

Offering Geometrical Pattern in the Second Shell of Building Improvement of Solar Energy Performance

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Abstract

Currently, Iran is faced with the consumption of energy for over 1.3% in the building sector and, considering the issue, the importance of designing buildings with optimal use of energy is felt more than ever before. Moreover, due to the fact that the cities have become denser and buildings have become taller, the vertical surfaces of the façade are increased in proportion to the underneath surfaces. Thus, the vertical walls of the building have the highest capacity for use of solar energy in the building. Blending of the solar systems with the building constituents like walls and others can increase the cost-effectiveness of the application of these systems and eventually improve the energy efficiency in the building. The present treatise aims at designing second shell in high-rise buildings through taking advantage of geometrical patterns so as to enhance the efficiency of the building shell. Use has been made of a descriptive-analytical research method herein. The entire information has been collected through library searches based on a descriptive method. All of the information and samples have been analyzed in Design Builder Software parallel to the finding of answers to the study goals and questions. In the current research paper, the geometrical samples in the façade of the building have been simulated using solar panel systems in different geometrical forms by the assistance of Design Builder Software. It was made clear that the use of cubic form amongst the Euclidean geometries and multiplane forms in the solid geometry is followed by a considerably higher annual output in comparison to the other forms.

Keywords: High-rise buildings, Double-skin façade, Geometrical form of façade, Solar energy

INTRODUCTION

The ascending trends of population growth along with the limited volume of the urban land and the daily increasing demand for the housing would be followed, on the one hand, by the increase in the price of the land suitable for urban development and, on the other hand, renders it necessary to construct high-rise buildings, especially in the metropolises. Urbanization development and daily increasing demand for housing, shortage of the land suitable for urban development as well as the promotion of the culture of using space and increase in the urban open spaces have all caused a shift in the construction pattern towards the high-rise buildings ^[1].

Considering the limited volume of the land in the metropolises and proposition of high-rise building construction for supplying the adequate light in these buildings, the constructions have been navigated towards the use of glass façades. Use of glass in the external shell is envisioned to be the weakest part of the building in terms of energy dissipation for it causes energy wastage and acoustic pollution dispersion into the building. Investigations indicate that these buildings are not consistent with the building industry's policies in the energy consumption reduction section. Therefore, a solution should be found that can enable the supply of adequate light and simultaneously minimize the energy wastage in the high-rise buildings ^[2].

The high consumption of energy has currently become one of the most essential socioeconomic challenges of the countries and there is definitely a need for novel technologies in this regard. Based thereon, the use of novel energies has become particularly important globally. The sun is a huge source of energy. Furthermore, the irradiation of the sunlight on the planet earth for one hour suffices the supply of the energy for a year on this earthly sphere ^[3].

The use of solar energy in building construction is of great importance for the sun irradiates rays on the buildings during the day. The building's vertical walls have the highest capacity for the use of solar energy in future buildings. The present study tries designing a second shell in the high-rise

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buildings via taking advantage of the geometrical patterns to improve the efficiency of the building’s skin [4].

A Review of the Prior Research:

The effect of the equatorial factor on the energy has been investigated. In designing the geometry, the level of parameters like geometrical aspects and the ratio of the windows’ surface area to position, the sun’s irradiation angle, cooling loads, panels’ transparency, designing of foldable panels, daylight rate and light distribution have been examined subject to the effect of designing [5].

Part of the studies on the geometrical pattern and layering has been conducted by Latifi and others who have simulated the designs through a physically simulated platform. To do so, a new method has been introduced for analyzing the optimal thermal performance in the building shell through the use of temperature sensors and Energy Plus Software [6].

The effect of the geometrical designing of two skins on the energy performance of the multi-floor administrative buildings has been investigated. The studied parameters pertain to the geometry of the surface of the external skin and the depth of the air hole between the two shells. In this article, two major geometrical designs have been explored: one of them being a complex plastic geometry and the other one being a simpler design. The results indicated that the larger the diversion from the flat and fixed façade, the more the thermal load is increased. The load and potential of energy production have also been studied subject to the various climatic conditions [7].

