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Climate Change Mitigation Approach for School Buildings in Palestine: A Combination of Energy Efficiency and Energy Production

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Abstract The rising energy demand for school's buildings in Palestine is one of the problems facing the energy sector. This paper aims to provide estimation for the potential production of electricity from the installation of PV systems on the roof of schools' buildings, to produce its energy needs and to provide electricity to its surrounding buildings. The most used school building types were selected for the installation of the photovoltaic (PV) system. The produced electricity from the installation of PV systems was estimated using PVSOL software. The energy consumption for the selected type of the schools was simulated using design-builder thermal simulation software. A comparison between energy production and consumption was done for two climatic zones, with different tilt angles and different scenarios for the school's building envelope and indoor systems. The results show that the PV systems on schools' buildings can supply their estimated consumption, and provide a surplus in electricity production. This surplus can be a base for the transition to renewable energy in the residential areas surrounding school buildings. The study concluded that the installation of PV systems should be combined with building envelope thermal improvements or a combination of envelope improvements and heating and cooling systems.

Keywords Climate Change, Renewable Energy, PV, Palestine, School Buildings

1. Introduction

The demand for electric power has increased worldwide [1]. Many countries annually establish electric power production plants, which in turn leads to an increase in the demand for fuel used to operate these electric power plants. This fact negatively affects human and animal health, because of the emission of greenhouse gases (GHG) [2]. Such gases cause harmful pollutants to the environment, which is one of the biggest causes of climate change and global warming [3]. It is now acknowledged that using non-renewable resources of energy is the main factor in climate change around the world [4]. Full dependence on such resources has been a global problem for the last three decades [5]. Hence finding alternatives for energy resources based on renewable energy is vital for reducing the effects of climate change [6].

Therefore, the whole world initially turned to the use of renewable energy sources, mainly solar energy, which is the focus of many scientists and researchers today [7]. Moreover, many governments in developed countries supported this approach because of its economic and environmental returns. The use of renewable energy sources saves millions of dollars, whether by reducing production from non-renewable sources or by reducing the effects of greenhouse gas emissions that have many negative effects on the environment and human health [8, 9]. Moreover, the Investment in solar energy contributes to improving the economy by encouraging innovation and creating job opportunities for research in the field of improving energy efficiency and preserving countries' energy resources [10]. As a result, using solar energy as an alternative energy resource is an important field of study that should be adapted to different types of buildings, especially educational buildings [11].

The photovoltaic (PV) system is an efficient solution for renewable energy in most countries around the world [12]. It is now recognized that the increasing installation of PV systems on building roofs assists in decarbonizing the economy for a sustainable environment [13]. Moreover, PV technology is a major tool for low-carbon buildings [14], which has become a demand for building codes in the European Union to reduce buildings' energy consumption and the greenhouse gas effects [15]. The PV system has also clear economic benefits, which are the significant reduction of electricity bills [16]. From that standpoint, the investment in PV systems can assist in solving the problem of electricity consumption. In addition to the environmental benefits of the PV system which represents a pollution-free source of energy [17].

In Palestine, -as well as other countries in the Middle East, solar energy is efficient due to the high solar irradiation, and the availability of sunshine around the year, which reaches more than 3000 hours per year [8, 18]. In addition, Palestine has no energy resources like oil and natural gas and depends almost only on imported energy [19]. Hence, renewable energy, especially solar energy can play an important role in providing the country with the needed electricity, especially in the Gaza strip where the shortage of electricity leads to electricity blackout and affects the educational process [19].

The PV system is considered a potential source of renewable energy that can be applied in most building types in Palestine [20]. In the housing sector, for example, the installation of PV systems in the residential buildings on the rooftop can provide 0.5 to 6 times the households energy consumption depending on the location, building size and number of households in the building, tilt angle, and the installed power [19]. The system performance depends on two factors: the orientation of the panels on the roof and the tilting angle of them, which controls the amount of energy gained from solar radiation [21].

Although Palestine is considered among the countries with high literacy' rates, where the percentage of literates reached 97.5% in 2020 for people above the age of 15 years [22], the education systems suffer from shortage in the infrastructure. The shortages are mainly in the availability of well-trained teachers, insufficient school's building infrastructures, mainly the lack of facilities like libraries and labs and most importantly the lack of a comfortable thermal environment [23]. For this reason, a strategy to provide the schools with the needed energy from efficiency measures and renewable energy to overcome this uncomfortable thermal environment is required. School buildings are important types of buildings that are suitable for installing PV systems. On one hand, it has a large roof area, which is mostly oriented to the south, which facilitates installing PV panels. On the other hand, -and based on estimated information of the education ministry-schools consume much energy in Palestine, and there has been an increase in electricity consumption in the Palestinian schools in the past few years due to the expansion of many schools to accommodate the increasing number of students [24]. The monthly electricity bill is approximately 450-500 dollars per school [25]. Moreover, the educational sector in Palestine is growing fast because of the growing population and the need to provide more quantity and quality access to school education [26]. This fact led to a rapid movement of constructing new school buildings as well as extending many other existing schools, which makes the study of energy consumption in this sector vital for the sustainable development of schools' buildings in Palestine. Such buildings may consume much energy to provide a suitable environment for students unless a comprehensive study for energy saving is conducted. The indoor thermal environment of schools has a great effect on the student's health and their quality of learning [27, 28]. However, to achieve a suitable indoor thermal environment higher electricity consumption can be the price to pay in Palestine.

Among the actions taken to contain this increase, the Ministry of Education has implemented several projects to generate electricity from solar energy, which is funded by donors. In Tubas Governorate, for example, the projects that have been implemented amounted to 10 schools in the city of Tubas, the town of Tammun, and the town of Al-Fara'a during the past five years [24]. There is a tendency to increase the pace of these projects to respond to the increase in demand for electricity, especially in the Jordan Valley governorates, where high temperatures increase and the need to use electric air conditioners for cooling increases, which in turn consumes high electrical energy. The ministry of education tries to improve the school's indoor thermal environment through the introduction of design guidelines and pilot projects [24, 26]. However, heating or cooling systems are rarely used in schools to maintain a comfortable thermal environment, due to the lack of budget and resources [27]. According to a study in 2020 [29], there were 1825 public schools in the West Bank, Palestine in 2018 according to the data provided by the ministry of education. And according to the same study, the total floor areas for the schools range from 200 to 5,000 square meters. Besides, the average annual electricity consumption ranges between 2,598 and 40,345 kWh/year and the corresponding consumption for square meters is in the range of 1.27 to 46 kWh/m^2 per year. The study unveiled the high variation in the school size and school electricity consumption.

The electricity consumption in school buildings is mainly used for lighting, laboratory equipment, computers, small portable heaters, and fans [30]. Recently there is an increase in the installation of air conditioning units at schools which will lead to higher energy consumption. This increases the need for alternative resources of energy for school buildings.

The installation of PV systems on the school buildings rooftop in Palestine proved to be economically encouraging with a payback period of fewer than 5 years, besides its environmental and increasing energy security benefits [31]. A study by Alsamamra and Shoqeir found that installing PV systems on the rooftop in all the schools in Palestine can provide around 5% of the total annual energy consumption in Palestine [32]. Besides, the school buildings provide a potential environment for investment in PV systems due to the larger roof area for each building, and the limited use of electricity in schools compared to the residential buildings.

