Technical and Energy Assessment of Building Integrated Photovoltaic Systems applied to the UAE Office Buildings

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ABSTRACT

In the market, the embodied energy payback time (EPBT) is the scale to measure and compare the viability of PV systems against other technologies. Although the impact of PV panels on the operational energy is significant, it is not considered at the time of EPBT estimation. Including savings in operational energy gained over the PV system life leads to shortening the total EPBT. This study shows that the ratio between PV outputs and savings in energy due to PV panels is about 1:3. For the southern and western PV façades of the UAE office buildings, the embodied energy payback time is 12-13 years. When reductions in operational energy are considered the payback time can be reduced to 3 years. It is obvious that the reduction in the operational energy due to the PV panels represents an important factor when the EPBT is estimated

Keywords: BiPV, embodied energy, UAE commercial buildings.

INTRODUCTION

Developments in the design and manufacture of photovoltaic cells have recently been a growing concern in the UAE. The government started investing in renewable energy technologies that will make this country less dependent on conventional energy and showed a significant effort regarding the development of such technologies and especially solar energy which could play a key role in bridging the gap between the supply of fossil fuels and the energy demand. Such investments can be seen in several projects concerned with the design; manufacture, supply, installation and commissioning of solar power and solar photovoltaic systems such as the Masdar PV project to invest over $2 Billion in solar production. This investment represents one of the largest ever made in solar energy, and will fund a three-phased manufacturing and expansion strategy to produce the latest generation of photovoltaic (PV) modules [1].

Today, the use of solar cell in the UAE represents one of the most promising, reliable and environmentally friendly renewable energy technology which has the potential to contribute significantly to the energy and environmental system in this area. A study conducted by the CSEM-UAE Innovation Centre [2] showed a linear increase in photo-generated output due to the increase in solar radiation despite the drop in PV module efficiency and change in power output due to high range of PV module temperature (50-60ºC) and high ambient temperature on the site. To be cost effective, two main requirements are needed for such a technology: First, the energy associated with the manufacturing of PV systems should be small compared with energy production during the system operation. In other words, the energy payback time should be short compared with the system lifetime. Second, the design of such a technology should help in improving the energy performance of buildings as the buildings are one of the largest consumers of energy and that the PV has significant influence on heat transfer through the building envelope due to the change of thermal resistance.

LITERATURE REVIEW

This study reviews the PV literatures from two points of view. First, the embodied energy of PV system and second, the design of building integrated PV (BiPV). Many studies into the embodied energy have suggested different assumptions and various results. Some came to the conclusion that the useful electrical energy output of the PV cell would never exceed the embodied energy contained within all the inputs of the manufacturing, installation and lifetime operating processes of the PV cell. Other studies suggested that the amount of energy that was put into the process of making the PV cell would be equalled to the amount of the electrical output of the cell within a few years of operation. In the UK for example, Wilson and Young [3] indicated that the embodied energy payback time for photovoltaic modules applied to dwelling was in the range of 8-12 years, while Blakers and Weber [4] found that the EPBT was in the range 8 to 11 years, compared with typical system lifetimes of around 30 years. In India Nawaz and Tiwari [5] showed that the EPBT was in the range of 7-26 years and it depended largely on the solar radiation, efficiency of PV system and the balance of system (BOS). Crawford, Treloar, Fuller and Bazilian [6] indicated that the EPBT was between 4 and 16.5 years. A comprehensive review of research into the embodied energy of PV was carried out by Bankier and Gale [7] who concluded that the likely EPBT of a typical domestic sized rooftop grid connected PV cell was approximately 4 years.

Simultaneously, various published studies concerned with the PV design and its impact on the operational energy, came to different assumptions and conclusions. Yun, McEvoy and Steemers [8] for example, showed a complex interrelationship between ventilated PV façades and the overall energy performance of buildings and indicated that the PV façade values of a narrow building remained higher than those of deeper buildings. Wang, Tian, Ren, Zhu and Wang [9] stated that the PV roof with ventilated air-gap was suitable for use in summer because this integration led to the low cooling load and high PV conversion efficiency. In winter, a BiPV with a none-ventilated air gap was more appropriate due to the combination of the low heating-load through the PV roof and high PV electrical output. Gan [10] found that reducing possible overheating of PV modules and hot spots near the top of modules required a minimum air gap of 12-15 cm for multiple module installation and 14-16 cm for single module installation depending on roof pitches.

Based on the above review, the current study examines the use of PV as a wall cladding system applied to commercial buildings in the harsh climate of the UAE. The principal difference of this study is that it considers not only the influence of the PV on the heat transfer through building envelope but also the EPBT of the PV panels considering the reduction in the operational energy.

