An Overview of Solar Assisted Air-Conditioning System Application in Small Office Buildings in Malaysia

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Abstract:- In many regions of the world especially tropical weather in Malaysia, the demand for cooling of indoor air is growing due to increasing comfort expectations and increasing cooling loads. Air-conditioning, the most common cooling mechanism for providing indoor cooling in buildings has become a necessity in most buildings. However, air-conditioning is the dominant energy consuming appliances in most of today office buildings. Today most of the small office buildings deployed conventional cooling technologies which typically uses an electrically driven compressor system that exhibits several clear disadvantages such as high energy consumption, high electricity peak loads demand and in general it employ refrigerants which have several negative impacts on the environment. Because of the high energy cost, the decrease of fossil fuel resources and the rise of environmental pollution, the utilization of low level renewable energy sources such as solar energy in refrigeration systems has become a way to address these problems. The solar assisted air-conditioning system uses the heat from the solar radiation to drive a thermally-driven chiller such as absorption chiller. Solar assisted air conditioning system produces cooling with considerably less electricity demand than conventional air-conditioning systems. With current solar collector technology like evacuated tube solar collector which able to produce high temperature approximately 88°C, it has made heat source from solar energy viable to drive the absorption chiller to produce chilled water for indoor cooling purposes. In addition, the working fluids like Lithium Bromide used in the absorption chiller does not contribute to global warming, contrary to most working fluids in conventional compression chiller. With such great potential application of solar assisted air conditioning system in Malaysia tropical weather, this paper provide an technical overview and economic feasibility of a solar assisted air conditioning system under Malaysian climatic conditions.

Key-Words: High energy consumption, Peak load demand, solar assisted air conditioning system, solar energy, absorption chiller, evacuated tube solar collector, Malaysian climatic conditions.

1. Introduction

In tropical weather country like Malaysia, the demand for cooling of indoor air is growing due to increasing comfort expectations and increasing cooling loads. Air-conditioning is the most common cooling mechanism and it has become a necessity for providing indoor cooling in the all office buildings in Malaysia. However, air-conditioning the dominant energy consuming appliances and it consumed approximately 40% of the total electricity consumption in comparison to lighting and other electrical appliances in office buildings. Small office buildings like shop-office buildings constitute approximately 57% of total office buildings in Malaysia[1]. Most of the small office buildings deployed conventional cooling technologies which typically uses an electrically driven compressor system that exhibits several clear disadvantages such as high energy consumption, high electricity peak loads demand and in general it employ refrigerants which have several negative impacts on the environment. Because of the high energy cost, the decrease of fossil fuel resources and the rise of environmental pollution, the utilization of low level renewable energy sources such as solar energy in refrigeration systems has become a way to address these problems. The solar assisted air-conditioning system uses the heat from the solar radiation to drive a thermally-driven chiller such as absorption chiller. Solar assisted air conditioning system produces cooling with considerably less electricity demand than conventional air-conditioning systems.

2. Main components in a solar assisted air conditioning system

The main components in the solar assisted air conditioning system can be divided into five main components namely:-

1. solar collector
2. hot water & chilled water storage
3. chiller (cold production)
4. cooling towers
5. fan coils

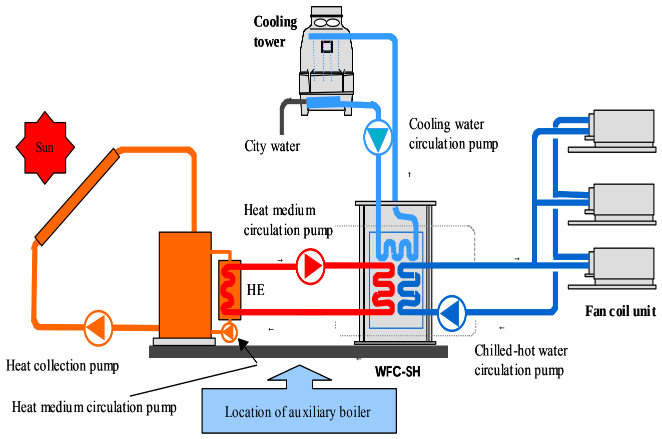

Fig. 1. Main components of a solar assisted air conditioning system (Source: YAZAKI)

3. Evacuated tube solar collector

The solar collector is one of the main components in a solar assisted air conditioing system that convert solar energy to the thermal energy that drives the chiller or cold production component[2]. Refer to Figure 1. Due to the high temperature requirement to drive the chiller in particular the absorption chiller, evacuated tubes solar collector will be a better choice due to its efficiency and ability to produce high temperature in comparison to flat plate solar collector. The average driving temperature for absorption chiller is between 80°C to 90°C depends on type of models by different manufacturers.

