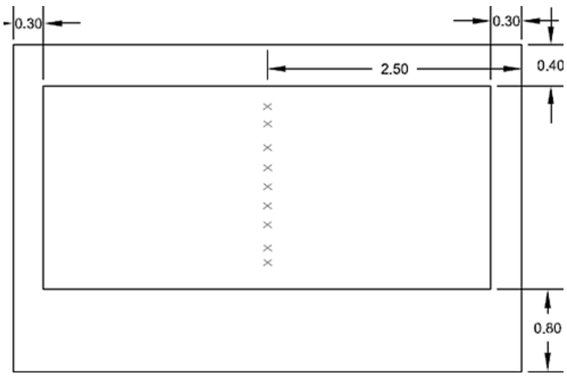

Fig. 2: The limitation considered for the window model - The specified points are the centers of the windows.

The window is located in the middle of the wall's width and the height from the floor to its center is one of the variable parameters. In this case, the window dimensions will vary from 2.2 m in 4.4 m to zero square meters. Other walls are internal and adiabatic.

The thermal conductivity coefficient for each of the elements of the sample investigated, are shown in Table 2. The material of the window investigated is PVC, and according to the section 19 of the national building regulations [13], its heat transfer coefficient is 2.9 W / m^{2}K. Insulation is not used in the side of the window.

The number of required lamps and their lighting power were calculated by DIALux 3 software. It should be pointed out that the installation system is considered as an ideal and constant system, so that the system is set for the minimum temperature of 20 ° C in winter and for the maximum temperature of 25 ° C in summer. For lighting calculations, the schedule of the presence of the occupants was considered from 6 o'clock in the morning to 12 o'clock at night. Lighting control system is based on sensitivity to the presence of people and daylight.

The thermal load of the lamps depends on the efficiency of the lamps available in the room. The lighting power is calculated 184 watts in DIALux software. The lighting required for the living room was considered 135 lux, based on the section 13 of the national building regulations [14].

Based on the results of the Weathertool software, the optimal direction of buildings in Rasht City was determined to be the south, which is in accordance with Kasmaee's research [15] in relation to the orientation of the majority of houses in Rasht. Therefore, in the modeling, the optimal window dimension is calculated and analyzed in the south direction.

4. Results and discussion

Structural features of windows, such as width, height and its position affect the amount of incoming solar radiation and thus affect the amount of buildings thermal and lighting energy consumption. Afterwards, the effect of each variable parameter on the amount of energy consumption for heating, cooling and lighting energy consumption was investigated separately. First the window height and its position were considered as constant parameters and its width as the variable one, then the height was considered variable and finally its length and width were considered fixed and the position of the window variable.

4-1.The effect of the window width on the amount of annual energy consumption

In this section, the effect of the window width on the amount of energy consumption of a living room has been investigated for lighting, heating and cooling energy consumption separately. As can be seen in Figure 4, the height of the window is considered constant and equal to 1.6 m (half the height of the wall), its location is considered within a meter from the floor, and its center is considered in the middle of the wall. The window width varied from 2.4 m to 4.4 m by 0.4 m intervals in 11 different states.

As can be seen in Figure 5, the width of a window has a considerable impact on the amount of savings in energy consumption for lighting and cooling, and it has affected the heating energy less.

Table 2. The thermal conductivity coefficient for simulated sample materials W / m^{2}K

Room’s components	Window	Internal walls	Floor	Roof	External wall
U values(W/m^{2}K)	2.9	2.5-adiabatic	1.4	0.6	1

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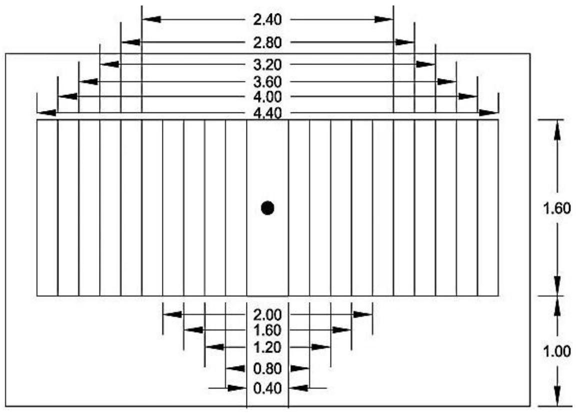

