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An Evaluation of the Potential of Building Integrated Photovoltaic Panels in Reducing Electricity Consumption of Public Schools in Kuwait

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Abstract

Electricity consumption in Kuwait is on the rise, and the residents of Kuwait have recently experienced programmed electricity cuts during the hot summer months. The government of Kuwait sells electricity at a highly subsidized rate to its residents. However, newer sources of energy are being investigated to fuel the energy needs of the country. Since the percentage of sunshine during the year in Kuwait is rather high, solar energy becomes a viable option. The purpose of this study is to evaluate the potential of monocrystalline photovoltaic solar panels in meeting the energy needs of the government schools in Kuwait. In 2006 there were 664 government schools in Kuwait, and new schools are being built every year. Schools in Kuwait are large, and their design is simple. This creates a large roof area, which is suitable for PV panel installation. Ten schools were randomly selected in three different areas in Kuwait. The schools were relatively new (built after 1990), and of different educational levels. School plans, electric bills, and occupancy information were gathered from various ministries. The area of each school plan in the horizontal (roof), north, east, south, and west directions was calculated. Using the PVSYST5 software, the solar panels output in each direction was calculated, using a tilt angle of 30 degrees for the roof and 90 degrees for the elevation. 90% of the roof area was utilized and 50% of the total elevation areas. The results showed that the roof area is the most viable direction for energy generation, producing 211 kWh/m^2. Several schools needed only a fraction of their roof areas to fully cover their energy demand. CO_2 emission savings were also calculated to be an average of 676 metric tons/year per school. It can therefore be concluded that installing PV panels on school roofs is a viable option for solar energy generation.

Keywords: photovoltaic panels, urban planning, green cities, smart buildings, sustainable development

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NOMENCLATURE

Acronyms

PV Photovoltaic
BIPV Building Integrated Photovoltaic

Abbreviations

A Abdullah Al-Mubarak Residential Area, Kuwait
F Fahad Al-Ahmad Residential Area, Kuwait
S Saad Al-Abdullah Residential Area, Kuwait

School Educational Level Indicator

1 Kindergarten
2 Elementary School
3 Middle School
4 High School

School ID #

Randomly assigned from 1-10

1. INTRODUCTION

Since the oil boom in Kuwait in the 1960's, Kuwait has witnessed a tremendous growth on so many levels. A modern infrastructure of roads, hospitals, ministries, and multiple housing projects were constructed. With the increasing demand for an expanding work force, along with a population growth rate of 2%, the population of Kuwait has risen from 467,339 in 1965 to 2,193,663 in 2005 [1]. It is estimated that since the official census of 2005, the population of Kuwait has risen to 3 million residents in 2011, and it is currently estimated at around 5 million in 2020.

The pressure on the infrastructure has therefore increased, and few improvements were made since the sixties. In recent years, programmed cuts in electric power have been implemented during the summer months when consumption reached peak values. On June 13, 2010, electricity consumption in Kuwait reached 10,823 megawatts at noon, while the maximum production capacity is about 11,200 megawatts [2]. The Kuwait Ministry of Electricity and Water has led several campaigns to reduce the electricity consumption of the public. Recommended electricity conservation measures included setting the thermostat to 25 degrees during the hot summer months, in addition to switching off unused lights and appliances. The same measures are also encouraged in all governmental buildings, including ministries and schools. No new power plants have been built in Kuwait for two decades [2].

Therefore, the utilization of solar power has therefore been considered by the Kuwaiti government in order to meet the increasing energy demands of the growing population. One example of this recent interest is the agreement made between the Kuwait Institute for Scientific Research and the Ministry of Education in Kuwait to evaluate the effectiveness of powering government schools with solar energy. The study is expected to be carried out on a selected number of schools in Kuwait. A total PV output of 100–150 kWh is expected to be produced in some schools [3].