Fig 2. Evacuated Tubes Solar Collector (Source: Thermomax, UK.)

Currently, there are two types of evacuated tubes solar collector, namely heat pipe type and the direct flow through type evacuated tubes solar collector. The heat pipe evacuated tubes solar collector consists of a heat transfer fluid that transfer the heat between the absorber and the header.

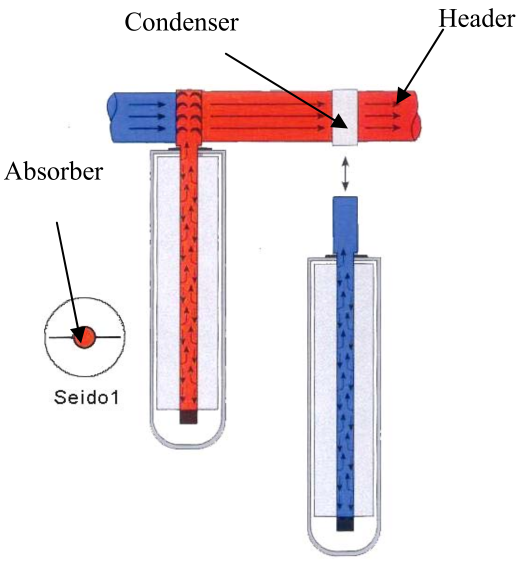

Fig. 3. Heat Pipe Evacuated tube solar collector. (Source: SUNDA Solar, China)

In a heat pipe evacuated tube collector, the heat-pipe type 'dry' connection is made between the absorber and the header; this makes the installation process easier and permits the defectives tubes to be exchanged without emptying the solar circuit. However, the collector must always be mounted with a certain tilt angle in order to allow the condensed internal fluid of the heat pipe to return to the hot absorber [2]. Generally, the heat pipe is filled with alcohol or water in a vacuum, which evaporates at temperatures as low as 25°C. The vapour thus occurring rises upwards. At the upper end of the heat pipe the heat released by condensation of the vapour is transferred via a heat exchanger (condenser) to the heat transfer medium as it flows by. The condensate flows back down to the heat pipe to take up the heat again.

In the direct flow through type evacuated tube solar collector, the heat transfer medium is led via a tube in tube system to the base of the glass tube, where it flows back in the return flow and thereby takes up the heat form the highly spectral-selective absorber or it flows through a U-shaped tube[5]. Refer to Fig. 4.

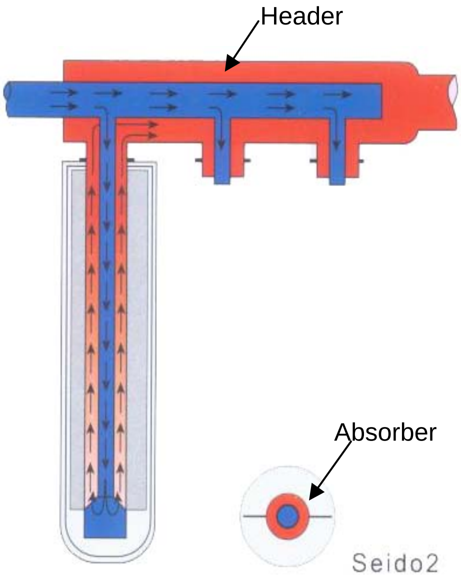

Fig. 4. Direct Flow Through type evacuated tube solar collector.
(Source: SUNDA Solar, China)

The advantages of evacuated tube solar collector are:-
1. It achieves a high efficiency even with large temperature differences between absorber and surroundings.
2. It achieves a high efficiency with low radiation.
3. It achieves high temperatures to drive thermal driven chillers for solar assisted air conditioning system.
4. It can be easily transported to any installation location because of its low weight and the tubes can be installed individually [5].