Currently, school buildings are not equipped with heating and cooling systems due to the shortage of funding [27]. Because of that, the school buildings suffer from an uncomfortable indoor environment and there is an urgent need to find a solution. The ministry of education has introduced guidelines to improve the building envelope to provide a more comfortable indoor thermal environment [25]. These improvements include introducing thermal insulation, shading, energy-efficient glazing types, building materials, and building orientation. This has led to improvements in the school's indoor thermal environment [27]. However, because of climate change and the need to improve the indoor thermal environment in schools, there is still a need to supply the schools with the necessary heating and cooling. This heating and cooling system will lead to an increase in energy demand and installing a PV system can be the solution to cover this demand. The electricity produced from PV systems on the roof of school buildings can provide the schools with the electricity needed for school’s operation and can provide a solution to cover the rising demand for electricity in the Palestinian territories.

At the international level a study for the benefits in terms of the cost and tariffs of the installation of PV systems on the rooftop of the school buildings in arid climate of Algeria and Kuwait, where the systems showed self-sufficiency and high performance ratio of 0.74 and 0.85 [33, 34]. The studies addressed the importance of the implementation of the PV systems on the urban energy demand as these buildings have combinations of large rooftop areas, unused rooftops and the good distribution of schools in urban areas. A study in Turkey founds that the installation of PV systems on the rooftop of school’s buildings has a coefficient of performance factor of 2.5 and in some cases the electricity production can exceed the electricity consumption in schools by 60% and the payback period is less than 8 years [35]. A study for the application of PV systems on the rooftop of educational facilities in South Korea, USA and UK show that the use of these PV systems can help achieve the national carbon emissions reduction targets for these countries [36].

Many scholars discussed the subject of energy conservation in school’s buildings in Palestine. The study [31] presented a performance evaluation of the 7.68 kWp grid-connected PV systems for one year on the rooftop of selected three schools in Palestine. The results of the study provided economic analyses for the use of PV systems in the Palestinian schools and concluded that the payback period of this system is <5 years, and the internal rate of return is around 20%. Besides these results, the study presented the impacts of PV school systems in decreasing the losses, raising the voltage level, and positive impacts on the environment [31]. The study [30] aimed to assess the environmental comfort in the popular school types in Palestine. It investigated the environmental comfort parameters, based on subjective and objective approaches, of school buildings. The study adopted a comparative approach between two different climatic zones of Palestine, Nablus and Jericho. Four values are used for the comparison: thermal comfort, visual comfort, acoustical comfort, and functional comfort. The results of the study showed the importance of these values to be provided for students in a natural –passive- way as an indirect way of energy conservation [30]. Another study by Saadeh, 2014 [26] aimed to develop the current school buildings to meet the standards of the green buildings design considering energy efficiency. Which was a try to reform a pilot pattern for the green buildings in Palestine, using minimal material technologies? As a result, neither of the previous studies had discussed the subject of climate change effects in Palestine, nor examined the PV system of school buildings as a method of energy conservation for different school building types and its thermo-physical properties in diverse climate zones of Palestine [26].

Accordingly, there is a need for studying the efficiency of energy usage of the different school buildings in Palestine as one of the important public building types that consumes electricity. And also, there is a need to calculate the potential electricity produced from the PV systems on the rooftop of the schools. In that sense, there is a need to evaluate the electricity production from installing PV systems on school rooftops and the energy consumption for different school building types, whether it’s new or old schools. There is also a need to compare electricity production with electricity consumption and evaluate the potential surplus that can cover the energy demand for the households in the neighborhood. Achieving this aim will pave the way for a more sustainable future in the energy sector and help the education sector to cope with the pressing challenges of climate change. This paper provided much-needed evaluation by the ministry of education, architects and engineering community and the private sector, for the benefits of utilizing available rooftop areas in school’s buildings to provide the needed electricity to operate the schools and use any surplus to cover parts of the energy demands in residential buildings.

2. Materials and Methods

Two steps were followed to evaluate the electricity production from PV systems on the rooftop of the school buildings in Palestine: Determine school typologies, and simulate the energy consumption in school buildings. The Simulation for energy production from PV systems is also conducted to compare this production with energy consumption for different school buildings in different climatic zones. The following sections clarify the conducted steps and methods.

2.1. School Buildings Typologies

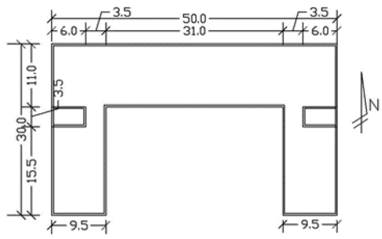
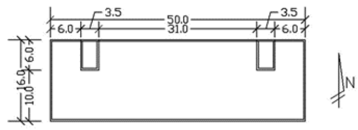
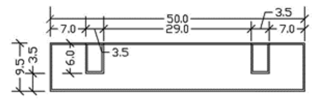
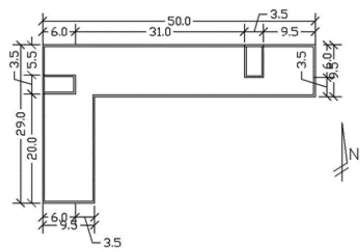
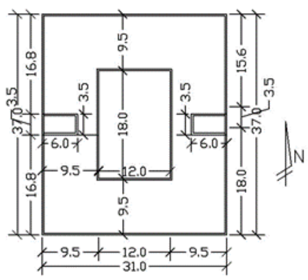
Since the building laws and regulations do not present certain typologies for the school buildings, the ministry of education, mainly the building and facilities section, established the rules and regulations for building typologies. The established regulations include building orientation, building shape, number of floors, building materials, windows and shading and interior furniture [26]. The presented study takes into account these requirements in selecting the most used building types below. A field survey was conducted to determine the most used school buildings types in terms of building shape, total area, and roof area. Then the most popular building types were selected to be representative for the evaluation of the electricity production from the installation of PV systems on the available rooftop.

The architectural types of schools in Palestine are characterized by linear shape configurations, which are rectangles whose dimensions change according to the dimensions and number of classrooms. As for the dimensions of the classroom, it is usually 6 meters * 8 meters, so that the largest side is directed to the north, in addition to the corridor in front of the classroom, which is usually 2.5 meters wide. Therefore, the surface area of each classroom is approximately 70 square meters, including the corridor adjacent to it and the thickness of the walls. Accordingly, the patterns of schools most present in Palestine can be summarized in two main patterns as follows:

1. Classification according to the building parts: The main building, which is the classroom building, and its orientation is usually north-south to get the best natural lighting in the classrooms by directing it to the north, and the corridor is directed to the south to avoid direct sunlight entering the classrooms, or the corridor is central, and the classrooms are oriented to the north and south around the corridor, School annexes which usually consist of the library, laboratories, teachers' and chairman's rooms, and bathroom units. Which often complements an I or L or U shape or O shape buildings.
2. Classification by circulation type: Linear type, where the spatial design of this style is characterized by the presence of linear corridors that follow the shape of the building and are usually oriented to the main square of the school, and Central type: The space design of this style is characterized by the U or O-shaped movement corridors, and the rows and other attachments are wrapped around a central space, either exposed to the outdoor (courtyard) or covered with a transparent covering, usually to introduce natural lighting to the center of the building.

The average number of floors in the previous types is two floors, and some schools are consisting of three or four floors. These floors are often added in stages and according to the future expansion of the school. As for the one-story schools, they are very few. In addition, two staircases are designed for each school in general, even in small schools, for future expansion, and the staircases are often at the end of the corridors. The surfaces of the staircases are used to construct the lightning rod, while the water tanks are placed on the roof of the stairs. Table 1 below shows a summary of the most used school buildings types and their floor and rooftop areas.

