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Investigating the national criteria and standards of building window in the sustainable architecture of Iran

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ABSTRACT

An important principle of sustainable architecture and practice is thermal and lighting performance. Thermal and lighting performance in buildings is the relation of façade characteristics to environmental sustainability. Traditionally, thermal and lighting analyses for buildings are employed independently of façade design configurations. Application of an integrated model that balances these two performance indexes would serve to optimize window configuration. Also available standards define variable characteristics for building components in different climates which affects the total energy consumption of buildings. Thermal and day lighting performances are affected by many interfacing factors such as glazing size and properties, shading properties and its control system, the dimension of the room and its orientation. Choosing window features is a key step on building design. This paper presents the appropriate window characteristic and the optimal window to wall ratio (WWR) based on integration of thermal and lighting analyses into a parametric design process by evaluating 450 various window configurations. The model compared annual energy consumption of a typical living room located in a mild humid climate. Additionally the single and double glazed windows are both simulated. Finally there is a comparison between the simulated results and the results which are calculated and analyzed by considering the Iranian national building code. The results indicate that if the range of WWR be between 19.8 to 23 % the single-glazed window will be a better choice but when it is between 23 to 25% the double-glazed window will be the best.

KEYWORDS: “window size”, “energy consumption”, “Lighting”, “Thermal”, "national building code part 19".

1.INTRODUCTION

Utilizing renewable energy in buildings will decrease fossil fuel consumption, air pollution and the greenhouse effect. Solar energy, as the most important renewable resource, affects thermal and lighting energy consumptions, which are related to characteristics of the fabric of a building.

Supplementing total energy consumption with solar radiation is a well-known way to save energy. However, daylight needs to be regulated in order to avoid excess illumination that may cause visual discomfort, overheating problems, and considerable increase in the cooling load [1,2]. Discrepancy between the effect of a window on thermal and lighting energy consumption is currently an important research topic [3]. As defined in EN 15603 [4], the configuration of a façade can affect the following three terms of a building’s annual energy demand: the energy need for heating (EH), the energy need for cooling and dehumidification (EC), the energy need for lighting (EL). Other terms of the total energy demand of a building – i.e. energy needed for ventilation and humidification, hot water and other services are not directly affected by the transparent part of a facade [5].

The observance of principles and criteria is an inevitable affair in the sustainable design for reducing energy consumption. It has tried in series of Iran Building National Regulations books until by writing a range of principles and criteria, their observance and enforcement is actualized for designers and engineers. Especially, the characteristic of building elements and components in different climates with approach of energy saving and decreasing its loss have been addressed in Subject 19 of The Building National Regulations [6]. There are many correlative factors that affect thermal and daylight performances such as glazing size and properties, shading devices and their control systems, room aspect ratio and orientation [7].One of building elements that has a strong influence on energy saving is the exterior wall of building and the characteristics of its window in its different fronts.

The wall has included 3sectors: transparent, translucent and opaque sectors. The characteristics of the opaque sector have been fully expressed in Subject 19. [6] While because of being complex, the influence of transparent and translucent sectors on the rate of energy consumption and the interference of outer factors such as sunlight, solar-gain, natural air conditioning, the visual comfort and other factors for these sectors, there are not many rules and standard.

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The impact of WWR on day lighting and thermal performances of a building have been investigated since 1977 [8]. Hassounehet al. [9] presented influence of windows characteristics and area on the thermal energy balance of apartment buildings in Amman. However, the effect of solar radiation on lighting energy consumption is not mentioned. Goia et al. present a methodology of considering the optimal transparent percentage in a façade module for low energy office buildings [5]. They studied the impact of the window-height on total energy consumption. The methodology of optimizing the window size and related parameters are really influential. Grynninga et al. [3] 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. Shikder et al. [10] defined a method to optimize window size and its location on a south wall in a patient's room. They used Ecotect and Radiance software for Thermal and Lighting analysis, and DF method, but the electricity energy consumption for artificial lighting had not been considered in the study. In addition the relationship between CO2 emissions and energy consumption is investigated in Pakistan [11].

