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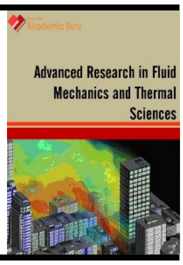

Energy saving potential of an air-conditioner – Ice thermal storage (AC-ITS) system

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ABSTRACT

Air-conditioning (AC) systems are the most common energy consuming equipment in commercial buildings in Malaysia. An Ice Thermal Storage (ITS) application is capable of reducing the power consumption of the air-conditioning system and its corresponding costs as it transfers the peak of electricity consumption from on-peak to off-peak hours. In this study, an analysis was performed on a conceptual AC-ITS system to estimate the annual saving in operating cost when compared to an existing AC system installed at Perpustakaan Raja Zarith Sofia (PRZS) building located in Universiti Teknologi Malaysia, Johor. First, the cooling loads of the building based on the Carrier Cooling Load Method were determined. Based on the cooling loads the system equipment was selected. From the cooling load profile, the chiller-charging and -discharging scheduling of the ITS system were determined. The estimated annual operating cost of the present AC system is approximately RM 437,877. By employing the ITS-AC system, a potential saving of about RM 299,901 per year can be achieved, representing a 68.5 % saving per year.

Keywords:
Carrier Cooling Load Method, COP, annual operating cost, cost saving

1. Introduction

The conventional central air-conditioning systems application always lead to great electrical costs due to its compressor power consumption [1-3]. Numerous studies have been carried out to minimise this problem, in which one of the possible considerations is by incorporating an ice-based thermal energy storage (ITS) into the conventional air-conditioning system [4-6]. Sanaye and Mohammad [7] have conducted a study for optimizing values of design parameters. Exergy efficiency and total annual cost have been considered in the analysis. The comparison of ITS system in full and partial operating modes with that for traditional system showed a reduction in electricity consumption. Mohammad *et al*. [8] have carried out a comparative analysis between a conventional AC system with ITS and phase change material (PCM) systems to evaluate their exergitic, economic performances and environmental impact. They found out that the ITS and PCM systems capable of lowering the power consumptions and emission productions compared to the traditional AC system.

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Pu *et al*. [9] performed an exergy analysis to examine the effect of incorporating ITS in an air conditioning system on energy usage. The results showed that as the average cumulative exergy consumption increases, the cooling load of the ITS system decreases slightly. Ruan *et al*. [10] carried out a study for optimizing a thermal energy storage (TES) systems in building combined cooling, heating and power (BCHP) plants using a mathematical model approach. The ITS is one of the major sub-systems that is introduced in the BCHP. They concluded that the BCHP options show higher energy saving and better economic performance than the conventional system. As the conclusion of the above investigations, all of the studies are towards winning a solution to reduce the electricity consumption of an AC system due to the high energy usage of the compressor, which also leads to greenhouse gases emission.

The ITS application is compatible with any chilled water cooling systems. It is capable of managing energy use based on the time-of-day rather than the cooling requirements [11]. The proper chiller is used to cool a glycol solution to a temperature usually between 20°F-22°F (-6.7°C-5.6°C). A pump is used to push the chilled glycol through the ice storage coils which are located in the storage tank containing water. The ice formation process occurs during the non-peak periods, where electricity is less expensive. During the high price on-peak periods, the chiller, glycol and condenser water pumps and cooling tower fans are turned off. A chilled water pump circulates the cooling water through the ice storage tank where it is cooled to the desired temperature and distributed throughout the system. This article presents an analysis of an AC-ITS conceptual system to estimate the operating cost annual saving when compared to an existing AC system installed at Perpustakaan Raja Zarith Sofia (PRZS) building located in Universiti Teknologi Malaysia, Johor.

2. Description of the AC-ITS System

An AC-ITS system has six major components which consist of chillers, cooling towers, heat exchangers, pumps, thermal storage coils, and the air handling unit of the building. The typical air-conditioning system that incorporates ice thermal storage uses glycol chillers, as illustrated in Figure 1.

