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PERFORMANCE OF SOLAR AIR-CONDITIONING SYSTEM USING HEAT PIPE EVACUATED TUBE COLLECTOR

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ABSTRACT

This paper presents the performance of solar air conditioning system using heat pipe evacuated tube collector. The currentsolar airconditioning system is not competitive with electricity driven air conditioning system due to their high investment cost.The electricity driven chiller has higher peak load during the daytime whereassolar air conditioning system were converting the low grade solar energy into high grade solar energy and protects the environment with energy conservation.Meanwhile, its overall thermal energy conversion efficiency is relatively low compared to conventional air conditioning.The experiment was carried out for 10 working hours from 08:00 to 18:00during June 2010. The obtained results show that the system technically viable. The heat pipe evacuated the tube efficiency, coefficient of performance (COP) of the double effect lithium bromide (LiBr) and water (H2O) absorption chiller, and the overall system efficiency were analysis. It can be seen that the solar collector efficiency varies from 26 to 51% during daytime and stored energy can be used for several hours during nighttime. The absorption chiller COP varies from 0.7 to 1.2 throughout the experiment and overall system efficiency varies from 27 to 48%. There is further research needin order to improve the overall system efficiency and it iseconomically profitable.

***Keywords**:* tube collector, absorption chiller, thermal analysis, COP, economical analysis.

INTRODUCTION

The experimental location has latitude of 2.983ºN and longitude of 101.617ºE. The annual average daily solar insolation for Malaysia wasfrom 4.21 kWh/m² to 5.56 kWh/m²(Azhari et al., 2008). The system using the double effect LiBr and H2O absorption chiller with cooling capacity of 105kW and 30RT. The system was consists of 84solar panel heat pipe evacuated tubes with absorber area of 235.2m². The collectors were arranged in four rows, in which two rows facing due south. This allows the collector to collect more solar insolation throughout the day.The system has hot and chill water storage tank about 8m³ each and both are well insulated. The solar cooling system serves a cooling space of 557m². However, the system still requires some electricity to operate its pumps and fans. Some auxiliary conventional source is also required from time to time to maintain its operation during periods of insufficient sunshine.The research was determining the thermal energy efficiency of the system of the heat pipe evacuated collector, COP of double effect LiBr absorption chiller, and the overall system efficiency. The system was running automatic with minimum average collector temperature at 60ºC and the system parameters were not changed throughout the study. The schematic diagram of the system is shown in Figure 1.