Another concern is the air pollution emissions in the country. Power plants in Kuwait are still using fossil fuels to produce electricity, and 1 kWh of electricity produced emits 0.49 kg of CO_2 into the air [4]. Increased CO_2 emissions are now believed to be a major contributor to a worldwide increase in temperature, the melting of the ice caps, and the consequent rise in sea level. The government of Kuwait, being a UN member, has obligations towards the health of its local environment, and the global environment as a whole; committing to solar energy is one way of fulfilling those roles. Other Gulf Cooperation Council (GCC) members have already started investing in solar energy. For example, the UAE is investing over 2 billion US dollars in the "manufacture, supply, installation and commissioning of solar power systems and solar photovoltaic systems such as Masdar PV project" [5].

According to Benemann et al. the first building integrated photovoltaic system (BIPV) was installed in Aachen Germany in 1991, in the form of a "curtain wall facade with isolating glass" [6]. Since then, several advances have been made in BIPV, and photovoltaic modules are now abundant in the market.

BIPV elements are different types of photovoltaic materials that can be used on top, or instead of, the roof, the skylights, or the facades [7]. BIPV modules can be integrated into new buildings as part of the design, or retrofitted onto older structures to provide power for the building. If the BIPV modules are designed to replace traditional building elements such as the roof, the skylights, or the facades, then the cost of the building materials and labor allocated for such elements can be reduced. These benefits make the BIPV market the fastest growing photovoltaic market. There are several forms of building integrated photovoltaic modules, such as: (1) a flat roof, which is a thin film solar cell integrated to flexible polymer roofing membrane; (2) pitched roof modules, which are shaped like multiple roof tiles; (3) solar shingles, which are modules designed to look and act like regular shingles, while incorporating a flexible thin film cell; (4) facades, which can be installed on existing buildings, giving them more appeal, and possibly increasing the resale value of the building; (5) glazing, which is a type of a semitransparent module that can replace some architectural elements that are commonly made with glass, such as windows and skylights.

From the previous discussion we may conclude that integrating photovoltaic modules into government school buildings in Kuwait would be a step towards securing the long-term energy needs of hundreds of schools around the country, as well as reducing CO_2 emissions from power plants in Kuwait. The lifetime of most solar panel systems is about 25 years, making them a viable investment. Additionally, designs that integrate BIPV reduce building and energy costs in the long run.

With the world growing more aware of the environmental problems that are caused by fossil fuel burning, countries such as France, Germany, and the USA are heavily investing in renewable energy research. In the future, it is predicted that fewer nations will depend on oil as the primary source of fuel, therefore, it is essential for GCC countries, including Kuwait, to invest in BIPV in order to achieve long term economic and environmental benefits.

2. STUDY METHOD

For this study, ten schools of different educational levels were randomly selected in Kuwait, distributed among the Jahra, Ahmadi, and the Farwaniya Governorates. All schools were built after 1990. School plans were obtained from the Public Authority for Housing Welfare and the Ministry of Education. Figure 1 shows the site plan for one of the new intermediate schools. Electricity bills for each school were obtained from the Ministry of Electricity and Water, and site visits were conducted to determine the occupancy numbers for each school. Roof areas and elevation areas were calculated based on the school plans. Since builing-embedded walls receive little or no sunshine, they were ignored. Table 1 summarizes the schools' research identification numbers, academic level, location, roof areas, number of occupants and electricity consumption.

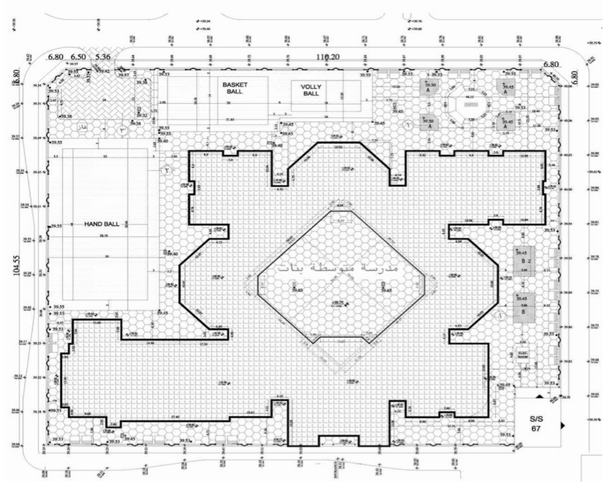


Fig. 1 Site plan of the new intermediate school.