The main disadvantage of the evacuated tubes solar collector is it is more expensive than a flat plate collector.

3.1 Sizing of evacuated tube solar collector area

A very simple assessment of the solar collector dimensions in a solar assisted air conditioning system can be made using a rule of thumb approach. The required collector area per cooling capacity is defined by:
1) Incident solar radiation for Malaysia (G) = 800 w/m^2 or 0.800 kW/ m^2
2) Solar collector efficiency (η) = 0.7 or 70%
3) Chiller C.O.P = 0.7 or 70% (Using 'BROAD' Chiller = 23kW)

$$A = \frac{1}{G.\eta.\ C.O.P} \left(\frac{m^2}{kW} \right) \quad (1)$$

$$= \frac{1}{0.800 \times 0.7 \times 0.7} \quad (2)$$

$$= \frac{1}{0.392} \quad (3)$$

$$= 2.55\ m^2 \text{ per kW} \quad (4)$$

For 23kW absorption chiller
= 23 x 2.55 (5)
= 58.65 m^2 coverage area of evacuated tubes

Each evacuated tubes has 0.1 m^2 area:
= 58.65 ÷ 0.1 (6)
= 587 evacuated tubes required
= 20 sets of evacuated tubes (1 set has 30 tubes)

4. Absorption chiller

Absorption chillers are applied in most of the solar assisted air conditioning systems which are in operation today. Refer to Fig. 5.

The main challenges to achieve a further penetration of absorption chillers in solar assisted air conditioning systems are the following:

1. The machines on the market are intended for large scale applications but there is a demand for smaller absorption chillers;
2. LiBr absorption chillers need a cooling tower;
3. Efficiency and capacities are small at low driving temperatures;
4. More expensive collector types like evacuated tubes are required in combination with absorption chiller to guarantee a sufficient efficiency[3].

Although Adsorption chillers have a higher efficiency at low driving temperature than Absorption chillers but Absorption chiller is still preferred because Adsorption chillers are more expensive per kW cooling capacity than absorption chillers[3].

In addition, adsorption chillers are generally bigger and heavier than absorption chillers. Therefore, todate, absorption chillers installation are more favourable in comparison to adsorption chillers.

Fig. 5 YAZAKI Model WFC-SC10, 10RT or 35kW hot water driven absorption chiller. (Source: YAZAKI)

Absorption chiller produce a refrigeration effect through use of a heat source, as opposed to the more commonly encountered compressor-driven machines that use electric power to generate a cooling effect. Absorption chiller do not consume as much electricity as compressive chillers, and they do not require the use of chlorofluorocarbon (CFC) or hydorchloroflourocarbon (HCFC) refrigerents. They are best suited to situations where there is a plentiful, low-cost heat source such as solar thermal [6].

There are generally 2 types of absorption chillers. "Indirect-fired" chillers use steam, hot water or hot gas as energy input. "Direct-fired" chillers utilize a dedicated combustion heat source. Both types work through the absorption cycle, whereby a refrigerant (typically Lithium Bromide and water) absorbs and discharges heat as it changes state. Water flows through a four – stage process of evaporation, condensation, evaporation, absorption-moving heat as an integral part of the process. The Lithium Bromide undergoes a 2 stage process of dilution and concentration-attracting or releasing water in the loop.