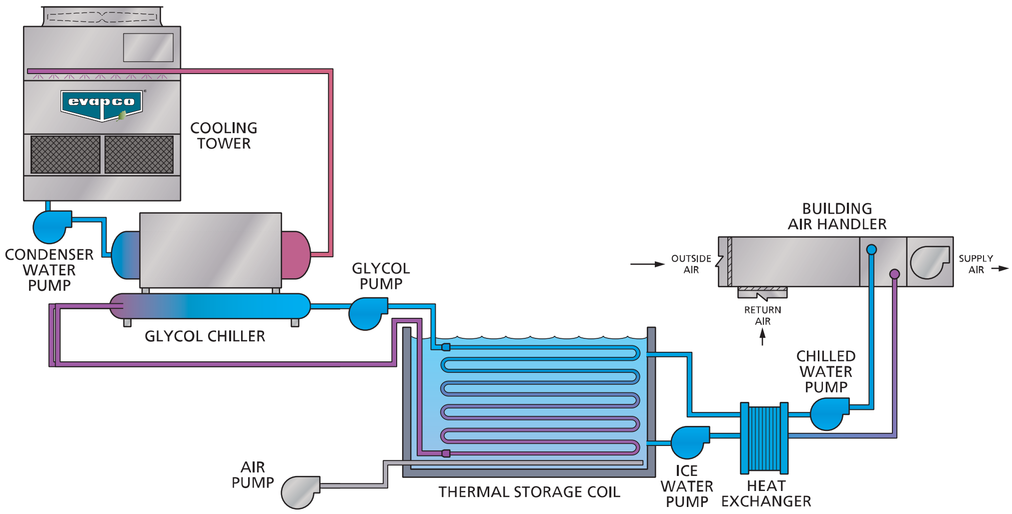

Fig. 1. Schematic diagram of an AC-ITS system [12]

The system can be classified into two types, partial thermal storage and full thermal storage systems. In the full thermal storage system, the chillers generate ice at night when electrical utility rates are lowest. During the daytime, when the utility rates are higher the ice is then melted to provide cooling to the building. As for the partial thermal storage system, a smaller size chiller operates in conjunction with the ice storage to meet the peak loads.

3. Methodology

Perpustakaan Raja Zarith Sofia (PRZS) building located in Universiti Teknologi Malaysia, Johor was considered as the case study for designing an AC-ITS conceptual system and estimating its operating cost saving potential. The procedure for developing the system and calculating its operating cost was done through the following steps:

a) The weather data was obtained from the Malaysian Meteorology Department.
b) The cooling load calculation of the selected building was carried out to determine the size of the storage tank and chiller.
c) The type of the ITS tank was chosen either external melt or internal melt as it is the basis of the thermal ice storage system design.
d) The design criteria of the AC-ITS equipment was determined based on the design day cooling load profile.
e) The electricity tariff was reviewed as these are needed in the thermal ice storage design process.
f) The type of the storage tank was determined based on the local electricity tariff, either partial storage or full storage.
g) The charging and discharging scheduling for the AC-ITS was determined based on the design day cooling load profile.
h) The total operating cost and potential cost saving were estimated.

3.1 Cooling Load Calculation

The equipment selection of the AC-ITS system was based on the total design day cooling load profile of the building. The cooling load was calculated using the Carrier Cooling Load Method as described in [10]. Several assumptions have been made throughout the cooling load estimation as listed below:

a) The roof of the building is assumed flat.
b) The number of occupants is always constant.
c) Only computers, scanners, printers and close circuit TV camera are considered as heat gains from appliances.

The cooling load consists of three elements, which are external heat gains, internal heat gains and infiltration. The external heat gains are due to the heat gained from solar radiation through the glasses and conduction through the floors, ceilings, walls and roof. While the sources of the internal heat gain are from the electric appliances, occupants and lightings. The infiltration heat gains are induced by the infiltration of the outdoor air into the building through wall cracks and untreated openings. They can be divided into two components, sensible and latent heat gains.

The total cooling load was determined by summing up all the heat gain components. The calculation was carried out using a selected design day weather data. In this study, 22nd December 2015 was picked as the design day. The weather data was obtained from the Malaysian Meteorology Department.

3.2 AC-ITS System Components Selection

A modular internal melt ice-on-coil storage tank and full storage operating system were selected in this study as they are the basis of the overall AC-ITS system. In an internal melt system, the ice on the tubes is melted from the inside out. The glycol that cools the building circulates through the thermal storage coils melting the ice that was generated during the ice formation. The term full storage refers to systems where the entire system load is cooled from the ice storage, and it provides the largest amount of energy cost savings. Based on the selected AC-ITS system, the design criteria was fixed as shown in Table 1.