Table 1. A summary of school research identification numbers, academic level, location, roof areas, number of occupants and electricity consumption. School level 1 is kindergarten (ages 4-6), level two is elementary (ages 6-10), level 3 is middle school (10-14) and level 4 is high school (ages 14-18). Average electricity consumptions is in kWh/year. Area codes are A: Abdullah Al-Mubarak, F: Fahad al-Ahmad, S: Saad Al-Abdullah.

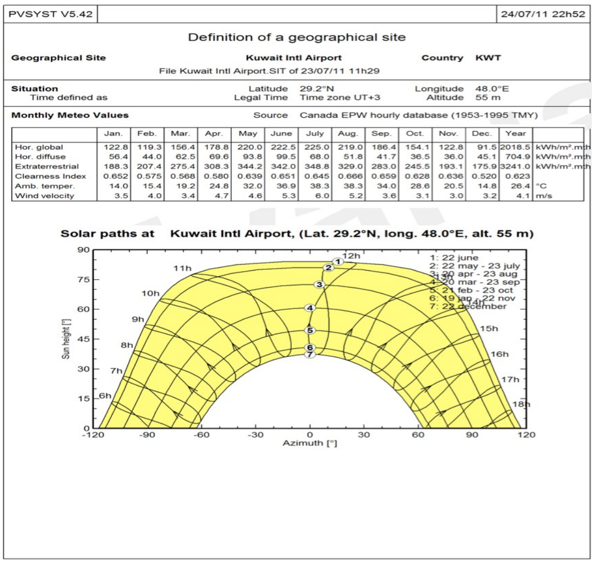
ID#	Site	Level	Pupil	Roof m^2	kWh/year
1	A	3	763	5179	735600
2	F	3	528	5179	2228600
3	A	1	202	4457	552684
4	S	2	773	4393	663668
5	S	2	765	4393	624944
6	S	4	783	9033	168725
7	S	4	808	9033	320450
8	F	3	397	5179	1494120
9	S	3	722	5179	556180
10	F	1	175	4457	1337500

2.1 The PVSYST Simulation

The PVSTST5 software was used to calculate the power output from monocrystalline, ventilated, standard photovoltaic panels. The PV panels are assumed to be tilted at 30 degrees facing south for the flat roof panels, and tilted at 90 degrees for the north, east, south, and west facades [14]. The optimum tilt angle was reported by Al-Mumin et al. (2006) to be 20 degrees, while Qasem et al. (2011) report an optimum tilt angle of 30 degrees [10, 20]. The theoretical optimum of 20 degrees is in reality prone to dust collection, therefore a 30 degree tilt angle is more efficient in practice. The meteorological data was imported into PVSTST5 as an EnergyPlus weather file (EPW file), compiled by Kuwait International Airport (figure 2) [21]. The monocrystalline panels were selected for their high efficiency, despite their high cost.

Solar panel spacing estimation was calculated using the BAXI Solar Panel Spacing calculator [22]. Figure 3 shows a diagram of the solar panel spacing calculation. The BAXI solar calculator is a tool that is used to calculate how far apart the panel base points should be in order to avoid overshadowing. This is done by inputting the latitude of Kuwait (29˚ N), and a collector angle of inclination equaling 30 degrees. Using trigonometry, if the length of the panel is assumed to be 1.9 m, and it is tilted at 30 degrees, then the projected distance of the lengths on the horizontal direction (adjacent) is 1.6 m. In other words, the panels can be arranged next to each other without the need for any extra space between them.

A 10% reduction was used to account for obstructions in the roof such as electric utilities and water storage. As for the elevation, a 50% reduction in area was assumed to account for doors, windows, and walls that remain mostly shaded. Finally, the total electricity output from PV cells was compared to the electricity demand of each school. CO_2 emission savings were calculated using a reduction of 0.49 kg CO_2 per kWh produced from the PV cells [4].