METHODOLOGY

This study examines the BiPV from two points of view including embodied and operational energy. The embodied energy is the sum of initial embodied and installation energy. The embodied energy requirement is determined by adding together the energy input during resource winning, production and installation of the PV system and the other system components. To assess the embodied energy, this requirement is compared with the energy output. This method is known as the energy payback time (EPBT). The impact of PV panels on operational energy is assessed by measuring the savings in cooling and heating energy using building energy simulation.

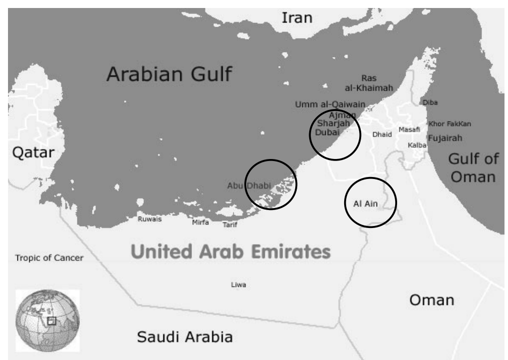

Figure 1 Locations of the three cities

Climate is a major factor that impacts the energy output of the PV panel, therefore, three cities in the UAE were examined, namely, Al-ain, Abu Dhabi and Dubai. Figure 1 shows the locations of the three cities. The average irradiance on the horizontal panels in Al-ain, Abu Dhabi and Dubai is within the range of 1975, 1950 and 1930 kWh per square metre per year respectively. Averages of horizontal and tilted plan in different directions are shown in Figure 2, where the solar radiation level seems to be almost the same in the three locations. It is important to mention that those abovementioned averages were calculated by using the MeteoNorm software [11] based on real weather data provided by the Directorate of Meteorology.

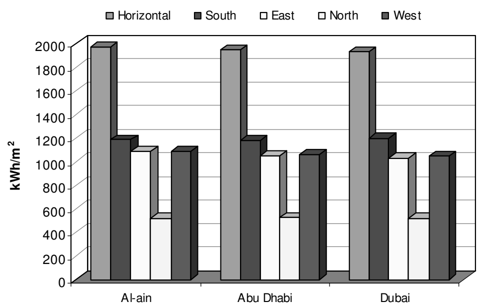

Figure 2 Averages of irradiance on the horizontal and tilted planes

It is known that building design and its constructional details can affect the relative importance of the performance and embodied energy contained of the PV especially the support structure of the PV panel. Therefore, a real case study was chosen to allow a realistic estimate of the performance of PV cells in their application to the UAE buildings as well as to ensure a good representation. It was decided that the building type selected would be offices, since it is probable that they will become the most important large scale application for PV technology in the UAE in the future. The case study building, therefore, is an air conditioned office, where the PV panels are required to be applied in addition to the existing cladding. Table 1 gives details, and Figure 3 shows the architectural characteristics and concept diagram of the four façades of the case study building.

Table 1 Building description for the simulation program

Parameters	
No. of Floor	3
Total Area	4075 m^2
Floor Height	3.7 m
Orientation	East to West
External walls	200 mm concrete masonry units (CMU) block-24 mm of plaster inside and outside
thermal resistance	0.38 m^{2}k/W
Wall area	North: 485 m^2 East: 300 m^2 South 585 m^2 West: 300 m^2
Roof	200 mm concrete, slab 50 mm screed, 50 mm sand and 10 mm ceramic tiles
Glazing	6 mm double reflective glass
Glazing Area	North: 285 m^2 East: 125 m^2 South 185 m^2 West: 125 m^2
WWR	North: 0.37 East: 0.30 South: 0.24 West: 0.30
PV Area	North: 190 m^2 East: 130 m^2 South 240 m^2 West: 130 m^2
Infiltration rate	5.0 m3/h/m^2
Ventilation rate	7.5 L/s/person
Equipment	20 W/m^2
Lighting	18 W/m^2
HVAC	Central

