# SOLAR PV-DRIVEN AIR CONDITIONER

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## ABSTRACT

A solar air conditioner driven by PV panels was developed. An air conditioner using ac power source with 200W rated input power was driven directly by 430Wp solar PV module. In order to maintain a stable cooling, a 12Ah/24V buffer battery was used. An inverter is used to convert PV power into ac current to drive the air conditioner. The present study focuses on the runtime and operational probability of solar air conditioning under different weather conditions. It was found that the operation probability OPB of the solar air conditioner is 100% at solar irradiation > 550W/m$^2$ and around 80% at solar irradiation 400W/m$^2$ at cloudy condition. The runtime fraction *RF* (actual running time/demand time) is 0.6-0.8 in clear days. The dynamic effect of thermal mass of the air conditioner improves the cooling performance.

Keywords: solar air conditioning; solar cooling

## 1. Introduction

It is known that the cooling load of a building and the energy consumption of air conditioner are in phase with solar radiation intensity. Air conditioner powered by solar PV is quite a promising solution to reduce the energy supply from grid during peak hours.

The design of the air conditioner directly driven by solar PV is basically a stand-alone solar system, but without or with a small energy storage. The compressor requires a steady power input for smooth operation. But solar radiation is not stable. Thus, two problems are encountered: (1)the sudden current surge at the startup of compressor could interrupt the system operation; and (2)the loss of load power and cooling capacity during cloudy periods may be high. The present study intends to design a solar PV driven air conditioner and carry out a field test to investigate the operation probability and daily runtime fraction of solar cooling at different solar radiation intensity.

## 2. Design of Solar PV-Driven Air Conditioner

A small air conditioner using AC power source with 200W rated input power and 500W cooling capacity was designed and built for the experiment. Two solar PV modules (215Wp/1.57 m$^2$, 15.28% peak efficiency) were connected in series to build a 430Wp/24V solar PV system. This will give about 300W instantaneous power generation at clear weather (>700 W/m$^2$) which will be enough to drive the compressor. A 600W inverter with conversion efficiency 0.85 was used to convert the dc PV power into ac power to directly drive the air conditioner.

In order to maintain a smooth running of compressor during variable radiation, buffer storage (12Ah/24V lead-acid battery) was used with a solar charge control (Huang *et al*, 2010). See Fig.1. The battery can supply about 20 minute’s energy (67Wh at about 23% battery DOD) to the air conditioner when solar energy is not available.

In order to overcome the problem of compressor startup with sudden surge current, a capacitor was installed in parallel with the battery. A super-capacitor with 6.67F which is enough for 45A/0.12s surge current of compressor was used. The delay time for compressor restart is set at 2 minutes by a delay timer to make sure that the restart works well.

The present system did not use MPPT (maximum-power-point tracking control) for optimal power output tracking of PV module. The PV system design is based on nMPPO (near maximum-power-point operation)

(Huang *et al*, 2006) which match the performance of solar PV modules with the battery voltage range. This avoids the energy loss of MPPT and reduces the cost as well as keeps higher reliability. The air conditioner is used to supply cooling to a small room (3m wide, 6m long, 3.5m tall). The present study focuses on the operation probability and runtime fraction of solar cooling at different solar radiation intensity.

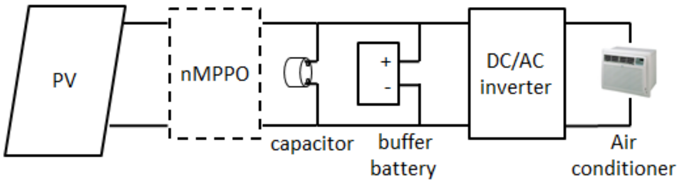


**Fig.1: Solar PV-driven air conditioner.**

## 3. Test Result

The operation probability (*OPB*) of solar air conditioner in a day is defined to evaluate the system performance. *OPB* is defined in eq.(1) as the ratio of the total running time of the air conditioner to the total occurrence time of solar radiation, at specific intensity $I_T \pm \Delta I_T$ where $\Delta I_T$ is the radiation increment chosen as 50W/m$^2$. *OPB* is used to evaluate the instantaneous running probability at a given solar irradiation.

$$OPB = \frac{\sum_j \Delta t_{on,j}}{\Delta t_{I_T}} \quad \text{(eq.1)}$$

Another performance index called "runtime fraction" (*RF*) is defined as the total running time $t_{ON}$ of the air conditioner to the total service time $t_{total}$ , eq.(2).

