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Determination of the Optimal Orientation in the Cold Climate Administrative Buildings; Case Study: Kermanshah

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ABSTRACT

The per capita energy consumption in Iran is higher than that of many of the countries. In between, the government's policies have become aligned with getting the energy cost closer to the reality and this has increasingly drawn the attentions to the efficient energy solutions in the building sector. One of the effective solutions in reducing the energy consumption is the climate-based designing of the buildings in general and the determination of the optimal orientation of the building in specific. This way, the first and the most important duty of an architect is aligning the building to a direction that receives the highest and the lowest amounts of sunlight during winter and summer, respectively. Besides influencing the reduction in the thermal need of the building, the enjoyment of the sunlight optimizes the quality of the interior environment thereby causing more healthiness and productivity of the residents and the resultant creation of abundant economic interests for the country. Considering the intensity of the sun's irradiation on the orthogonal surfaces in various geographical directions as well as the various hours and seasons, Olgyay obtained the most appropriate directions for four climatic regions in the US and it can be also applied for the other regions with the identical conditions and latitudes, including Iran. The present study aimed at the investigation of the authenticity and accuracy of the optimal orientation defined for the buildings in the cold climate of Iran (Kermanshah). Since the simulation knowledge enables the study of the complex behavior of the building according to climate and assists the designers in adopting proper climate-based method, Design Builder was the software chosen in the present study for the determination of the building's optimal orientation. To do so, a type of administrative building repeatedly constructed in this city was simulated in the aforesaid software with features close to reality and the initial energy required by the building was subsequently computed in various directions. The results obtained from the present study indicated that western-eastern stretch was the best orientation for the administrative buildings in Kermanshah considering the energy consumption rate.

Keywords: Optimal Orientation, Energy Consumption, Cold Climate, Administrative Buildings, Kermanshah.

