Demonstration of An Office Powered By Solar PV System

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Abstract

The purpose of the present study is to demonstrate the concept of peak-suppression by energy saving and replacement of peak load by solar PV energy supply to replace nuclear power. An office with 150m^2 floor area and 14 employees was chosen as the demonstration site. The results show that retrofit for energy-saving reduces 65% energy and the solar PV system supplies 20%. The total energy reduction is 85%. The total investment of the solar PV system and the retrofit of energy-saving devices is around USD30,000. The net total energy saving in 20 years is USD 80,000, including M&O cost. The system has been run about one year. The measured average total power consumption of the office is reduced from 10.2 kW to 3.6 kW (after retrofit) in which solar PV supplies about half.

Keywords: solar PV energy, distributed solar system, solar energy office

1. Introduction

Grid power demand during peak load is caused mainly by energy consumption of air conditioning systems. Solar PV system is the best solution for peak-shaving. In addition, the utilization of solar PV power system should be for self-consumption, rather than feeding back to grid and causing transmission problem when solar PV is widely adopted. That is, solar PV distributed system will be one of the future major energy supplies in the world.

Since Taiwan is located in subtropical area, there is a peak load around 13:00 during summer around 34GW. From a long-term study, the power consumption of air conditoning contributes about 9 GW. Energy saving of air conditioning systems is thus most important.

Taiwan Government has set up a energy-efficiency classification for all air conditioners since 2010. Five categories are defined according to the energy efficiency ratio (EER) (W/W) and cooling capacity. See Table 1. However, EER of majority of air conditioners in the market or ever installed is below 3.5 (Category 3~5) . In 2010, 70% of air conditoners belongs to Category 5. Large potential of energy saving is feasible since the EER of the most advanced air conditioner in the market is higher than 5.6.

Table 1: Category of air conditioners

Type	Cooling capacity, kW	EER (W/W)				
Category		1	2	3	4	5
Integral-type	<2.2 2.2~4.0 4.0~7.1 7.1~10	>3.4	3.25~3.4	3.1~3.25	2.95~3.1	< 2.95
Split-type	<4.0	>4.17	3.93~4.17	3.69~3.93	3.45~3.69	<3.45
	4.0~7.1	>3.87	3.65~3.87	3.42~3.65	3.2~3.42	<3.20
	>7.1	>3.81	3.59~3.81	3.37~3.59	3.15~3.37	<3.15

Besides, lighting consumes about 10~15% energy in Taiwan. It is known that LED (light-emitting-diode) can save more than 50% lighting energy. Thus, lighting energy saving using LED is also feasible.
The cost of solar PV energy is reduced dramatically recently to bring the grid-parity age to come. Energy from solar PV is equal or cheaper than from the grid. High-efficiency air conditioning, LED lighting, and low-cost solar PV are all technically mature and available in the market for energy saving.

doi:10.18086/swc.2015.08.12 Available at http://proceedings.ises.org

The purpose of the present study is to demonstrate the concept of peak-suppression by energy saving first and then replacement of peak load by solar PV energy supply. This may be able to completely abandon nuclear power in Taiwan, as shown in Fig.1. An office in a 7-floor building located in Taipei with 150m^2 floor area and 14 employees was chosen as the demonstration site.

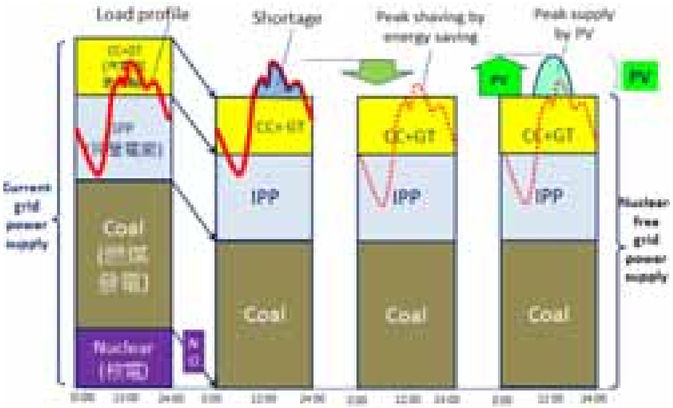

Fig. 1: The concept of nuclear power abandon by energy saving and using solar PV energy.