	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	122.8	119.3	156.4	178.8	220.0	222.5	225.0	219.0	186.4	154.1	122.8	91.5	2018.5	kWh/m².mth
Hor. diffuse	56.4	44.0	62.5	69.6	93.8	99.5	68.0	51.8	41.7	36.5	36.0	45.1	704.9	kWh/m².mth
Extraterrestrial	188.3	207.4	275.4	308.3	344.2	342.0	348.8	329.0	283.0	245.5	193.1	175.9	3241.0	kWh/m².mth
Clearness Index	0.652	0.575	0.568	0.580	0.639	0.651	0.645	0.666	0.659	0.628	0.636	0.520	0.623	
Amb. temper.	14.0	15.4	19.2	24.8	32.0	36.9	38.3	38.3	34.0	28.6	20.5	14.8	26.4	°C
Wind velocity	3.5	4.0	3.4	4.7	4.6	5.3	6.0	5.2	3.6	3.1	3.0	3.2	4.1	m/s

Fig. 2 PYVSYST5 definition of the Kuwait International Airport geographic site

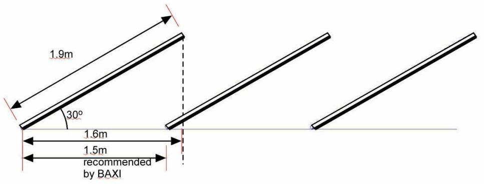


Fig. 3 Solar panel spacing using the BAXI calculator

3. RESULTS AND DISCUSSION

3.1 Areas of the Roof and Facade

Figure 4 illustrates the total area of the roof for each school. The high schools (schools 6 and 7) had the largest areas in all directions, and were oriented in the same way. Intermediate schools (1,2,8,9) had similar total areas, but the walls were oriented in different directions. The Elementary schools (schools 4 and 5) had the smallest areas in all directions. Figure 5 summarizes the elevation area for each school in the horizontal, south, east, west and north directions, and figure 6 summarizes the average area in each direction for the combination of all 10 schools. The largest average area in a single direction was the horizontal (roof) area of 5648 m^2, followed by areas facing west with an average of 2017 m^2. The averages of the areas facing south, east, and north were comparable, with the values of 1370, 1488, and 1424 m^2 respectively. The average roof area was almost 3 times the average of the areas facing west.

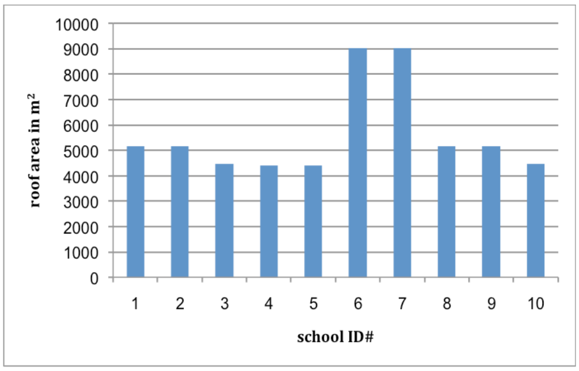
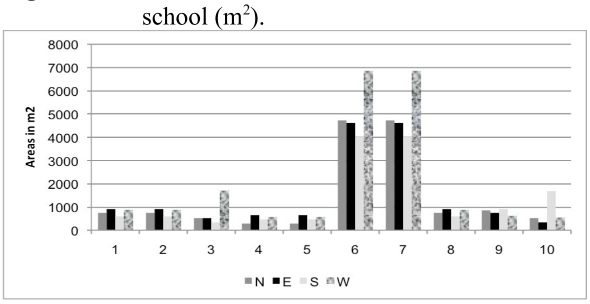


Fig. 4 Total roof area for each school (see table 1 for school identification reference).

Fig. 5 Elevation areas in each direction for each school (m^2).