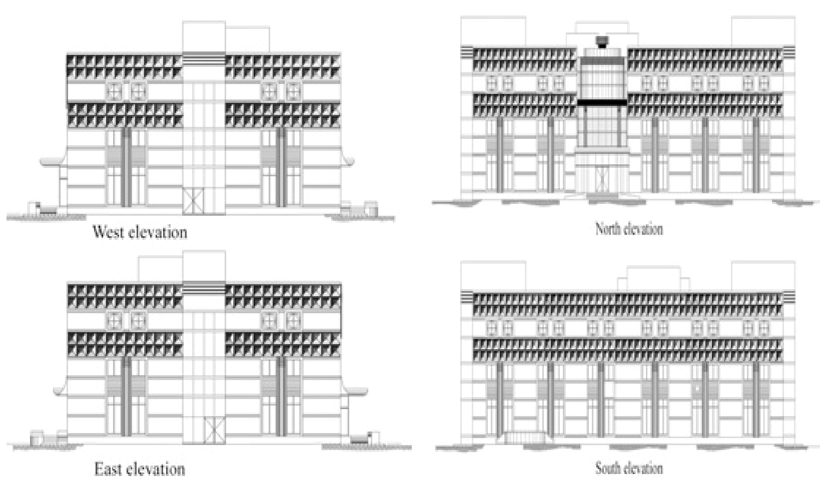

Figure 3 Architectural characteristics and concept diagram

An assumption was made that the PV panels would be integrated into the envelope of the case building as a wall cladding system with a tilted of 90^{o}. Figure 4 provides a comparison between the exiting wall system and the BiPV. As illustrated, the support structure is an aluminium frame used to fix the PV panels leaving an air-gap of 12-15 cm between the panels and the existing wall. Sanyo single crystalline silicon solar cells are used and assumed to have an efficiency of 15.2%. The specifications of the PV system are given in Table 2. Since electricity is the major form of energy inputs of a PV system and the outputs are in the form of electricity, electric energy in kWh was taken as the basic energy units. Some suppliers, at present, offer 20-years guarantees and PV panels might last between 40 and 50 years. Therefore, the lifetime of the PV system is assumed to be 30 years.

Table 2 Description of the PV system

Module		Sanyo_HIP-H097	
Description		Length (m)	width (m)
Rated power	175 Wp		
Area	1.15 m^2	1.31 m	0.88 m
Efficiency	15.2%		
PV cell type	Crystalline		
Max power point voltage	52.9 volts		

Orientation of PV	PV Array area (m^2)	Total PV rated output (kW)
South	145	19.8
West	85	12.6
East	85	12.6
North	130	22.1
Total	445	67.1

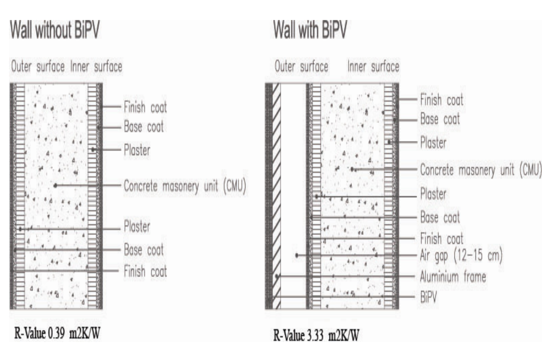

Figure 4 Existing and proposed wall systems

At the modelling stage, architectural, mechanical and internal loads and use patterns of the case building are simulated using the Energy-10 software [12]. It uses an exact energy-balance method and is based on the finite difference technique that allows running simultaneous combination between the building and its systems. Energy-10 is able to model and simulate the performance of a photovoltaic (PV) system using the Sandia model [13]. It can evaluate hour-by-hour PV system behaviour taking into account the system efficiency and the impact of climate parameters on this efficiency. Based on monthly utility bills and building design and operation, the base case of the simulation program was first calibrated, as shown in Figure 5. The calibration was based on real weather data for Al-ain city where the building is located. The case model was then simulated under the weather conditions of Abu Dhabi and Dubai.

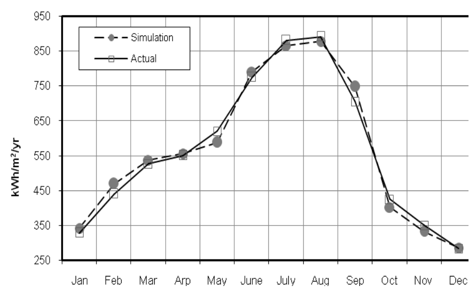

Figure 5 Calibration of simulation model

RESULT AND DISCUSSION

In this section, the payback time of PV system is first estimated without any consideration for the reduction in operational energy. The impact of PV panels, as a wall cladding system, on the operational energy is then explored. The embodied energy and reductions in operational energy are then combined in order to estimate the total energy produced by the PV façade.

Energy Input of BiPV

The energy input of a PV system is made up of the energy used for the production and installation of the system. The PV module is called the system, while other components are called the BOS. The BOS consists of the following: wiring, power electronics, structures, support frames, transport and installation. The structures and support frames are likely to be the most energy intensive. When the system is installed on a building wall, the structures is generally be dispensed with. If the PV array forms part of the wall structure then the energy embodied in the displaced wall components can be set against the embodied energy in the PV array. Sometimes, it is difficult to estimate the energy savings possible by displacing façade materials with PV panels, because many different types of materials are in common use. For example, an aluminium façade could be replaced with a PV façade, saving large amounts of energy because aluminium is an energy intensive material. In contrast, cladding tiles or coated metal have relatively low embodied energy [14].