Since, Through well-designed and regularly cleaned skylights, windows, doors, and glass-block wall areas, useful quantities of daylight may be provided in buildings [12], and designing buildings with the lowest possible cost base is an essentiality in sustainable architecture, Also the impact of industrial design on sustainable architecture is investigated in 2014[13] Choosing window features is a key step on building design [14]. First, the standard criteria of the simulated model and all thermal and lighting parameters are defined. Next, thermal and lighting analyzes are integrated and the optimal window configurations and WWR is investigated. Finally the results of the simulation of two different modes of optimal window (single and double-glazed window of a located on the residential building of Rasht City) are compared with the energy consumption calculation based on corresponding standards. Also the raised characteristics in The National Standard [15] and National Regulations [6] have been simulated and calculated then compared with each other in the designed model.

2. METHOD

Optimizing Window characteristics in very first steps of the design has no effect on the initial cost of the construction but will reduce the costs generated during the operation of the building. For this reason a model is prepared to integrate thermal and lighting analysis in a parametric process to optimize window size and position on building's façade and solve the incoherency between thermal and lighting functions by determining the appropriate transparent to opaque area ratio (window wall ratio (WWR)) and width to height ratio (WHR).

The process of the building modeling based on energy consumption has three main parts of input, analytical calculations and output results in terms of the light and heat. It is displayed in Fig1. This process has four main steps: defining the building features and its requirements, validating input weather file data by empirical experiment, determining input parameters for the lighting and thermal analysis and clarifying variable parameters and fitness function for optimization algorithm.

The obtained results of the model have been classified in three sectors of thermal energy consumption (cooling, heating), electrical energy consumption based on natural lighting rate, and a range of optimized window configurations, so that the set of results can provide with respondent, a general schema of the thermal and lighting energy computations for the designed building.

In this paper, according to the mild and humid climate of the northern part of Iran, the optimal configurations of the south oriented window (the main direction [16]) of residential buildings are determined. Thus, designers can ensure of the appropriate heating and desirable lighting over the year with saving in the energy consumption by using the defined WWR range.

The integrated thermal and daylight simulations are carried out using Energy Plus V8-1-0 [17], Daysim 1.08[18] and Radiance 2.01[19] software performing calculations on hourly basis for the entire year. The integration process is designed byRhinociros5software and its Grasshopper 0.9.0075, Honeybee 0.0.55, Ladybug 0.0.58plugins. Furthermore, Dialux software 4.11 has been used to calculate the required number of lamps and total consumed watt.

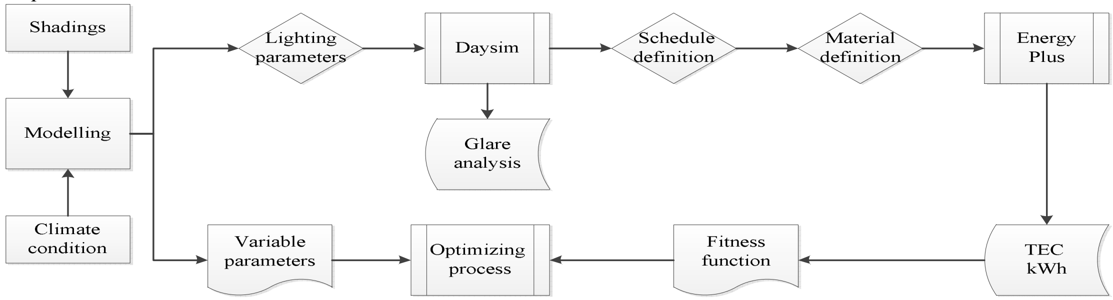

Figure 1: process of modeling

3. Description of the simulated model

Firstly, the characteristic of thesimulated common living room in Rasht city of Iranis defined in this chapter.The value of the parameters like thermal conductivity of the exterior wall and window used in thermal and lighting analyzes are carried out of The Building National Regulations, Subject 19 [6].Then, the effect of two proposed models of window in standard of ThatRegulation on the rate consumption of lighting, heating and cooling energies is investigatedbysimulating 450 windows with the different dimensions in the southern side of Rasht City residential building.

These two models have been selective based on the type of window and are placed in two categories of double and single-glazed windows. Consequently, both models have been simulated in the considered room and its results have been compared with each other.