2. Retrofit of energy equipment and solar PV supply

2.1. Retrofit for energy saving

1. Energy consumption before energy-saving retrofit

The office of the Department of Mechanical Engineering, National Taiwan University, with 150m^2 floor area and occupied by 15 employees, was chosen as the demonstration site (D-1). The major energy consumption of the office comes from air conditoning, lighting, and PC. The power and daily energy consumption of air conditioners, lighting, and laptop PC was calculated and listed in Table 2. It is seen that the total power consumption for air conditioners, lighting, and PC reaches 10.16 kW and the daily total energy consumption reaches 81.3 kWh. 64% energy is consumed by air conditioners.

Table 2: Energy consumption before retrofit.

Daily consumption @8 h/day	Power input, kW	Daily energy, kWh/day
(1)Air conditioning		
Room 1: One split-type MW3299 BFR: cooling 7.3kW, COP 2.92	2.5	20
One window-type : cooling 5.8 kW, COP 2.9	2	16
Room 2: One window-type MW550BR: cooling 5.8kW, COP 2.9.	2	16
Energy consumption	6.5	52
(2)Lighting		
Room 1: Recessed fluorescent (47W)26 sets	1.222	9.8
Room 2: Recessed fluorescent (47W) 4 sets	0.188	1.5
Energy consumption	1.41	11.3
(3) PC		
Room 1: 13 laptop PC, 150W each	1.95	15.6
Room 2: 2 laptop PC, 150W each	0.3	2.4
Energy consumption	2.25	18
Total energy consumption (air conditioners, lighting, PC)	10.16	81.3

2. Energy-saving retrofit and energy consumption

To reduce energy consumption, four retrofitting was carried out: (1)air conditioning system is renewed with high-efficiency split-type air conditioner (Hitachi RAC-22NB) with COP 5.6; (2)lighting is retrofitted with LED luminaire with 100 Lm/W; (3)all lap-top computers are changed into notebook PC; (4)the window glass is covered with low-E film to block IR part of solar radiation penetrating into the office. The above four retrofits results in 65% energy saving as shown in Table 3, at average power 3.6 kW (from 10.2 kW) and daily energy consumption 28.6 kWh/day (from 81.3 kWh/day).

Table 3: Energy consumption before retrofit.

Before energy-saving retrofit			After energy-saving retrofit			Energy saving
Old equipment	Power input, kW	Daily energy, kWh/day	New equipment	Power input, kW	Daily energy, kWh/day	
(1)Air conditioner						
Room 1: One split-type MW3299 BFR: cooling 7.3kW, COP 2.92	2.5	20	Five Hitachi split-type RAC 22NB: cooling 2.2kW, COP 5.6	2	16	20%
One window-type : cooling 5.8 kW, COP 2.9	2	16				
Room 2: One window-type MW550BR: cooling 5.8kW, COP 2.9	2	16	One Hitachi split-type RAC22NB: cooling 2.2kW, COP 5.6	0.4	3.2	80%
Energy consumption	**6.5**	**52**		**4.4**	**19.2**	**63%**
(2)Lighting						
Room 1: Recessed T8 fluorescent (47W)26 sets	1.222	9.8	Recessed T8 LED (30W): 20 sets	0.6	4.8	51%
Room 2: Recessed T8 fluorescent (47W) 4 sets	0.188	1.5	Recessed T8 LED (30W): 4 sets	0.12	0.96	36%
Energy consumption	**1.41**	**11.3**		**0.72**	**5.76**	**49%**
(3)PC						
Room 1: 13 laptop PC, 150W each	1.95	15.6	13 NB, 30W each	0.39	3.12	80%
Room 2: 2 laptop PC, 150W each	0.3	2.4	2 NB, 30W each	0.06	0.48	80%
Energy consumption	**2.25**	**18**		**0.45**	**3.6**	**80%**
Total energy consumption (air conditioners, lighting, PC)	**10.16**	**81.3**		**3.57**	**28.6**	**65%**

Based on running time 8 h/day

2.2. *Solar PV system design*

A 6 kWp hybrid solar PV system is installed to replace another 20% energy. That is, 85% energy consumption is reduced in total.