In the current case, PV panels are assumed to be applied in addition to the existing cladding materials. In new buildings, however, the common cladding materials such as stainless steel, aluminium and stucco can be replaced with PV panels. This substitution effect means that while there is a growth in embodied energy due to the PV modules, there is also a reduction due to the smaller number of aluminium or plaster panels required for the cladding. The embodied energy required for production, fabrication and packaging to form 1 m^2 of PV panel and the balance of systems (BOS) is shown in Table 3. As tabled, the production of Czochralski silicon by far the most energy intensive following by the support structure which is aluminium frame in the current case.

Table 3 Energy requirements for each level

Element	Energy (kWh)	Reference
Production of MG-Si	45	[6]
Production of EG-Si	200	[6]
Production of Czochralski silicon	420	[6]
Cell fabrication	120	[6-7]
Panel assembly	190	[6-7]
Support structure / wall	271	[5]
BOS	204	[6-7]
Battery	46	
Inverter	33	
Overall O&M	125	
Total	1450	

Energy Output of BiPV

The value of energy output is dependent on three factors: the conversion efficiency of the photovoltaic system; the amount of illumination that the system receives and the local environmental conditions including. It must be emphasised that the efficiency of PV system is dependent on the manufacturing technology that was used to make the photovoltaic cells. Energy-10 calculates the energy output considering the cell efficiency during actual operation considering the system parameters and climatic conditions. Figure 6 shows the energy output of the four PV façades with respect to the three examined locations. Clearly, the western PV façades in the three cities deliver more PV power despite that the amount of incident irradiance in the south direction is the largest.

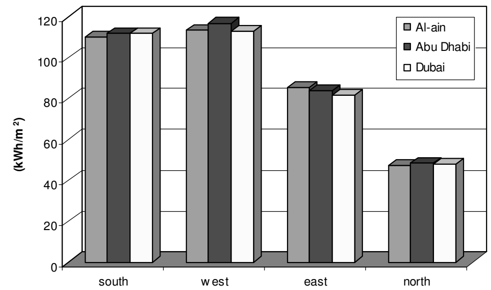

Figure 6 Energy output of the PV systems

Many studies concern with PV systems suggest that the south orientation delivers the largest PV power [15-17] and that the relationship between the incident irradiance and the delivered PV power is essentially linear [18]. So, further analysis was carried out to explore the performance of PV façades in the UAE.

Figure 7 shows the monthly irradiance on the southern planes with a tilt angle of 90^o and 24^o (site latitude) as well as in the western plane with a tilt angle of 90^o. The irradiance on the southern plane with a tilt angle of 90^o is higher than that on the western plane with the same tilt angle. The Sanyo single crystalline silicon solar cells used have an efficiency of 15.2%.

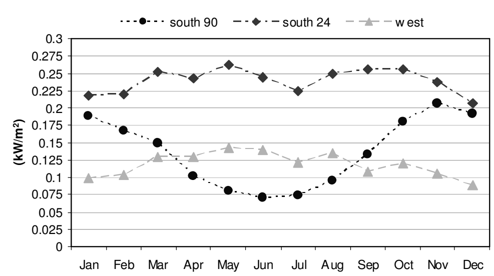

Figure 7 Month irradiance on tilted planes

Figure 8 illustrates the output of the southern and western PV panels based on the standard test condition (STC) i.e., incident solar irradiance: 1 kW/m^2, solar spectrum distribution: AM1.5G, module temperature: 25 1C. According to Figures 8 and 9, the relationship between the incident irradiance and the delivered PV power is linear and the south orientation, particularly with a tilt angle equal to the site's latitude, produces the largest amount of output power. In this case, this is 24°. The same result was obtained by Gong and Kulkarni [19]. It was highlighted that the optimal tilt angle for a south-facing surface is equal to the site's latitude.

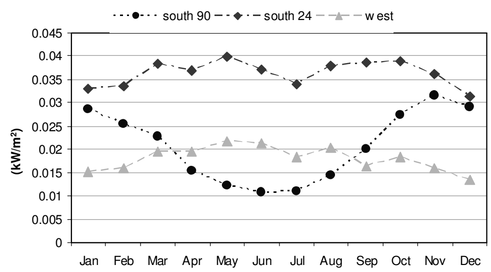

Figure 8 Output of the southern and western PV panels based on the standard test conditions

However, the weather conditions in the UAE are quite different from the standard test conditions (STC). The general characteristics of the UAE's climate resemble those of arid and semi-arid zones. Summer is very dry with temperatures rising to about 48 °C in coastal cities, with accompanying humidity levels reaching as high as 90%. In the southern arid regions such as Al-ain city, temperatures can reach above 50 °C. Figure 9 shows the daily average hourly statistics for dry bulb temperature. It is clear that the average maximum temperature occurs between 11.00 and 4.00 pm where the sun is between the southeast and southwest directions. Figure 10 shows the wind wheel of Al-ain city. It is clear that wind from a north-west direction throughout the year is the characteristic of Al-ain city, as in most cities in the UAE.