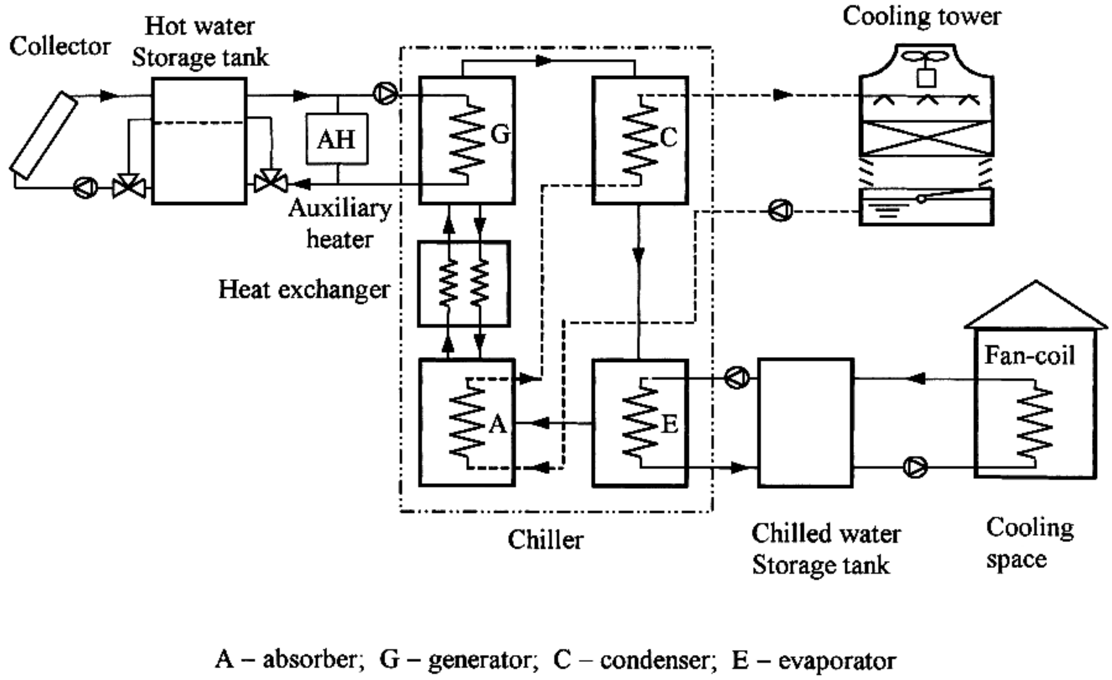

Figure 1: The schematic diagram of the solar air-conditioning system (Li et al., 2000).

LITERATURE REVIEW

It is reported that in 1998,a new integrated compound parabolic concentrator (CPC) reflector evacuated solar collector with modified double effect absorption chiller to operate with 150 ºC hot water is installed on a building for cooling. The 106.5m² collector array consisted of 336 evacuated tubes. The daily collection efficiencies of almost 50% and instantaneous collection efficiencies of about 60% were achieved throughout the firsttwo years of operation. The daily chiller COP of about 1.1 was achieved as well (Duff et al.,2004; Hamza et al., 2008).Normally, the single or double effect lithium bromide absorption chillers are commonly driven by hot water.In order to operate the chiller need a hot water temperature of 88 to 90ºC.The solar evacuated tubes were used to provide the heat source. It is reported from the experimental data on the performance of such systems (Bong et al., 1987). The heat pipe evacuated tube collector has high performance compared to flat plate collector, it used toobtain solar cooling effect for a longer period in a daytime (Ward et al., 1978).The efficiencyfor the heat pipe evacuated tube collector can be formulated (SRCC, 2010):

$$\eta_c = 0.526 - 1.3253\frac{P}{I} - 0.0042\frac{P^2}{I} \quad (1)$$

Where ;

$P = Tave - Ta$; η_c = *Collector Efficiency; Tave = Average collector temperature, ºC*

Ta = Ambient Temperature, ºC; I= Solar Insolation, W/m²

Monthlyaveragedtwenty-two years meteorology data for thelatitude of 2.983ºN and longitude of 101.617ºEdata obtained from NASA surface meteorology and solar energy is shown table 1(NASA surface meteorology and solar energy, 2010).

Table 1: Solar Energy Parameters from NASA Surface Meteorology and Solar Energy

Latitude, 2.983ºN Longitude, 101.617ºE	22-year AverageJul 1983 - Jun 2005
Averaged insolation incident on a horizontal surface ($kWh/m^2/day$)	4.98
Averaged radiation incident on an equator-pointed 17º tilted surface ($kWh/m^2/day$)	5.10
Averaged daylight (hours)	12.2

The COP of an absorption air conditioner can defined as the ratio of the heat transfer rate into the evaporator to the heat transfer rate into the generator. It is reported that LiBr and H2O working fluid absorption chiller has a higher COP compare than for the other working fluid such as ammonia (NH3) and H2O (Wilbur et al., 1975). The doubleeffect LiBr and water absorption chiller could reduce heat transfer irreversibility, thereby having aCOP value from 0.7 to 1.2 and auxiliaryenergy could produce a higher COPwhen solar energy is not available or insufficient (Liu et al., 2004).

Therefore, the overall efficiency of the system can be formulated(Mittal, Kasana, & Thakur, 2005);

$$\eta_{system} = COP \times \eta c \quad (2)$$

where : η_c = *Collector Efficiency; COP = Coefficient of Performance of Absorption Chiller;* $\eta system$ = *Overall System Efficiency*

EXPERIMENTAL DESIGN

The experiment was carried out for 30 days from 1st – 30th June 2010 for 08:00 to 18:00 working hours. The data logger used to measure the collector inlet and outlet temperature, the ambient temperature and electrical energy consumption for every an hour during the experiment. The collected data were analysed using the theoretical formulation to determine the efficiency of the solar collector, and the overall efficiency of the system and energy consumption of the system. The solar air conditioning system operation was observed from building automation system shown in Figure 2.