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1. INTRODUCTION

Millions of oil barrels and kilowatt hours of electricity are annually consumed for supplying the needs of the population residing the cities and villages as well as heating and cooling their work and life spaces, transportation, performing daily activities and others (Keirstead, Jennings, & Sivakumar, 2012, p. 3848). In between, the building sector accounts for 40% of energy consumption and greenhouse gases' emission (Rodriguez- Soria, Dominguez- Hernandez, Perez-Bella, & Del Coz-Diaz, 2014, p. 79). The rapid growth in the consumption of the energy resources for heating and cooling the buildings, increase in their prices as well as the bioenvironmental problems all underline the importance of savings in energy consumption in the building sector (Aksoy & Inalli, 2006, p. 1742). Making efforts for reducing energy consumption has directed the mankind towards more research and study for finding its more proper substitutes amongst the renewable energies (Mahdavinejad, Bemanian, & Motarvar, 2013, p. 41). Since energy is of a particular stance in the achievement of a sustainable city (Mahdavinejad, 2013, p. 36); it has become a challenging topic in the developing countries including Iran (Mahdavinejad & Setayesh Nazar, 2017, p. 92). This way, considering the effective role of energy in the physical development of the artificial environment (Heidari, Mahdavinejad, & Sotudeh, 2018) and the increase in its consumption parallel to the growth in the human communities, it is necessary to pay attention to the energy resources' constraints and prevention of confrontation with energy crisis as well as making emphasis on energy savings through proper management of energy consumption. The goal of energy management is reducing and rationalizing the energy consumption in such a way that it is deemed economically justifiable and, in the meanwhile, not resulting in the emergence of the adverse effects in the thermal comfort and welfare levels of the residents (Habib, Barzegar, & Cheshmehghasabani, 2014, p. 56). Besides enabling the energy consumption savings, the buildings that are constructed based on the methods and scales of energy productivity cause a reduction in the costs as well as in the amount of the carbon dioxide emissions hence largely working in favor of the society (Pacheco, Ordóñez, & Martinez, 2012, p. 3560). One of the saving solutions to the building energy consumption is preventing the energy wastage which is per se predominantly influenced by the amount of heat transferred through the surfaces, density factor as well as the interior temperature (Rodriguez-Soria et al., 2014, p. 78). However, besides consideration of the thermal insulations, the enjoyment of the proper solutions can largely influence the amount of energy consumed in the building (Mahdavinejad, 2013, p. 35). In all of the climates, the buildings constructed based on climatic designs minimize the necessity for the mechanical heating and cooling through making use of the natural energies existent in their peripheries (Ibid, p. 37). Additionally, they cause more comfortability of the residents to a large extent (Modiri, Zahabnazouri, Alibakshi, Afsharmanesh, & Abbasi, 2012, p. 141). To do so, there are many solutions including the orientation and form of the building, the amount of the transparent surfaces and so on and the consideration of many of these solutions pertains to the designing phase (Pacheco, Ordóñez, & Martinez, 2012, p. 3560; Aksoy & Inalli, 2006, pp. 43-1742). The building's designing phase is the first defensive line against the climatic factors outside the building (Mahmoudi & Nivi, 2011, p. 37) and is the best time for taking the sustainable strategies into account because they are less costly in respect to the strategies that are considered after the buildings were constructed (Pacheco, Ordóñez, & Martinez, 2012, p. 3560). In fact, the saved sums of money in the long run contribute and underline the implementation of the climate-based designing methods as the best type of investment for the proprietors while bringing about an improvement in the comfortability conditions inside the building (Mahmoudi & Nivi, 2011, p. 37). As an empirical rule in the solar-based designing, the building's form and orientation should be always particularly taken into consideration (Hemsath & Band Hosseini, 2015, p. 526). However, amongst the parameters taken into account in the designing phase, orientation is the most important consideration and one of the cases that have also been extensively researched (Pacheco, Ordóñez, & Martinez, 2012, p. 3561). The selection of the building's placement orientation depends on factors like the land's natural posture, the extent to which the private spaces are required, control and reduction of sound as well as two factors of wind and irradiation. In fact, the use of climatic principles in architectural designing and giving the building a proper orientation considerably contributes to the mitigation of the harms and optimal use of sun's irradiation and the favorable winds (Modiri et al., 2012, p. 141). In a study that was conducted by Morrissey et al. in 2011, the building's orientation has been suggested for the enjoyment of the maximum solar benefits as a less costly option (Morrissey, Moore, & Horne, 2011, p. 568).

Placement of the building in an optimal orientation has a lot of advantages:

1. It is a less costly criterion applicable during the preliminary stages of designing.
2. It reduces energy demands.
3. It meets the need for more complicated static systems.
4. It increases the other static techniques.
5. It increases the quality of the daylight and reduces the need for the artificial light and lowers the thermal load inside the building.
6. It enhances the efficiency of the solar controllers (Pacheco, Ordóñez, & Martinez, 2012, p. 3562).

In cold regions, the buildings should be aligned towards an orientation that enables the highest amount of solar energy absorption. In the meantime, the building designers should compute the irradiative flux of the sun for various hours of the day and different days of the year (where in the place and angle of the sun's irradiation change) so as to determine the building's orientation in such a way that the amount of the absorbed irradiation does not cause extreme heat in the building (Modiri et al., 2012, p.142). Considering the intensity of the sun's irradiation on the orthogonal surfaces in various geographical directions and at various hours and seasons, Victor Olgyay obtained the most appropriate directions for four climatic regions in the US and it can be also used for other regions with the similar conditions and identical geographical latitudes like Iran (Kasmaei, 2011, p. 127) (Fig. 1). It is called the diagrammatic method and it is very useful in the investigation and determination of the most appropriate orientation for the placement of the building in such a manner that the building is aligned towards a direction in which it receives the lowest irradiation of sun during the hot seasons and the highest irradiation of sun during the cold seasons of the year. It means that these two properties should be concomitantly existent (Modiri et al., 2012, p. 148).