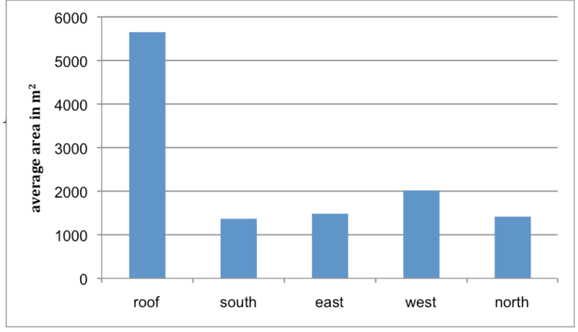


Fig. 6 Average area in m² in each direction for all 10 schools.

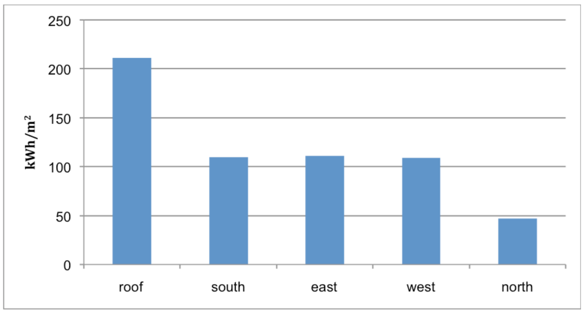


Fig. 7 PV electricity production from roof and elevation in kWh per m² in each direction for all 10 schools.

3.2 Power Output from the PV Simulation

Figure 7 demonstrates the total electricity production from both the roof and the elevation in kWh/m² in the horizontal (roof), south, east, west and north directions. The largest output per unit area was produced from the roof panels (211 kWh/m²), and the lowest was produced from the north panels (47 kWh/m²). The production from the south, east and west panels was comparable (120, 111 and 110 kWh/m² respectively).

Figure 8 illustrates the PV electricity output in kWh for only the roof PV installation. The highest output was from the roof of the high schools (schools 6,7) at 1,712,951 kWh, and the lowest output was from the roof of elementary schools (schools 4,5) at 845,098 kWh.

Figure 9 illustrates the total PV electricity output in kWh from both the roof and the elevation PV installations for each school. The high school plans (schools 6 and 7) had the largest total electric output of 2,698,670 kWh, and the elementary schools (schools 4,5) had the lowest output at 936,387 kWh.

The result of the power production per unit area for the roof (211 kWh/m²) is identical to the findings of Al-Mumin et al. (2006), although Al-Mumin et al. used an optimum tilt angle of 20 degrees. The results of the power production per unit area for the elevation are similar to the findings of Radhi (2010). Al-Mumin and Radhi results showed that the south, west and east directions were comparable in their kWh/m² production of electricity from PV (see table 2). The northern elevations produced the least power per unit area.

From the previous results we can conclude that the roof area produces almost twice the PV electric output of any of the following directions: the south, west or the east facing elevations. The PV electric output from the roof is nearly four times the output of the north-facing elevations. Therefore, the roof PV electric output is the most viable source of energy for all the schools.

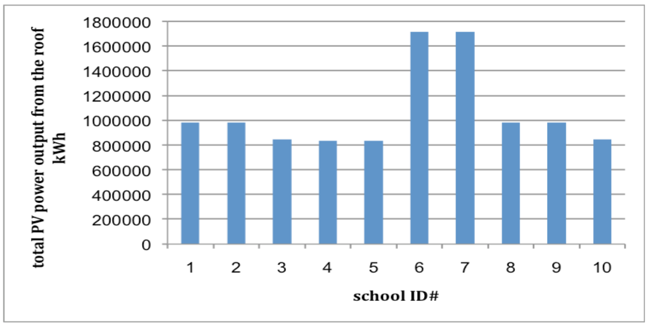


Fig. 8 Total PV output from the roof only for each school.

