PV Pre-cooling System for the Engineers Association Branch in Latakia

Rand Ismail[1,*], Doha Jdeed[2], Bilal Zaarour[3]

[1]Master in Building Information Modeling and Management, Syrian Virtual University, Syria
[2]Professor in Department of Automation Industrial, Faculty of Technical Engineering, Tartus University, Tartus, Syria
[3]Textile Industries Mechanical Engineering and Techniques Department, Faculty of Mechanical and Electrical Engineering, Damascus University, Damascus, Syria

Emails: ismail.rand95@gmail.com ; dohajdeed@tartous-univ.edu.sy ; Bilalzaarour121@hotmail.com

Abstract:

This study presents pre-cooling technology using a solar photovoltaic energy system where the increasing in air-conditioning demand during summer results in a rise in the amount of electrical energy consumed from the electric network, as well as an increase in electricity bills. Air conditioners are operated in governmental facilities during official working hours, at the time of the peak demand for electricity, when electric costs are the highest. In order to shift the cooling demand out of the peak period into a lower electric cost period, reducing the energy consumption of the building and the value of the electricity bills, this study was conducted on the technology of pre-cooling using solar photovoltaic energy system. The Engineers Association Branch in Latakia was conducted as a case study. The results showed that applying the Photovoltaic (PV) pre-cooling system led to a significant decrease in the cooling demand during thek hours, and reduces the daily consumption of the electric power from the electric system, as the demand was decreased from 85 kWh to 21,250 kWh. Besides, the value of the electricity bills was decreased by 83%. Pre-cooling lowered the PV system capacity that was needed to operate the building's air conditioning equipment by 50%. A reduction of 42.5 kg of CO2 emissions per day could be achieved using PV-pre-cooling system.

Keywords: Pre-cooling; Renewable energies; Solar photovoltaic plants; Building air conditioning; Sustainability and sustainable development

1. Introduction:

Buildings are responsible for a large part of global energy consumption [1], and therefore they could be considered as the major source of greenhouse gas emissions [2], which in turn play a major role in global warming [3], especially that AEC projects are mainly characterized by change [43]. A large part of this energy is consumed in the residential, governmental and commercial buildings for cooling purposes [4], as air conditioning has become an urgent necessity in order to control air temperatures and internal humidity of the building with glass interfaces especially in Summer [5]. This demand may coincide with the period of peak demand on the electric power, which maximise the bills.

Pre-cooling is to charge the thermal mass of the building out of the peak demand period [6], by reducing the temperature of the thermal mass. This is usually done by decreasing the set point temperature a few hours before the expected peak period [7], that force the air conditioners to turn on

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at this period, and then they turn off at the peak demand period. The indoor temperature rises slowly due to indoor and outdoor heat gains, which creates an opportunity to delay the operation of the air conditioner during peak time, thus reducing the cost of electricity consumption [8]. In addition, pre-cooling can be applied using solar photovoltaic energy systems, by absorbing solar energy and operating air conditioners to pre-cool the building which results in less demand for cooling during peak hours.

Several studies have been conducted to show the results of pre-cooling. In Australia, pre-cooling has been implemented in a large office building. This kept the temperature remaining between the lower and upper thermal comfort limits during the 24-hour of the day. Results over several days showed that pre-cooling can lead to up to 35% reduction in peak power, 28% in power consumption and 34% in energy bills [9]. The results in [10] showed a cost saving ratio up 30%. It has been shown that precooling may not be profitable with a long peak period.

A study was conducted in Hong Kong to pre-cool a residential building using a solar photovoltaic system. The results showed that the demand of cooling during the evening was almost equal to zero, and was significantly reduced in the early morning, while the demand was about 5 kWh per day without the PV system, compared to 19 kWh without pre-cooling [11]. The effect of pre-cooling using PV solar system on saving the electricity bills was investigated in Phoenix by comparing different types of buildings. Pre-cooling performance in Block buildings was better compared to wood-frame buildings, with savings up 61$ and 21$ in bills per year, respectively. In addition, it was found that the PV pre-cooling could provide thermal comfort during the day [12].