Fig. 3. The variable values of the window width in the simulation

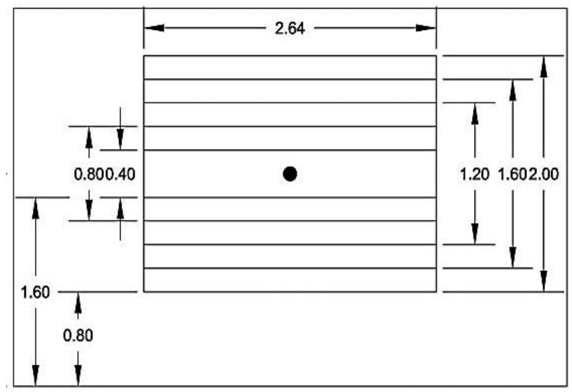

Fig. 5. The variable values of window height in the simulation

So that, the greater the width of a window was, the less the lighting energy consumption has become and the more the heating and cooling energy consumption has become, because the surface of the transparent wall becomes large and more energy will be wasted. From Figure 5, it follows that the width of a window can affect the lighting energy up to 20%, the cooling energy up to 20%, and the heating energy up to 7%, throughout the year.

4-2.The effect of the height of a window on the annual energy consumption

The effect of the height of a window on the amount of energy consumption of a living room has been separately investigated for lighting, heating and cooling. As shown in Figure 6, the width of the window is considered constant and equal to half the height of the wall, 2.64 m, and its center is considered in the height of 1.8 m.

Its height is considered variable from 0.4 m to 2 m by 0.4 m intervals in 5 different states. As can be seen in Figure 7, the height of a window has a greater impact than its width has, on the amount of savings in lighting energy consumption, so that the change in height, in suitable and sustainable design, will save the electric energy of a room, up to 40%. The height of a window has affected the heating and cooling energy less. So that, the greater the height of a window is, the less the lighting energy consumption becomes (up to 40%) and the more the cooling (up to 10%) and heating (up to 7%) energy consumption becomes; Because the penetration depth of light into the endpoints of a room becomes greater, and the surface of the transparent wall becomes large and subsequently more energy will be wasted.

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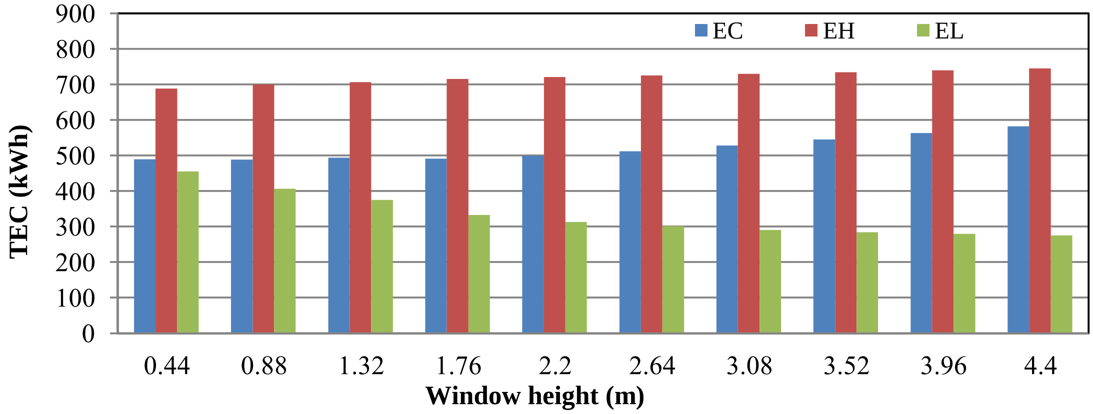

Fig.4. The effect of the width of a window on the amount of annual energy consumption, separately for lighting, heating and cooling

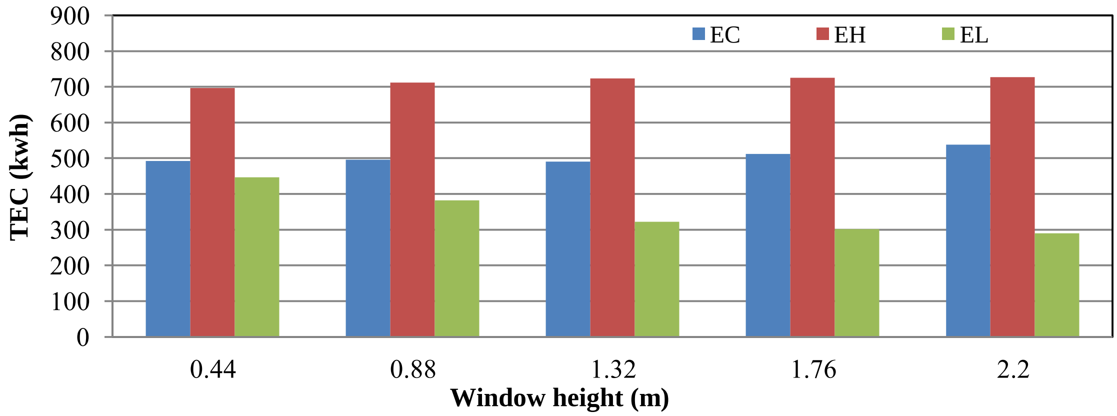

Fig.6. The effect of the height of a window on the amount of annual energy consumption, separately for lighting, heating and cooling

4-3- The effect of the location of a window on the amount of annual energy consumption

The effect of the location of a window facing south, on the amount of energy consumption of a living room has been separately investigated for lighting, heating and cooling.