In order to predict the actual energy production of photovoltaic (PV) modules, it is necessary to estimate the module temperature as a function of real weather conditions [20]. Energy-10 calculates the energy output considering the cell efficiency during actual operation. In the current case, the system parameters are the same in the four building façades; however, the cell temperatures of the solar arrays vary drastically due to the hourly ambient temperature and availability of wind in the north and northwest directions. Figure 11 shows the efficiencies of PV modules due to south and west orientations with respect to the real weather conditions. As shown, the efficiency of the southern panel falls from 15.2 % to 9.5 and 8.0% during the summer months, while the efficiency of western panel falls to 11.0% and 10.5% during the same period. At noon in the summer months, the southern PV module temperature increases, leading to a drop in the southern PV module efficiency by 5-6%. The ambient temperature in the afternoon and availability of wind in the West and North-west directions lead to a drop in the efficiency by 3-4%. It is important to point out that there is an agreement between these results and findings reported in Ref [21], where the module temperature is decreased by about 1.45°C per m/s wind speed increase.

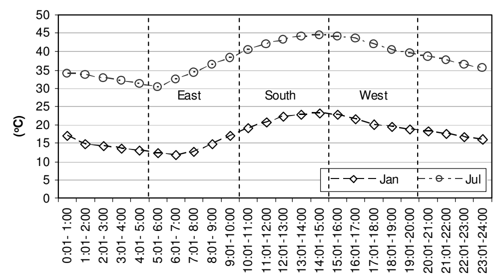

Figure 9 Daily average hourly statistics for dry bulb temperature

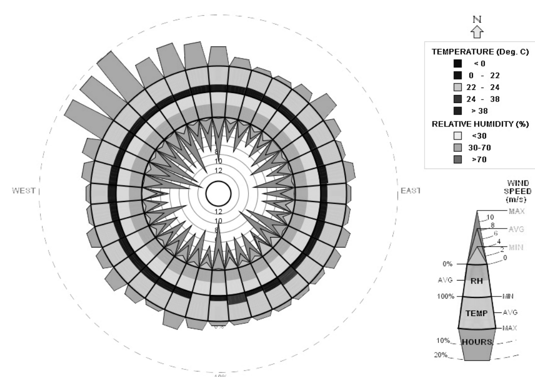

Figure 10 The wind wheel of Al-ain city

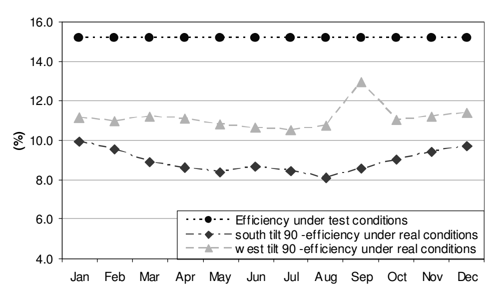

Figure 11 Efficiencies of PV modules due to orientations

As a result, the outputs of the PV modules were found to be less than the estimation based on standard test condition (STC). In addition, the drop in the efficiency of southern panels was found to be higher than that of the western panels. As a result, the output power of the western module was higher than that of the southern one. Figure 12 illustrates the variation of total PV output due to different surface orientations and tilt angles. Although the southern module with a tilt angle of 90° receives more solar radiation than the western module, it produces less power, due to the increase in module temperatures. However, this is not the case with the southern PV module with an optimum tilt angle (24°). The amount of irradiance it received was enough to produce larger output even with the drop in efficiency.

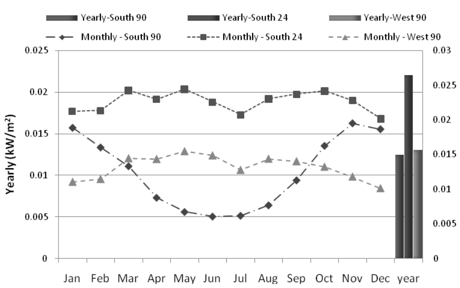

Figure 12 Variation of total PV output due to different surface orientations and tilt angles

On a broader context, the base case building in Abu Dhabi shows that for a humid hot climate the output of the western PV façade is the highest in the three cities, while the building in Al-ain shows the lowest energy output with respect to the southern PV façade. The most likely reason is the high temperature of Al-ain that reaches above 50°C. It is clear therefore that the variation in temperature and relative humidity in the urban environment influences the PV module output. This can be seen in the PV conversion efficiency which is lower in the dry PV system than that of the humid system.