Table 1. The selected most used school building types in Palestine

Type	Dimensions	Total floor area m^2	Stairs roof area m^2	Roof Area m^2
U shape		1820	34	910
I-1 shape		1600	34	800
I-2 shape		950	34	475
L shape		1320	34	660
O shape		1830	34	915

2.2. Simulation for Energy Consumption in School Buildings

The schools' total floor area in the previously discussed types has a wide range (200 to 5,000 square meters), and the previous studies for energy consumption also have a wide variation (1.27 to 46 kWh/m² per year) depending on the school construction, lighting systems, climate zone whether it uses heating and cooling systems or not. Because of this variation, the research method for determining energy consumption used a computer simulation for a selected school type (L shape, as it is the most used type) for four different scenarios as follows:

Scenario-1: energy consumption for schools with no improvements in building envelope thermal properties or lighting system (no thermal insulation or shading devices, the glazing is single clear, the infiltration is high and the lighting systems is fluorescent and incandescent) used, and no heating or cooling systems installed.

Scenario-2: energy consumption for schools with no improvements and with heating and cooling systems installed.

Scenario-3: energy consumption for passive schools that have improvements in the building envelope (including thermal insulation in the external walls and roof, shading devices installed at southeast and west facades, double glazing is used and low infiltration applied, and the lighting systems used are high frequency and LED lights) and no heating and cooling system. Scenario-4: electricity consumption for schools that have improvements and are provided with heating and cooling systems.

The simulation was done for two selected climate zones, zone 4 in West Bank and climate zone 6 in Gaza Strip. These two climatic zones have been selected because they represent the highest population density in the west bank and Gaza strip. The weather data files were used for the city of Jerusalem in Zone 4 and the city of Gaza in zone 6.

The simulation for energy consumption in school buildings for L shape type has been done using the design-builder simulation tool version 6.1.7.007 which uses EnergyPlus simulations, engine. The study assumes that each school is occupied 5 days a week for ten months starting Aug. 20th to June 20th. Two main holidays were defined as winter and summer. Working hours from 8:00 am to 2:00 pm, the density of occupants: for classrooms: 1 person/1.4m² and for offices 1 person/10m². The simulation model was constructed using as-built data for the school's building envelope and lighting systems based on the above-mentioned scenarios. The building envelope consists of stone, concrete, concrete block, and plaster for external walls (thermal insulation which is expanded polystyrene of 5 cm thickness is used in new school buildings). Internal walls consist of a hollow concrete block of 10 -15 cm and plaster from both sides. Glazing is single clear for old schools and double clear glazing for newly constructed schools and the window wall ratio is based on the as-built elevations. The infiltration rate was estimated for 1 ach for old construction and 0.3 ach for new constructions. In the case of heating and cooling used (scenarios 2 and 4), the set-point temperatures were fixed at 18°C for heating and 25°C for cooling. Weather data files were used for the two selected cities from the Meteonorm software.

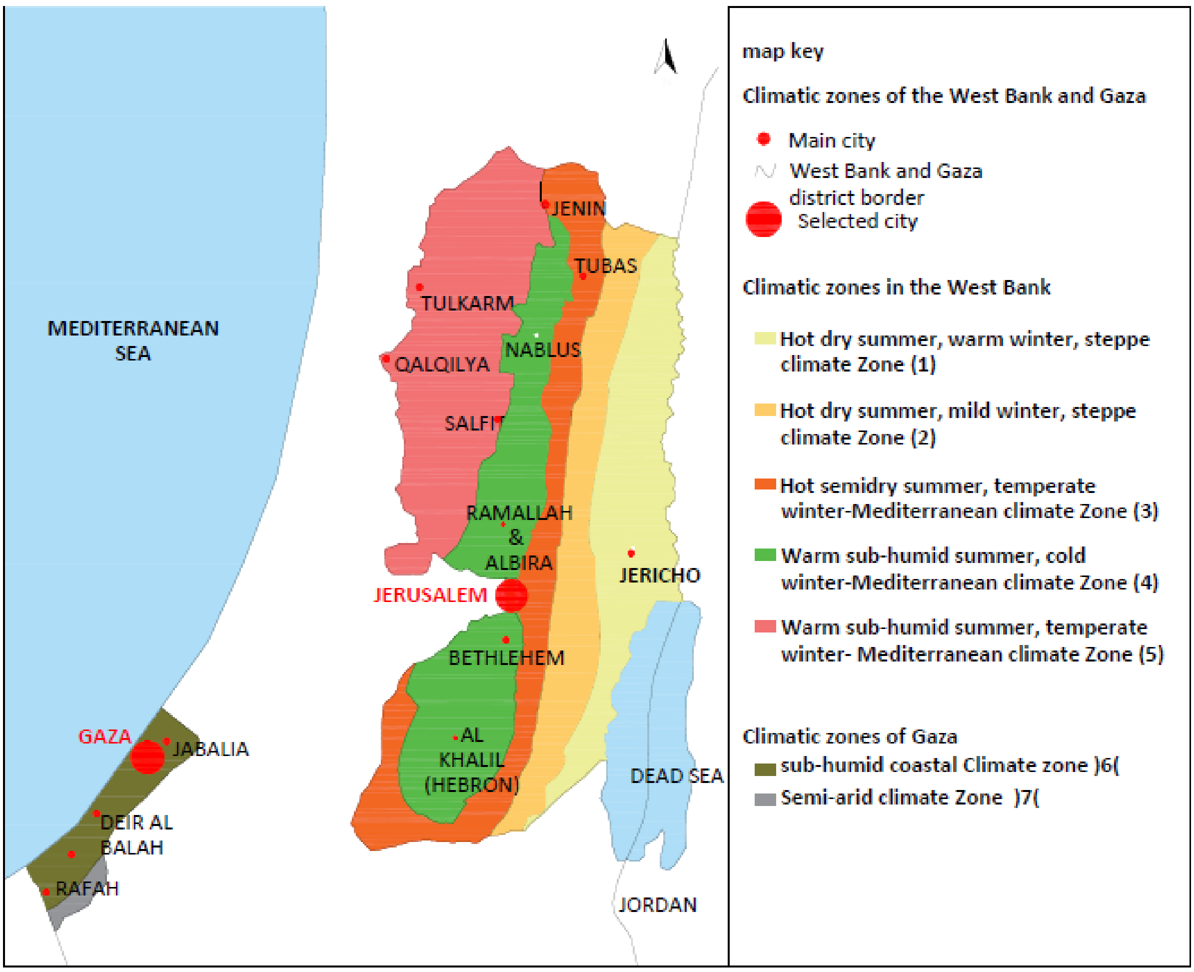


Figure 1. A map for the West Bank and Gaza strip showing the selected climatic zones and the selected cities [37]

2.3. Simulation for Energy Production from the PV System

The annual electricity production from the installation of PV systems on the school rooftop was calculated using a computer simulation tool PVSOL 2021. The PV systems were installed on the available roof area, this area is calculated for each building type by deducting the areas occupied by stairs and the shaded areas by stairs and building parapets from the total roof area as can be seen in table 1. The PV systems were oriented to the south (optimum orientation in this region) and the systems were installed at different tilt angles to compare and select the highest production from the PV systems. Four different cities were selected in the above-mentioned climatic zones (zone 4 and 6) to be the location for the PV installation on the rooftop of the schools. Commercially available PV panels with high efficiency (above 20%) and an output of 420 W for each panel were used in the installed system. The optimization of the system output was carried out using the software for different tilt angles and different orientations. Then three tilt angles were selected for the simulation of electricity production, 27° was used as it represents the optimum tilt angle in Palestine, and 7° was used as it represents the angle with maximum installed power, with low spacing between arrays, and high total energy production, and finally, 17° was used as a middle value. The produced electricity will be connected to the grid, and the tariff for selling and buying the product will be according to the available laws and regulations.

