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Energy Consumption Based on Shape and Orientation in Tehran

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A B S T R A C T

Overusing non-renewable resources has resulted in several environmental problems. Presenting different solutions in terms of environmental protection will lead to save energy in different parts of the buildings. One of the methods which can be useful in controlling the energy consumption is the analyzing the shape and the orientation of the building. The main purpose of this study is to analyze the energy consumption in office buildings in the city of Tehran based on geometrical shape and orientation. The methodology of this research is simulating the data using the "Design Builder" software. The main geometrical forms based on the area and number of determined floors in hot and cold seasons and their positions was calculated. It was revealed that in order to have the minimum energy consumption in the building, circular shapes followed by rectangular shapes with zero angles in proportion with Tehran city coordination with eastern-western elongation (Landscape mode) was the greatest alternative. Based on the results of this study, having circular shape buildings would decrease the usage of energy. This study is useful in designing office buildings and developing sustainable environmental conditions by decreasing the energy demands in order to achieve a sustainable environment in Tehran.

Keywords: Sustainable Development, Energy Efficiency, Building Orientation, geometrical forms

1. Introduction

Buildings constitute a large part of energy consumption in the world. Energy-efficient buildings contribute in maximizing the solar heating in the winter and in minimizing it in the summer. Sustainable architecture seeks to minimize the negative environmental effect of buildings by increasing efficiency and moderation in the use of materials and energy. The balance of the energies used in such strategies of building-design as creating a comfort space by providing a passive solar system and designing optimal energy-use form can have a favorable effect on energy consumption, reduced environmental temperature and the effect of heat islands (Perez, Coma, Matorell, & Cabeza, 2014). Currently, more than 81 percent of the global energy consumption and more than 95 percent of energy consumption in Iran is provided by fossil fuels (Sharifi, kiyani, & Khoshakhlagh, 2013). Also, more than 35 percent of energy consumption is related with construction (Lechner, 2014). In addition to the fact that office buildings in general have higher energy consumption compared with other buildings due to their use type and time, 79 percent of energy consumption in the USA and 72 percent of it in the UK is related to lighting and ventilation (Siew, Che-Ani, Tawil, Abdullah, & Mohd-Tahir, 2011). According to the statistics of the energy consumption, the buildings in Iran consume energy by more than 2.5 times more than the world average, and so they are a source of pollution. Also, more than 98 percent of this consumption is provided by fossil fuels (Nasrollahi, 2011). As a result of their appropriate structure according to the climatic conditions, such buildings can result in the decreased use of non-renewable energies and a correct understanding of energy consumption by the users.

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There are passive design strategies that can affect the building energy needs such as form, orientation and building occupancy. Previous studies reveal that orientation and shape of the building can be effective in reducing energy consumption (AlAnzi, Seo, & Krarti, 2009; Catalina, Virgone, & Iordache, 2011; Olgyay, 2015; Hemsath and Alagheband Bandhosseini, 2015; Fallahati & Mahdavinejad, 2015). In addition, among the solar related parameters, heating and lighting are two important factors in reducing energy consumption which are under influence of building orientation (Wong & Fan, 2013; Mardookhy, Sawhney, Ji, Zhu, & Zhou, 2014). Accordingly, Orientation has the greatest impact on the energy consumption of a building (Pacheco, Ordóñez, & Martínez, 2012; Abanda & Byers, 2016). So far, various simulation studies have been conducted on the relationship between building geometry and energy performance (Thomsen, Schultz, & Poel, 2005). However, due to different weather conditions and buildings performance, there is a wide range of outcomes that can be used to examine simultaneously heating, cooling and lighting. Exploring the optimal shape of the building and finding the orientation with maximum gain of energy was the aim of this study. The examination was performed by considering Tehran's weather conditions in order to design a more environmental friendly building.

The method of this study is conducted in two areas. The first area includes data collection and analysis. Therefore, it is descriptive, scientific and analytical including library studies. The second area includes designing several models and comparing them in the software Design Builder in order to find the best form, among the ones examined, in terms of reducing energy consumption. This constitutes the method (observation and experiment).