EPBT of BiPV

The EPBT for 1 m^2 PV system in the three examined locations are given in Table 4. The total energy requirement to produce and install 1 m^2 PV of cladding system is 1450 kWh/m^2. The useable panel output in Al-ain, Abu Dhabi and Dubai are 110, 111.6 and 111.7 respectively, giving EPBTs for the western panel of 12.8, 12.4 and 12.8 years. Some of these energy payback times are well short of the likely system lifetime of 30 years. However, after simulating the northern PV façade in the three cities, the EPBTs became 30.5, 29.8 and 30.3 years.

Table 4 EPBT for 1 m2 of PV panel

	PV electricity output (kWh/m^2)	Energy pay-back time
Al-ain		
South	110	13.2
West	113	12.8
East	85	17.1
North	48	30.2
Abu Dhabi		
South	111.6	13
West	116.7	12.4
East	83.8	17.3
North	48.6	29.8
Dubai		
South	111.7	13
West	112.9	12.8
East	81.8	17.7
North	47.9	30.3

Energy required to produce 1 m^2 of PV panel is 1450 kWh

Impact of PV on Operational Energy

The operational energy is the energy used in buildings during their operational phase. As the PV panels have significant influence on the heat transfer through the building envelope due to the change of thermal resistance, it can impact the cooling and heating loads and the general operational energy. Therefore, the focus here is on the impact of PV façades on the cooling load and annual energy consumption. Two different cladding systems are used including the original wall system and ventilated air-gap (12-15 cm) PV façade as shown in Figure 4. The cooling load and total energy consumption were obtained through hourly, monthly and annual simulation for the two examined cladding systems. Figure 13 shows the reduction in annual cooling energy due to applying the PV system. Figure 14 illustrates the saving in cooling energy as a function of PV orientation.

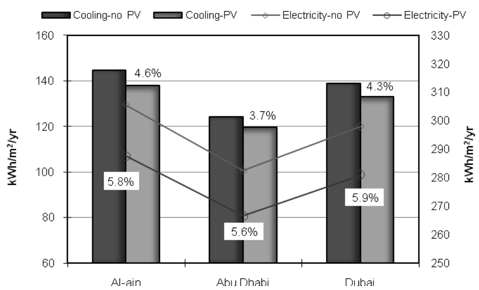

Figure 13 Total cooling energy due to changing the location

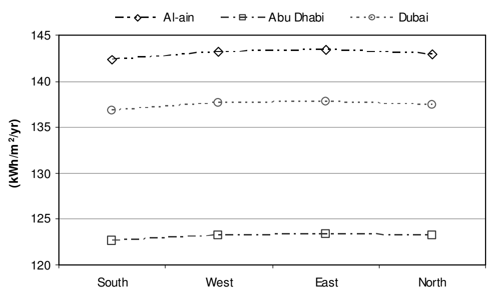

Figure 14 Reduction in cooling load as a function of PV orientation

It can be seen that the southern PV panels are the most effective energy saver in terms of cooling load and that the total heat gain and cooling load of the existing façades are slightly more than those of the PV façades. This is because the PV panels work as a thermal insulation layer. However, it is important to note that the change in cooling loads through different cladding materials depend also on many other factors, such as initial insulation level, finishing solar absorption and local climate. In the PV case, the heat gain is reduced significantly due to PV natural convection of air in the gap. Therefore, decreases of 4.6%, 3.7% and 4.3% have occurred in Al-ain, Abu Dhabi and Dubai respectively. The energy used for fans was also decreased and consequently, the total energy consumption is declined by 5.8%, 5.6% and 5.9%.

Combined Impact of the PV Façades

Table 5 shows the PV outputs and savings in operational energy due to PV panels. It is clear that the reduction in operational energy is within the range of 1.1-2.2% for the northern and southern façades in the three locations. Decreases of 49866, 45522 and 47835 kWh have occurred in Al-ain, Abu Dhabi and Dubai respectively due to the use of 145 m^2 PV panels in the southern façade. An assumption can be made that each square meter of the PV panels saved about 334, 313 and 329 kWh of energy per year in such a building in those cities.