Finally, the requirement of heating energy has been calculated by helping the computational code of National Standard 14,253 [15] for the obtained optimal window of simulating 450 windows with the different sizes that is placed in the range of The National Regulations conditions for the efficiency of sunlight. Theobtained result has been compared with the result of simulated model.

The conducted investigations byKari et al. [20] and Fayaz [21] concerning the interpretation and analysis of few traditional houses in Rasht City areused to determine the appropriate dimensions of Rasht City commonliving room. The specified dimensions of living room aredetermined based on the average common dimensions of Rasht City living rooms. According to Figure 2, the living room isselected with the width of 5m, depth of 6m and height of 3.2 m. Distance of the window isconsidered on both sides of wall with size of one and a half bricks, equal to 30 cm, ceiling thickness width of 40 cm and a minimum height of window from floor, equal to the working plane (0.8 m).

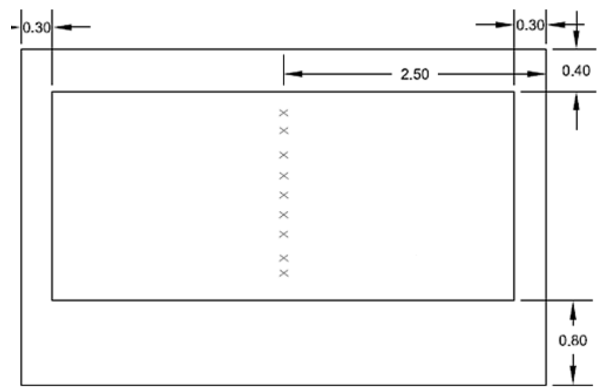

Figure 2: The considered area for Window design(The specified points are center of the windows)

The window has been placed in the middle of the wall width and its center height from thefloor is one of the variable parameters.(Fig 2) In this case, the widthand height of the window will change, respectively, from 0 to 2.2 m and 0 to 4.4 m and finally, the size and location of positioning the window have been limited to 450 states. Other walls are inner and adiabatic. It is necessary to being noted that the simulated zone has been located on the second floor of a building.

3.1. Determination of the thermal conductivity coefficient for the exteriorwall of investigated room based on The National Regulations, Subject 19

Rasht is a city with the low energy consumption in Section 19 of The National Regulations book [6] that its predominant need is the heating energy. Furthermore, according to [6], a residential building with characteristics of group 3would have possibility of the proper efficiency from solar energy when ithas 3 following conditions:

1. It has not the cooling predominant need;
2. Its window areaof the wall in direction of the southern-east to southern-west is more than 9.1 useful infrastructure of building (11% of it);
3. The blocks of radiating sunlight to building are seen with an angle less than 25 degrees relative to the horizon.

Based on the proposed prescriptive solution in this source [6], to determine range of the thermal conductivity coefficient for the exteriorwall of the building, its type of window is very important so that two groups of the double-glazed and single-glazed windows have been introduced.

3.1.1. Determining the thermal conductivity coefficient of exteriorwall with a single-glazedwindow

According toSection 19 of The National Regulations book [6], the minimum thermal resistance of exterior wall with the external insulation has been equal to 1.8 m^2.K/W and thus, its maximum thermal conductivity coefficient have been obtained 0.55 W/m^2.K .Consequently, the thermal conductivity coefficient of each of the investigated elements is shown in Table 1.

Table 1: Thermal conductivity coefficient of the typical simulated elements of living room

Building's elements	Window (W/m²K)	Internal Wall (W/m²K)	Floor (W/m²K)	Roof (W/m²K)	External Wall (W/m²K)
Thermal conductivity coefficient (U)	5.8	2.5	1.4	0.6	0.55

3.1.2. Determination of the thermal conductivity coefficient for the exterior wall with a double-glazedPVC window

A minimum thermal resistance of exteriorwalls that also is with the outer insulation, has been considered equal to 0.8 m^2.K/W for the wall with a double-glazedwindow containing that if considering inner and outer air layer(the thermal resistance of 0.17 m^2.K/W), its maximum thermal conductivity coefficient becomes equal to 1.03 m^2.K/W.

Consequently, the thermal conductivity coefficient of the surface for each of the investigated typical elements has been shown in Table 2. The investigated window is PVC and in accordance with Section 19 of The National Regulations, has the heat transfer coefficient of 2.9 W/m^2K.

