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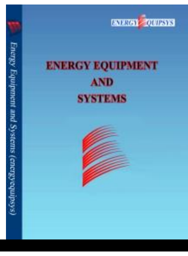

Determining the best layout of photovoltaic systems in zero energy buildings using statistical inference approach

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ABSTRACT

Regarding the world's energy status and the irreparable damages caused by the use and dependence on fossil fuels, the design and construction of buildings with zero energy buildings (ZEB) has been considered in recent years. Moving towards the use of renewable energy sources, such as solar energy by using photovoltaic panels to provide energy in the construction sector, is a global imperative in recent decades. In zero energy buildings, due to the limited available space to occupy the roof by photovoltaic panels, considering the best layout of panels and different technologies to access the highest output production capacity on one hand and cost-effectiveness of the project, on the other hand, are important.
The paper presents a basic investigation on optimal layouts of photovoltaic. In this paper, all of the obtained information has been compared from a statistical inference Approach. Also, the obtained information about power capacity and areas of the panels, regarding the layout of the panels, was analyzed by inferential statistics, due to the limits of the installation space, the layout of the panels in the directions (North-South) and (East-West) with a 15 degree angle, has the highest output power capacity, which according to the analysis done by the software, due to insignificant differences of these two layouts in power capacity, and lower required area in eastern-western layout with a 15 degree angle, this layout was evaluated more economical.

Keywords: Zero Energy Building; Photovoltaic; Renewable Energy; Statistical Inference.

1. Introduction

The building sector is one of the largest energy consumers. It accounts for more than 40% of Europe's energy consumption [1]. The idea and theory of utilizing buildings with zero energy consumption have attracted a lot of attention with regard to the elimination of pollutants and greenhouse gases.

In the last century, due to the ending of fossil fuels and the emergence of environmental crises in the world, moving towards reducing the use of fossil fuels is being implemented. In recent years, the general policies of the world's governments have tended to reduce the elimination of pollutant gases, for example, the EU has forced its members to build buildings with zero energy consumption [2].

The examination of the renewable energy perspective by countries around the world will be a new way for measuring the extent to which these systems will penetrate in the decades to

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come. In this regard, top energy companies in the world in numerous reports have provided statistics and forecasts for the use of renewable energy in the form of scenarios, which a number of these scenarios will be examined for a better understanding of the topic in this paper. The scenarios have been presented in three sections of pessimistic, optimistic, and moderate. The pessimistic scenario that imagines the worst future for renewable energy was provided by oil companies, the central intelligence agency of the United States and the International Energy Agency (IEA). In pessimistic scenarios, the maximum share of renewable energy by 2050 is only 15 to 20 percent. In other scenarios in the form of moderate scenarios, that Global Climate Change Board of Europe support this scenario, the share of renewable energy consumption is estimated from 25% to 40%. The third scenario is called the optimistic scenario. The Global Energy Assessment Report (GEA) estimates the share of renewable energy up to 95% by 2050. Another scenario, "Sustainable Development", presented by the Global Energy Agency and the "Roadmap" presented by the German Climate Change Association, the estimated share of renewable energy in the world by 2050, 35% and 50% respectively [3].

In the "sustainable growth" scenario which was presented by oil companies in 2010, the share of renewable energy by 2015 would be 50%. By considering above mentioned scenarios, even if the optimistic scenario is to be discarded and moderate scenarios are taken as the basis, the importance of using renewable energy in the future will be more pronounced. The reports highlight the increasing use of renewable energy in the coming years. There are many motivational factors that encourage governments and people to use new energies. Some of these factors include: creating employment opportunities, industrial development, risk reduction, fluctuations in fossil fuels, climate change, environmental sustainability, incidents and nuclear waste. The mentioned factors, especially the environmental pollution of fossil fuels and the ending of these fuels, have doubled the increase in the use of new energies. As far as, the planning of some countries has outstripped the presented outlook. For example, the International Energy Agency in 2000, planned the installation of 34 gigawatts of wind turbines in the world by 2010, but in 2010, the capacity of wind turbines in the world instead of 34 gigawatts reached 200 gigawatts, which is about 6 times [3]. It is predicted that renewable energy consumption will increase by an average of 2.6%/year between 2012 and 2040 [4].