Since Syria has a very good solar radiation rang, and the global solar maps show that the number of solar hours in Syria is 5 hours, Figure (1), [13], so the photovoltaic solar plants are economically feasible in it.

Recently, due to the increasing complexity of construction projects [14], the adoption of Building Information Modeling (BIM) has increased [15] [16], where it is recommended that governments establish policies to mandate the use of BIM [44]. Thus, BIM has become a daily basis in construction projects [17] to make them more efficient [18], and to overcome more than 70% of the Architecture engineering construction (AEC) problems [19]. Also, BIM helps in conducting building life cycle assessment [20] but it is still being adopted less than expected [21], and almost never in developing countries [22], because there is not enough experience, standardization, and protocols [23], in addition to the lack of desire for change [24]. Thus, a methodology of several steps must be applied to implement BIM. These steps are to increase the knowledge of BIM and its benefits, the willingness of AEC and organizations, identify and remove obstacles besides identify factors affecting implementation [25], in addition to improve the performance of BIM by using the BIM maturity matrix in companies [26]. In Syria, the transition from CAD to BIM has begun, and this must be encouraged by the government and experts [27]. Also, engineers must be qualified by the Syrian educational institutions [28] in order to be able to analyze the situation of current projects depending on BIM [29], and to solve the problems [30,31]. BIM can be applied in several fields [32], even in the study of nanofibers [33]. Moreover, it can be helpful in sustainable design as it helps in reducing energy needs in buildings and analyzing renewable energy options by energy modeling [34]. BIM energy analysis tools help predict a building's energy performance and thermal comfort for building occupants [35]. These tools save time and money as well as achieve more energy efficient buildings [36]. Therefore, awareness about BIM and its tools should be spread is Syria to be used in the future projects in designing photovoltaic energy systems in buildings.

In this paper, a PV pre-cooling of the Engineers Syndicate branch building in Latakia was studied. This building was chosen because it is an administrative building, and has a high-capacity cooling system, which reverses on the electric bills increasing. In order to reduce the power assumed from the electric system, we proposed a PV pre-cooling system for the building. BIM tools were not used in this study due to the unavailability of the building's 3D scheme.

2. The cooling system in the building:

The power is consumed in studied building during the day from 08:00am to 03:00pm, and operating of air conditioners lasts for four hours a day in summer. The conditioning system consists of 20 conditioners with different capacities as showed in Table (1).

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Table 1: The conditioning system.

Air conditioner	Capacity (watt)	count	capacity	Operating h/day	The capacity consumed per day (Wh)
1 ton	1000	4	4000	4	16000
2 ton	1750	2	3500	4	14000
0.5 ton	500	2	1000	4	4000
1 ton	1000	11	11000	4	44000
2 ton	1750	1	1750	4	7000

3. Pre-cooling technology:

The sunrise in Syria in summer is estimated at approximately 5:45am, while it sets at 19:43pm, so the duration of the daylight in the summer lasts for 14 hours, and the temperature begins to rise at about 10:00am.

The pre-cooling technology means to set the set point temperature of the cooling system at a lower value, usually lower than the normal used set point by 2 to 4 degrees. In another word, if you set the set point of the cooling system on 24˚C, then you could set it on 22˚C in pre-cooling technology. In the case of pre-cooling at peak time using PV system, by setting the air conditioners at a temperature of 22˚ at 09:00 am for two hours, where the electrical power generated by the PV system is sufficient for cooling the air inside door, in order to maintain the temperature at 22˚C all over the next two hours. Later, the temperature will start rising at a moderate rate, as it will remain within the limits of thermal comfort during the working hours.

4. The PV pre-cooling system:

Applying the PV pre-cooling technology may be considered one of the most economic solutions of this case of study. PV pre-cooling system means to use the PV system in order to produce the needed power for pre-cooling system.

We will calculate the needed PV system capacity to achieve pre-cooling.