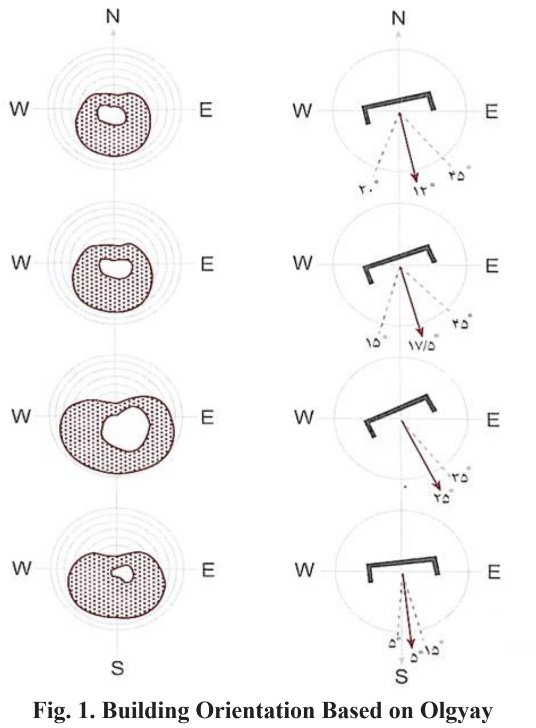

Fig. 1. Building Orientation Based on Olgyay Method Respectively for Cold, Temperate and Humid, Hot and Arid and Hot and Humid Climates
(Kasmai, 2011, p. 127)

It can be stated that all of the theories that deal with the investigation of the relationship between the building' orientation and the sun's irradiation (such as Olgyay method) agree that the southward direction is optimal for receiving heat in winter and controlling the sun rays during summer; meaning that the longest wall should be aligned southward (Pacheco, Ordóñez, & Martinez, 2012, p. 3562). Surely, this orientation provides the reception of the highest solar energy during winter and the lowest reception of solar energy during summer; however, besides the sun irradiation, temperature also is very effective in the improvement of the buildings' interior conditions and this has not been taken into account in the prior research. In addition, the importance of the irradiation depends on the climate type as well as the various seasons of the year. For example, the achievement of comfortability in summer needs a lower irradiation of the sun onto the building bodies. It can be asserted that the building's orientation should be determined in relation to the optimization of the other parameters like the total receivable solar rays, building's form, the ground floor's plan, the amount of the annual energy demand (Pacheco, Ordóñez, & Martinez, 2012, p. 3562) and the properties of the plan, type of the constructional materials and the exterior surfaces of the walls (Kasma'ei, 2011, p. 127). In general, in order to create comfort in a building, the orientation should be selected in such a way that it is followed by the best sun irradiation during the cold seasons and the best current during the hot seasons of the year. Sunlight is always necessary for lighting of the buildings; but, since it is eventually transformed into heat, its amount should be determined according to the type of the building and the climatic conditions of the place (Modiri et al., 2012, p. 143). The present study has been carried out for investigating the accuracy and authenticity of the optimal orientation defined for cold climate of Iran in Kermanshah though employing simulation software because today's simulation knowledge simplifies the study of the energy efficiency in the buildings and enables the prediction of the complex behavior of the building according to climate. In fact, the simulation instruments are capable of aiding the designers in adopting proper climatic methods in the designing phase, including the selection of the building's optimal orientation.

2. BACKGROUND OF THE STUDY

Many studies have been conducted about the correct orientation of the buildings; some of which have been given below. According to the studies performed by Little Fair in 2001, the majority of the books, guides and other written documents have suggested a building in regard of the static solar techniques that are faced southward but some of them have stated that an orientation with a 20 to 30 degrees of inclination towards the south is the best choice.

Shaviv studied the orientation of the transparent building surfaces in 1981. The results of his investigations indicated that the transparent surfaces should be aligned southward for achieving the best saving of energy, especially in hot and humid climates, and that the southeastward is the next favorable orientation if the former is found impossible.