Nomenclature

q	Solar radiation (w/m^2)
w	Solar constant number
r	Real distance of the earth to the sun (m)
δ	Declination
τ	The sun's hour angle
φ	Latitude of the place
GEA	Global energy assessment
EU	European union
IEA	International energy agency
ZEB	Zero energy buildings
ST	Solar thermal
PV	Photovoltaic

2. Photovoltaic energy

The intensity of the sunlight that reaches the earth varies from one place to another. In general, as the area approaches the equator, the amount of this radiation is increased. Equipment for the supply of electricity from a photovoltaic system includes photovoltaic panels, network insulators, batteries, insulation Network AC, and inverter, as shown in Fig. 1. [5].

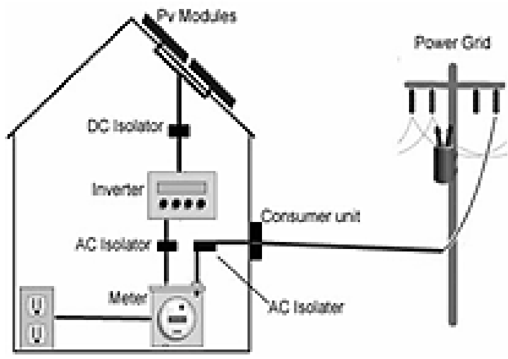


Fig. 1. Schematic of connection of photovoltaic system in building [5].

The efficiency of the photovoltaic panels depends on the other parameters, such as

atmospheric air and the installation angle of the panels. Also, the appropriate maintenance of these equipment has a profound effect on their lifetime and efficiency.
The following formula can be used to calculate the amount of solar radiation [6]:

$$q = \frac{w \sin\alpha}{r^2} \quad (1)$$

q: Heat flux of solar radiation (w/m^2),
w: Solar constant number,
r: Real distance of the earth to the sun (m),
δ: Solar angle,
τ: The sun's hour angle,
ω: Latitude of the place,
α: the angle between the Sun's rays and a perpendicular line to the horizontal plane.

$$\sin\alpha = \sin\delta \times \sin\varphi + \cos\delta \times \cos\varphi . \cos\tau \quad (2)$$

According to Eq. (2), we use the Eq. (3) to calculate the value of δ :
Declination (δ): Declination is defined as the angle between the line joining the centers of the Sun and the Earth and its projection on the equatorial plane, and it is due to the rotation of the Earth on its own axis [6].

$$\delta = \frac{23.45\pi}{180} \cos\left[\frac{2\pi}{365}(172 - D)\right]. \quad (3)$$

In Eq. (3), the value of (D), determines the day number of the year, compared to January 1st. [6].

Due to electricity consumption peak in June, July and August in the world, Electricity Companies are forced to do peak-shaving in various ways such as rationing, closure of large industries, or the construction of power plants to increase the capacity of the electricity network, while In June, July and August, the amount of solar radiation in world cities is highest. In this situation, by using zero energy buildings, in the long term, we can avoid high costs of network capacity increase and industry closure in peak hours [7].

3. Choosing the best system to achieve zero energy building

A study compared different systems to achieve zero-energy buildings [8]. In this research, three different systems are considered according to Table 1.

1. Photovoltaic system with the solar heating system (PV-ST).
2. Synchronous Photovoltaic and solar heating system with photovoltaic panels cooling system (PV/T).
   The PV/T collector not only produces heat water but also shows more electricity output than a pure PV collector at the same environmental conditions [9].
3. A photovoltaic system without any supplemental system (only PV).

In accordance with Fig. 2 in the obtained results of Table 1, a photovoltaic system without any supplemental system (only PV), is the best option for building with zero energy consumption.