$$RF = \frac{t_{ON}}{t_{total}} \quad \text{(eq.2)}$$

*RF* is used to evaluate the daily performance of solar air conditioner. The results in Fig.2 show that *OPB* of the solar air conditioner is 100% at solar irradiation > 550W/m$^2$ and around 80% at solar irradiation 450W/m$^2$ which is under cloudy condition. Fig 3 and Tab. 1 show the variation of daily runtime fraction *RF* (based on total cooling load time $t_{total}$ = *8 h*). *RF* is around 0.65 at partly cloudy weather ($H_T$ =15-18 MJ/m$^2$day) and >0.8 at sunny weather ($H_T$ >19 MJ/m$^2$day). The performance can be improved using more advanced control technology.

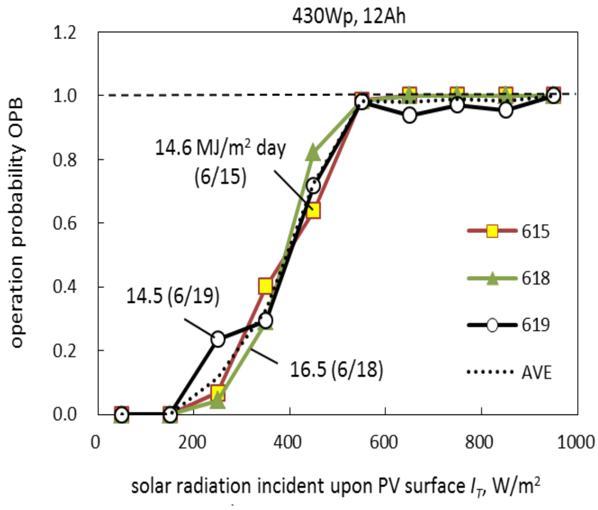


**Fig.2: Test results of operational probability.**

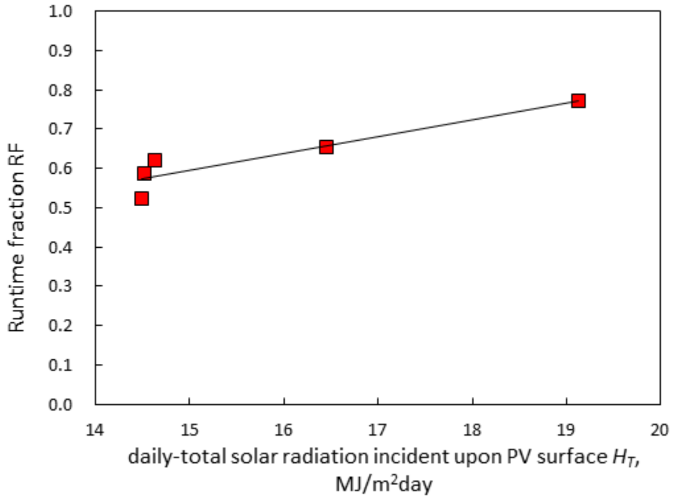


**Fig.3: Runtime fraction.**

**Tab. 1: Test results.**

| Date (2011) | Daily-total solar irradiation $H_T$, MJ/m$^2$day | PV energy generation, MJ/day | Efficiency of PV | Total energy consumption, MJ/day | *RF* (%) |
|---|---|---|---|---|---|
| 6/14 | 14.4 | 4.35 | 0.115 | 3.55 | 52.4 |
| 6/15 | 14.6 | 4.63 | 0.121 | 4.25 | 62.2 |
| 6/18 | 16.4 | 4.97 | 0.115 | 4.56 | 65.4 |
| 6/19 | 14.5 | 4.42 | 0.116 | 4.05 | 58.9 |
| 6/20 | 19.1 | 5.65 | 0.113 | 5.46 | 77.3 |

Solar cooling is not available during low radiation periods. This can be realized when the temperature of cold air from the air conditioner is the same as the room temperature. Fig 4 shows the instantaneous performance of the air conditioner at variable solar radiation. It is seen from Fig 4 that this occurs 6 times in daytime at periods 8:30-10:40 and 12:10-15:40, with rapid-changing solar radiation. Among them, four times happen for less than one minute. That is, the time duration of loss of PV power supply is longer than the cooling supply. This is due to the thermal effect of the air conditioner. The mass of air conditioner stores some cold energy to release at durations of PV power loss. The loss of cooling power continues about 37 minutes from 15:57 to 16:34 at continuous cloudy condition. This indicates that dynamic effect of thermal mass of the air conditioner could stabilize in part the cooling performance even at very low solar radiation.