The solar PV system is an isolated-type hybrid solar PV system (HyPV) which operates in Stand-alone PV Mode or Grid Mode, automatically. Fig.2 No solar PV energy is fed back to grid. When solar power generation and battery storage is sufficient, it operates in Stand-alone PV Mode and the load is powered completely by solar energy. When solar power generation and battery storage is not sufficient, it will switch to Grid Mode and the load is supplied completely by grid. The intelligent controller (MCU) performs optimal switching control between Stand-alone PV Mode and Grid Mode to reduce cycling of battery and ATS. The microprocessor-based MCU also carries out solar charging and system protection control, etc.

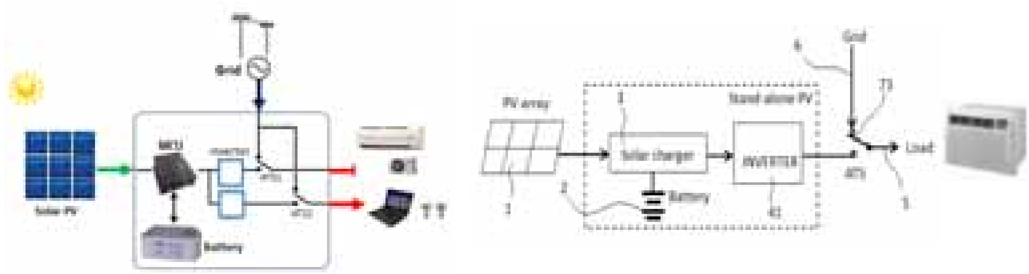

Fig. 2: Hybrid solar PV system (HyPV)

The HyPV utilizes nMPPO (near maximum-power-point operation) system design (Huang *et al*, 2006) to eliminate the conventional MPPT (maximum-power-point tracking control) but still keep optimal performance. This reduces MPPT energy loss and hardware cost and increases the reliability. The HyPV also utilizes direct PV charging control technique for battery to avoid energy loss and malfunction of conventional charger. This reduces cost and increases reliability. Fig.3 shows the installation of HyPV on roof-top for energy supply of the office.

Fig. 3: Hybrid solar PV system for office energy supply.

The design of 5.88 kWp solar PV system is shown in Table 4. To increase power generation, 1A-3P (one-axis 3-position) sun tracker is used to mount PV panels. The energy generation will be increased by 25% in Taipei (Huang *et al,* 2007). The solar PV system is divided into two 2.94 kWp subsystems. No.1 supplies 4 air conditioners (220VAC). No.2 supplies power to drive 2 air conditioners (220VAC) and LED lighting and PC's (110VAC) (Fig. 3). The installation is as shown in Fig. 4.

Table 4: PV system design.

Solar PV system:	
(1)energy generation capability, kWh/kWp-yr	900
(2)PV installed capacity, kWp	5.88
(3)system loss	10%
(4)power enhancement by 1A-3P	1.25
(5)average daily generation, kWh/day	16.31
(6)highest daily generation, kWh/day	24.47
(7)lowest daily generation, kWh/day	2.35
(8)max load, kWh/day	28.6
Battery storage:	
(1) Li-battery capacity, kWh	2.88
(2) running time at full load, hr	0.8
(3) running time for A/C, hr	1.2
(4) running time for lighting, hr	4.0

Fig 4: Chassis of HyPV for MCU, inverter and battery etc.

3. Test results

The installation of HyPV system including measuring system was completed in July 2014. The performance was monitored continuously from August, 2014. Fig. 5 shows the 5-month operation for No.1 unit which is used to supply 4 air conditioners. According to statistical data from the government monitoring network around Taiwan, the daily PV energy generation per unit PV installation is 2.47 kWh/kWp per day (900 kWh/kWp-yr). Fig. 6 shows that the 5-month performance of No.1 obtains 2.17 kWh/kWp per day in average which is 12% lower than the statistical data. This is due to low load energy consumption in fall season while air conditioner is not frequently used.