- **PV panels capacity:**

The capacity of photovoltaic panels is calculated according to the equation (1) as follow [37], taking in consideration that the number of solar hours in Syria is 5 hours (fig 1) [13].

$$P = \frac{E}{PSH} \qquad (1)$$

Where:

P: Total panel capacity

PSH: The number of useful radiation hours per day

Total electrical energy (E) required per day to operate air conditioners for 2 hours is:

$$E = \text{total capacity} \times \text{Operating hours per day}$$

From table (1): Total power for ACs = 21250 w

$$E = 21250 \times 2 = 42500 \text{ Wh}$$

We take a safety factor of 1.25:

$$E = 42500 \times 1.25 = 53125 \text{ Wh}$$

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$$P = \frac{53125}{5} = 10625 \approx 11000 \text{ W} \approx 11 \text{ KW}$$

Thus, the required capacity is 11000 W.

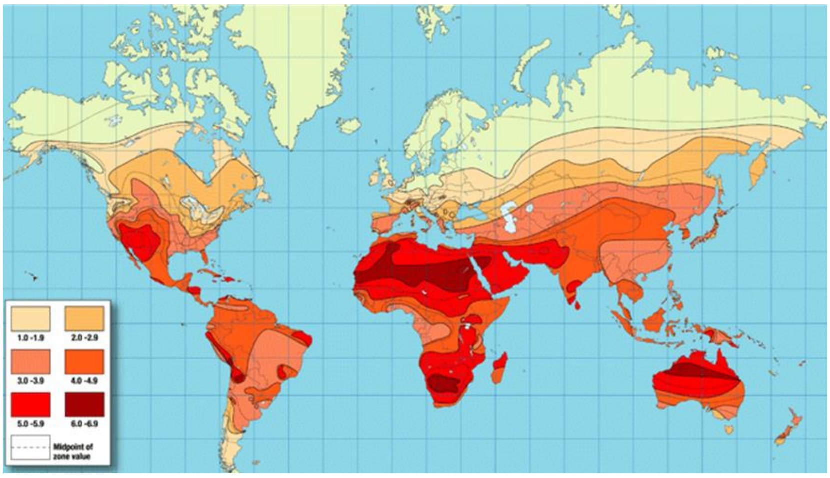

Figure 1: The number of solar hours according to the Global Solar Atlas

- **Inverter capacity:**

The capacity of the inverter must be greater than the required load by (20-30)% [37] [38], and could be calculated as in equation (2).

$$VA_{inv} = \text{Total power for ACs} \times \text{FC} \qquad (2)$$

Where:

VA_{inv}: Inverter power

CF: Safety factor

From table (1): Total power for ACs = 21250 w = 21.250 KW

$$VA_{inv} = 21250 \times 1.25 \approx 26563 \text{ W}$$

- **Battery capacity:**

The capacity of the batteries is expressed in Ampere-hour (Ah). Various factors are taken into consideration while choosing the size of the batteries or battery bank, including the total load, discharge depth, and the battery nominal voltage.

Total capacity of battery according to the equation (3) is as follow [39]:

$$Ah_{(bank)} = \frac{E}{V_b \times DOD} \qquad (3)$$

Where:

$Ah_{(bank)}$: The total capacity of the battery system.

DOD: Depth of Discharge.

$$Ah_{(bank)} = \frac{53125}{48 \times 0.80} = 1384 \text{ Ah}$$

The 48 volt system was chosen because of the high value of the load [40]. The number of the required batteries is calculated using equation (4) [39], considering the capacity of the single battery is 200 A:

$$\boldsymbol{N}_{(\boldsymbol{batteries})} = \frac{Ah_{(bank)}}{Ah_{(battery)}} = \frac{1384}{200} = 6.92 = 7 \text{ batteries} \qquad (4)$$

Where:

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$N_{(batteries)}$ Batteries number