In another research, the energy savings was investigated in a large-scale building model that had been aligned southward in 30- to 45-degree and 60 angles. The results indicated that the highest energy saving is achieved when the largest wall of the building is rotated 30 degrees towards the south (as cited in Pacheco, Ordóñez, & Martinez, 2012, p. 3562).

In 2011, Jaber and Ajib examined the best building orientation, window size as well as thermal insulation thickness for a residential building in Mediterranean region. The results signified that about 27.59% of the annual energy consumptions can be saved through the selection of the best orientations, optimum size of the windows and shades and the proper thickness of the insulation (Jaber & Ajib, 2011, p. 1830).

Aksoy and Inalli performed a study in 2006 in Elazig in a cold climate in Turkey and determined zero and 80-degree rotation of the building towards the south as the most appropriate orientation for a building with an almost two to one ratio of length to depth (Aksoy & Inalli, 2006, p. 1742). Mingfang defined the southward direction as the best orientation for the reception of the solar energy in winter as well as its control in summer (Mingfang, 2002).

The results of the studies performed by Mahdavinejad and Fallah Tafti in 2015 demonstrated that the optimal orientation of the building in Tehran is largely dependent on the static elements receiving the solar heat, their orientations as well as their positions in the buildings. In the meanwhile, amongst all the factors investigated in this research, the surface area of the glassworks in the building was found playing the largest part in the determination of the building's orientation (Mahdavinejad & Fallah Tafti, 2015).

3. BUILDING ENERGY SIMULATOR SOFTWARE PACKAGES

The building energy simulator software packages are essentially applied for calculating and determining the building's energy consumption in a certain period of time as well as the estimation of the peak of the thermal loads of the heating-cooling systems, hence the study of the buildings' energy efficiency. This way, simulation can contribute to the lowering of energy consumption (before the construction of the buildings) through modeling the various strategies. In fact, there is no method other than this instrument available for attaining energy saving techniques during the designing stage. These architectural techniques can be employed for specifying the orientation, form, openings' ratios, shades, natural ventilation and so forth in the buildings.

During the recent years, simulation software packages have undergone rapid advances and the various versions of these applications are repeatedly offered. There are various energy simulation software with different capabilities and characteristics, amongst which Energy Plus is one of the most popular and effective energy simulation applications capable of modeling many of the mechanical, environmental, structural and architectural attributes; however, since the software offers the outputs in the form of a text file, Design Builder is applied for the graphical illustration of the results.

3.1. Design Builder Software

Design Builder is the software working with Energy Plus engine and it is a graphical software package that can model and analyze the natural ventilation, daylight, blinds and even more complex shutters along with shading effects and so forth. The software uses the real hourly climatic data according to ASHRAE 55 Standard[1] for the calculation of the thermal-cooling loads of the building and it is capable of offering the following results in annual, monthly, daily and hourly and/or even smaller than hourly forms:

A. Energy consumption

B. Functional temperature, mean radiative temperature, interior temperature as well as humidity

C. Outputs related to the thermal comfort: DISC, PMV and others based on ASHRAE 55 Standard

D. Heat transfer through walls and floors and ventilation, joints and so forth

E. Thermal and cooling loads

F. The amount of carbon dioxide production (Nasrollahi, 2009, pp. 148-150).

It is worth mentioning that Nasrollahi (2009) dealt in a PhD architectural dissertation about the "Climate and energy responsive housing in continental climates: the suitability of passive houses for Iran's dry and cold climate" that was conducted in Berlin's Industrial university with the investigation of the ways of reducing energy consumption in the residential buildings in Iran's cold climate. He also investigated the standard coordination of the passive houses with the climatic, economic and technical conditions in Iran and used Design Builder Software for doing so (Nasrollahi, 2009). In a Ph.D dissertation by Sarkardehi under the title of "feasibility study of combining the two static (cooling-heating) systems with the objective of energy savings in the residential buildings that was carried out in 2018 in Isfahan's Art University, as well, Design Builder has been utilized in the simulation part (Sarkardehi, 2018). Moreover, in an MA dissertation called "designing and analyzing the efficient and optimum atrium pattern in administrative buildings in Tehran", Abdullahzadeh has employed the software for modeling the various aspects of the building (Abdullahzadeh, 2013). Due to the particular capabilities of this software and considering the fact that the results obtained from it have been validated in a great many of the studies, the current research paper has used this simulation program for achieving the optimal orientation.

4. METHODOLOGY

Kermanshah is located in 34º 23' of the northern latitude and 47º 03' of the eastern longitude in a cold region in Iran. According to Olgyay's bioclimatic diagram, this region has cold winters and dry and hot summers. The mean of maximum and minimum temperatures in the large cities of the region have been presented in Table 1.

Table 1. The Mean of Maximum and Minimum Temperatures in the Large Cities of Cold Climate Regions in Iran

Cities	(Mean minimum temperature in winter in ºC)	(Mean maximum temperature in summer in ºC)	Properties
- Hot and arid summers - Cold winters	35 to 40	0 to -5	Tehran, Shiraz, Mashhad and Kermanshah

(Kasmai, 2011, p. 99)

The optimum orientation defined for the buildings of this city are the very orientations specified for the cold region in diagrammatic method used by Olgyay. Due to the reasons that were explained before, the veracity of this orientation has been challenged in this study; thus, in order to investigate the effect of the building orientation on energy consumption in the administrative buildings of Kermanshah and, resultantly, for attaining an optimal orientation, a two-storey administrative building was selected. Since the city does not have a dominant type of administrative buildings and the only prevalent common aspect of the administrative buildings in the city is the closed office space, these features were taken into account in selecting the intended sample. Furthermore, the majority of the administrative buildings in this city have mechanical heating and cooling systems and not much attention is paid to the enjoyment of natural energies in them (Fig. 2).

Fig. 2. Selected Administrative Building

Then, the intended building was simulated using Design Builder in such a way that, after transferring the 2D file of the building from Autocad Software, the required 3D data of the building were inserted and the building was delineaed and its interior spaces were also zoned based on the types of their uses (Fig. 3). After the 3D drawing of the building, the entire information related to the building, including the details of the internal and external walls and even the type of the color used in them, the materials of the doors and windows, the type of the windows, the type of the applied heating and cooling system and all of the data contributing to the construction of the building with close-to-reality properties were inserted (Fig. 4) and, in the end, the climatic file of the intended city (Kermanshah) was loaded so that the required outputs could be extracted.