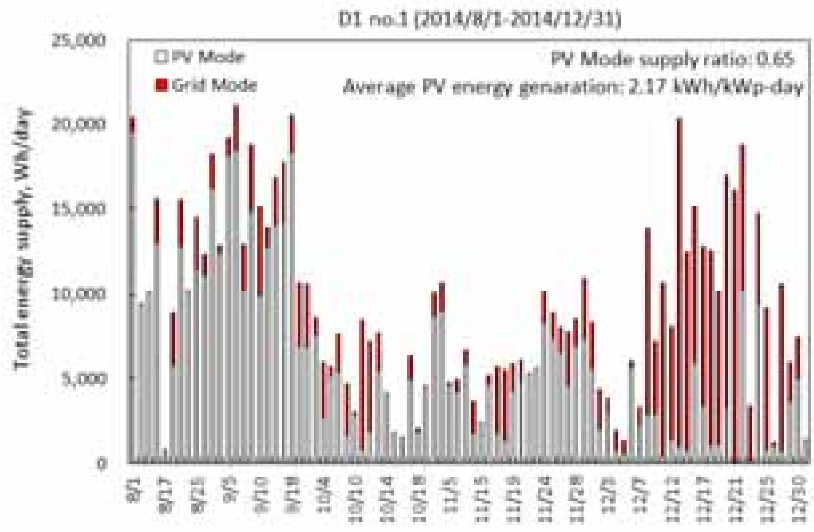

Fig 5: Long-term performance in No.1 unit.

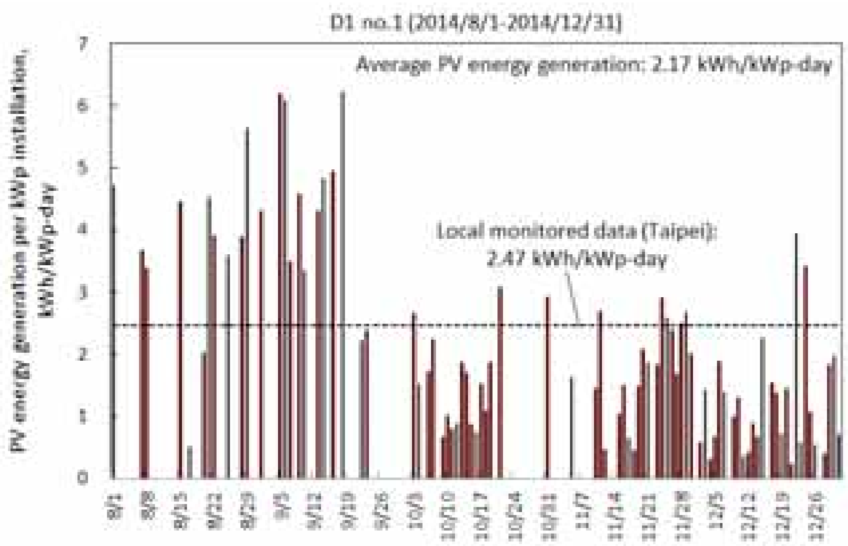

Fig 6: PV generation per kWp installed in No.1 unit.

The daily total energy supply (PV-Mode and Grid-Mode) of No.2 unit is shown in Fig 7. It reaches 2.67 kWh/kWp per day, 8.1% higher than the statistical result. This is due to the fact that the load energy of LED lighting and NB is supplied by No.2 unit which is not changed all year round.

Table 5 is the long-term results in PV energy generation and solar fraction. It shows that the PV energy generation per PV installed reaches 2.42 kWh/kWp per day (Fig.8), approaching the statistical result (2.47). This means that no PV energy generation loss for the whole D-1 system, even it is operated only in weekdays and at low load condition in fall season.

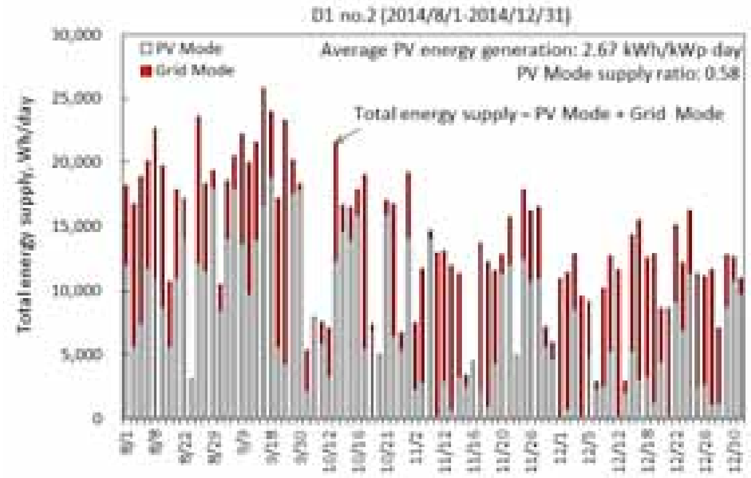

Fig 7: Long-term performance of No.2 unit.