STUDY METHOD:

The study has been conducted based on library research and software simulation. In the present study, the information related to high-rise building construction, double-skin façade and solar energy as well as geometrical modules has been gathered according to the intended site’s topography and the climatic conditions in the city of Mashhad. The information has been collected based on library searches. The information gathering is the process in the course of which the preliminary findings are attained for initiating the research. Then, the turn comes for working with software; the information is inserted into the software (Mashhad’s climatic conditions + modeling) to deal with the samples’ analysis in the building façade. The information related to the climatic conditions in the city of Mashhad has been collected using Meteonorm Software and its output has been inputted in Design Builder. The modeling was firstly carried out by sketching; then, each of the designed patterns was modeled in the software and, in the end, the most optimal pattern with the maximum solar energy absorption rate was calculated and selected during a whole day by Design Builder. In fact, the evaluation of the data and their analysis help find answers to the study questions and to accomplish the study goals, i.e. offering a pattern and making suggestions for further studies. All of the information has been collected through library searches based on a descriptive

method and all of the sample evaluations were undertaken in Design Builder.

High-Rise Buildings:

From building engineering perspectives, a building can be called high-rise when its height causes its design to be considerably influenced by the lateral forces stemming from earthquake and wind. Based thereon, in terms of height, buildings over ten storeys are to be enumerated amongst high-rise buildings [8]. Urban planners and designers mostly consider buildings comprised of ten or more storeys as the high-rise buildings. In diagram (1), references have been made to the various kinds of tall buildings in terms of height, use and number of shells [1].

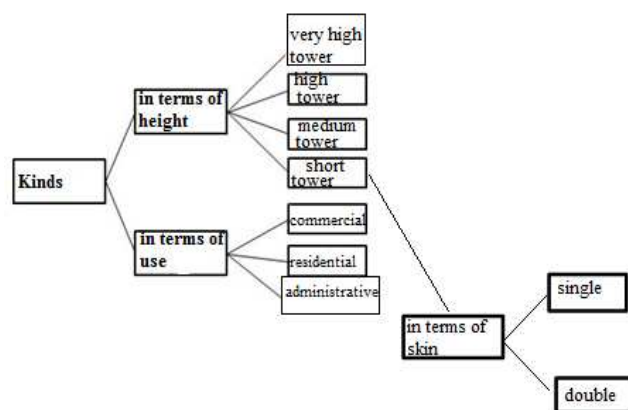


Diagram 1: kinds of high-rise buildings [1]

High-Rise Buildings’ Façade:

In building construction, the external (outside) surface of a building is called façade whereon important things are actualized in terms of architectural space: the physical and visual relationship of the interior and the immovable and movable relationship of the exterior, i.e. the form and use. If the volume is 3D, it would have an external form expressed by the surfaces and the façade is composed of these same surfaces in a general description. In its specific sense, the discussion on façade begins from where the important and original surface(s) transfer the largest deal of information about the building’s volume due to being exposed to the view and it is the awareness of the surfaces and their values that the façade can be embodied. Disregarding the theoretical discussions, the building façade is not practically apart from the delineated façade in the process of building designing; the building volume is in practice more displayed through plan and façade as topics related to surface. The building façade takes one of the following forms in terms of description:

A. Single-Skin Façade:

The selection of the building skin is often a ponderable process because the façade’s skin has significant effects on the environment as well as the residents of the buildings. Thus, the selection of the environment-friendly skin for a

building causes augmentation in the value of the building projects and a reduction in the adverse environmental effects. Single-skin facades are divided based on the type of masonries used and the most common of them are made of clay blocks, light concrete blocks, insulated constructional materials and novel technologies ^[9].

B. Double-Skin Facades:

Double-skin facades can be promising and effective suggestions. Besides supplying the required transparency, the double-skin facades can store the solar irradiations adsorbed through the exterior glass façade (during winter) and/or reduce it through proper ventilation (during summer). This way, thermal comfort and high quality of the internal air are improved while the thermal and chilling loads are reduced. But, the double-skin façades are made of multilayer structures including an external skin, an intermediate space and an internal skin. The external and internal skins can be made of simple glass and/or simple or hard double glazed windows. The shading equipment is installed as a moderator against the sun's irradiation usually in the intermediate hollow space between the internal and external skins for temperature control ^[10].