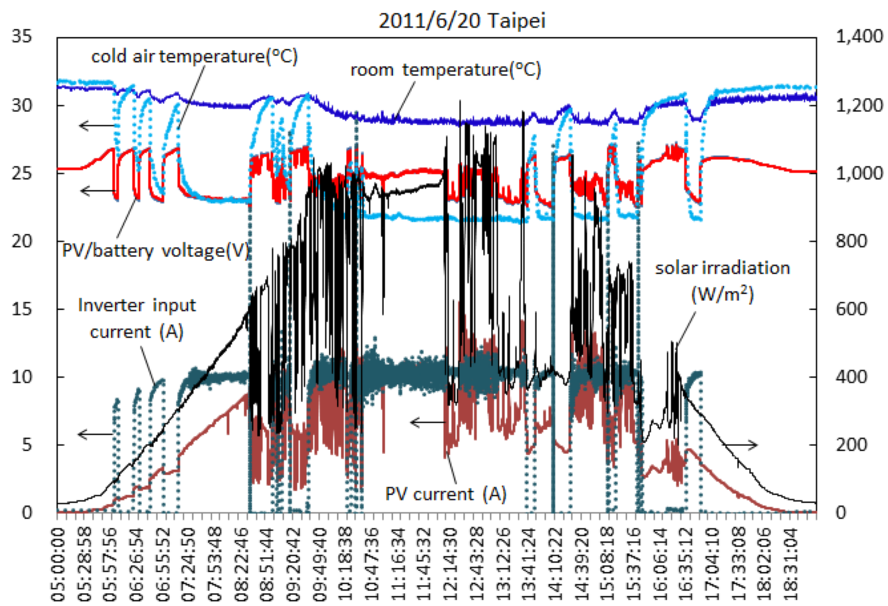


**Fig.4 . Instantaneous performance of solar air conditioner.**

OPB and RF of PV-driven air conditioning is related to the system design. We define two parameters, $r_{bp}$ and $r_{pL}$, to reflect the relationship between PV power generation, load power, and battery storage.

$$r_{bp} = \frac{DOD \times E_{bat}}{W_{pv}} \qquad \text{(eq.3)}$$

and

$$r_{pL} = \frac{W_{pv}}{W_L} \qquad \text{(eq.4)}$$

where $E_{bat}$ is the rated capacity of battery (Wh); *DOD* is the depth of discharge of battery, $W_{pv}$ is the rated PV maximum power generation, $W_L$ is the average load power (W). $r_{bp}$ can be interpreted as the time (h) to fully charge the battery at maximum PV power generation. The PV system with a higher $r_{bp}$ means that it needs a longer time to charge the battery, due to a smaller PV panel installed or a large battery used.

$r_{pL}$ is the ratio of maximum PV power generation to load power. The PV system with higher $r_{pL}$ (>1.0) means that the PV power generation is higher than the load power and RF and OPB may be higher.

For the present PV-driven air conditioning system using lead-aci battery with DOD 50%, $r_{bp}$= 0.33 h, and $r_{pL}$=2.15.

To investigate the effect of system design on OPB and RF, we installed another PV-driven air conditioning system with the following design:

- Solar PV panel installed: 1.38 kWp
- Li-battery capacity: 720 Wh (DOD 80%)
- Power consumption of air conditioner: 200~800W (average 500W)
- Cooling capacity of air conditioner: 2.2 kW

For the new 1.38 kWp PV-driven air conditioning system using Li-battery with DOD 80%, $r_{bp}$= 0.42 h, and $r_{pL}$=2.76. The test result of Fig.5 shows that OPB reaches 100% at solar irradiation > 500 W/m$^2$ in clear day, close to the previous case. The runtime fraction *RF* (actual running time/demand time) is 0.6-0.9 in clear days as shown in Fig.6, very close to the previous case.