Finally, the energy consumption for different scenarios was compared to energy production from the PV installation. The comparisons were applied to the four different scenarios and the two climatic zones. Jerusalem city was selected to represent climate zone 4 and Gaza city to represent climate zone 6. In the case of surplus in the energy production in comparison to the consumption, this surplus will be directed to cover residential energy consumption in the neighborhood. In this case, the average monthly energy consumption for a single household (apartment or single house) is estimated based on a previous study [2] to be 442 kWh for Jerusalem and 265 kWh for Gaza city. In the future, this average monthly consumption for 2030 will be 785 kWh in Jerusalem and 475 kWh for Gaza city as estimated by the same study.

3. Results and Discussion

3.1. School's Energy Consumption

Energy consumption for heating, cooling, lighting, and equipment has been simulated using the Design-Builder tool, for the four different scenarios and in two different climatic zones. The results show that for the two climatic zones scenario 3 has the lowest energy consumption per square meter followed by scenarios 1, 4 and the highest energy consumption was for scenario 2 as seen in table 2. This is mainly because scenarios 1 and 3 have no heating and cooling loads as the schools operate passively, and because scenario 3 has building envelope thermal improvements compared to scenario 1. On the other hand, scenarios, 2 and 4 have the highest energy consumption because they have heating and cooling systems; scenario 4 has a lower energy consumption compared to scenario 2 because it includes building envelope and lighting systems improvements. Lighting has the highest energy consumption followed by heating, cooling, and equipment in climate zone 4. In climate zone 6 the highest energy consumption was for lighting followed by cooling, heating, and equipment.

Table 2. Energy consumption in school buildings (total floor area of 1320 m²) for different scenarios and two different climatic zones

Climate zone/ City	Scenario	Heating (Kwh/m²)	Cooling (Kwh/m²)	Lighting (Kwh/m²)	Equipment (Kwh/m²)	Total Energy (Kwh/m²)	Total energy consumption
Zone (4) Nablus	Scenario -1	-	-	26	10	36	47,520
	Scenario -2	20	16	26	10	72	95,040
	Scenario -3	-	-	17	10	27	35,640
	Scenario -4	13	10	17	10	50	66,000
Zone (6) Gaza	Scenario -1	-	-	25	10	35	46,200
	Scenario -2	14	21	24	10	69	91,080
	Scenario -3	-	-	16	10	26	34,320
	Scenario -4	7	14	16	10	47	62,040

3.2. Electricity Production from PV Systems on the School's Rooftop

For the different cities in Palestine, the kW power of the installed PV systems produces electricity in the range of 1504 - 1566 KWh/year at the tilt angle of 7° and 1559 - 1626 KWh/year for the tilt angle of 17° and 1568 - 1641 for the optimum tilt angle of 27°. Hebron city has the highest production followed by Gaza, Jerusalem, and Nablus as can be seen in figure 2. This is in line with other studies that show high production from PV systems in this targeted region [19]. The production at low tilt angles of 7° and 17° for a 1 KWP has no significant difference (the difference is in the range of 10 to 15 kWh annually). The production from the PV systems installed at the optimum angle and the low tilt angle of 7° is significant (the difference is in the range of 64 - 80 KWh annually). In this regard, installing the PV systems at the optimum tilt angle will give the highest efficiency for the system.

Regarding electricity production, each building type produces electricity based on the available roof area, the tilt angle, and the selected city as can be seen in figures 3-7. As expected the PV systems installed at the tilt angle of 7° produce the highest electricity as the number of solar panels installed is the largest due to the close arrangement of solar panels. The PV systems installed at tilt angles of 17° have the second-highest production and finally, the systems installed at the optimum angle of 27° have the lowest electricity production. For the selected cities Hebron has the highest production and Nablus has the lowest.

Regarding the building type, the roof area is the most important factor for the total electricity production. Building types for O and U shapes have the highest electricity production as they have the largest roof area. The I-2 shape has the second-highest production followed by L and I-1 shapes. The annual electricity production from the O shape buildings can reach up to 197,640 kWh, followed by the U shape of up to 192,010 kWh, I-2 shapes of up to 171,200 kWh, and L shape of up to 143,220 kWh, and finally the I-1 shape of 105,450 kWh. These results are for PV systems installed at a tilt angle of 7°. If we use the optimum tilt angle of 27° for a more cost-efficient PV system (but gives less total production) the annual electricity production from the O shape buildings can reach up to 169,275 kWh, followed by U shape of up to 164,710 kWh, I-2 shape of up to 146,400 kWh, L shape of up to 122,760 and I-1 shape of up to 90,250 kWh. The electricity production for the systems installed at a tilt angle of 17° is close to the production at the optimum tilt angle (with no significant difference compared to the difference between 17° and 7°) as can be seen in figures 3 to 7. In this regard, the PV system can be installed at the optimum tilt angle for cost and production efficiency or the tilt angle of 7° for the highest total production.

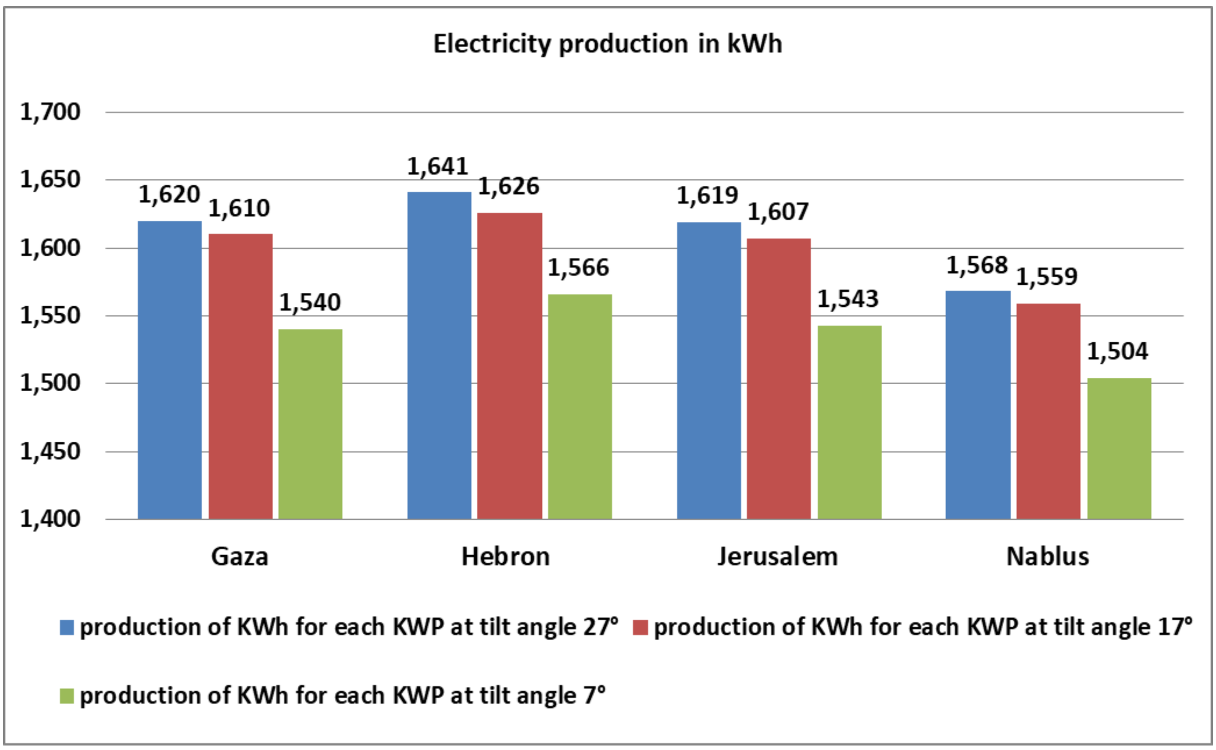


Figure 2. Annual electricity production in kWh from each kWp installed at the rooftop schools at different tilt angles in different cities