Geometrical Architecture:

Architecture is the organizing of the spaces and geometry is a sort of knowledge that has been employed since long ago for organizing and arranging shapes and contexts of space as well as for regulating the movement of the structural forces in the buildings. Geometry is the knowledge of the properties and relationships between the shapes, sizes, volumes and spaces ^[11].

Geometry is investigated and studied in various branches like Euclidean and non-Euclidean geometry, analytical geometry, linear geometry, flat geometry, solid geometry as well as an array of other branches and fields. The geometry is amongst the most fundamental architectural infrastructures by way of which the relationships between the forms and volumes and spaces and sizes as well as their proportions, the method of configuring the components and the interrelationships between the whole and the parts can be investigated ^[12].

But, the thing that is related to classical geometry and used for the positing of such issues as the delineation of the shapes and volumes and/or dividing and measuring of them has been precisely transferred into Autocad. Issues of classical geometry like the method of dividing an angle or the methods of delineating hexagons are no longer complex subjects for research and Autocad software easily performs these simple instructions. Since the computational activities pertinent to classical geometry have been simplified to a large extent, the opportunity is provided for carefully examining the relationships between the complex and free-form shapes and volumes and the thing needed in the making of complex shapes and volumes in a computer can consequently become the main subject of research on geometry. New areas have

been studied and investigated in geometry under the title of advanced geometry ^[12].

- **Application of Geometry in Buildings:**

It can be stated that the fundamental science of forms and the geometrical order existent in them has entered the process of architectural construction and designing. The construction of an architectural work is commenced with the elements and their interrelationships. Geometry can influence this process through interaction with forms and geometrical shapes as the primary elements thereof as well as on the proportions, angles and transformations as the interrelationships existing between the posited elements. The structures and constructs form the basis and foundation of the construction process. In fact, structures are generally organizing systems following diverse scientific principles. Structure means a regular collection. Mathematics can be put forth as the scientific basis of the structures and constructs. Math is the system of elements and relationships and takes their performance into account. This concept is, as an example, the basis and foundation of a creative approach applied by Richard Buckminster Fuller in his works. In general, mathematics is the science of structures and patterns ^[13].

- **Application of Geometry in Façade:**

In general, vertical shapes are more positive and more influential than the horizontal surfaces hence they are more useful for defining the volume of space and corroboration of the spaces' enclosure for the individuals residing therein ^[14].

Vertical elements constitute a form for preserving the surfaces of the building's floor and ceiling and considered as façade. They control the visual and spatial continuity between the interior and exterior environments of the building and are effective for the passing of air, light, sound and so forth into the building spaces ^[14].

As the border between the interior space and the peripheral environment, the building wall is expected to prevent the energy wastage, control the external factors and optimally apply the environment's capacities thereby to contribute to the supply of the users with comfort and simultaneously reduce the energy consumption by the ventilation systems and lighting equipment that account for a large quotient of energy use in the building sector and, in ideal states, play a notable role in the supply of the energy. The importance of the issue is particularly clarified when the expansion of high-rise building construction in the larger cities and reduction of horizontal surfaces like roof in respect to the building's substructure leads to the constraints on the utilization of solar energy based on common methods like solar collectors. This is while the vertical dimensions are in better proportion to the building's substructure hence the energy demand in the building ^[14].

The objective is offering a solution for blending solar energy collection by the building façade in such a way that solar energy can be adsorbed with an acceptable output and transformed into electricity ^[14].

Solar Energy's Application in the Façade:

The amount of solar energy received by the earth on a yearly basis is almost 3.1 million Exajoules. According to a comprehensive report by the international energy association, the global energy consumption is 462 Exajoules per year and it is expected to be doubled till the end of 2030. The large inconsistency between the production and consumption statistics clearly indicates that the earth receives energy 6900 times more than the energy used in the world. If this energy is appropriately harvested, even a small part of the sun's very high energy can surpass our needs [15].

Iran is situated in 25- to 40-degree northern latitude in a region that is in the highest ranks in terms of solar energy reception amongst the other spots worldwide. In order to take advantage of the sunlight and make optimal use of it in the

façade, the solar panels can be employed in such a way that these panels are placed on the forms designed on the façade and the solar energy can be subsequently maximally exploited with the irradiation of the sun thereon. In addition, taking the topography into consideration for the selection of a site is considered as one of the important factors for it considerably contributes to the solar energy reception [16].