2. Methodology

The topic of this study is an examination of the shape and orientation in designing office buildings in Tehran. Shape and orientation of the building are counted as effective factors on reducing energy consumption (Thomsen, Schultz, & Poel, 2005). Regarding to decreasing energy consumption, four basic forms (triangle, rectangular, square and circle) were modeled with constant area and the number of floors by Design Builder/Energy Plus building energy simulation software. Since orientation has an enormous effect on energy consumption, all the shapes were orientated by 10 degrees. Hence, the shape with minimum of energy-use was the aim. The results determined the total consumption of each form in cooling, heating and lighting in cold and warm seasons.

One of the most comprehensive available software of building simulation is Design Builder. This software has the benefit of energy plus motor which was developed in 1999 and released in 2005. U.S department of energy created a simulation software named energy plus which able to simulate thermal energy and energy consumption. In order to access graphical interface, design builder was developed as a friendly use interface of energy plus (Bajenaru, Damian, Frunzulica, 2016). Design builder can simulate energy consumption which includes cooling, heating and lighting use. This software is approved by ASHRAE standard (ANSI/ ASHRAE 140, 2004) system (Tronchin & Fabbri, 2008).

3. Geometry Theory

The building is located in Pardisan Park with the geographical coordination of 51.33 ° E and 35.50 ° N (Alijani, 2006). Given the use of the place and physical program analysis required in office places, the area of each floor is considered to be 1,100 square meters, with 3 floors which includes the basements and two floors over it.

The office building is used 5 days of the week (Saturday to Thursday) at 8am to 6pm with 0.18 people/m2 occupancy density. Since the effective of season on energy consumption, all the results were considered annual (from January 1st to December 31st). Table 1 depicts the constant parameters of the study.

Table 1. Constant parameters of the study

Office Information		
Activity Template	Generic Office Area	
Occupancy	Density:0.18 people/m2	Schedule: office-open off- occupancy (8 AM-18 PM, Thursdays Fridays): off
Metabolic	Activity: light office work/standing/walking	Factor:0.92
Clothing (clo):	Winter clothing:1	Summer clothing:0.7
Lighting: Target luminance(lux):300		Default display lighting density(w/m2):13
Environmental Control		Heating Set point Temprature:22C
		Heating Setback:12C
		Cooling Set point Temprature:24C
		Cooling Setback:28C
		Ventilation Set Point Temperature: Natural Ventilation:22C
		Max in-out delta (delta C): -50 C
		Minimum fresh air:10
Computers: on Gain:57 w/m2 Radiant Fraction:0.2		Schedule: office-open off- occupancy (8AM-18 PM, Thursdays Fridays): off
Office Equipment: on Gain:35 w/m2		Schedule: office-open off- occupancy (8AM-18 PM, Thursdays Fridays): off
Miscellaneous: off Catering: off		Process: off

Accordingly, the proportion of window to wall ratio has a significant impact on the annual heating and cooling loads of buildings (Field, 2017). Besides, Nasrollahi (2014) claimed that the glazing ratio of office buildings in Tehran is considered as approximately 60 percent in order to minimize total energy consumption. So, the proportion of the glazing to whole building were considered as 60 percent. Table 2 demonstrates the scope in the openings of the study.

Table 2. Scope in the openings of this study

Openings Tab	
Glazing Template	Double glazing, clear, internal blinds
External Windows	Glazing type: DblClr 6mm/6mm Air Layout: Preferred height 1.5, 30% glazed
Dimensions	Type: 3 preferred height Window to wall%: 60.00 Window height (m): 1.50 Window spacing (m): 5.00 Sill height (m): 0.80
Operation Schedule	office schedule

The geometric concept of the office building was based on four basic forms in architecture included square, rectangle, triangle and circle form. All the elements of geometric theory were taken to achieve the best shape and orientation. The shapes are depicted in Figure 1.

Figure 1. Morphology of buildings

4. Results and Discussion

The initial analysis is conducted in order to achieve the best form regarding reduced energy consumption in cooling, heating, and lighting sections. Presented results were exported from the simulation software Design Builder. After examining the four main forms and performing the calculations according to the aforementioned factors, the energy consumption in the intended annual forms is demonstrated in Table 3.