Table 2: Thermal conductivity coefficient of the typical simulated elements of living room

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

4. RESULTS

Rate of the heating, cooling and lighting energy consumptionof the common living room with a south oriented double glazed window are compared with each other in figure 3 for 450 states of thewindowsize and location of the southern wall, respectively, from the low ((0 m^2)) to high (8.8 m^2) window area. Also according to The National Regulations [6] the minimum window to floor area ratio (WFR) has to be 11% which this value is equal to when WWR is 20%. Thus, the range of 3.2_8.8 m^2 of window area which is in the range of requirements for energy efficiency should be specified.

As seen in Figure 3, especially in range of the efficiency of sunlight [6], whatever the area becomes greater, rate of the lighting energy consumptionreduces and in contrast with it, the cooling energy increases, that is caused by overheating effect of the space. It is concluded from this figure that this criterion will respond better for cities with more heating energy consumption.

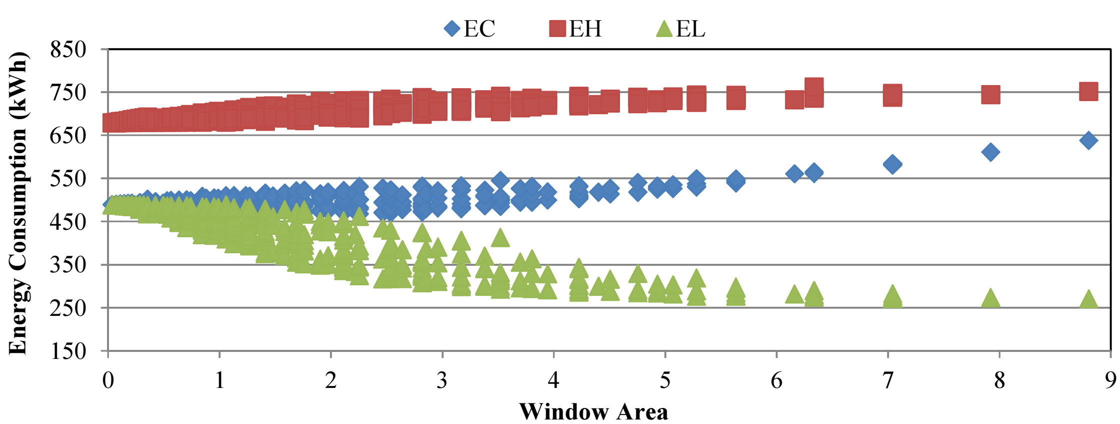

Figure 3: The trend of changing rate of the annual consumed energy with being enlarged the area of window with the separation of lighting, cooling and heating energies

The obtained optimal results of the simulated windowwith respect to the rate of lighting, heating, and cooling energies consumption are observed in Table 3.

Consumption of the obtained annual optimal heating, cooling and lighting energies are 1515.3 kWh that is due tothe influence of southern window with height of 0.8 m and width of 3.96 m that its window-to-wall area ratio (WWR) is equal to 19.8%, which in fact, almost is the same determined boundary by The National Regulations.

Table 3: Five obtained superior solutions of simulating southern window of the residential building

Ec(kWh)	Eh(kWh)	El (kWh)	Total Energy Consumption (kWh)	Width (m)	Height (m)	%WWR
479.4	736.9	299	1515.3	3.96	0.8	19.8
483.8	727.8	304.3	1515.9	2.64	1.2	19.8
475	733.2	307.8	1516	3.52	0.8	17.6
470.9	730	316.7	1517.6	3.08	0.8	15.4
472.9	737.7	308	1518.3	4.4	0.64	17.6

4.1. The comparison between twotypes of the window considering thermal and lighting energy consumption

Rates of the annual consumed heating, cooling and lighting energies for these two window modelingare compared with each other by simulating the living room of residential building located in Rasht City theresults are shown in Figures 4-6. The range of optimal WWR is between 20 % and 25 % based on The National regulations which noted that WWR should be greater than 20%.

As seen in Figure 4, rate of the heating energy consumption from WWR 19.8-23% in the building with the double-glazed window is more than building with a single-glazed window. However, when the window area becomes greater, building has acted better with characteristics of the double-glazedwindow from WWR 23 to 25%.