Considering the developing trends of high-rise building constructions, the vertical walls of the buildings (façade) as compared to the horizontal walls (roof) have more capacity for the use of solar energy in the high-rise buildings [17].

RESULTS AND DISCUSSION:

Simulation and investigation of the geometrical patterns:

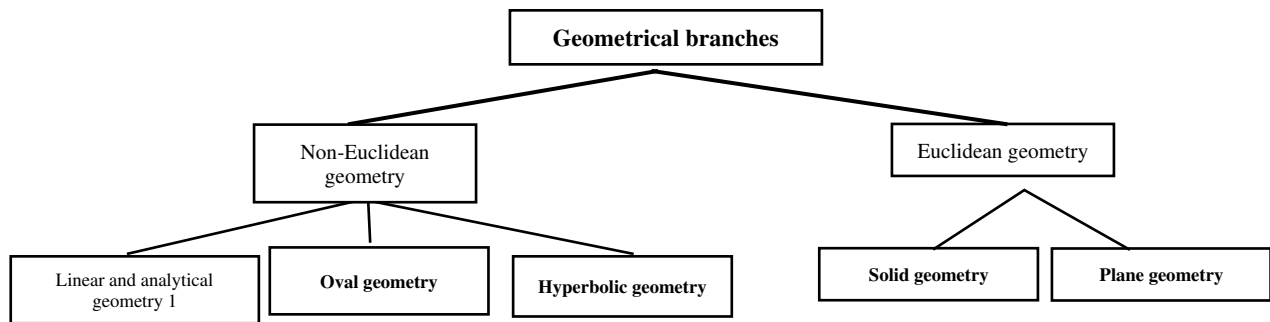


Diagram 2: geometrical branches

In order to design and simulate the preliminary models in the high-rise buildings, use has been made of 3D shapes with large volumes as the subclasses of the Euclidean geometry. Since the goal is making use of the sunlight by the solar panels, the proper option is the spatial shapes that are neither 2D nor linear and they can be applied in the façade to take the best advantage of the sunlight. Additionally, in an assessment that was conducted in Design Builder and the comparison that was carried out between the plane (2D) shapes and spatial (3D) shapes as shown in diagram (4) for various months of the year, solid geometry was found as the most appropriate option for the geometrical designing of the building façade because it has the highest solar energy adsorption and produces the highest amount of electricity.

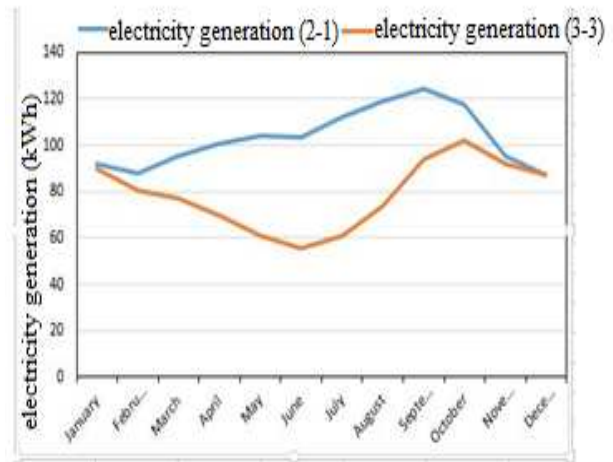


Diagram 3: comparison of the flat shapes (3-3) and solid shapes (2-1)

A fixed non-multiplane volume (circular shape) features the minimum external surface hence the lowest light absorption. But, the buildings nearly cubic or flat in shape possess the maximum external surface hence the highest light absorption. Resultantly, the multiplane shapes (flat surfaces) are envisioned as the optimum forms in terms of light absorption in the buildings' facades for they maximize the light absorption from the building skin [18].

Solid forms are of two types, namely multiplane and non-multiplane, with the latter being significantly different from the former in terms of light absorption in the buildings' façades. It was made clear in the end that the multiplane shapes are more suitable because they maximize the light absorption from the buildings' skins. In terms of light absorption, the façade should be in such a way that enables the maximization of the exterior surface.