Table 3. Calculation of energy consumption in different forms

Form	seasons	Date/Time	Lighting Wh/m2	Heating (Gas) Wh/m2	Cooling (Electricity) Wh/m2	Total (Lighting, Heating, Cooling) Wh/m2	Total average
Triangle	Warm months	12:00:00 AM	63640	6470.875	111253.05	181363.9	
	Cold months	12:00:00 AM	63640	38256.6	90078.4	191975	186669
Rectangular	Warm months	12:00:00 AM	63640	6225.09	104400,9	174266.2	
	Cold months	12:00:00 AM	63640	37093.97	81777.03	182511	178361.6
Square	Warm months	12:00:00 AM	63640	6215.09	101766.06	171622.2	
	Cold months	12:00:00 AM	63640	38870	80421	182931	177276.6
Circle	Warm months	12:00:00 AM	63640	6619.461	97390.53	167650	
	Cold months	12:00:00 AM	63640	39848.42	76767.58	180256	173953

According to the average resulting from the total energy consumption in different seasons, the circular form has the lowest consumption based on the total consumption of energy. The diagrams of energy consumption in cold and warm seasons are shown in figures 2 and 3; The diagram represents the comparison of energy consumption in the circular form in the warm and cold season on an annual basis which provides information on the amount of heating, cooling and lighting. In addition, according to the diagram, the amount of energy used in heating in warm season is significantly less than the consumption in cold seasons. Moreover, considering to changes in the season from cold months to hot months, the quantity of energy consumed in hot seasons has improved. Moreover, after the circular form, square and rectangle, respectively, have the lowest consumption of fossil fuels. The triangular form has the highest energy consumption.

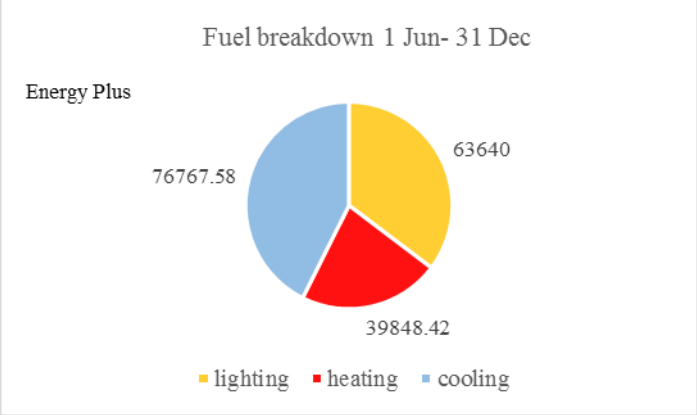

Figure 2. Diagram of energy consumption in the circular form in cold seasons

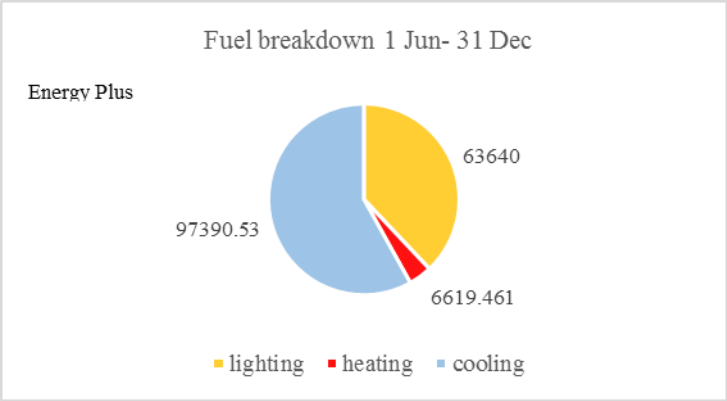

Figure 3. Diagram of energy consumption in the circular form in warm seasons

According to the data from the software, the lowest amount of energy consumption belongs to the circular form, but, since the orientation of the building is also influential, other results were also analyzed considering the rotation of square, rectangular, and triangular forms around their axes 10 degree by 10 degrees according to the latitude and longitude of Tehran in all the days of the year. Table 4 represents the angles which reduce energy consumption. these angles are based on the rotation at all levels, the most effective for each of the forms in the table and its results are once again compared with the circular form, the results of which are shown in Table 4.