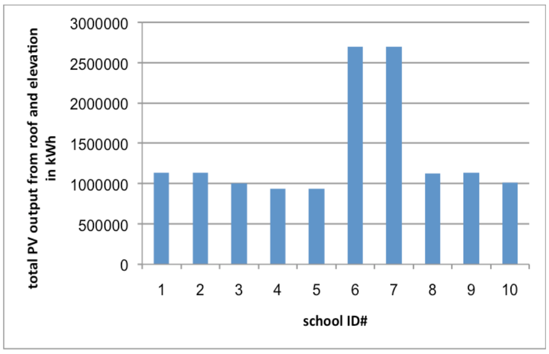


Fig. 9 Total roof and elevation output from the PV cells in kWh for each school (for school reference see table 1).

Table 2 A comparison of the PV electric output results of this study with the findings of Al-Mumin et al. (2006) and Radhi (2010) in kWh/m²

Orientation	Kuwait (present study)	Radhi (Dubai, 2010)	Al-Mumin (Kuwait, 2006)
South	110	111.7	117
West	109	112.9	105
East	111	81.8	105
North	47	47.9	45

3.3 Percentage of Electricity Demand Covered by PV Installation

Figure 10 shows a comparison between the energy demand and the supply from PV electricity output. Table 3 shows that the PV supply covered more than 100% of the demands of seven schools, and covered less than a 100% of the demands of 3 schools (schools 2,8 and 10). Figure 11 illustrates the roof area needed to produce a 100% of the electricity demand of each school. Table 4 shows that seven schools needed an area that ranged from 9.9%–79.7% of the roof area. Three schools needed an area exceeding the available roof area at (152%, 158% and 227%). It is possible that these three schools have a higher than average energy demand, and an energy audit of these buildings is warranted to evaluate any possible sources of energy waste.

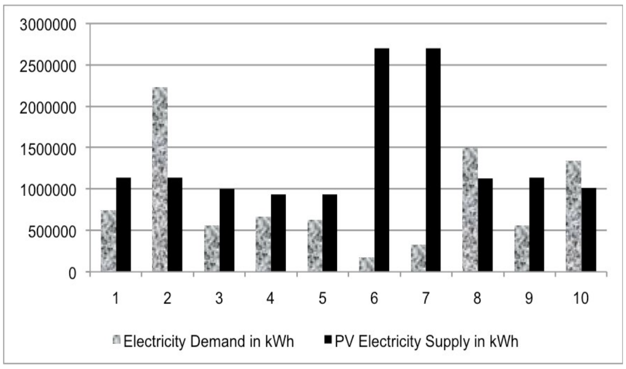


Fig. 10 PV electricity supply exceeds school electricity demand in 7 schools out of 10 (for school reference see table 1).

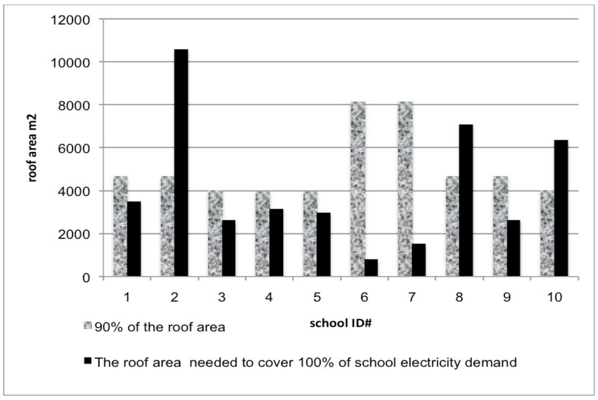


Fig. 11 A comparison between the area needed to provide the maximum PV output (90% roof area) to the roof area needed to cover a 100% of schools' energy demand.

Table 3 Percent of total PV electric output over electricity demand for each school

School ID#	% Covered by PV
1	154%
2	50%
3	181%
4	141%
5	149%
6	1599%
7	842%
8	75%
9	203%
10	75%

Table 4 Percent of roof area needed to output 100% of the electricity demand for each school.