As shown in Figure 8, the width of the window is considered constant and equal to 2.2 m, and its height is considered equal to 0.96 m and constant. In these dimensions, 4 variable states are created in the proposed model for the location of the window center: 1.40, 1.60, 2.00, 2.20 meters, which is illustrated in the figure.

As shown in Figure 9, the location of a window has affected the amount of savings in energy consumption for lighting more than it has affected the heating and cooling energy consumption.

But in general and for these constant dimensions which seems logical in terms of architecture, the higher the location of a window goes, the less the lighting and cooling energy consumption becomes,

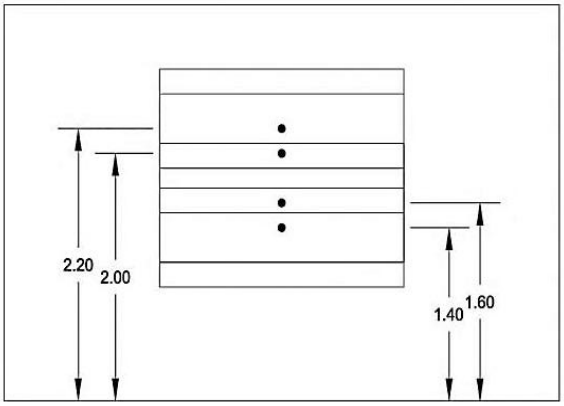

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Fig.7. The variable values of the window location in the simulation

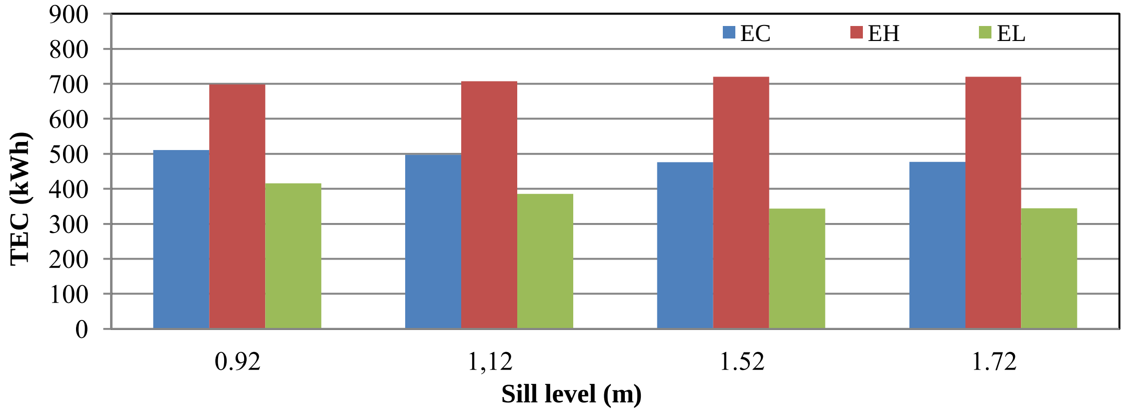

Fig.8. The effect of the location of a window on the amount of annual energy consumption, separately for lighting, heating and cooling

And it is the only variable that its energy saving processes in these two forms of energy consumption does not contradict each other. In this state, the lighting energy saving is about 18%, and the cooling energy saving is about 6%, and the heating energy consumption has increased up to 3%.

5- Conclusion

This article has investigated the structural effects of a PVC window with a thermal conductivity coefficient of 2.9 W/m^2K, whose location was on the south wall of the building, on the heating and lighting annual energy consumption in KWh. After investigating 11 different states for the window width, 5 states for the height and 4 states for the location, it is concluded that the height of a window has had a greater impact than its width and the location of its center have had, on the amount of energy consumption, especially on the lighting energy consumption, and then the window width and its location affect the total energy consumption, respectively. Therefore, in the initial step of a design, more attention should be paid to the height of the window. Also, during the performed research we notice that because of the low thermal conductivity coefficient and thus the low heat loss through windows, lighting energy consumption is actually considered the main factor for determining the dimensions of a window.

It should be noted that this article has only investigated two factors, lighting and thermal factors, and the effective factors, i.e. visual comfort and the type of ventilation are not considered. Also this research can be investigated and analyzed for other climates, in the future.

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