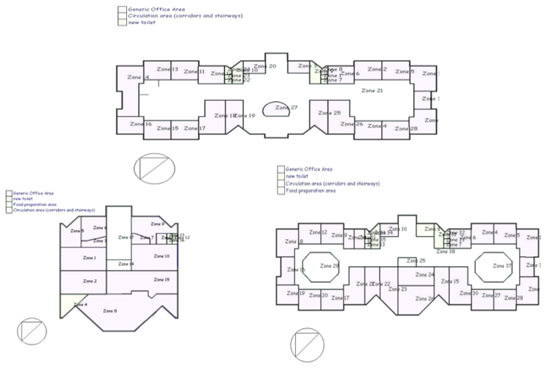

Fig. 3. The Plan of the Building Simulated in Design Builder Software

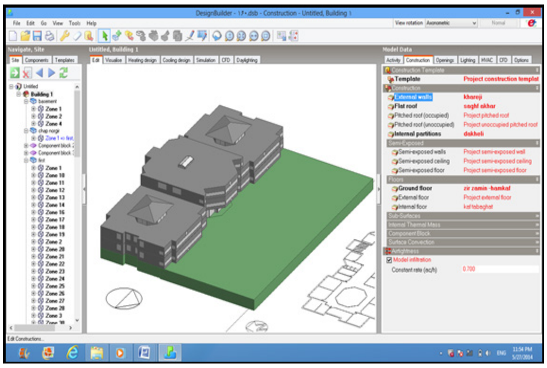

Fig. 4. The Building Simulated in the Software Environment

5. RESULTS OBTAINED FROM SIMULATION

After simulating the building, the northern direction was rotated in respect to the building ten degrees by ten degrees and the heating and cooling energy consumption of the buildings was calculated each time for the hottest and coldest month of the year and also annually. The results obtained from these simulations (108 simulation operation times) have been given in Table 2.

Table 2. The Annual Energy Consumption in the Hottest and Coldest Months of the Year in Various Directions for Achieving an Optimal Orientation

Clockwise rotation of the northern direction in respect to the building	Annual energy consumption (KWH/M^2)	Energy use in the hottest month of the year (KWH/M^2) AUG 15th - JUL 15th	Energy use in the coldest month of the year (KWH/M^2) JAN 15th - FEB 15th
10	225.78	12.63	8.68
20	227.3	12.75	8.73
30	229.55	12.9	8.82
40	231.92	13.07	8.87
50	234.02	13.21	8.89
60	235.55	13.32	8.88
70	239.79	13.4	8.84
80	237.37	13.44	8.8
90	237.51	13.46	8.79
100	237.3	13.45	8.76
110	237.61	13.41	8.76
120	235.41	13.34	8.75
130	233.65	13.23	8.72
140	231.4	13.09	8.63
150	231.71	12.92	8.56
160	226.32	12.76	8.49
170	224.53	12.63	8.46
180	223.73	12.59	8.44
190	224.38	12.63	8.47
200	226.07	12.75	8.56
210	228.47	12.91	8.64
220	230.97	13.07	8.7
230	233.24	13.22	8.76
240	235.09	13.33	8.78
250	236.43	13.4	8.81
260	237.13	13.44	8.79
270	237.44	13.45	8.81
280	237.35	13.43	8.83
290	236.81	13.4	8.85
300	235.79	13.31	8.86
310	234.24	13.21	8.87
320	232.18	13.07	8.87
330	229.53	12.91	8.8
340	227.55	12.75	8.72
350	225.89	12.63	8.67
360	225.21	12.59	8.64

6. ANALYSIS OF THE SIMULATION RESULTS

To better understand the issue, the results obtained from the simulation have been displayed in charts (1) to (3). According to these diagrams, the optimal orientation of the building was achieved when the northern direction was rotated 180 degrees in respect to the building, i.e. when the building was stretched west-eastward.