School ID#	% area needed
1	74%
2	226%
3	65%
4	79%
5	75%
6	9%
7	18%
8	152%
9	56%
10	158%

3.4 Metric Tons of CO_2 Saved

Figure 12 illustrates the amount of CO_2 saved in metric tons per year in each school. The highest amount of CO_2 savings was 1,322 metric tons/year from high schools (schools 6 and 7). The lowest amount of CO_2 savings was 458 metric tons/year from elementary schools. The average savings of CO_2 per school was 676 metric tons/year. The total CO_2 savings for all 10 schools was 6,764 metric tons CO_2/year. Given that there are 664 government schools in Kuwait, as previously mentioned, the total CO_2 savings for all schools in Kuwait may add up to 448,864 metric tons CO_2/year, the equivalent of half a million metric tons CO_2/year. According to the UN Millennium Development Goals Indicators Program, CO_2 emissions from Kuwait have risen from 45,423 thousand metric tons in 1990, to 76,743 thousand metric tons in 2008—a 41% increase [23]. Therefore, PV installations in schools could help reduce this harmful increase in emissions. It can therefore be concluded that PV installations on school roofs in Kuwait will be a step in the right direction for an environmentally conscious future.

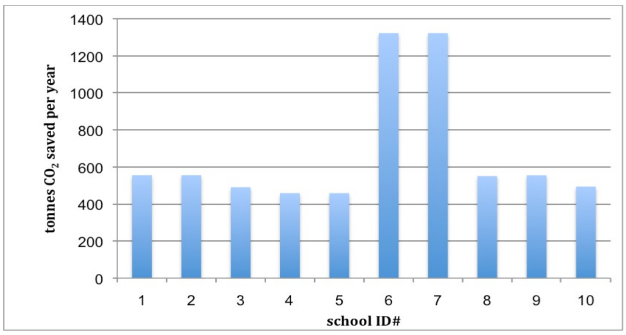


Fig. 12 Tonnes CO_2 saved in each school per year.

4. LIMITATIONS OF THE STUDY

The study was based on an ideal scenario where 90% of the roof and 50% of the elevations have PV installations, and may therefore exceed the results found by some other studies. This assumption should be double-checked to assess the percentages of the roof and elevation areas that are available for PV installations. Furthermore, the study did not include the costs of the PV installation, which can be addressed in future studies.

Additionally, there are some concerns regarding the study which may be addressed in future studies. In 2011, it was estimated that there are 154 days of dust per year in Kuwait, and this may reduce the efficiency of the PV panels [28]. The effects of dust may generally be mitigated by using a 30 degree tilt angle instead of the theoretical optimum of 20 degrees [10]. Additionally, temperatures in Kuwait in the summer (June-July) range from 30 degrees to 50 degrees, possibly reducing the efficiency of the panels, or decreasing their lifetime [29]. Lastly, the government of Kuwait places restrictions on selling excess energy back to the grid. This raises concerns regarding the optimal way to store the excess energy produced by PV panels, and the costs of storage.

5. CONCLUSION

The results show that high school building plans possess a superb potential for producing electricity from PV panels. Compared to the other educational levels' school plans, high schools have almost twice the roof area available for PV installation. This translates to twice the PV power output and twice the metric tons of carbon dioxide savings than the other school plans. This makes the horizontal orientation the optimum orientation for PV installation in schools, both due to the large unshaded areas available for PV installation, and the utilization of a 30 degrees panel tilt angle that is used solely on the roof. The PV power output of the northern orientation was the smallest at one quarter of the roof PV output, and therefore it is not considered a viable orientation for energy production.

Based on the encouraging results found in this study, it is recommended that the government of Kuwait conduct a thorough case study for PV installation on the roof area of one school. This will enable the government to judge the feasibility of installing roof PV systems in government schools in Kuwait on a wider range, and evaluate the potential energy and cost savings in the long run.

Moreover, other educational spaces and facilities such as museums can also utilize BIPV. This will help reduce electric consumption that is powered by fossil fuels, and switch over to cleaner technologies for energy production, minimizing air pollutants, protecting public health, as well as mitigating associated pollution hazards from other sources of energy, and supporting sustainable development.

CONFLICT OF INTEREST

The authors declare that they do not have conflict of interest.

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