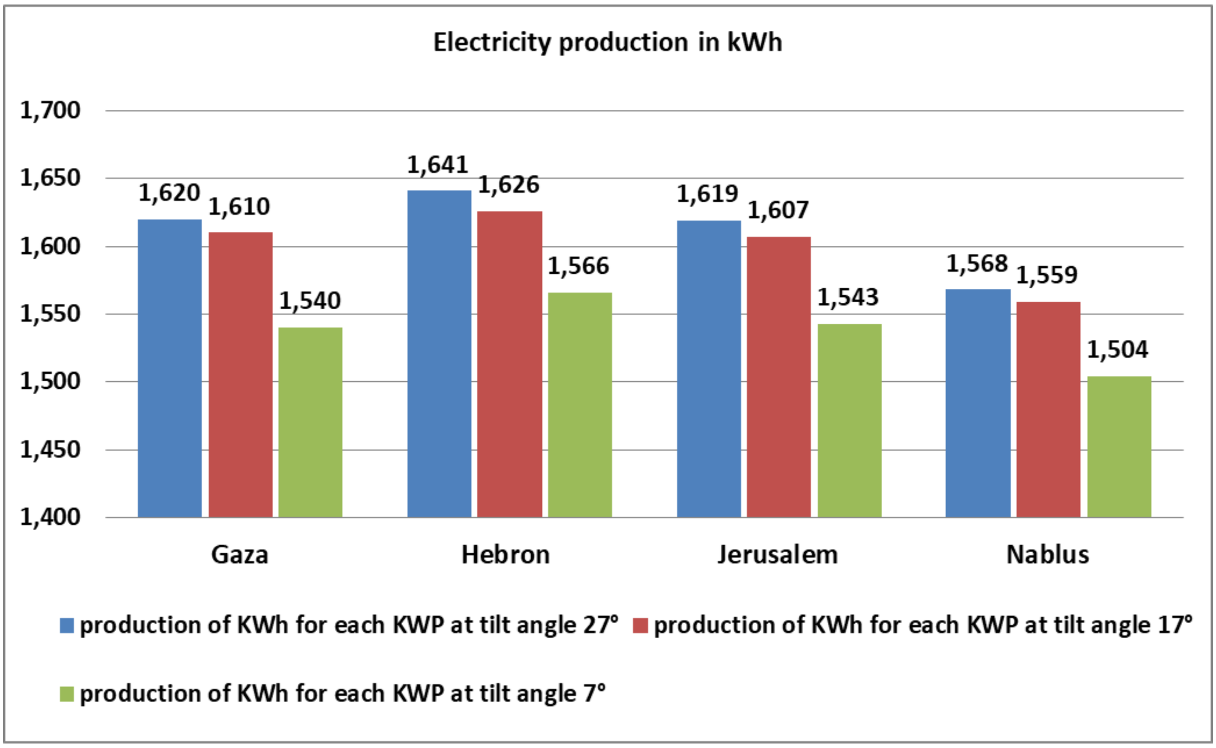


Figure 3. Total annual electricity production from PV system on the I-1 shape school's building in different cities

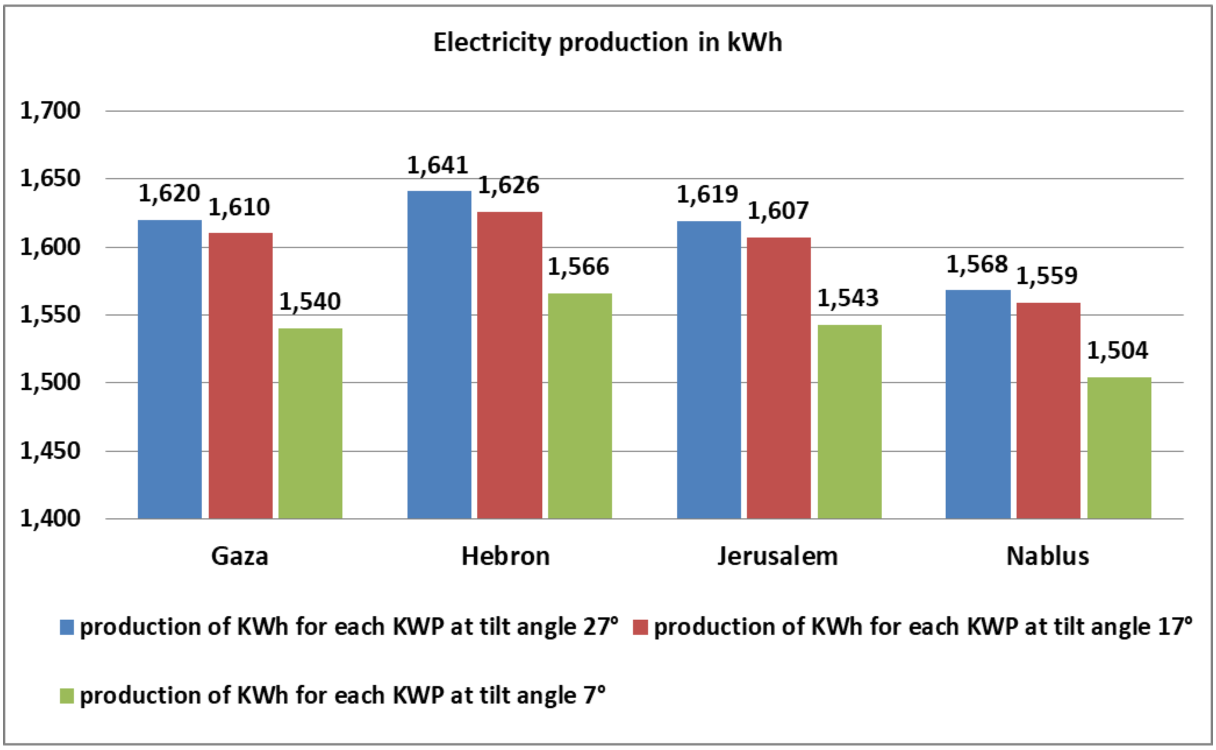


Figure 4. Total annual electricity production from PV system on the I-2 shape school's building in different cities