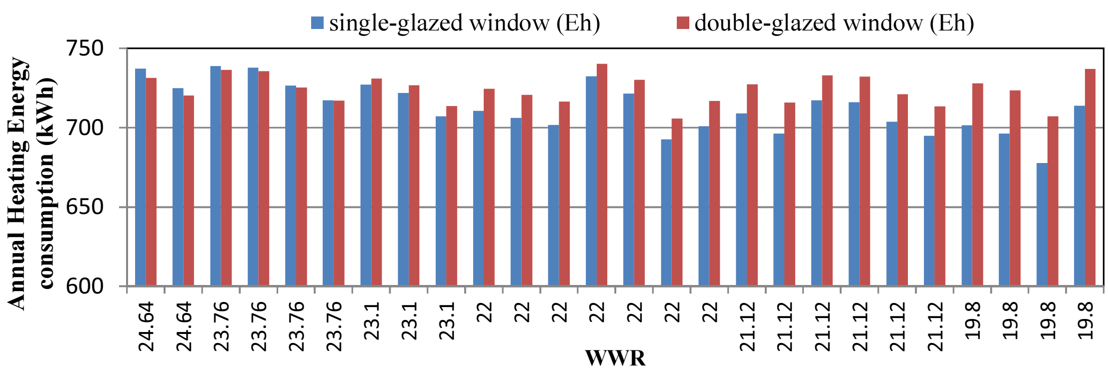

Figure 4: Comparing rate of the heating energy consumptionin two states of the building with characteristics of doubleand single-glazed window according to The National Regulations

As seen in Figure 5, rate of the annual cooling energy consumption in 26 types of the simulated window that have the characteristic of sunlight efficiency from the view of The National Regulations, from WWR 19.8-25%, in building with the characteristics of double-glazed window is more than building with a single-glazed window.

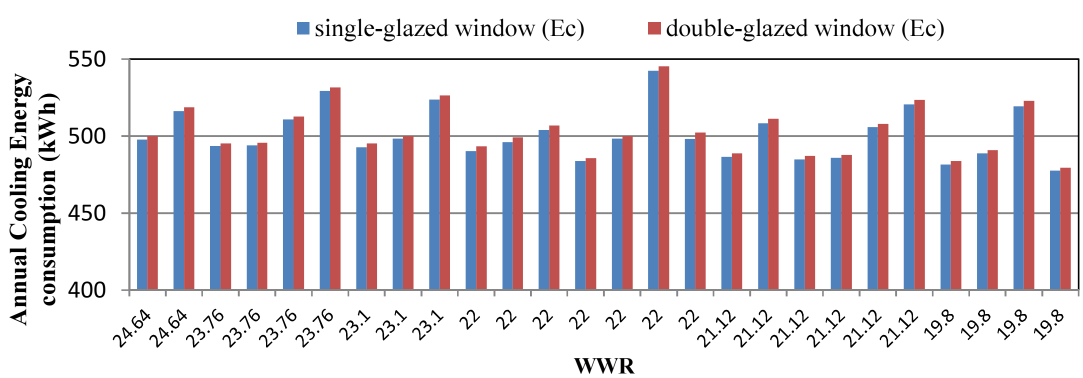

Figure 5: Comparing rate of the cooling energy consumptionin two states of the building with characteristics of doubleand single-glazed windows according to The National Regulations

As seen in Figure 6, rate of theannual lightingenergy consumption in building with features of double and single-glazed window in 26 types of the simulated window that have the feature of sunlight efficiency from view of The National Regulations and its WWR is in the range of 19.8 to 25%, is the same due to equality of the window size.Because in both cases, the area and location of the simulated window are the same.

Figure 6: Comparing rate of the lighting energy consumptionin two states of the building with characteristics of double and single-glazed windows according to The National Regulations

4.2. Calculating rate of the heating energy consumption of the considered living room whith a double-glazed window

The rate of the heating energy consumption is calculated for the investigated living room with double-glazed window in January month by using the adapted National Standard 14,253 [15] from EN Standard [4].The resultsof the calculationare compared with thoseof the simulated model having the characteristics of double-glazed in The National Regulations [6]. Thus, first the abbreviated used formulas of Source [15] have been defined and then, the results have been compared with each other.