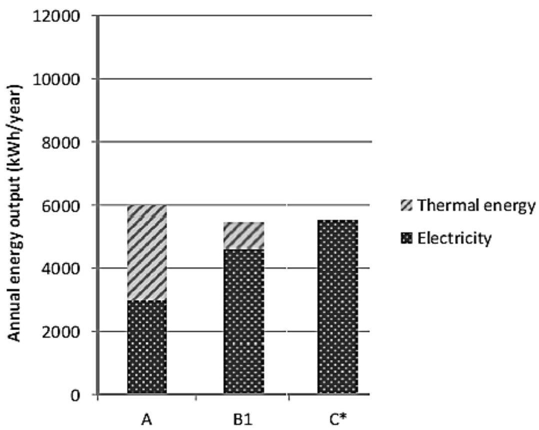


Fig. 2. Comparison of power generation capacities in conventional solar systems [8].

Table 1: Comparison of power generation using different solar systems.

Symbol	System type	Power capacity (kw)
A	Photovoltaic system with solar heating system (PV-ST)	3.4
B1	Synchronous Photovoltaic and Solar Heating System with Photovoltaic Panel Cooling System (PV/T)	5.1
C*	Photovoltaic system without any supplementary PV system (only PV)	6

In buildings with zero energy consumption, due to the limited roof space, it is necessary to have the best layout to have the largest area. Obtaining more space for installing more panels requires higher rent for land, and in many conditions, there is no other way except the use of the roof of the building, so, the photovoltaic system must be designed in such a way that more surface and power capacity can be provided [10].

Having a higher area leads to obtaining higher power. A higher power output means increasing the safety factor and saving more power for hours when solar power is not available or the intensity of the solar radiation is low [11].

In another study, examined a building with the goal of achieving the most obtainable power. In this study, the photovoltaic system was studied with Si-mono, Si-Poly, CIS, and high-eff Si-mono technologies. The layout of each panel was also tested in different arrangements. In accordance with Fig. 3 the layout of panels in the south along a 40 degree angle as a layout (A), the layout of panels in the south along a 15-degree angle as the layout (B), the layout of panels in the northern - southern with a 15-degree angle as the layout (C) and the layout of panels in the eastern-western direction with a 15 degree angle as the layout (D) are considered [8].

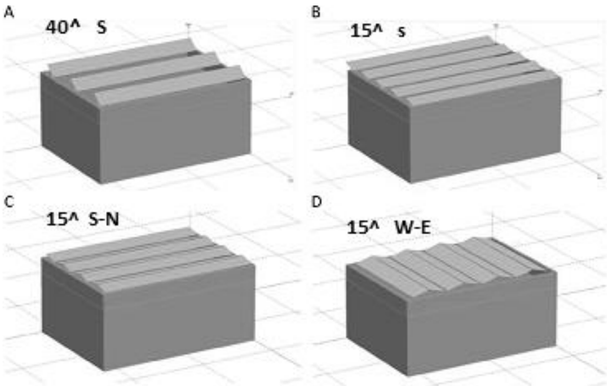


Fig. 3. Schematic of different layouts of photovoltaic panels.

By examining the climatic information of the place by the Climate Consultant 6.0 software, the state of solar radiation on the panels at the 15-degree angle of the south, is in accordance with Fig. 4, the angle of 40 degrees of the south, is in accordance with Fig. 5, and 15 degrees of east-west, is in accordance with Fig. 6 (7A) and (7B), the 15 degree of the north-south is in accordance with Fig. 7 (8A) and (8B).