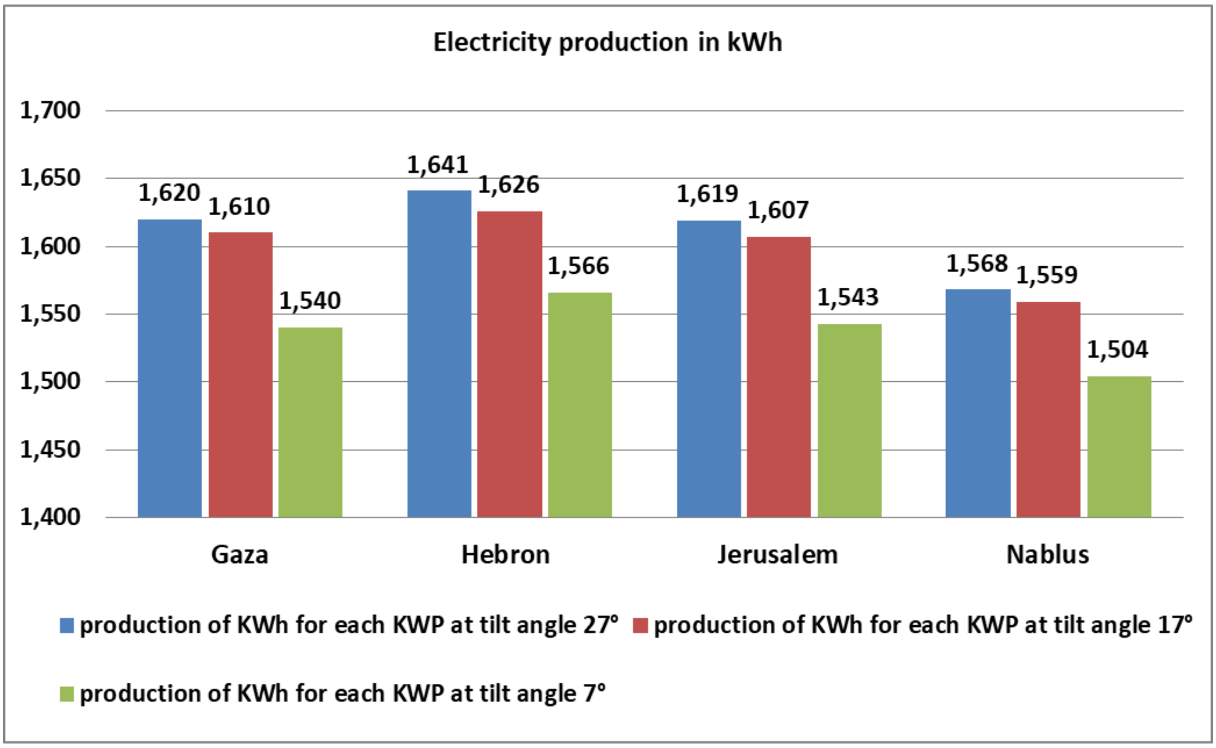


Figure 5. Total annual electricity production from PV systems on the L shape school's building in different cities

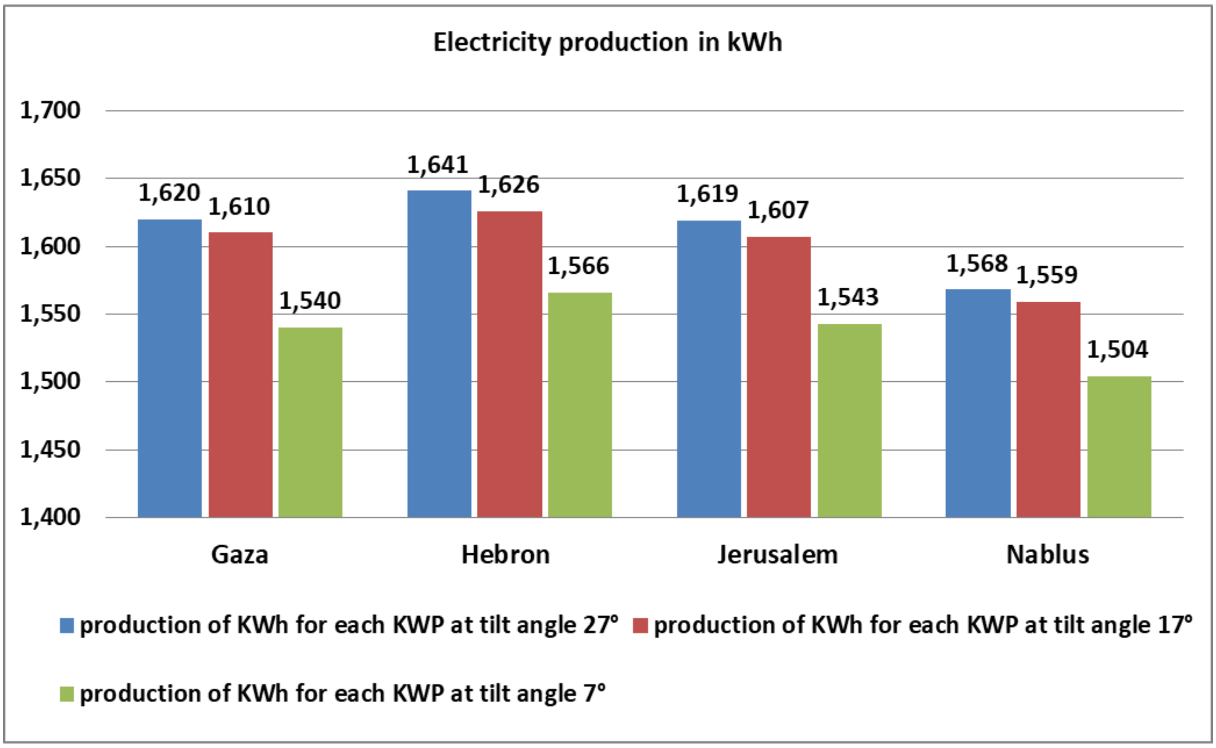


Figure 6. Total annual electricity production from PV systems on the U shape school's building in different cities

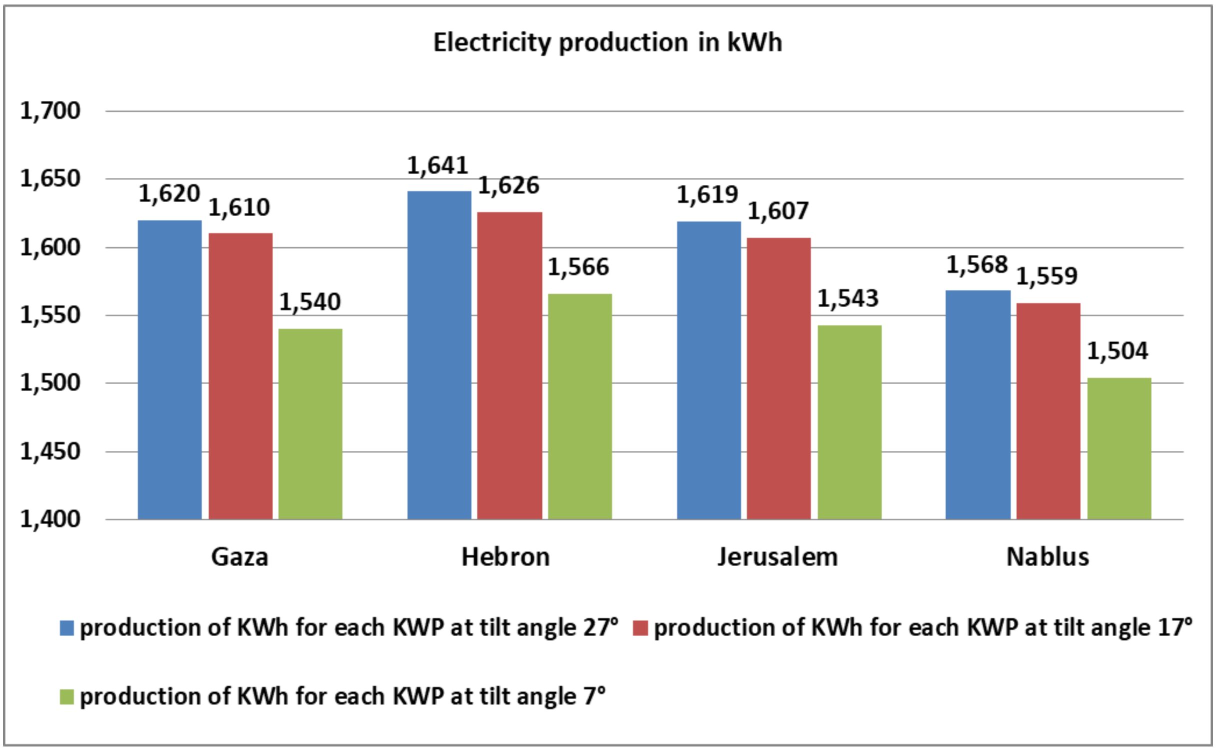


Figure 7. Total annual electricity production from PV systems on the O shape school's building in different cities

3.3. Comparison of Consumption and Production

As the tilt angles 27° and 17° have no significant difference in the total electricity production, the tilt angles 27° and 7° were selected for the comparison between the energy production and consumption. And the L shape building type was selected for this comparison as it represents the most used building shape; energy consumption for other building shapes can be estimated based on the results from the L shape type. Also, future studies can target other school building shapes.