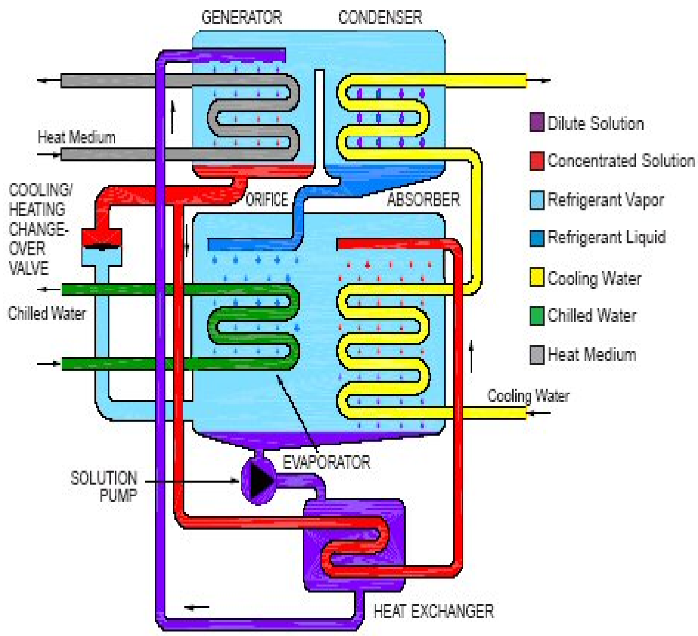

Fig. 6 Schematic Diagram of the absorption refrigeration cycle. (Source: YAZAKI)

An absorption chiller machine consists of 4 interconnected chambers. In the generator chamber, heat evaporates water from the lithium bromide/water solution. The concentrated lithium bromide is transferred to the absorber chamber, while the water vapour is condensed in the condenser chamber. The water flows to the evaporator chamber to continue the cycle. In the evaporator chamber, water changing state draws heat from chilled water circulating through the chamber. This water vapour passes into the absorber chamber, where it is attracted by the lithium bromide. The vapour pressure is reduced by the absorption of water and more water vapour can evaporate to continue the process.

With free heat source from the sun, and with fewer moving parts to maintain, absorption chiller are more cost effective than electrical driven compressor systems. Their overall co-efficient of performance (COP) can be as low as 0.7 (versus 3.0 or higher for a vapour-compression chiller).

However, they generate nearly as twice as much waste heat as compressive refrigeration machines. This affects overall energy consumption and cooling tower sizing; for each unit of refrigeration, an absorption chiller must reject around 2.5 units of heat versus approximately 1.3 units for vapour compression machine [6].

5. Storages systems

The main purpose of storage in a solar assisted air conditioning system is to overcome mismatches between solar gains and cooling loads. The most common application is the integration of a hot water buffer tank in the heating cycle of the thermally driven cooling equipment. In a solar assisted ari conditioning system that uses absorption chiller, there are 2 possible plces for integrating thermal storage. See figure 7.

Excess solar heat can be stored in the heat storage unit and is made available if the solar heat is not sufficient. The second option is that the excess cooling power of the solar system and the thermally driven chiller is stored in a cold storage unit and is made available if the cold production does not meet the cooling load [2].

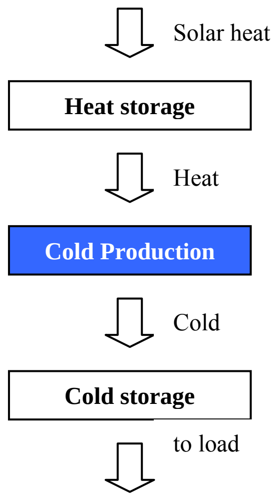

Fig. 7 Energy storage typologies in a solar assisted air conditioning system (Source: Henning, H.M., 2007)

The hot water storage tank unit fulfills several task:

1. It stores heat from fluctuating heat sources like the solar from times where excess heat is available for times where too little or no heat is available;
2. It extends the operation times for auxillary heating devices;
3. It reduces the needed heating capacity of auxillary heating devices;
4. It delivers sufficient energy to the thermally driven chiller.

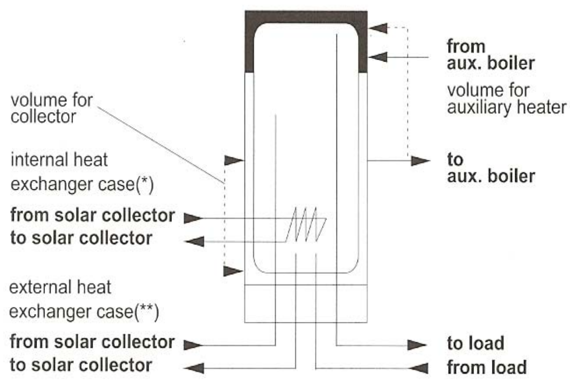

Fig. 8 Schematic Diagram of Hot Water Tank for solar assisted air conditioning System
(Source: Henning, H.M., 2007)

6. Fan coils

A fan coil system is a heat exchanger with a fan that simply circulates indoor air over it. The heat exchanger is supplied with chilled water. Each of the fan coil units have a thermostatically controlled built-in fan that able to draws air from the indoor space and then blows it over finned tubes of the heat exchangers where chilled water for cooling is circulated [2]. The cold medium is produced by the absorption chiller. Generally fan coils can be ceiling mounted, concealed or recessed vertical floor units.