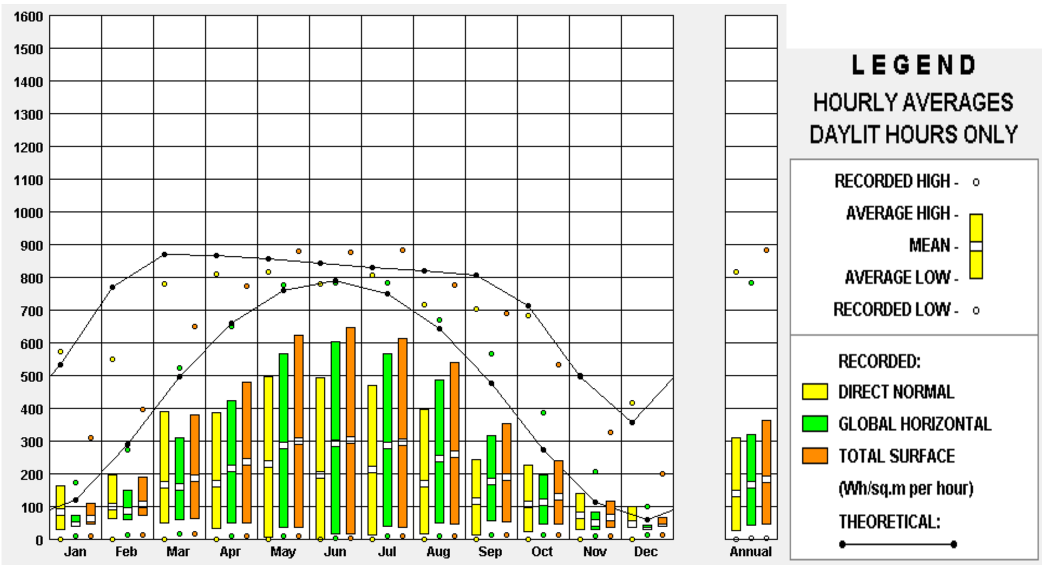


Fig. 4. Solar radiation at 15° south (wh/sq.m per hour).

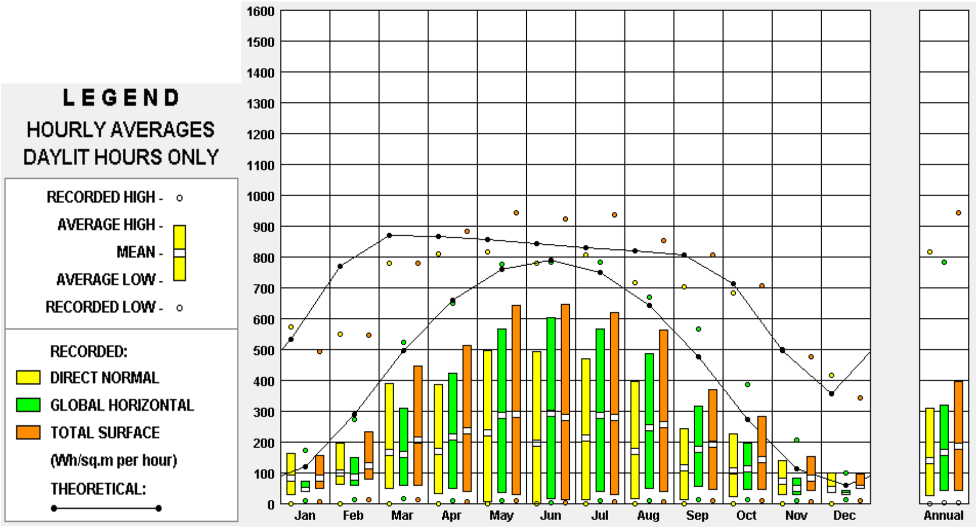
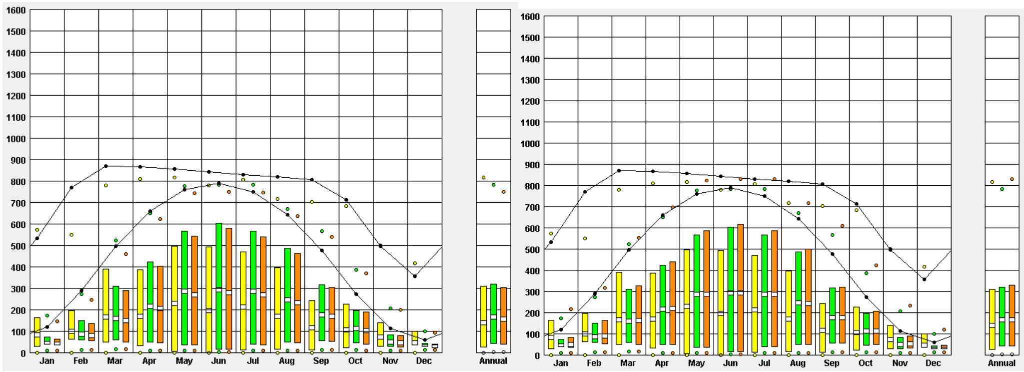
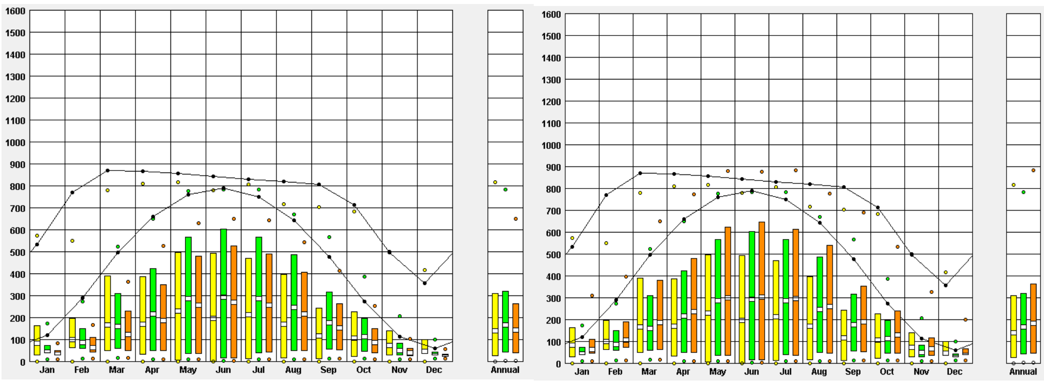