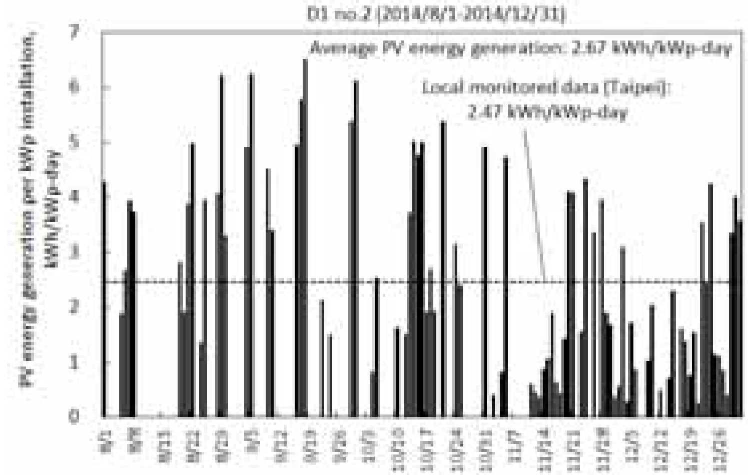

Fig 8: PV generation per kWp installed of No.2 unit.

Table 5: Performance of D-1 system in 2014.

D-1	No.1		No.2			No.1+No.2	
	PV generation per kWp installation, kWh/kWp-day	Solar fraction	PV generation per kWp installation, kWh/kWp-day	Solar fraction	No.1 PV generation loss, %	PV generation per kWp installation, kWh/kWp-day	Solar fraction
2014/8	3.71	0.88	3.5	0.61	-	3.61	0.745
2014/9	4.4	0.87	4.67	0.68	8.6	4.54	0.775
2014/10	1.59	0.75	3.7	0.7	52.7	2.65	0.725
2014/11	1.77	0.73	2.15	0.48	17.7	1.96	0.605
2014/12	1.21	0.29	1.95	0.4	33.3	1.58	0.345
Average	2.17	0.65	2.67	0.58	18.8	2.42	0.615

Fig 9 shows that the 7-month total energy supply (load) of D-1 in 2015 is lower than the estimation (28.6 kWh/day), except in summer. The PV-Mode supply ratio is 0.75. The load demand in March is quite low which increases the PV generation loss. However, the PV energy generation reaches 20.94 kWh/day in summer (June and July), 28% higher than average prediction. Fig.10.

The design of D-1 system is based on the concept of PV energy for self-consumption and small battery storage to reduce cost. The battery is used as a buffer to stabilize the instantaneous load only. The long-term test results for a year shows that the PV energy generation loss is low.

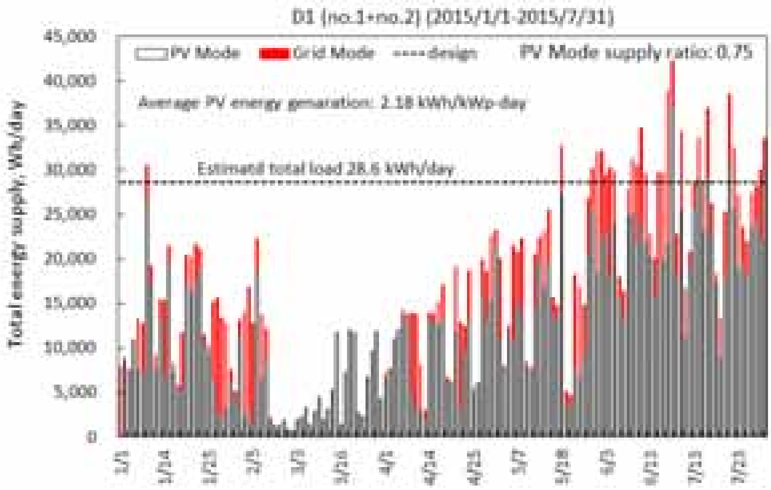

Fig 9: Total energy supply (load) of D-1 in 2015.