RESULTS AND DISCUSSION

The average collector temperature is one the main parameter for the□*c*, efficiency of solar collector.The average collector temperature of heat pipe evacuated collector against time from 08:00 until 18:00 for 30 days as shown in Figure 3. The average collector temperature has increases rapidly from 08:00 to 09:00 as the sunrise and gradually increases until 14:00 to 15:00. It reached the maximum temperature from 12:00 to 15:00. The average collector temperature gradually decreases after 15:00. The maximum and minimum of the average collector temperatures were 101.5ºC and 36.8ºC respectively. This maximum temperature can be achieved during a clear sky and sunny day with very good insulation to prevent heat losses to the environment. The minimum temperature was due to rainy and cloudy day. The mean temperature of average collector temperature is 69ºC. Since, the system needs a minimum average collector temperature of 60ºC to operate. Therefore the system was running steadily most of the time. The average collector temperature of heat pipe evacuated collector against time from 08:00 until 18:00 for 15th June 2010 as shown in Figure 4. The solar cooling system starts operate about 9:00am after average collector temperature reached at 60ºC. The average collector temperature gradually increases with time and reached the maximum temperature 81.35ºC at 14:00 and starts decreases after 16:00. Since, the average collector temperature was about 74.45ºC after the sunset, the system still can operate with the storage energy until it reaches the minimum operational temperature 60ºC.

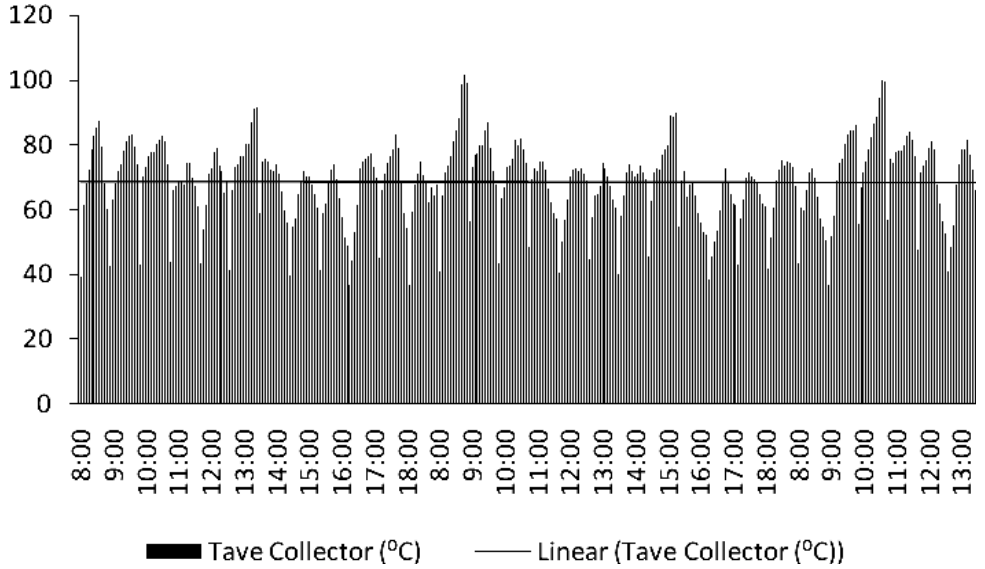

Figure 3: Average collector temperature against time (30 days)

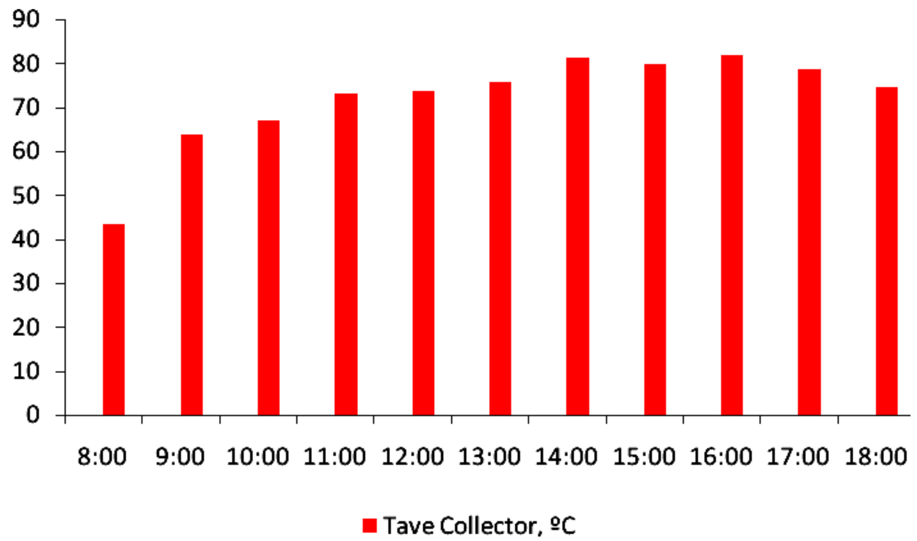

Figure 4: Average collector temperature against time (15th June)