Fig. 5. Solar radiation (Wh/sq.m per hour) at 40° south.



(A) (B)

Fig. 6. Solar radiation (Wh/sq.m per hour) in (A: at 15°east), (B: at 15°west).



(A) (B)

Fig. 7. Solar radiation (Wh/sq.m per hour) in (A: at 15°south), (B: at 15°north).

In Figs. 5, 6, 7 The yellow bars show the amount of solar radiation measured as if the sensor was pointed directly toward (or normal to) the sun. This is sometimes called Beam Radiation. Notice that the theoretical maximum value for the Direct Normal Solar Radiation peaks in February when the earth's orbit brings us closest to the sun.

The green bars show the amount of solar radiation that is recorded falling on a horizontal surface. In theory, it is composed of all the diffuse radiation from the total sky vault plus the direct radiation from the sun-times the cosine of the angle of incidence. Notice that the Global Horizontal Radiation peaks in summer because that is when the sun is highest in the sky and is thus more perpendicular to a horizontal surface. This is sometimes also called Total Horizontal Radiation [12].

The comparison between the amount of solar radiation at 15 and 40 degrees Figs. 4, 5 shows that the increase in the installation angle of panels in May to September does not have a significant effect on the absorption of more solar radiation, and only at low solar radiation angles (for example, at the end of the day) adjacent panels' shade problem occur.

According to the survey, photovoltaic system type high-efficiency Si-mono produces 6, 8, 14, and 11.7 kilowatts in different layouts of A, B, C, D, respectively. According to Table 2, these numbers, show that photovoltaic panel type, high-efficiency Si-mono produce more power than other types of photovoltaic technologies. Also, according to this study, the best layout to achieve zero energy building is the arrangement type (C) due to the limited roof space of the building. These results are based on descriptive comparisons without any statistical analysis.

4. Methodology of Statistical analysis

Statistical inference is the process of using data analysis to deduce properties of an underlying probability distribution. Inferential statistical analysis infers properties of a population, for example by testing hypotheses and deriving estimates. It is assumed that the observed data set is sampled from a larger population [13].

Inferential statistics can be contrasted with descriptive statistics. Descriptive statistics is solely concerned with the properties of the observed data, and it does not rest on the assumption that the data come from a larger population. Descriptive statistics is a method that is used to summarize large amounts of data. Some of these descriptions are used in the conclusion of the articles. For example, the magnitude of a number indicates the superiority of the used method, while this difference may

Table 2. The obtained data from the occupied area and the power capacity according to the layout and technology of the panels [6].