Table 1
Design criteria of the AC-ITS system

Design parameters	Magnitudes
1. Indoor temperature, T_{room}	24.5°C (76.1°F)
2. Relative humidity, ϕ	50%
3. Storage supply temperature, $T_{ice,out}$	3.33°C (38°F)
4. Storage return temperature, $T_{ice,in}$	15.56°C (60°F)
5. Chilled water supply temperature, $T_{water,out}$	−3.89°C (25°F)
6. Chilled water return temperature, $T_{water,in}$	1.11°C (34°F)
7. Condenser supply temperature, $T_{cond,out}$	32°C (89.6°F)
8. Condenser return temperature, $T_{cond,in}$	37°C (98.6°F)

The AC-ITS conceptual system of the PRZS building consists of chillers, cooling towers, distribution pumps, chilled water pumps, condenser water pumps, ice storage tanks and Air Handling Units (AHUs). The selection of each component was based on the total average cooling capacity, the total heat rejection from the building, chilled water flow rate and air change rate per hour.

The chiller type was picked based on the average cooling capacity for a 12-hours period. The total of heat rejection of the building was calculated using Equation (1) below:

Total heat rejection, $\dot{Q}_{reject}$ = heat rejection factor# × total average cooling capacity (1)

#The heat rejection factor for a full load system was assumed as 1.25 [11].

The chilled water flow rate, $\dot{m}_{water}$ was determined through the following equation:

$$\dot{m}_{water} = \frac{\dot{Q}_{reject}}{c_p \times (T_{water,in} - T_{water,out})} \tag{2}$$

where c_p is the specific heat of water in kJ/kg.K. The AHU selection was carried out by computing the amount of volume of ventilation air flowing, C_v (cubic feet per hour) as described in Equation (3).

$$C_v = B \times S \text{ (CFH)} \tag{3}$$

where B is the air volume required per square feet of floor surface and S is the area of the floor in square feet. The value of B was obtained from [11].

Table 2 summarizes the specification of the selected components of the AC-ITS conceptual system for the PRZS building.

Table 2
The AC-ITS system components

Components	Specifications
1. Chiller	Full load capacity – 200 RT Quantity – 2 units Power required – 196 kW
2. Cooling tower	Refrigeration capacity – 250 RT Quantity – 2 units Fan power – 11 kW
3. Distribution pump	Total pump head – 20 ft Mass flow rate – 400 US gpm Power required – 15 kW
4. Chilled water pump	Total pump head – 52 ft Quantity – 3 units Mass flow rate – 340 US gpm Power required – 25 kW
5. Condenser water pump	Total pump head – 73 ft Quantity – 3 units Mass flow rate – 450 US gpm Power required – 30 kW
6. Ice storage tank	Capacity – 486 ton-hour Quantity – 9 units Dimension per tank (meter) – $2.26 \times 6.93 \times 2.59\ (l \times w \times h)$
7. Air handling unit	Air volume flow rate – 2500 CFM Motor power – 15 kW Quantity – 4 units

3.3 Cost Saving Analysis

The cost estimation of the conceptual AC-ITS system is merely focusing on the total operating expenses for one year. The primary goal is to evaluate the effect of incorporating the ITS into the present air-conditioning system installed at Perpustakaan Raja Zarith Sofia (PRZS) building located in Universiti Teknologi Malaysia, Johor on the potential cost saving. The analysis was performed for the current air-conditioning system and the conceptual system. The assessment only focused on the power required by motors to drive related components. Total operating cost for one year of both systems was then compared to determine the potential cost saving. The estimation was based on the electricity tariff provided by the local electricity company as below:

a) On-Peak hours: 8:00 am to 10:00 pm: RM0.19/kWh
b) Off-Peak hours: 10:00 pm to 8:00 am: RM0.10/kWh

3.3.1 Cost estimation of the present AC system

In the present AC system, the electrical power was consumed by several motors to drive the chillers, cooling towers, chiller water pumps, condenser water pumps, split unit AC and AHU. Table 3 summarizes the consumed power for each component.