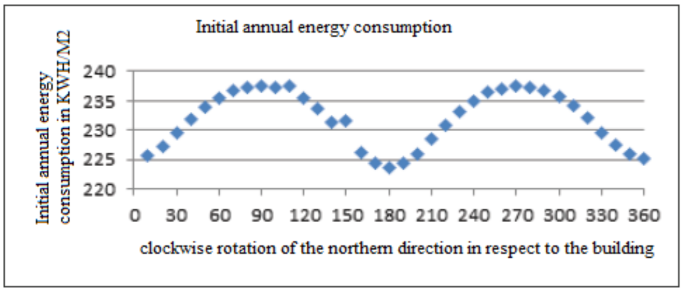

Chart 1. The Initial Energy Consumption of the Building in Various Orientations

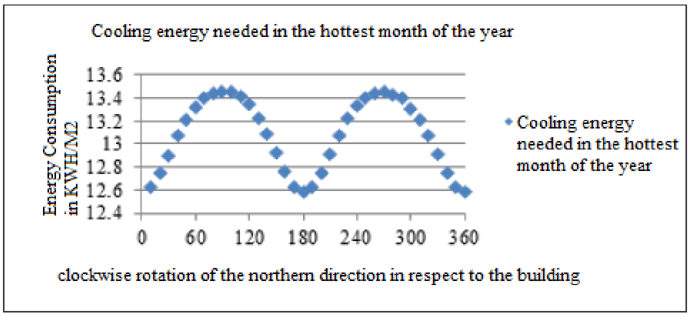

Chart 2. The Cooling Energy Required by the Building in Various Orientations

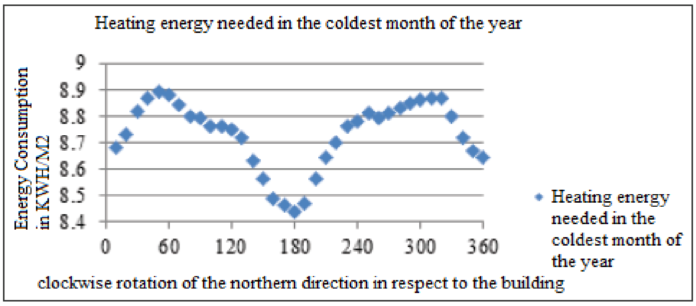

Chart 3. The Heating Energy Required by the Building in Various Orientations

In this orientation, the building had the lowest amount of annual energy consumption as well as the lowest amount of heating and cooling energy consumotions in the coldest and hottest months of the year in comparison to the other orientations as well as the defined optimized direction of the building (Fig. 5).

Fig. 5. The Optimal Orientation of the Building (West-Eastward Stretch)

As it is seen in chart 4, when the building was placed aligned with the obtained optimal direction, the annual energy consumption of the building was 223.73KWH/M2 that was about 2.5KWH/M2 lower in contrast to the optimal orientation defined for this climate. In addition, the annual heating and cooling energy consumptions were also lower in this orientation (Chart 5).

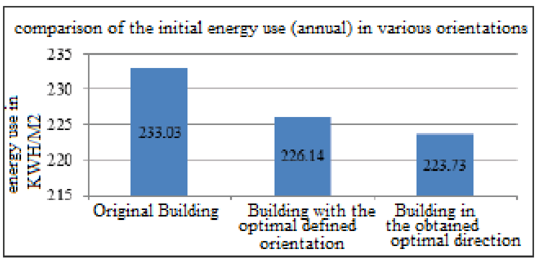

Chart 4. Initial Energy Consumption in Various Orientations of the Studied Building

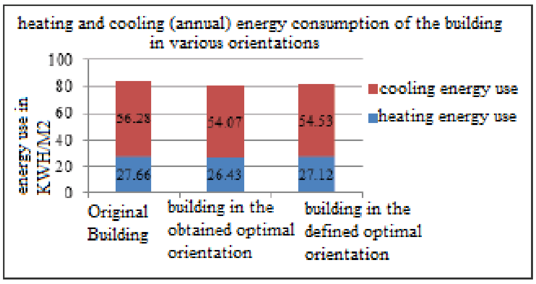

Chart 5. Comparison of the Heating and Cooling (Annual) Energy Consumptions in Various Orientations

7. CONCLUSION

According to the importance of the building's orientation in the discussions about the savings in energy consumption, the present study simulated a repetitively constructed administrative building in Kermahshah in Design Builder and calculated its required energy in various orientations to define an optimal orientation for the building. The results indicated that the lowest annual energy consumption of the building in west-eastward stretch was 223.73KWH/M2 which was lower in contrast to the energy consumption in the building's real orientation, i.e. 2233.03. It is worth mentioning that in the optimal orientation offered for the buildings of this region, the initial annual energy consumption by the buildings in this region was 226.14KWH/M2 that was about 2.8KWH/M2 (about 1.2%) higher thann the time the building was stretched west-eastward. It is noteworthy that the research has to be repeated in the buildings with different uses for the generalization of the obtained orientation. In the meantime, the existence of a lot of confusions in the building types of each section can influence the results obtained in this software.

END NOTE

1. American society of heating, refrigerating and air-conditioning engineers

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