Currently, there are 2 types of fan coils available in the market. They are namely 2-pipe and 4-pipe systems. The 2-pipe system uses 2 pipes, one pipe for the supply and the other pipe for the return of the cold medium to the heat exchanger. The 4-pipe system unit is equipped with 2 independent coils, one for heating and one for cooling. Cooling and heating valves for controlling coil capacities are often factory-installed, and their control devices are hidden inside the units's cabinet, or they are wall-mounted, or remotely mounted [2].

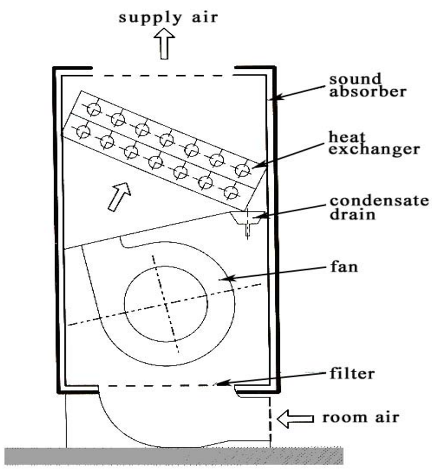

Fig. 9 Cross section of a typcial simple fan-coil unit with one heat exchanger for air cooling.
(Source: Henning, H.M., 2007)

The advantages for fan coils system are the followings:

1. The fan coil system only requires piping installation, which takes up less space than air ducts.
2. Unoccupied building spaces may be separated by simply turning off the local fan coils or diverting the cold medium flow to the fan coil.
3. Zones can be individually controlled and managed with a centralized control unit[2].

The disadvantages of fan coils system are:

1. condensate must be removed from each unit
2. interior zones may require additional fresh-air-ventilation with separate ducts
3. heat recovery may be more difficult to achieve
4. potentially noisy system since the air fans are located inside occupied areas[2].

Most fan coils are equipped with a device to dispose condensate in those cases where control of indoor humidity is possible. Condensation occurs, depending on indoor conditions, when air is cooled below its dew point[2].

7. Cooling Tower

A cooling tower is a device where cooling water is brought into contact with ambient air to transfer rejected heat from the coolant to the ambient. There are 2 basic types of cooling tower: open-circuit systems, where there is direct contact between the primary cooling-water circuit and the air, and closed circuit systems where there is only indirect contact between the 2 fluids across heat exchanger walls [2].

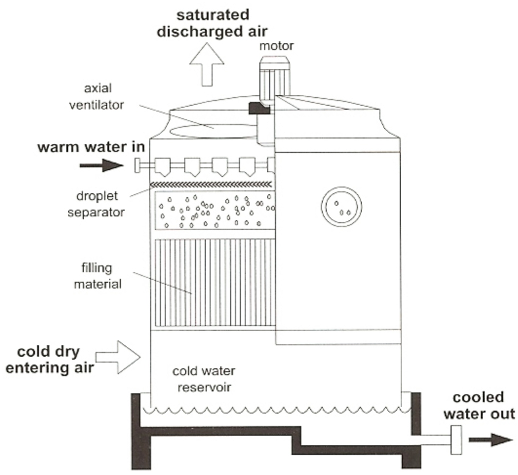

Fig.10 Schematic drawing of an open type wet cooling tower
(Source: Henning, H.M., 2007)

Open circuit systems are commonly known as 'open cooling towers', 'wet cooling towers' or just as 'cooling towers'. A characteristic feature of all such systems is, that they mostly use latent heat transfer where the coolant, which has to be water, is cooled by evaporating about 2-3% of the coolant itself [2].

8. Coefficient of Performance

A basic figure to describe the quality of the conversion of heat into cold is the thermal Coefficient of Performance, COP, defined as the useful cold, Q_{cold} , per unit of invested driving heat, Q_{heat} [8]:

$$COP = \frac{Q_{cold}}{Q_{heat}} \quad (7)$$

The COP of an absorption chiller is shown at Fig 11.