Layout (arrangement)	Technology	(Panel area square m^2)	Power capacity (kw)
A	Si-mono	30.4	4.6
A	Sipoly	29.7	4.3
A	CIS	24.6	2.9
A	(Si-mono high-eff)	29.4	6.0
B	Si-mono	40.5	6.1
B	Sipoly	39.6	5.8
B	CIS	36.8	4.4
B	(Si-mono high-eff)	39.1	8.0
C	Si-mono	70.9	10.7
C	Sipoly	69.3	10.1
C	CIS	61.4	7.3
C	(Si-mono high-eff)	68.5	14
D	Si-mono	59.1	8.9
D	Sipoly	46.2	6.7
D	CIS	58.9	7.0
D	(Si-mono high-eff)	57.1	11.7

be accidental and, in other words, not significant, and so it will lead to imposing additional costs on building a zero-energy building. Therefore, the descriptive comparison will always be error-prone. Statistical inference is a way of deducing a conclusion from the collected data. Statistical inference enables the researcher to answer questions as like as "Is there a difference?" or "Is there a relationship?" in mathematical language. So it compares the results with the elimination of the accidental factors [14]. All of the results in this section, were done by SPSS software.

4.1. Comparison of the occupied area by each layout

Based on the output information that is presented in Table 2, it can be concluded descriptively that layout (C) covered the highest area. Thereafter, layouts D, B, A covered the highest area that this matter is in line with descriptive statistics. In addition, the amount of dispersion and the 95% confidence interval for area means of panels are given in Table 3.

To examine the effect of different layouts and to compare the results, the hypothesis test is considered which include two supplements of equality and inequality of the average levels of different layout.

$$\begin{cases} H_0:\ \mu_A = \mu_B = \mu_C = \mu_D \\ H_1:\ The\ Opposite\ \ hypothesis \end{cases} \tag{4}$$

According to the Analysis of Variance (ANOVA) Table 4, in these comparisons, the P-value (Sig) is zero. Therefore, it can be said that rejects the assumption H_0, indicate the equality of means, and accept the claim H_1 [14]. In another word, the effect of the arrangement type on the occupied space is significant. Simply it means that, with the confidence level of 99%, it can be claimed that the panel area has a direct relationship with the type of layout, and the area of the panels varies by changing the layout.

Regarding the acceptance of the claim that there is a difference in panel area with a change in layout, it is necessary to make the results clearer by performing post-tests.

Table 5 and Fig. 8 show the results of the inferential classification of different layouts. In this research, Tukey, LSD, and Duncan methods have been considered and indicated that each layout is in a separate category, which is written in ascending order.

Tukey's range test is a single-step multiple comparison procedure and statistical test. It can be used on raw data or in conjunction with an ANOVA (post-hoc analysis) to find means that are significantly different from each other [15].

The Post Hoc Tests, consider an average of panel areas two by two, according to different layouts. In these tests, hypothesis H_0, means that the assuming of equality of area panels by the change in the layout is rejected. These results are the same for different categorization methods [16].

Table 3. Area of panels (Descriptive Statistics)

Layout	**N**	**Mean**	**Std. deviation**	**95% Confidence interval for mean**	
				Lower bound	**Upper bound**
A	4	28.5250	2.65000	24.3083	32.7417
B	4	39.0000	1.57692	36.4908	41.5092
C	4	67.5250	4.20347	60.8363	74.2137
D	4	55.3250	6.14946	45.5398	65.1102
Total	16	47.5938	15.85974	39.1427	56.0448

Table 4. ANOVA results to examine the effect of panel layout on their area.

Source of variation	**Sum of squares**	**F**	**Sig.**
Between groups	3577.987	73.401	.000
Within groups	194.982		
Total	3772.969		

Table 5. Layout classification based on Tukey, LSD and Duncan methods.