Table 4. Calculation of energy consumption in different angles of square, rectangular and triangular forms and their comparison with the circular form

Form	seasons	Degree	Date/Time	Lighting Wh/m2	Heating (Gas) Wh/m2	Cooling (Electricity) Wh/m2	Total (Lighting, Heating, Cooling) Wh/m2	Total average
Triangle	Warm months	50	12:00:00 AM	63640	6491.089	125500.01	195631.1	
	Cold months	50	12:00:00 AM	63640	34969.6	102316.6	200926.2	198278.65
Square	Warm months	90 180	12:00:00 AM	63640	6514.466	117675.6	187830.1	
	Cold months	90 180 360	12:00:00 AM	63640	36360.66	95745.04	195745.7	191787.9
Rectangular	Warm months	180 260	12:00:00 AM	63640	28956.45	59807.35	152403.8	
	Cold months	180 360	12:00:00 AM	63640	35359.94	99064.76	198064.7	175234.25
Circle	Warm months		12:00:00 AM	63640	6619.461	97390.54	167650	
	Cold months		12:00:00 AM	63640	39848.42	76767.58	180256	173953

According to the calculations of the "Design Builder", the examination of the building's orientation according to the geographical coordinates of Tehran and the calculation of cooling, heating and lighting sections in warm and cold seasons. Also, the numbers listed in each section of the table 4 are based on the energy simulation in the angels that after summing up of the numbers in different seasons and their average leads to the conclusion that the circular form still has the lowest energy consumption. Then there is the rectangular form with the completely eastern-western elongation which has the lowest amount of fossil fuel consumption in both cold and warm seasons.

5. Conclusion

Based on the data from "Design Builder" software, the best shape in terms of the reducing consumption was determined according to the geometrical form and orientation in relation to the geographical coordinates of the city of Tehran. Regarding to the simulations conducted by "Design Builder" software, the results are illustrated:

- Considering consumption factors such as the geographical coordinates of the city of Tehran, the building's type of usage, the area and the number of floors, time limitations, and the glazing ratio for ideal lighting, the lowest consumption of fossil fuels in office buildings belongs to the circular form. According to the diagrams provided by the software, this form has the lowest energy consumption in heating, cooling, and lighting section.
- According to the simulations conducted in order to determine the best form as given in Table 3, after the circle, square and rectangle have the lowest energy consumption. The triangular form has the highest consumption of fossil fuels given the geographical coordinates.
- According to the simulation conducted in terms of the building's orientation as shown in Table 4, the circular form still has the lowest level of energy consumption. After that, the rectangle with zero-degree angle and fully eastern-western elongation is the best option for reducing energy consumption in both warm and cold seasons of the year.

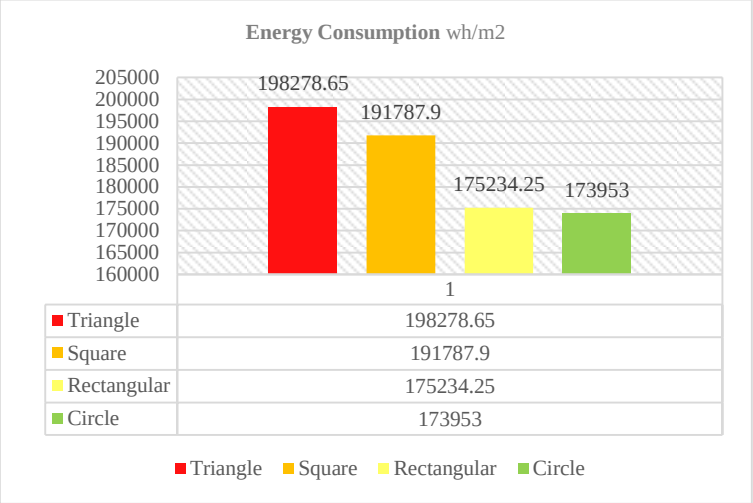

Figure 4. Diagram of energy consumption in the studied forms

- It is clearly initiated that orientation of the building has a key role in reduce energy consumption. Comparing the tables 3 and 4 clearly shows the significance of the building's orientation, because according to the optimal shape, the best options are respectively circle, square, rectangle, and triangle, whereas the calculations conducted in terms of the building's angle of rotation, the rectangular form obtains the second place, which illustrates the importance of the building's angle of rotation according to the geographical coordinates, the results which are outlined in figure 4.

Considering the discussion of the influence of shape and orientation of the building on energy consumption by Thomsen, Schultz, & Poel (2005) and comparing it with the simulations conducted by the software "Design Builder", it is completely approved.

Given the importance of the topic of shape in architecture of office buildings, and also of the building's shell for reducing energy consumption and increasing the building's efficiency, an examination of different kinds of awning as well as two-shelled and multi-shelled views in the city of Tehran is suggested for further study.

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