The required heating energy can be computed by Equation 1. Three parameters of the thermal loss, heat gain and its coefficient are defined in this equation.

$$Q_{H,nd,cont} = Q_{H,ht} - \mu_{H,gn} \times Q_{H,gn} \quad (1)$$

$Q_{H,nd,cont}$: Is heating energy demand of the building in state of the continuous operation, in MJ

$Q_{H,ht}$:Is the total heat loss for the heating mode, in MJ

$Q_{H,gn}$:Is the total heat gain for the heating mode, in MJ

$\eta_{H,gn}$: Is the dimensionless gain utilization factor

4.2.1. Rate of the heat loss:

How to calculate the rate of energy loss is shown in Equation 2.It has been formed from two parameters due to energy loss from the exterior wall and the ventilation.The calculation formula of each parameters is shown, respectively in Equations 3 and 4.

$$Q_{Hht} = Q_{tr} + Q_{ve} \quad (2)$$

Q_{tr}: The energy loss from the exterior wall

Q_{ve}: The energy loss from the natural ventilation

According to the conducted calculations for the modeled living room in Rasht City by helping The National Standard [15], rates of $H_{tr,adj}$, $\theta_{int,set,H}$and average outdoor temperature in january mouthare respectively obtained:17.3 W/m^2.K, 20 °C and 7 °C. Thus, rate of the thermal energy loss from the exterior wall(Q_{tr}) ofthe living room with characteristics of the double-glazedwindowon the basis of National Standard, is equal to consumption 525.6 MJ in January month.

$$Q_{tr} = H_{tr,adj}(\theta_{int,set,H} - \theta_{e})t \quad (3)$$

$H_{tr,adj}$(W/K): The overall heat transfer coefficient from the exterior wall

$\theta_{int,set,H}$ (℃): the set point Temperature in the heating mode

θ_e (℃):The average outdoor temperature in the month

t (Msec): Duration of the considered month that is equal to the number of days in the month at 0.0864

According to the conducted calculations for the modeled living room in Rasht City by helping The National Standard [15], rates of $H_{tr,adj}$, $\theta_{int,set,H}$and average outdoor temperature in january mouthare respectively obtained:23.4 W/m^2.K, 20 °C and 7 °C. Thus, the obtained rate of thermal energy loss from the naturalventilation (Q_{tr}) ofthe living room with characteristics of the double-glazed windowon the basis of the National Standard, is equal to consumption 788.4 MJ in January month.

$$Q_{ve} = H_{ve,adj}(\theta_{int,set,H} - \theta_e)t \quad (4)$$

$H_{tr,adj}$(W/K): The overall heat transfer coefficient from naturalventilation
$\theta_{int,set,H}$ (°C):the set point Temperature in the heating mode
θe (°C): The average outdoor temperature in the month
t (Msec): Duration of the considered month that is equal to the number of days in the month at 0.0864
Thus, the total heat loss of the building will be equal to 1445.5 MJ.

4.2.2. The rate of solar gain

The solar gainof the building (Eq5) is obtained from two internal sources:Q_{int}which is the heat gained from the equipments and occupants and is calculated from the Equation 6 and it is equivalent to 518.4 MJ and the direct heat gain from the sunQ_{sol} in terms of Mj that is observed in Equation 7.

$$Q_{gn} = Q_{int} + Q_{sol} \quad (5)$$

$$Q_{int} = \sum_k (Q_{int,mn,k})t \quad (6)$$

so that F_{sh}, the discount factor for shading, A_{sol}, the effective area of the solar absorption by the opaque and transparent walls, I_{sol} on the unit (W/m^2) of average the total energy of solar radiation (direct and diffuse) on a square meter of wall area, F_r, the shape factor between the building and the sky and $\emptyset_r$, the radiative power from the building area towards the sky in terms of (W) are the parameters. According to [15], F_{sh}, A_{sol}, I_{sol} *of* Rasht City, F_r and $\emptyset_r$ arecalculated, respectively, equal to 0.46, 3.7, 82, 0.5 and 9.9. Thus, the direct solar gainis equal to 348.8 MJ in January month.

$$Q_{sol} = (F_{sh} \times A_{sol} \times I_{sol} - F_r \times \emptyset_r)t \quad (7)$$

Thus, the The heating energy demand of the buildingis calculated equal to 867.1 MJ.