Table 3
Consumed power by the existing AC system

Equipment	Consumed Power (kW)
1. Chillers	258
2. Cooling towers	16.5
3. Chilled water pumps	45
4. Condenser water pumps	30
5. Split unit AC	56
5. AHU	162.7
Total	**568.2**

The estimation of the operating cost for one year was carried out as follows:

Operating hours for one year
= working hours per week × number of weeks per year
= [12 hours × 5 days (weekdays) + 9 hours × 2 days (weekend)] × 52 weeks
= 78 hours × 52 weeks
= 4056 hours/year

Total operating cost = Electricity tariff × number of operating hours
= RM0.19/kWh × 568.2 kW × 4056 hours
= RM 437,878.00

3.3.2 Cost estimation of the conceptual AC-ITS system

The electrical power was assumed to be consumed by several motors for driving the AC-ITS system components, namely, chillers, cooling towers, chilled water pumps, condenser water pumps, split unit AC and AHU. The analysis was carried out for two operating conditions, which are during charging (off-peak hours) and discharging (on-peak hours) modes. Table 4 summarizes the consumed power for each component during charging and discharging periods.

Table 4
Consumed power by the conceptual AC-ITS system

Modes	Equipment		Consumed Power, $\dot{W}_{in}$ (kW)
Charging (off-peak)	Chillers		196
	Cooling towers		11
	Chilled water pumps		25
	Condenser water pump		30
		TOTAL	**262**
Discharging (on-peak)	Distribution pump		15
	AHU		60
		TOTAL	**75**
Total operating cost for a year = Charging + Discharging			**337**

The estimation of the operating cost for one year is as follows:

Operating hours for charging in one year
= working hours per week × number of weeks per year
= [9 hours×5 days (weekdays) + 7 hours × 2 days (weekend)] × 52 weeks

= 59 hours × 52 weeks
= 3068 hours/year

Total operating cost = Electricity tariff (off-peak) × number of operating hours
= RM0.10/kWh × 262 kW × 3068 hours
= RM 80,439.00

Operating hours for discharging in one year
= working hours per week × number of weeks per year
= [12 hours × 5 days (weekdays) + 9 hours × 2 days (weekend)] × 52 weeks
= 78 hours × 52 weeks
= 4056 hours/year

Total operating cost = Electricity tariff (off-peak) × number of operating hours
= RM0.19/kWh × 75 kW × 4056 hours
= RM 57,535.00

Therefore, the total operating cost for the conceptual AC-ITS system per year is RM 80,439.00 + RM 57,535.00 = RM 137,974.00

4. Results and Discussion

Table 5 shows hourly cooling load (in kW) for each floor of the PRZS building. It can be observed that for the given floor, the cooling load remains almost unchanged from the first hour (1 AM) to the 6th hour (6 AM). This is because of the absence of heat gains from both external and internal sources to the building. The cooling load then increases gradually from the 7th hour (7 AM) until the 20th hour (8 PM). For all the floors, the highest cooling load occurs at the 15th hour (3 PM). The cooling load then decreases sharply from the 20th hour to the 21st hour (9 PM) and continues to decrease thereafter until the 24th hour (12 AM). It can also be observed that at any given hour, the cooling load is highest for the 4th floor of the building. It was found that the total cooling load for the building is 12,035 kW. The hourly cooling load profile was then used to determine the size of the ice storage tank and the sizing of the modified chiller for the present AC system.

Figure 2 shows the hourly variation of the total cooling load for the PRZS building. It is clearly seen from this figure that the peak load occurs at around the 15th hour (3 PM) with a magnitude of about 1,002 kW. The trend of the cooling load variation was used to set the scheduling of charging and discharging processes of the ITS system.

Figure 3 shows the charging schedule for the AC-ITS system during the weekdays. As seen from this figure, the chiller of the integrated AC-ITS system is operated during the off-peak hours for making ice in the stroge tank (charging process), when the electrical tariff is low. The charging process begins at around the 22nd hour (10 PM) and continues until the 5th hour (5 AM). Thereafter, the charging process is stoped. The energy stored in the ITS tank is then utilized to cool down the PRZS building, based on the hourly cooling load variation as seen in the figure, during which the electrical tariff is high. This is called the discharging process, which occurs from about the 7th hour (7 AM) and ends at about the 21st hour (9 PM). Since the electric tariff is low, the charging process will cost less. During the discharging process, the AC system is turned off. This further adds to the saving in the operating cost of the air-conditiong system for the PRZS building.