For Scenario-1: for schools with no improvement in building envelope or lighting system and no heating and cooling systems operating in the schools. The electricity production from the PV system will cover 2.5 up to 2.9 times the school's total energy consumption in climate zone 4 and 2.6 up to 3.03 times in climate zone 6 depending on the tilt angle of the installed PV system as can be seen in figure 8. Regarding the number of households that can benefit from the surplus in electricity production, 13.7 to 17.3 households' units' electricity consumption and this covers 7.7 to 9.7 household units' electricity consumption in 2030 for Jerusalem. For Gaza city, the surplus will cover 23 to 29.5 household units' electricity consumption, and 12.9 to 16.4 household units' electricity consumption in 2030 as can be seen in figure 9.

For Scenario-2: for schools with no improvement in building envelope or lighting system and with heating and cooling systems installed and operating in the schools. The electricity production from the installation of the PV system will cover 1.25 up to 1.47 times the school's total energy consumption in climate zone 4 and 1.3 up to 1.54 times in climate zone 6 depending on the tilt angle of the installed PV system as can be seen in figure 8. The surplus in electricity production can cover 4.7 to 8.3 households' units' electricity consumption, this covers 2.7 to 4.7 household units' electricity consumption in 2030 for Jerusalem. And for Gaza city, it covers the consumption of 8.9 to 15.4 household units and the consumption of 5 to 8.6 household units in 2030 as can be seen in figure 9.

For Scenario-3: for passive schools that have improvements in the building envelope and lighting system and no heating and cooling systems operating in the schools. The electricity production from the installation of the PV system will cover 3.4 up to 3.9 times the school's total energy consumption in climate zone 4 and 3.5 up to 4.08 times in climate zone 6 depending on the tilt angle of the installed PV system. The surplus in electricity production can cover the electricity consumption of 15.9 to 19.5 households' units, this covers the consumption of 9 to 11 household units in 2030 in Jerusalem. In Gaza city, the surplus covers the consumption of 26.8 to 33.2 household units and 14.9 to 18.5 household units in 2030.

Scenario-4: for schools that have improvements in the building envelope and lighting system and provided with heating and cooling systems. The electricity production from the installation of the PV system will cover 1.8 up to 2.11 times the school's total energy consumption in climate zone 4 and 1.9 up to 2.3 times in climate zone 6 depending on the tilt angle of the installed PV system. The surplus can cover the electricity consumption of 10.2 to 13.8

households' units and cover the electricity consumption of 5.7 to 7.8 household units in 2030 for Jerusalem. For Gaza, the surplus covers electricity consumption of 18.1 to 24.5 household units and 10.1 to 13.7 household units in 2030.

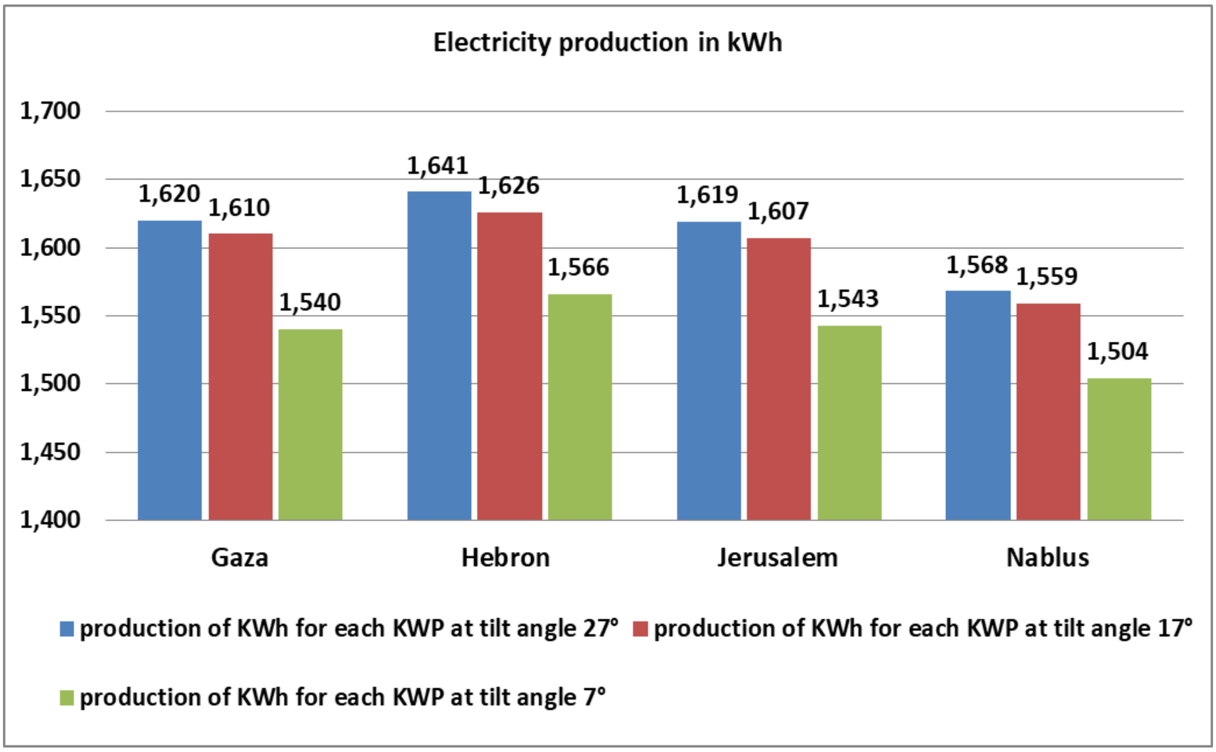


Figure 8. Comparison between school's consumption and electricity production from the PV systems on the school buildings at two different tilt angles