Figure 5 shows the average collector temperature and ambient temperature against time from 8:00until 18:00for 15th June. The heat pipe evacuated collectors can collect high level of heat with the steady sunshine with ambient temperature from 27.8ºC to 36.3ºC throughout the daytime. The heat pipe evacuated tube efficiency against time from 8:00 until 18:00 for 30 days as shown Figure6. The maximum and minimum efficiency of the heat pipe evacuated tube collector was 51% and 26% accordingly. The average efficiency of the heat pipe for 30 days of experiment was about 39%. The highest efficiency of the collector has achieved during the sunrise and gradually decreases with time until the sunset. Technically, we should get the efficiency is higher during the solar noon hours. However, we get higher efficiency during the sunrise due to the average daily solar insulation was about 0.408 kW/m²during the daytime. The resultsfor a day as plotted in heat pipe evacuated tube against time for 15th June in Figure 7.

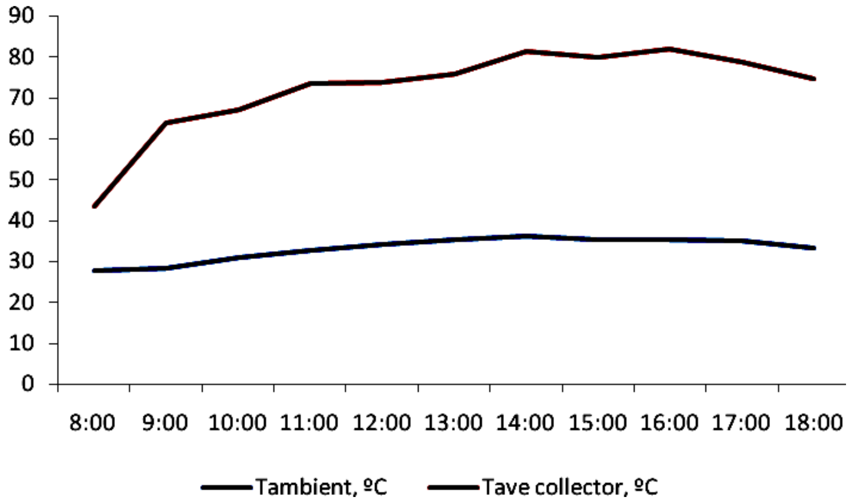

Figure 5: The average collector temperature and ambient temperature against time (15th June)

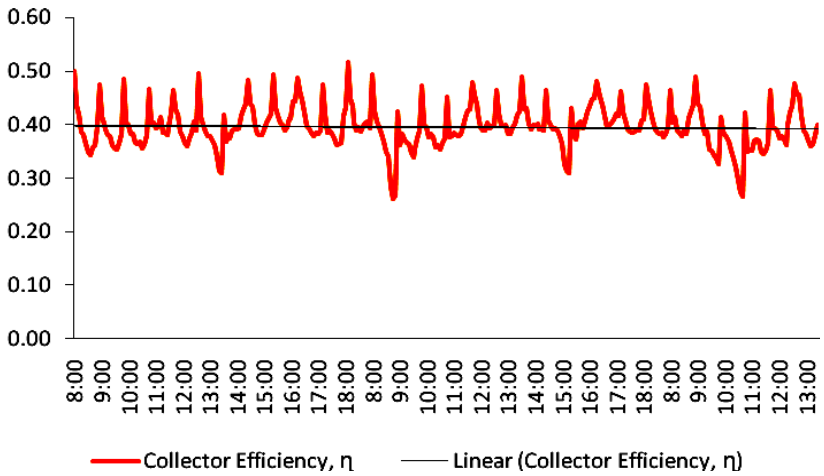

Figure 6: The heat pipe evacuated collector efficiency against time (30 days)