Table 5
Hourly cooling load demand for the PRZS building

Hour	Cooling Load (kW)				Total Cooling Load (kW)
	Floor 1	Floor 2	Floor 3	Floor 4	
1	7.93	13.32	15.12	37.94	74.31
2	5.00	7.45	9.26	32.08	53.80
3	5.00	7.45	9.26	32.08	53.80
4	5.00	7.45	9.26	32.08	53.80
5	5.00	7.45	9.26	32.08	53.80
6	5.00	7.45	9.26	32.08	53.80
7	16.07	18.74	18.89	41.71	95.41
8	171.44	160.33	165.21	181.42	678.37
9	191.91	173.86	174.37	190.57	730.71
10	206.92	194.92	193.56	209.76	805.16
11	219.80	209.53	206.15	222.34	857.82
12	229.86	219.69	213.92	230.11	893.58
13	234.14	228.90	220.92	237.11	921.08
14	241.14	233.70	223.21	239.40	937.44
15	258.73	251.22	238.09	254.28	1,002.32
16	244.69	238.84	226.89	243.08	953.50
17	236.55	233.19	225.91	242.09	937.74
18	236.14	227.11	222.85	239.04	925.14
19	207.57	197.33	194.94	211.13	810.98
20	189.76	179.65	178.49	194.67	742.58
21	13.79	25.04	26.84	49.66	115.33
22	13.79	25.04	26.84	49.66	115.33
23	10.86	19.18	19.18	20.98	43.80
24	7.93	13.32	15.12	37.94	74.31
Total	**2,964.00**	**2,900.17**	**2,854.63**	**3,316.09**	**12,034.92**

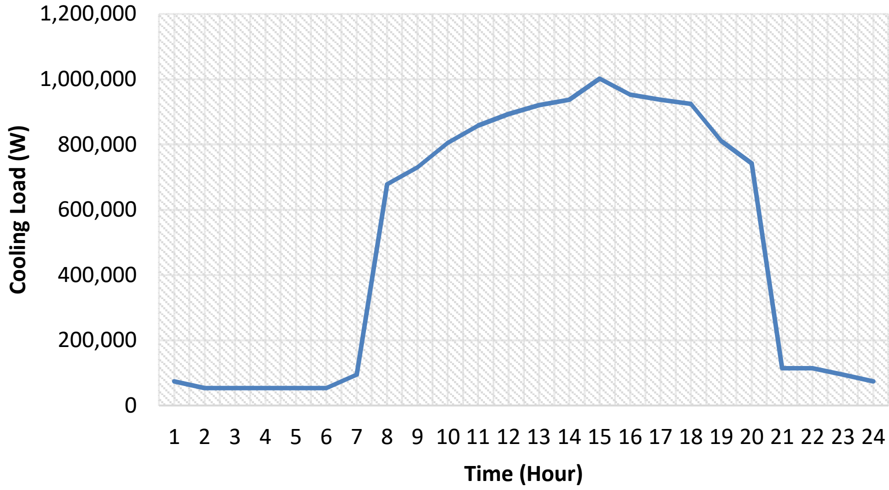

Fig. 2. Hourly variation of the total cooling load demand of the PRZS building.

Figure 4 show the charging schedule for the AC-ITS system during the weekends. As observed from this figure, charging process begins at around the 21st hour (9 PM) and continues until the 4th hour (4 AM). Thereafter, the charging process is stoped. The energy stored in the ITS tank is then utilized to cool down the PRZS building, beginning from the 7th hour (7 AM) until about the 18th hour

(6 PM). The charging time in this case is shorter compared to that during the weekdays. This is so because the cooling load demand is less than that during the weekdays.