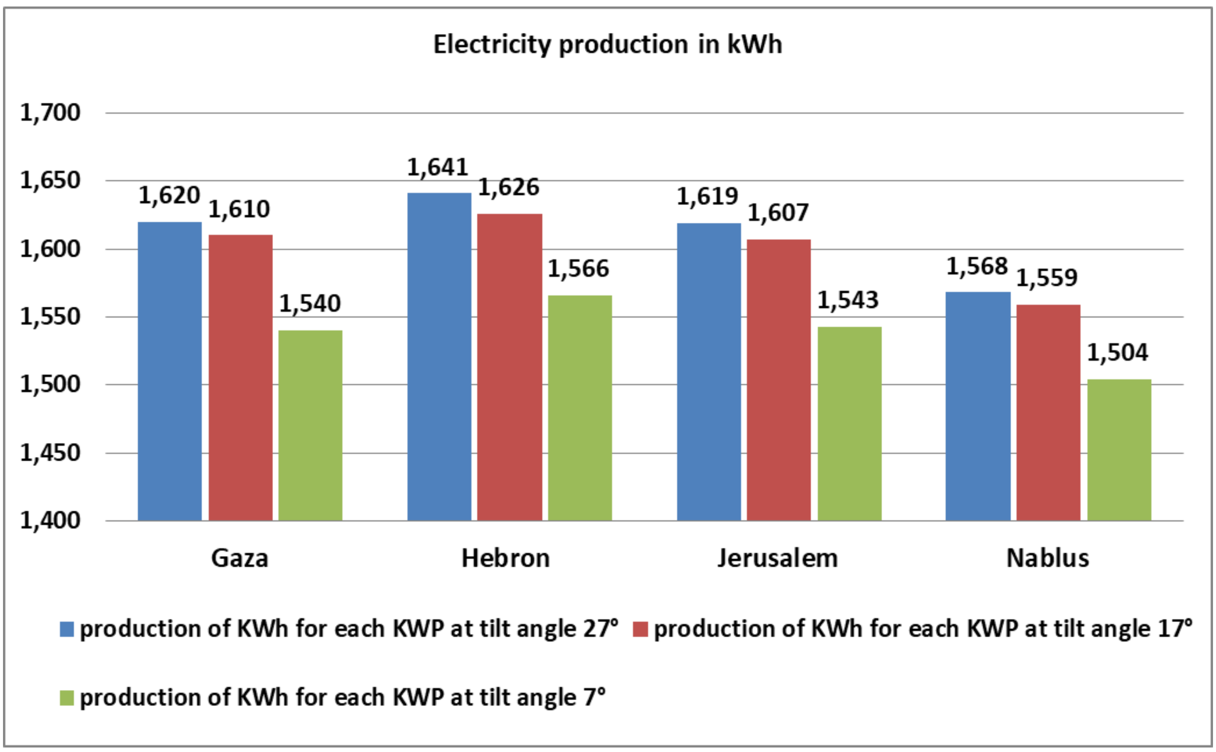

Electricity production in kWh
1,700
1,650
1,600
1,550
1,500
1,450
1,400
1,620
1,610
1,540
1,641
1,626
1,566
1,619
1,607
1,543
1,568
1,559
1,504
Gaza
Hebron
Jerusalem
Nablus
production of KWh for each KWP at tilt angle 27°
production of KWh for each KWP at tilt angle 17°
production of KWh for each KWP at tilt angle 7°

Figure 9. The number of household units that have full electricity coverage from the surplus of electricity production from the installed PV systems at the rooftop of the schools

For all scenarios, the electricity production from the installation of PV systems on all the available rooftop areas is higher than the school's energy consumption. This is a great opportunity to use the surplus of the electricity produced from the schools' rooftop to provide surrounding buildings -especially residential buildings- with the needed power. This will decrease the pressure on the electric company to respond to the increase in demand and pave the way towards more energy sustainability. Since the production is the same for the different scenarios, the energy consumption and the indoor thermal comfort conditions are the important factors to decide the best solutions. Scenarios one and three have the lowest energy consumption since no heating and cooling systems are installed, here scenario three is better than scenario one because it gives lower energy consumption while keeping better the indoor thermal environment. Scenarios two and four have higher energy consumption as they have heating and cooling systems installed, however, scenario four has lower energy consumption due to the improvements in the building envelope, which will improve the indoor thermal environment and reduce the demand for heating and cooling.

Regarding the surplus in the energy production, the number of the household units that their electricity consumption can be covered from the surplus in production depends on the region, the selected scenario (the condition of the school), and the tilt angle of the installed PV system as can be seen in figure 9. As the energy consumption in Jerusalem is higher than the consumption in the Gaza strip the surplus in the production for Gaza is higher for all scenarios. The systems at a 7° tilt angle is providing the highest surplus and consequently, the highest number of household units benefitted from this surplus for the current and future consumption, however, the cost of the installed systems is higher and the efficiency is lower. On the other hand, the systems installed at a 27° tilt angle are providing a lower number of household units benefitted (compared to the systems at 7°), however, the cost of the installed system is lower and the efficiency is higher. Regarding scenarios, scenario three will give the highest surplus and a good indoor thermal environment, scenario four will give the best indoor thermal environment, however, the surplus in the energy production is lower than scenario one, scenario two will give the highest surplus in the energy production, however a worst indoor thermal environment, and scenario two is the worst in terms of lower surplus from the energy production, however, it has a good indoor thermal environment.

4. Conclusions

The rising electricity consumption due to the rapid population growth, and the increasing quality of life for most middle eastern countries including Palestine, invest in renewable energy sources necessary. Moreover, climate change is one of the most pressing challenges facing this region, currently and in the future, especially for its effect on the energy sector. The availability of solar radiation in Palestine should encourage the public and private sectors to utilize this renewable energy source as an alternative to non-renewable energy. In that sense PV systems are one of the most feasible climate change mitigation tools especially for public buildings like school buildings, due to the large roof areas of these buildings and the distribution of the schools near the residential districts. This will make it efficient to connect the school's PV with the grid, so any surplus in the production can be utilized for the surrounding. The duration of operating the school building during the day also helps, as the schools will operate in the morning while the higher consumption for the residential buildings is mainly in the evening.

The study provides an important comparison between the school's electricity production for two climate zones: the West Bank, and Gaza strip by installing PV systems on the rooftop of the schools' buildings at different tilt angles. The selection of different school types and different scenarios regarding the schools' construction and operation provide a wide range of options for both old and new schools, and even for future schools, that can be equipped with heating and cooling systems.

Regarding the energy consumption in school buildings, the study concluded that this consumption will be variable according to the school construction and the installed systems and according to the required thermal comfort level. The old schools with no improvements in the building envelope and lighting systems and with the use of heating and cooling systems are the worst buildings in terms of energy consumption. Those school buildings with improvements will give much better results regarding energy consumption (30% lower consumption). When the schools are passive (no heating or cooling installed), the buildings with and without improvements will consume less energy than the school equipped with heating and cooling systems, however, the thermal comfort condition will be much affected especially for schools without improvement in the building envelope.

Comparing school consumption and production (when installing PV systems on the available rooftop) for all scenarios, the production is much higher than the consumption. Though the surplus production varies depending on the selected region, building scenarios, and the tilt angles for the installed PV system. Old passive school buildings as in scenario one will give the second-best performance when comparing production to consumption (with high surplus) but will suffer from the low thermal comfort performance. The old schools with heating and cooling systems as in scenario two are giving the worst performance comparing production to consumption. New schools or old retrofitted schools give the highest surplus in the electricity production when operated passively; however, they may suffer lower indoor thermal environment quality. These schools will give lower surplus and a high indoor thermal environment quality when operated with heating and cooling systems.

One of the limitations of the research is that the estimation of the energy consumption was based on the result from the simulation for only one building shape (L-shape), computer simulation can be done for all selected building shapes for more comprehensive results. Also, the cost of the selling and buying of the produced electricity, and the tariff and benefits of the electric company is important factor to be taken into consideration when evaluating the feasibility of the proposed solution. This can be the gap to be filled in future studies.

5. Recommendation

To overcome the need to improve the thermal indoor environment in the schools and provide renewable energy sources to cover the rising demand for those schools especially in the climate change era, the study recommends providing all the schools with building envelope improvements (scenario 3) and when needed to provide the schools with heating and cooling systems (scenario 4). The study also recommends installing PV systems on all the available rooftops of the schools at a tilt angle of 27° when seeking higher efficiency for the PV system and moderate surplus in the electricity production and at a tilt angle of 7° when seeking higher surplus.

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