Category	Layout	Average
1	A	28.52
2	B	29
3	D	55.32
4	C	67.52

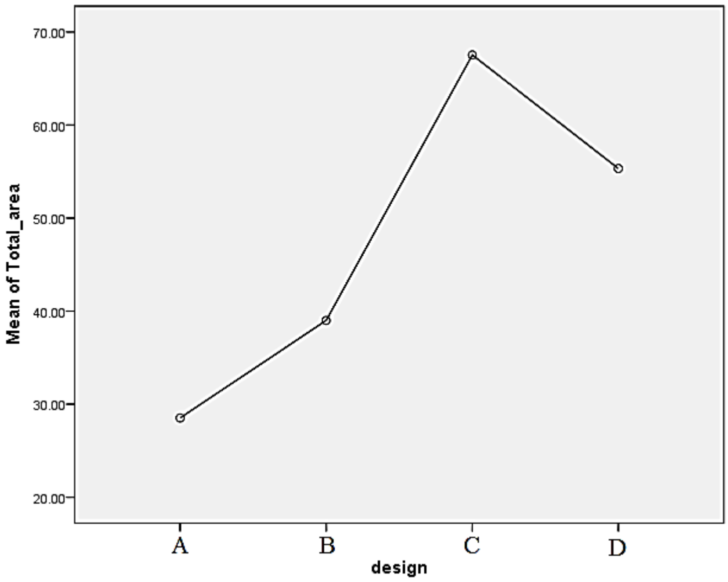


Fig. 8. Average occupied area by panels (m^2).

The inferential conclusion of Table 5, clearly shows that with regard to the average occupied area, the best type of panel arrangement is layout C. Figure 8 shows that the result of Table 5 in a graphical manner. The horizontal row represents the type of layout and the vertical row of the graph represents the occupied area.

So it can be concluded that due to the limited space of the roof of the zero-energy building, the best option that can cover the maximum area is the layout (C). Further, the average production capacity obtained by layout (C) is examined and compared with other layouts through statistical calculations to determine whether the change in the layout and use of more photovoltaic panels, which leads to an increase in the implementation costs of the project, has a significant effect on the increase power capacity.

4.2. Comparison of panels' power capacity

In this section, the power capacity by each of the layouts A, B, D, and C is analyzed statistically according to the Table 6, The significance of this difference means that the production capacity of each of the two layouts is different. However, if there is no significant difference between the type of layout and the power capacity, it means that by choosing any of the two layouts, the same results will be achieved.

According to the results of Table 6, with a change in the layouts, there is a significant difference in output power capacity.

Table 6: ANOVA results to examine the effect of the power capacity averages in each of the layout

Source of variation	Sum of squares	F	Sig.
Between groups	86.417	6.914	.000
within groups	49.992		
total	136.409		

The difference in power capacity by the panels in each layout is examined and the results are obtained in accordance with Table7. In base of Tukey, LSD, and Duncan methods. As it is shown in Table 7, comparing the output power capacity in the C, D layouts, the same results are observed. Therefore, with the change in layout, the occupied area by the panels has a significant difference with the same capacity power [16].

The important question that was raised here is that between layouts (C and D), regarding the similarity of power capacity by them, and also the costs of installing additional panels, which one has a lower average area. To answer this question, according to Table 7, it can be concluded that the use of layout (D) with High eff. Si-mono panels is the best choice to have the highest production capacity and also it is the most economical option in terms of the costs paid for specific power capacity.

5. Conclusion

Taking steps towards designing, building, and operating zero-energy buildings is a good way to reduce energy consumption in the building sector. Planning, designing, and constructing these kinds of buildings will reduce environmental pollution and reduce dependence on imported electricity and gas, and also reduce energy consumption. In order to provide energy in zero energy buildings, we have to install photovoltaic panels in the roof of the building due to space limitations. The best option should have at least two main features: Maximum production capacity and being economical. The economics of the project will be achieved when the maximum output power capacity is obtained by using the lowest area to install panels because in addition to the roof constraints for installing the panel, the installation of additional panels will lead to an increase in the costs of the project and it may make the project not economical.

Maximum power production is achieved provided that it is used with the highest technology and the arrangement of photovoltaic panels is in such a way that the maximum efficiency is achieved. Although the layout (C) is best in the base of descriptive comparison, but also the use of the technology high eff. Si-mono and (D) panel layout, which was presented in this paper, is the best option for zero energy buildings in the base of inferential statistics.

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Table 7. Capacity classification based on Tukey, LSD and Duncan methods

Category	Layout	Average of capacities	Averages of layouts
1	A, B	4.450, 6.075	28.525, 39.00
2	B, C	6.075, 8.575	39.00, 67.525
3	C, D	8.575, 10.525	67.525, 55.325

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