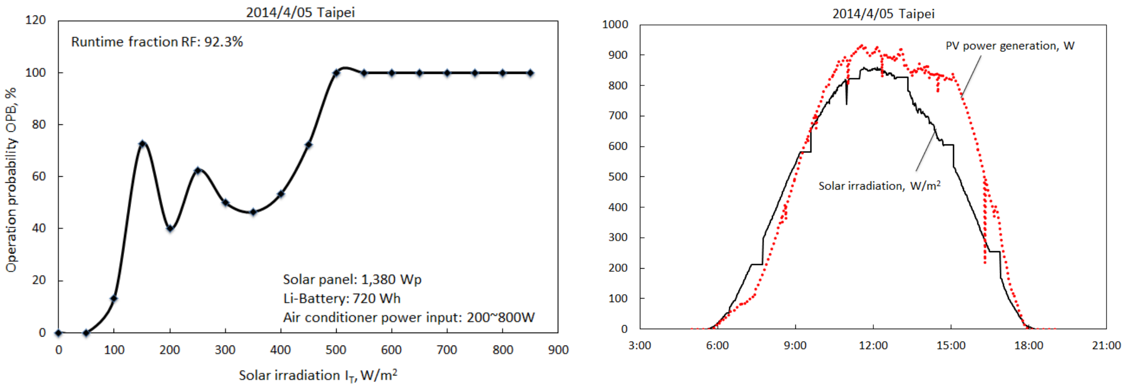


**Fig.5. Operation probability of 1.38 kWp solar air conditioner.**

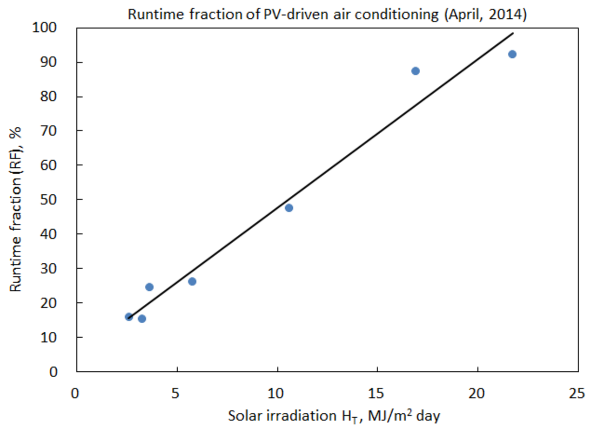


**Fig.6. Runtime fraction of 1.38 kWp solar air conditioner.**

The runtime fraction *RF* is proportional to solar irradiation as shown in Fig.6. *RF* is also related to the controller design. The 1.38 kWp solar air conditioning system uses a microprocessor to control the time to return to solar power supply during low solar radiation as shown in Fig.7 (Huang *et al*, 2014).

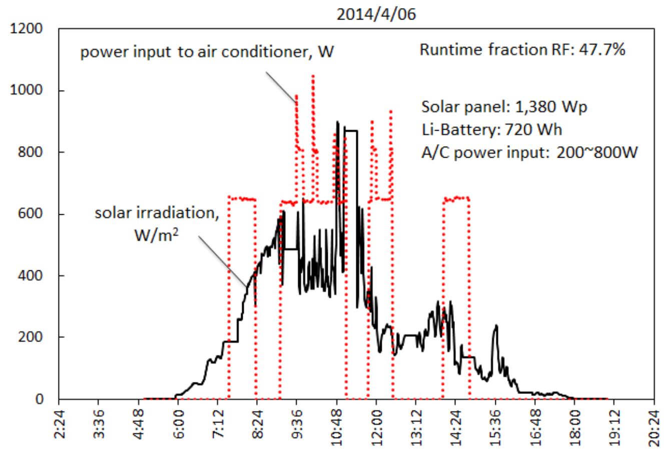


**Fig.7. Power input of air conditioner.**

## 4. Conclusion

The present study intends to develop a stand-alone solar air conditioner. The research focuses on the operation probability and runtime fraction of solar cooling from a field test. An outdoor test is carried out to measure the operation probability (*OPB*) and the runtime fraction (*RF*) at various weather conditions. It is experimentally shown that the operation probability of the solar air conditioner is 100% at solar irradiation >550W/m$^2$ (full solar cooling) and around 80% at solar irradiation 400W/m$^2$ (partly solar cooling) which is at cloudy condition. The total runtime fraction (actual/demand) is 0.6-0.8 in clear days. It is also found that the dynamic effect of thermal mass of the air conditioner could stabilize the cooling performance even at very low solar radiation.

## 5. References


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