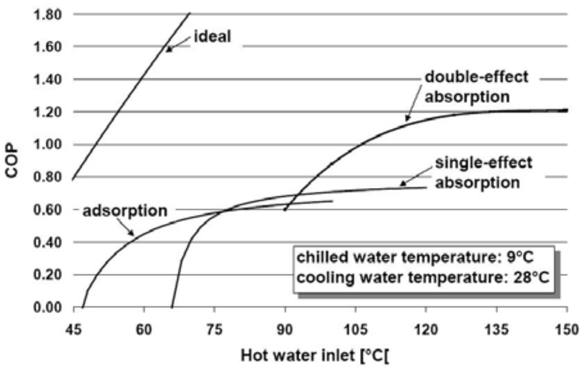

Fig. 11 COP curves of sorption chillers (Source: Henning, H.M., 2005)

8. Economic feasibility

The solar assisted air conditioning system payback period can be calculated based on a simple payback calculation. The payback calculation is subject to the current electricity tariff rate in Malaysia and cost of the solar assisted air conditioning system.

1. Current electricity tariff rate in Malaysia is USD 0.13 per kWh.
2. For 23kW or 6.6RT hot water driven 'BROAD' absorption chiller, the C.O.P is 0.7
3. Assume the operation of air conditioning in small office building is 10 hours per day.
4. Cost of Solar assisted air conditioning system based on 23kW 'BROAD' absorption chiller and evacuated tubes collector is USD 62,857.14.

Based on COP of 0.7, the chiller is running at (0.7 x 23kW) 16.1kW.

The cooling energy cost is 16.1kW multiply by USD 0.13 per kWh which equals to USD 2.07 per kWh per day. For 10 hours of operational time per day equals to USD20.70 per kWh per day.

Therefore, the payback is USD62,857.14 divided by USD20.70 per kWh per day equals to 3036.58 days which is 8.32 years.

The average lifespan of the major components of the solar asssisted air conditioning system like the evacuated tubes solar collector and absorption chiller are generally approximately 20 years. Therefore, there will be a great savings for the cost of electricity after the 8th year. Besides that, this is a green technology and there will be CO2 reductions over the lifespan of the solar assisted air conditioning system. The solar asssisted air conditioning system is only economical when it is applied in the right situation where there is abundant availability of natural heat resources. Tropical country like Malaysia with abundance of annual average of daily solar irradiation of 5.56 kWh/m^2 is ideal for solar assisted air conditioning system application [7].

7. Conclusion

Today although the dominating technology of thermally driven chillers is based on absorption, there are still not many manufacturers that produce small absorption chillers in the range of 50kW down to 5 kW. The well known small absorption manufacturers in the market are 'Yazaki', 'Broad' and 'Thermax' or 'Prochill'. For small office building application, solar assisted air conditioning based on small absorption chiller is highly in demand. It does not only lead to remarkable electricity savings but reduces the environmental impact especially the reduction of CO_2 from the environement. It is vital to maximize the application of the solar thermal energy by not only as driving heat source for the absorption chiller but also providing hot water supply to the users. With both of these usage, the economics viability of solar assisted air conditioning system can be further optimized.

Todate, there are not many installation of solar assisted air conditioning system around the world. This is to show that solar assisted air conditioning system is still at its infant stage. There are still no standardised design guidelines that exist and still lack of operational experiences. It is also important to note that solar assisted air conditioning system requires greater effort during the design phase than a conventional system for the same application [8]. Therefore, field data from monitoring of the solar assisted air conditioning system installation is very important in order to have a better overview of the performance in real operational time of this technology. With the worldwide sales of 69 millions units sold of air conditioning units (up to 20kW) and with the growth rate of more than 4%, small office applications using solar assisted air conditioning system has great future potential [9].

Although solar assisted air conditioning system has a high capital investment but with a payback period of 8 years, it has made this technology a viable investment for both the client and the developer of a small office building development. Finally, in order to promote and expedite on the diffusion of this potential technology, there must be a concerted efforts from both the government and the private sector to bring more awareness of this green technology to the public.

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