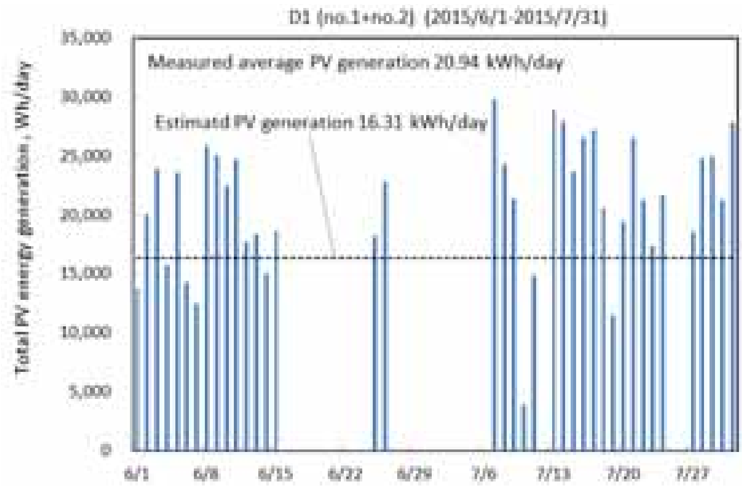

Fig 10: Overall performance of D-1 in 2015.

4. Economic Feasibility

The total investment of the solar PV system and the retrofit of air conditioning system, lighting devices, window insulation etc. is around USD30,000. The net total energy saving in 20 years is USD 80,000, including M&O cost. The system has been run about one year. The measured total power consumption of the office is reduced from 10.2 kW to 3.6 kW (after retrofit), about 65%. The solar PV system supplies about half of the rest of energy demand of the office. That is, 85% energy reduction in total.

The economic analysis (Table 5) shows that the total energy saving through retrofit and PV installation reaches 85% in Taipei (poor solar area) and 96% in Tainan (rich solar area). This indicates that the present demonstration system (D-1) can approach zero-energy office if installed in a solar rich area. The payback time is 8 yr in Taipei and 7.5 yr in Tainan.

5. Conclusions

The present study shows that, performing energy saving retrofit then utilizing solar PV energy to supply the remaining load demand in grid can solve the energy shortage problem, if nuclear power was abandoned in Taiwan. An office located in Taipei with 150m^2 floor area and 14 employees was chosen as the demonstration site (D-1). Four energy-saving retrofitting on air conditioning, lighting, PC, and anti-IR film on window glass results in 65% energy saving. A 6 kWp solar PV system is further installed to replace additional 20% energy. That is, 85% energy is saved in total. The solar PV system is an isolated-type hybrid solar PV system (HyPV) which operates under Stand-alone PV Mode or Grid Mode, automatically, by a power controller. No solar PV energy is fed back to grid. The total investment for the solar PV system and the retrofit for energy saving is around USD30,000. The net total energy saving in 20 years is USD80,000, including M&O cost. System D-1 has been run more than one year. The solar PV system supplies about 60% final energy demand of the office.

If energy-saving in air conditioning and lighting can reach 60% as D-1 did in the whole country, the nuclear power (18%) can be abandomed by using solar PV installation to supply the remaining load demand with proper energy storage.

Table 5: Economic analysis.

Office hour: 8 h/d, 22 d/mon 1 USD = 32NT		Before retrofit		After retrofit (Taipei)			After retrofit (Tainan)		
		Load power (kW)	Daily load (kWh/day)	Load power (kW)	Daily load (kWh/day)	Reduction	Load power (kW)	Daily load (kWh/day)	Reduction
Total consumption (A/C, LED, NB)		10.16	81.3	3.57	28.6	65%	3.57	28.6	65%
Energy-saving (A)	Grid power (kWh/mon)	1,788		628		65%	628		65%
	Unit price (NT/kWh)	5.78		4.7			4.7		
	Monthly bill (NT/mon)	10,338		2,953		71%	2,953		71%
PV supply (B)	PV generation (kWh/mon)	-		359			560		
(A)+(B)	Grid power (kWh/mon)	1,788		269		85%	69		96%
	Unit price (NT/kWh)	5.78		3.27			3.27		
	Monthly bill (NT/mon)	10,338		881		91%	224		98%
	Monthly energy saving (kWh/mon)	-		1,519		85%	1,720		96%
	Monthly bill reduction (NT/mon)	-		9,457		91%	10,114		98%
	20-yr total saving (NT)			2,269,633			2,427,339		
	Initial investment (NT)			906,400			906,400		
	Yearly return on investment (%/yr)			7.52			8.39		
	Payback time (yr)			8.0			7.5		

6. Acknowledgement

This study was supported by National Energy Program II, MOST 103-3113-E-002-006 made by Ministry of Science and Technology, Taiwan.

7. References

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