5.DISCUSSION

According to the calculation based on National standard Code [15] for the considered room, rate of the heating energy demandis obtained equivalent to 161 kWh.

As seen in Figure 7, the calculated rate of the heating energy demandaccording to The National Standard Code [15] is about 11%less than obtained solution of simulationbesed on The Building National Regulations[6].This discrepancy is because of the diversity of the inertia coefficient which increases the gained rate of space heat.

Furthermore, 0.5 cm^2 has been considered as gap of the window and thus for the air penetration from outdoor in the conducted simulation that is not included in the calculation. As it is proved subsequently by [22],since lamps have been fully under control in the simulation and conditions are ideal, the result of standard will be more.

Szczepaniak et al. [22] investigated accuracy of predictions of European Standard EN 15193, by comparing the standard mathematical approach with computer predictions of Daysim. The study determined that EN overestimates energy savings (for about 10%), especially in 'fully automatic' modes. It is noteworthy that analyzing software relates to commissioned lighting systems that are ideally maintained but this is not always the case in real circumstances, so possible savings are usually much smaller than the simulated results.

The papers [23] refers to the importance of presenting software in today architecture design of the thermal and lighting computations and for this reason, two Energy Plus and DOE software have been validated by helping a practical test in the paper. The obtained result of this research is such that the differences of computations for Energy Plus software with the obtained results of the experiment are, respectively in the subjects of natural lighting, the rate of electricity consumption for artificial lighting and also rate of reversible thermal energy consumption by helping the coil, 119.2%, 16.9% and 17.3%. Furthermore, this differences for DOE-2.IE software are, respectively, equal to 114.1%, 26.3% and 25.4%.

Based on a computerized analysis in another paper [5], the difference of results for calculations of two Radiance and Energy Plus softwares have been obtained equal to 20% in subject of daylight lighting.

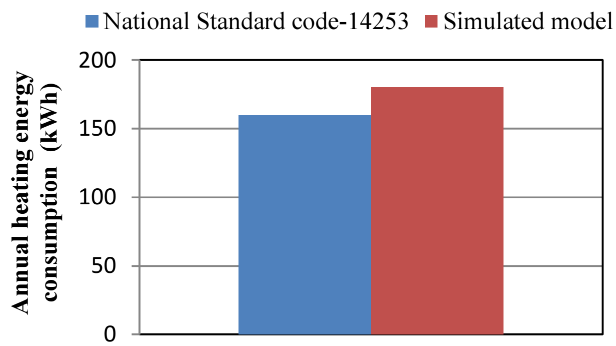

Figure 7: The comparison of the heating energy consumption result of the simulated building with the characteristic of double-glazed based on building national regulations and that of the calculation according to The National Standard

6.Conclusion

In this article a parametric model is utilized to develop a practical model of 450 window modes with different WWR, WHR and window locations of a residential building in a mild climate of Iran. The proposed methodology presents an integrated Energyplus and Daysim analysis with optimizing genetic algorithm approach in order to optimize building's window design to achieve thermal comfort and indoor daylight quality. According to the building national regulations two states of the window (single and double glazed window) are simulated and compared. Furtheremore The annual heating energy demand obtained from the simulated model based on building national regulations is compared with the results calculated according to the national standard 14523.

The result of comparing a building with two types of single-glazed and double-glazed windows is such thatwhen WWR is from 19.8 to 23 percent, the single-glazed window works better and when this rate is from 23 to 25 percent, doubleglazed window will has less annual energy demand.

In addition, if the double-glazed windowis selected for a building, it would be better that the country which the building is locatedhas the heating predominant need so that, the over heating effect would be decreases. Furthermore, we come to conclusion as a result of comparing heating energy consumption of the simulated model based on building national regulations with the conducted calculations of national standard, that shows the rate of heating energy consumption of the simulation approach is up to 11% more than the calculated one. that is because of the building inertia conditions rate of the air penetration through gaps in the designed model.

Rates of lighting and cooling energy has not been investigated by the computational method in this research. Also the simulation has been conducted limit to a living room in Rasht City which can also be calculated for other climates in the future researches.

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