Resultantly, the multiplane shapes should be selected for the façades and their different scales should be assessed. The present study has measured three scales of multiplane shapes: the minimum, intermediate and maximum use of the solar panels.

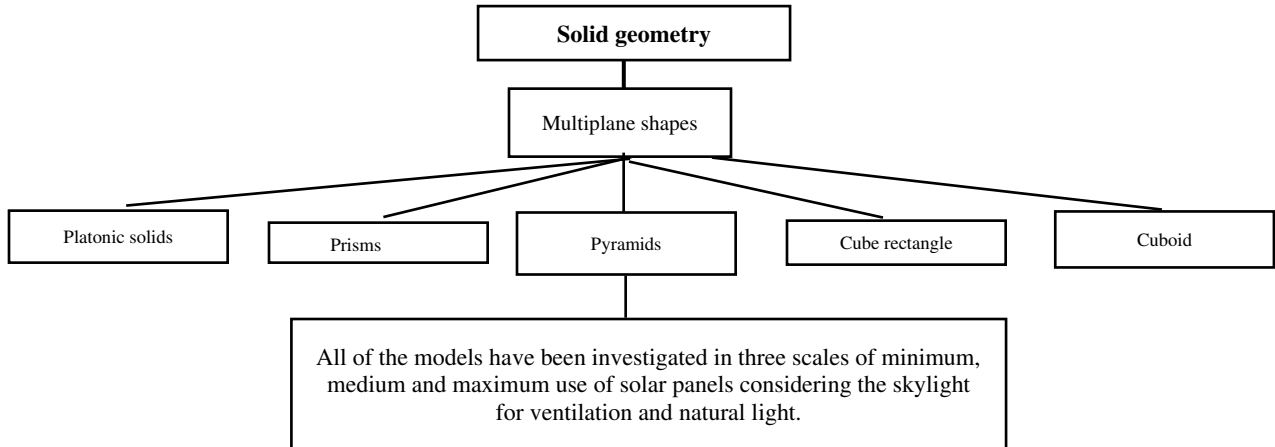


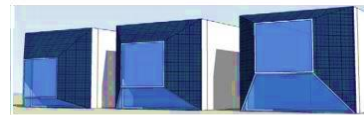
Diagram 4: conceptual model of the samples' attainment

Based on the studies performed on the geometrical shapes and considering the results obtained from Euclidean geometry, various kinds of multiplane shapes have been achieved each of which has been separately designed and simulated in the software in three scales: minimum use of solar panels; medium use of solar panels and maximum use of solar panels. Table (2) gives the simulated geometrical patterns.

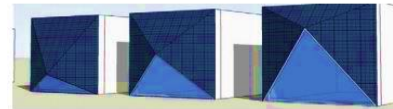
Table 2: simulation of the geometrical patterns in the software

Pattern numbering	Simulation of Geometrical Patterns in the software in three scales
1 st pattern	
2 nd pattern	
3 rd pattern	

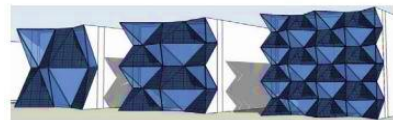
4th pattern



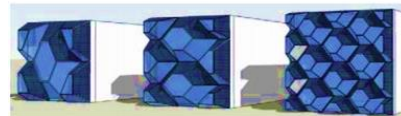
5th pattern



6th pattern



7th pattern



The results obtained from the evaluation and assessment of the geometrical patterns can be seen in diagrams (5) to (11). The guidelines to the use of the colors in the diagrams for demonstrating the three scales are as follow: blue (minimum use of solar panel); orange (medium use of solar panel); gray (maximum use of solar panel)