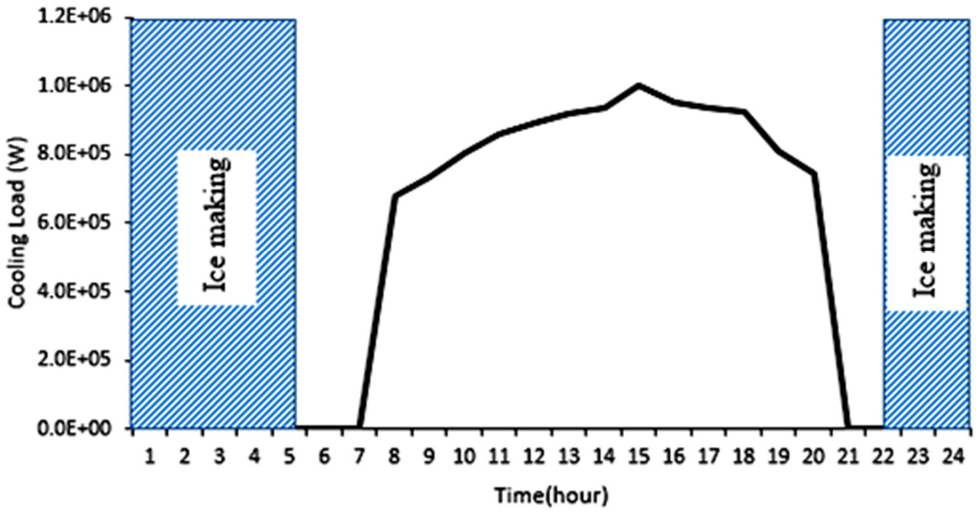

Fig. 3. Charging schedule for the ITS system during the weekdays

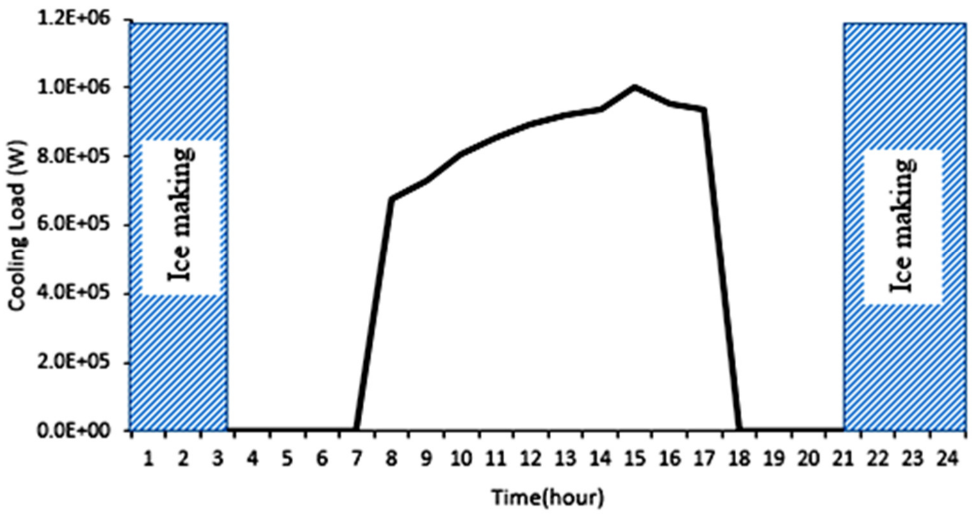

Fig. 4. Charging schedule for the ITS system during the weekends

The annual operating cost of both the conventional AC system and the conceptual AC-ITS system are shows in Table 6. It can be seen that the operating cost for the conventional AC system is about RM 437,877.65 per year. By incorporating the ITS into the present AC system, a potential saving in the operating cost of about RM 299,901.78 in one year. This represents a 68.5 % saving in the annual operating cost for the system, which can be considered as a very significant saving.

Table 6:
The annual operating cost and potential cost saving

Type of system	Conventional AC System	AC-ITS System	Potential Cost Saving
Annual operating cost	RM 437,878	RM 137,974	RM 299,902 (68.5 %)

5. Conclusion

A study on the assessment of potential saving on the annual operating cost of a conventional air-conditioning (AC) system installed at the Perpustakaan Raja Zarith Sofia building of Universiti Teknologi Malaysia was carried out, through the incorporation of an ice thermal storage (ITS) system, was presented. The ITS system is used to produce ice in the storage tank (charging) during the off-peak hours when the electricity tariff is low. The system is utilized to absorb the cooling load for the building during the peak hours (discharging) when the electricity tariff is high. It was found that the annual operating cost for the conventional AC system is about RM 437,967. The incorporation of the ITS system has a potential of saving about RM 299,902 or 68.5 % of the annual operating cost of the air-conditioning system.

Acknowledgements

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