Clearly, savings in operational energy due to the use of PV panel as a wall cladding material are large compared with the system output. It is noted that the ratio between the PV output and saving in energy due to the PV panels is in the range of 1:3–1:4 for the southern and northern façades showing the significance of considering the impact of PV system on the operational energy. It is obvious, therefore, that the consideration of such an impact can reduce the EPBT of the PV. For example, the EPBT for 1 m^2 PV system in the southern façade can be reduced from 13.2 to 3.2 years in Al-ain city, while it can be reduced from 13 to 3.4 years in Abu Dhabi and from 13 to 3.3 years in Dubai. Without considering such an impact, the PV system will not be cost-effective when it is applied to the northern façade. When this impact is accounted, however, the EPBT can be reduced from 30.2, 29.8 and 30.3 years to 5.6, 6.5 and 5.3 years in Al-ain, Abu Dhabi and Dubai respectively. Clearly, considering the interaction between the PV panels and the thermal performance of buildings in addition to the PV output makes significant difference in the estimation of EPBT.

CONCLUSION

To be cost-effective for the UAE office buildings, the EPBT of the PV technology should be short compared with the system lifetime. However, estimating the EPBT by comparing the PV output with the energy input of PV systems without any consideration to savings in operational energy is not sufficient to evaluate such a technology. It was shown that the total energy requirement to produce and install 1 m^2 of PV system on a building façade is 1450 kWh. 110, 111.6 and 111.7 kWh were estimated as the output of 1 m^2 PV system applied to buildings in Al-ain, Abu Dhabi and Dubai respectively, giving an energy payback time for the western panel of 12.8, 12.4 and 12.8 years. This difference is due to the variation in temperature which influences the PV module output. It was noted that the PV conversion efficiency is lower in the dry PV system (Al-ain) than that of the humid system (Abu Dhabi and Dubai). It was also observed that the reduction in operational energy in the aforementioned cities is in the range of 1.1 to 2.2% due to the northern and southern PV panels. This reduction in operational energy is due to the declination in heat gain and consequently the cooling load. The heat gain is reduced significantly due to PV natural convection of air in the gap. Therefore, decreases of 4.6%, 3.7% and 4.3% have occurred in Al-ain, Abu Dhabi and Dubai respectively. The ratio between the PV output and saving in energy was found to be within the range of 1:3–1:4 in the southern and northern façades showing the significance of considering the impact of PV system on the operational energy. Thus, when this impact is taken into consideration, the EPBT can be reduced from 13.2 to 3.2 years in Al-ain city, while it can be reduced from 13 to 3.4 years in Abu Dhabi and from 13 to 3.3 years in Dubai. It is clear therefore, that the consideration of the interaction between the PV panels and the thermal performance of buildings in addition to the PV output makes significant difference in the estimation of the EPBT. Based on the result and conclusion of this study, the following recommendations are made for the existing buildings as well as for similar future offices:

1. When the tilt angle of the surface is 90^o, the western PV façade generates the larger output in spite of the intensive solar radiation in the southern façade. This is simply because of the increase in the PV module temperature and drop in system efficiency at noon in the summer months.
2. The optimal tilt angle for a south facing surface in the UAE is 24^o. This would receive the optimum amount of direct-beam solar radiation over the entire year. Even with the drop in system efficiency a large amount of power can be generated.
3. As the PV panels insulate the wall and stop the heat flow from the outside, they can be used as an alternative of thermal insulation. The new building regulations in the UAE encourage the use of wall thermal insulation. Therefore, to encourage the use of PV technology, a trade-off between the PV panels and thermal insulation can be included in building regulations.

Table 5 PV output and operational energy saved by using the PV system

Electricity generated by PV panels

	Al-ain		Abu Dhabi		Dubai	
	kWh	kWh/m^2	kWh	kWh/m^2	kWh	kWh/m^2
South	15953	110	16181	111.6	16200	111.7
West	9635	113	9922	116.7	9595	112.9
East	7264	85	7122	83.8	6953	81.8
North	6176	48	6320	48.6	6231	47.9
Total	39028	89	39545	89.9	38979	88.6

Saving in operational energy produced by PV panels

	Reduction in total energy consumption		PV area	saving in total energy	Ratio
	(%)	kWh	(m^2)	consumption (kWh/m^2)	Output : Saving
Actual Bldg consumption 226664 kWh (Al-ain)					
South	2.2	49866.1	145	343.9	1 : 3.1
West	1.3	29466.3	85	346.7	1 : 3.1
East	1.1	24933.1	85	293.3	1 : 3.5
North	1.2	27199.7	130	209.2	1 : 4.4
Actual Bldg consumption 2069201* kWh (Abu Dhabi)					
South	2.2	45522.4	145	313.9	1 : 2.8
West	1.3	26899.6	85	316.5	1 : 2.7
East	1	20692.0	85	243.4	1 : 2.9
North	1.1	22761.2	130	175.1	1 : 3.6
Actual Bldg consumption 2174345 * kWh (Dubai)					
South	2.2	47835.6	145	329.9	1 : 30
West	1.3	28266.5	85	332.5	1 : 2.9
East	1	21743.5	85	255.8	1 : 3.1
North	1.2	26092.1	130	200.7	1 : 4.2