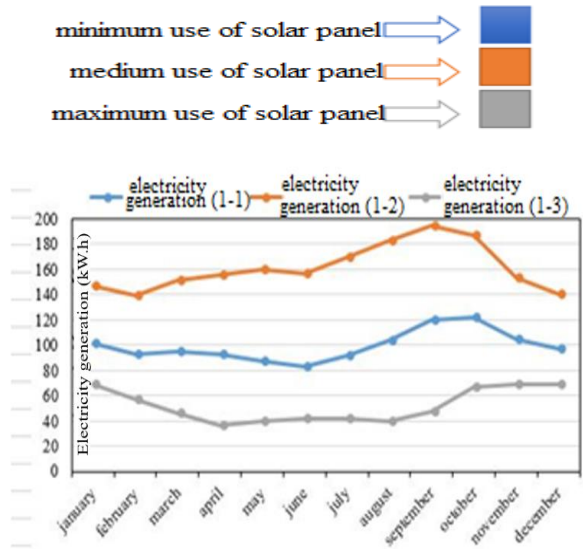


Diagram 5: investigation of the 1st geometrical pattern

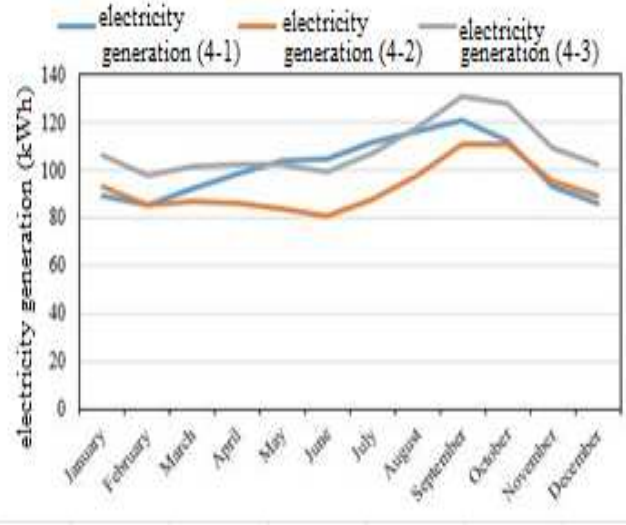


Diagram 8: investigation of the 4th geometrical pattern

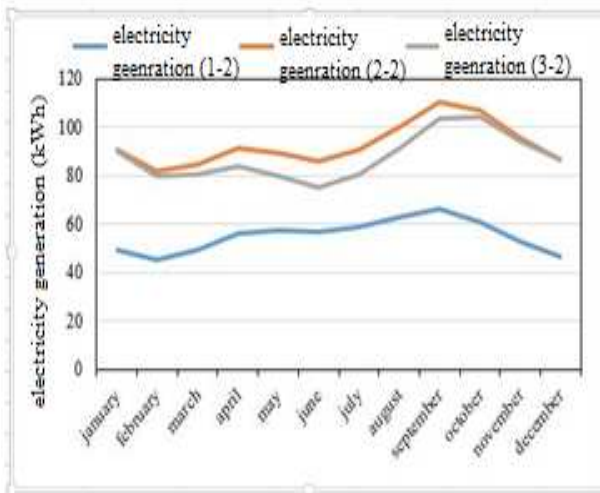


Diagram 6: investigation of the 2nd geometrical pattern

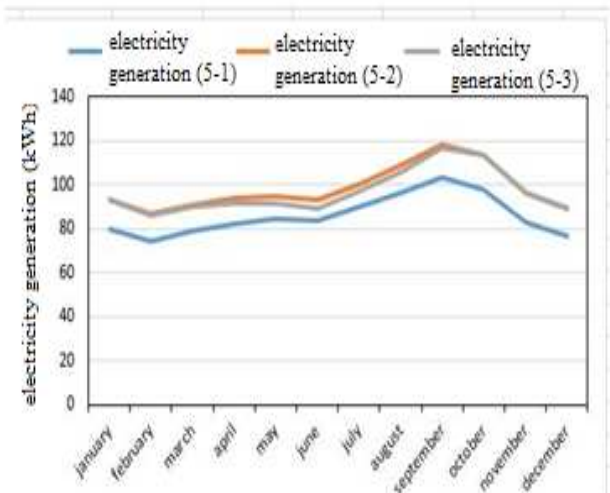


Diagram 9: investigation of the 5th geometrical pattern

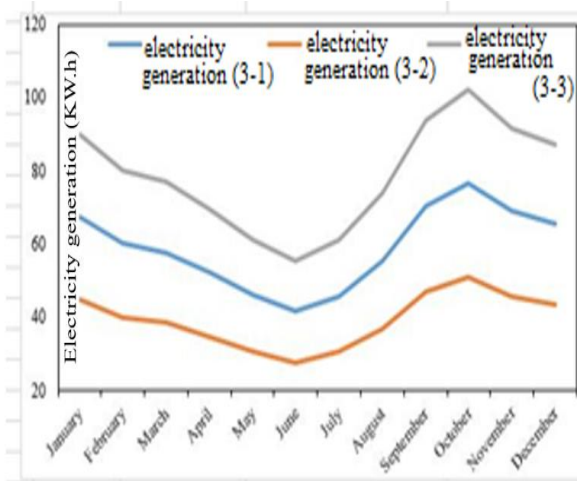


Diagram 7: investigation of the 3rd geometrical pattern

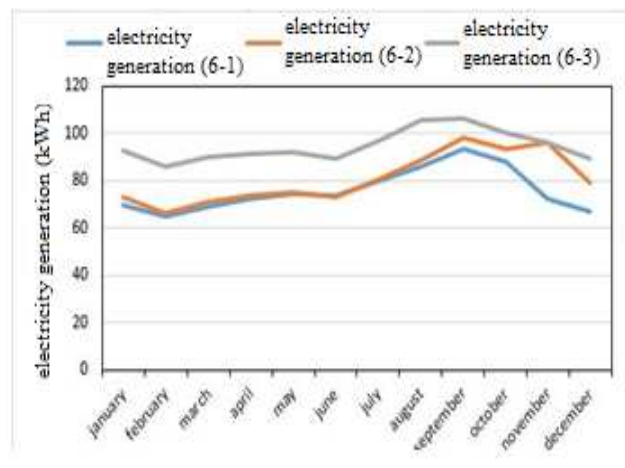


Diagram 10: investigation of the 6th geometrical pattern

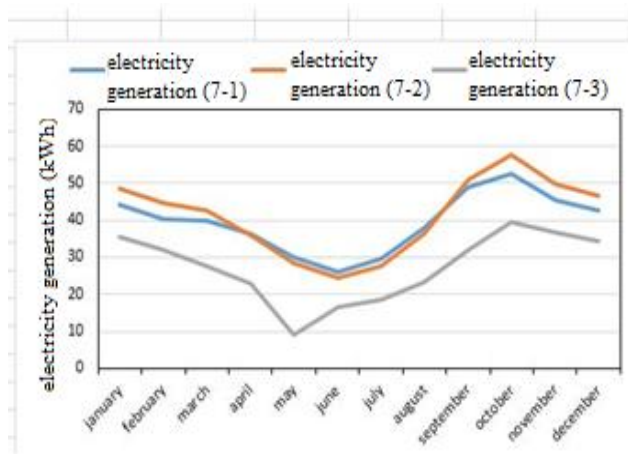


Diagram 11: investigation of the 7th geometrical pattern

CONCLUSION:

According to the investigations and explications of the diagrams obtained in part (2) for each pattern and based on the comparison of the patterns and the diagrams in separate, it can be concluded that the diagram (8) and the 4th pattern are the best geometrical pattern in contrast to the other patterns for the climatic and topographical conditions in Mashhad for the fact that the slope of the solar panels is larger in respect to the sunlight's direction and these panels can be installed in various angles (in accordance to the sunlight's rotation since the sunrise till the sunset) so that the highest sunlight can be absorbed during a day. Considering the optimum pattern selected herein, an average 125-kW electricity can be produced on a monthly basis or every cross-section set in the software. Additionally, in a tower designed using the software with 10 storeys, 6250kW electricity can be produced per month. In comparison, a tower was found producing about 110kW electricity per month. The results obtained in the current research paper can be applied for many purposes in line with the reduction in the consumption of fossil fuels and storing energy in tower-construction industry of Mashhad. Moreover, the study findings can considerably contribute to tower construction industry and heighten the quality of them in terms of the constructional materials and masonry used in the façade of the building as well as the storage of renewable energy in the buildings. If a residential tower can supply itself with its own energy-depending daily needs without damaging the urban environment, it can cause the enhancement of the quality of the facilities and environmental comfort conditions for the residents plus adding to the cleanliness of the city.

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