$Ah_{(battery)}$ The capacity of single battery

The cost of the electric kilowatt-hour in the afternoon period is equal to 0.0008$, according to the Electricity Investment Regulation in Syria, Annex 5 [41]. So, if there is any need to turn on the conditioning system at this period, for example from 02:00pm to 03:00pm, then the consumption value for conditioning per day (C_d) will be:

$$C_d = 0.0008 \times 21.250 = 0.017 \ \$$$

The consumption value for conditioning per month (C_m) will be:

$$C_m = 0.0008 \times 21.250 \times 30 = 0.51 \ \$$$

5. Results and discussion:

The required capacity of cooling system in summer could be calculated from table (1) as:

Since Total power for the conditioning system ACs:

$$ACs = 21250 \text{ w} = 21.250 \text{ KW}$$

Then the total required energy (E) will be:

$$E = 85000 \text{ Wh}$$

In the previous calculation, it was found that it required a 21.250kW to operate the cooling system at the peak period of the electric demand, which imposes additional fines. The cost of 1kWh of electricity at the peak period is (0.0012 $) [41], therefore, the Consumption value for conditioning per day is:

$$C_d = 0.0012 \times 85 = 0.102 \ \$$$

While, the consumption value for conditioning per month is:

$$C_m = 0.0012 \times 85 \times 30 = 3.06 \ \$$$

The results show that the value of daily consumption when conditioning system draws energy from the power system is 85 kWh. After applying pre-cooling, the value of daily consumption became 21,250 kWh, and the monthly electricity bills became 83% less than the monthly electricity bills without applying PV pre-cooling system.

The PV system capacity required to operate the cooling system before pre-cooling for 4 hours per day is calculated as follow:

Because of the losses resulting from the components of the PV system, the losses must be added to the total required energy per day, so we take a safety factor of 1.25 [37]:

$$E = 85000 \times 1.25 = 106250 \text{ Wh} = 106.250 \text{ kWh}$$

According to equation (1) [37], the required PV panels capacity is as follow, taking in consideration that the number of solar hours in Syria is 5 hours, fig (1) [13]:

$$P = \frac{106250}{5} = 21250 \approx 22000 \text{ Watt} \approx 22 \text{ KW}$$

Thus, the required capacity is 22000 Watt.

The inverter capacity according the equation (2) [37, 38] is:

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$$VA_{inv} = 21250 \times 1.25 \approx 26563 \text{ W}$$

Then according to the equation (3) [39], the battery capacity is:

$$Ah_{(bank)} = \frac{106250}{48 \times 0.80} = 2767 \text{ Ah}$$

The 48 volt system was chosen because the electrical load is high [40].

Considering the capacity of the single battery is 200 A, the number of butteries according to the equation (4) [39] is:

$$N_{(batteries)} = \frac{2767}{200} = 13.8 \approx 14 \text{ batteries}$$

The number of batteries is 14 batteries, each battery has a capacity of 48 V and 200 A.

Comparing the required PV system capacity before and after pre-cooling, calculations show that after pre-cooling using PV system, the demand for cooling reduced significantly during working hours, and the capacity of the required PV system decreased by 50%.

Applying PV pre-cooling system reduces the carbon dioxide emissions, as [42]:

$$\text{The amount of reduction in CO2 emissions} = 42.500 \times 1 = 42.5 \text{ kg}$$

The results show that a reduction of 42.5 kg of CO2 emissions can be achieved per day with PV pre-cooling system.

6. conclusions:

This work was conducted to investigate the changes that occurred when applying PV pre-cooling system at the Engineers Syndicate Branch building in Latakia, Syria. The results are encouraging to apply pre-cooling by using solar energy system due to the reduction in the electrical energy demand from the power system, in addition to the reduction in electricity bills. Besides, there was a reduction in the capacity of the PV system that was required for cooling. Moreover, the application of the PV system led to a reduction in carbon dioxide emissions released in the atmosphere.

Further research is needed to study the replacement of existing air conditioners in the building with solar hybrid air conditioners that consume less electrical energy, and conducting a study to improve the thermal insulation of the building as well is recommend.

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