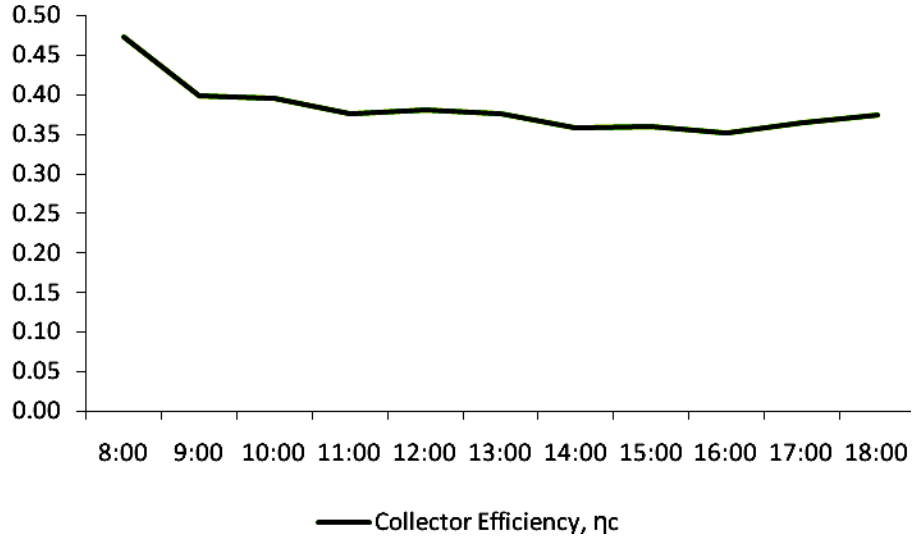

Figure 7: The heat pipe evacuated collector efficiency against time (15th June)

The overall system efficiency, η*system* was the determined for two different COP of the double effect absorption chiller. The maximum and minimum COP were 0.7 and 1.2 by considering these COP, the overall system efficiency against time for 30 days as shown in Figures 8 and 9. Figure 8 shows the average overall system efficiency for low COP operation was 27%. The maximum and minimum overall system efficiency was 36% and 18% for low COP operation. Figure 9 shows the average overall system efficiency for high COP operation was 48%. The maximum and minimum overall system efficiency was 62% and 31% for high COP operation. Therefore, the overall system efficiency varies 27 to 48% throughout the experiment.

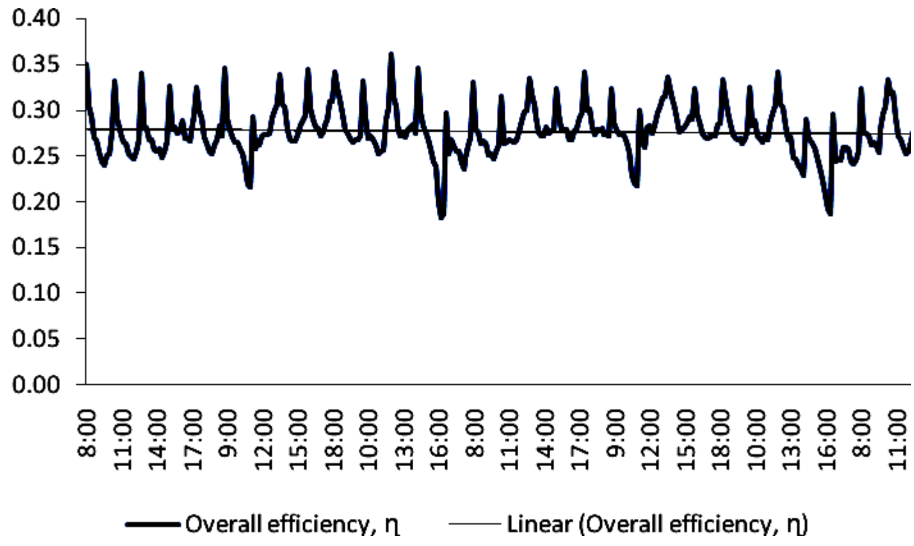

Figure 8:The overall system efficiency with COP of 0.7 against time (30 days)