References

[1] Abu Dhabi Water & Electricity Company (ADWEC). 2009. See: http://www.adwec.ae/maps_graphs/

[2] Kumar K, Sharma SD, Jain L, 2007. *Stand-alone Photovoltaic (PV) module outdoor testing facility for UAE climate*. CSEM-UAE Innovation Centre LLC. See:http://www2.ksu.edu.tw/ksuME/ISEM/files/3eGBIC07%20%20Presentation/Full%20Lnegth%20paper%20in%20the%20Proceedng/10%20Kapil%20Kumar.pdf

[3] Wilson R, Young A, 1996. *The embodied energy payback period of photovoltaic installations applied to buildings in the U.K*. Building and Environment 31 (4): 299-305.

[4] Blakers A, K Weber K, 2004. *The energy intensity of photovoltaic (PV) systems*. See: http://www.ecotopia.com/opollo2/pvepbtoz.htm.

[5] Nawaz I, Tiwari GN, 2006. *Embodied energy analysis of photovoltaic (PV) system based on macro- and micro-level*. Energy Policy 34 (17): 3144–3152.

[6] Crawford RH, Treloar GJ, Fuller RJ, Bazilian M, 2006.*Life-cycle energy analysis of building integrated photovoltaic systems (BiPVs) with heat recovery unit*. Renewable and Sustainable Energy Reviews 10 (6): 559–575.

[7] Bankier C, Gale S, 2006. *Energy Payback of Roof Mounted Photovoltaic Cells Energy Bulletin*. See also: http://www.energybulletin.net/node/17219.

[8] Yun GY, McEvoy M, Steemers K, 2007. *Design and overall energy performance of a ventilated photovoltaic façade*. Solar Energy 81(3): 383-394.

[9] Wang Y, Tian W, Ren J, Zhu L, Wang Q, 2006. *Influence of a building's integrated-photovoltaics on heating and cooling loads*. Applied Energy 83 (9): 989–1003.

[10] Gan G, 2009. *Effect of air gap on the performance of building-integrated photovoltaics*. Energy 34: 913–921.

[11] Remund J, Lang R, Kunz S. 2003. *Meteonorm V.5.0 Software and Handbook on CD-ROM*. Meteotest, Fabrikstrasse 14, 3012 Bern, Switzerland.

[12] National Renewable Energy Laboratory (NRELE), 2005. *Energy-10 User Manual.* Sustainable Buildings Industry Council, USA.

[13] King DL, Boyson WE, Kratochvil JA. 2004. *Photovoltaic array performance model, Photovoltaic System R&D Department.* Sandia National Laboratories. Available at: http://www.mauisolarsoftware.com/MSESC/The%20Sandia%20Peformance%20Model.pdf

[14] Radhi H, 2010. *On the optimal selection of wall cladding system to reduce direct and indirect CO_2 emissions,* Energy 35:1412-1424.

[15] Hussein HMS, Ahmad GE, El-Ghetany HH. 2004. *Performance evaluation of photovoltaic modules at different tilt angles and orientations.* Energy Conversion and Management 45: 2441–2452.

[16] Minemoto T, Nagae S, H Takakura H, 2007. *Impact of spectral irradiance distribution and temperature on the outdoor performance of amorphous Si photovoltaic modules*. Solar Energy Materials & Solar Cells 91: 919–923

[17] Mondol JD,Yohanis YG, Norton B, 2007. *The impact of array inclination and orientation on the performance of a grid-connected photovoltaic system*. Renewable Energy 32: 118–140

[18]Gong X, M Kulkarni, 2005 . *Design optimization of a large scale rooftop photovoltaic system*. Solar Energy 78 (3): 362–374

[19] Labed S, Lorenzo E, 2004. *The impact of solar radiation variability and data discrepancies on the design of PV systems*. Renewable Energy 29: 1007–1022

[20] Mattei M, Notton G, Cristofari C, Muselli M, Poggi P, 2006. *Calculation of the polycrystalline PV module temperature using a simple method of energy balance*. Technical note. Renewable Energy 31: 553–567

[21] TamizhMani G, Ji L, Tang Y, Petacci L, Osterwald C, 2003. *Photovoltaic module thermal & wind performance - Long -Term Monitoring and Model Development For Energy Rating.* NCPV and Solar Program Review Meeting, NREL/CD-520-33586 Page 936. Available at: http://www.nrel.gov/docs/fy03osti/35645.pdf

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