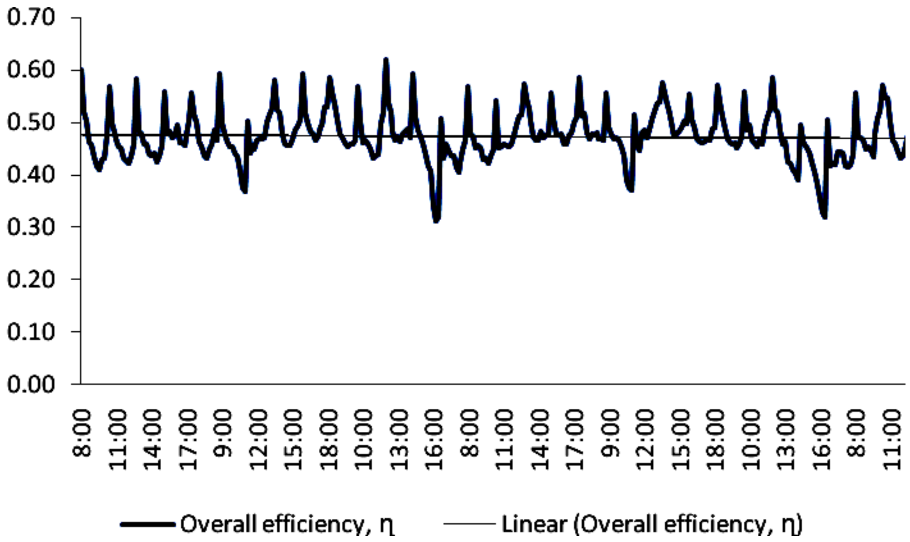

Figure 9:The overall system efficiency with COP of 1.2 against time (30 days)

The average energy consumption of the solar air conditioning is shown in Table 2. According to the current TenagaNasionalBerhad (TNB) tariff B rate on low voltage commercial building is RM 0.397/kWh.The cost for electrical consumption wascalculated for a year based on 8:00 to 18:00 working hours for the solar air conditioning system and tabulated in Table 3. Summary for the performance of solar air conditioning system experiment for 30 days from 1st until 30th June 2010 is shown in Table 4. Summary for the performance of solar air conditioning system experiment for 30 days from 1st until 30th June 2010 is shown in Table 4.

Table 2**:** Electrical energy consumption of solar air-condition

Description	**Power Consumption, kW**	**Remark**
Absorption Chiller	1.3	Absorption, 30RT For absolute and refrigerant pump only
Chill Water Pump	3.2	84usgpm@82ft Efficiency = 55%
Cooling Tower Pump:	4.0	162usgpm@ 65.6ft Efficiency = 67%
Cooling Tower	1.1	70HRT
Hot Water Pump	2.1	114usgpm@ 49.2ft Efficiency = 68%
Solar Hot Water Pump	1.5	42usgpm@ 98.4ft Efficiency = 70%
Total Energy Consume	13.20	

Table 3**:** Cost of electrical consumption

Description	**Unit**	**Solar air conditioning system**
Average daily power Consumption	kW	132
A month (30 days) electricity consumption	RM/month	1572.12
Ayear (365 days) electricity consumption	RM/year	19127.46

Table 4:Performance of solar air conditioning system experiment

Parameters	**Results**
Average collector temperature, ºC	60
Average ambient temperature, ºC	33
The range of heat pipe collector efficiency, (%)	26 to 51
The range of COP the double effect LiBr Absorption Chiller	0.7 to 1.2
The range of overall system efficiency, %	27 to 48
Average daily for 10 hours electric energy consumption, kWh	

CONCLUSION

This paper concludes the solar energy is able to produce sufficient energy to power the solar air conditioning system. The efficiency of heat pipe evacuated tube varies from 26 to 51% and able to produce enough energy to operate the system.The overall system efficiency varies from 27 to 48%. The energy consumption of solar air-conditioning system relatively small and the solar powered chilled water system provides zero energy cost comparing to electric driven chillers. The economical view is profitable after several years of installation. The environmental view is green energy causing no pollution to the surrounding. We should not only consider about economic benefits but also the problem caused by the pollution and its effect to the environment. Theimplementation of solar energy cooling system should be encouraged and not be underestimated.An intensive research on absorption chillers working fluids should do, in order making the fluids can operate reliably at low temperatures than the LiBr. This will eventually increases the efficiency of the absorption chiller and the overall system.

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NOMENCLATURE

COP	coefficient of performance
LiBr	lithium bromide
H2O	water
CPC	compound parabolic concentrator
Tave	average collector temperature(ºC)
Ta	ambient temperature (ºC)
I	insolation radiation(W/m2)
P	Average collector temperature -ambient temperature(ºC)
NH3	ammonia
TNB	TenagaNasionalBerhad

Greek Symbols

c	collector efficiency
system	overall system efficiency