CHAPTER II

REVIEW OF RELATED LITERATURE RESEARCH

Solar energy

The annual amount of solar energy incident on the surface of the earth is 795×10^{15} kWh. The radiation intensity outside the earth's atmosphere is between 1300 and 1400 wm^{-2}. This is called the extra-terrestrial radiation. Reflection, scattering and absorption by the atmosphere reduce this value by about 30%, so that about 1000 wm^{-2} is incident on the earth's surface at midday when the sky is clear. The so – called global radiation consists of two components, the direct and diffuse radiation. Direct (or beam) radiation comes directly from the sun, whereas diffuse radiation is incident from all sky directions. The sky thus appears to be equally bright in all directions. The diffuse component can be seen on sunny days as the blue sky. When the sky is completely overcast, only diffuse radiation reaches the surface of the earth.

The quality of the conversion from radiation to useful energy is described by the efficiency value, η, of the process:

$$\eta = \text{Useful energy/radiation on the receiver area} \qquad (2\text{-}1)$$

This quality must be taken into account all of the losses occurring in the system. Often, inadequacies in the systems or devices used to process the energy decisively affect the performance of the whole system.

Two types of solar radiation data are widely available. The first is monthly average daily total radiation on a horizontal surface $\overline{H}$. The second is hourly total radiation on a horizontal surface $\overline{I}$ for each hour for extended period such as one or more year.

In this study, the monthly average daily total radiation on a horizontal surface, $\overline{H}$. The steps of the calculation are as follows: (Duffie and Beckman. 1991:109)

$$\overline{H}_T = \overline{H}\left(1-\frac{\overline{H}_d}{\overline{H}}\right)\overline{R}_b+\overline{H}_d\left(\frac{1+\cos\beta}{2}\right)+\overline{H}\rho_g\left(\frac{1-\cos\beta}{2}\right) \qquad (2\text{-}2)$$

Where:

$\overline{H}$ = the monthly average daily radiation on a horizontal surface , (MJ/m^2.day)

$\overline{H}_d$ = the monthly average diffuse radiation on a horizontal surface (MJ/m^2 day)

$\overline{R}_b$ = the Ratio of beam radiation on tilted surface to that on a horizontal surface

β = the slope of collectors, (Degrees)

ρ_g = the ground albedo, 0.2 (non-snow cover)

- The monthly average daily extraterrestrial radiation, ($\overline{H_0}$):

The monthly average daily extraterrestrial radiation, ($\overline{H_0}$), is a useful quantity. (Duffie and Beckman. 1991 : 40) For latitudes in the range of +60° to – 60°, $\overline{H_0}$ can be calculated from the following equation using n and δ for the mean day of the month from Table 7.

$$\overline{H_0} = \frac{24 \times 3600}{\pi} G_{SC} \left(1 + 0.033 \cos \frac{360n}{365}\right) \times \left(\cos\phi \cos\delta \sin\omega_S + \frac{\pi\omega_S}{180} \sin\phi \sin\delta\right) \quad (2\text{-}3)$$

Table 1 Recommended average days for months and values of n, (Klein. 1977.)

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Date	17	6	16	15	15	11	17	16	15	15	14	10
Day of year(n)	17	47	75	105	135	162	198	228	258	288	318	344

Where

G_{SC} = the solar constant, 1,376 W/m^2

n = the day of the year.

δ = the monthly average solar declination, Degrees

ω_S = the sunset hour angle, Degrees

ϕ = the latitude of location, Degrees

- Clearness Index, K_T

The monthly average Clearness Index, $\overline{K}_T$, is the ratio of the monthly average daily radiation on a horizontal surface to the monthly average daily extraterrestrial radiation which can be defined by: (Duffie and Beckman. 1991: 77)

$$\overline{K}_T = \frac{\overline{H}}{\overline{H}_O} \qquad (2\text{-}4)$$

- The correlation between monthly mean daily diffuse and total radiation, $\frac{\overline{H}_d}{\overline{H}_0}$:

The correlation between the monthly mean daily diffuse and total radiation is introduced by the following equation (Sopin Wachirapuwadon. 1996: 15) :

$$\frac{\overline{H}_d}{\overline{H}_0} = -4.6408 + 26.5495\left(\frac{\overline{H}}{\overline{H}_0}\right) - 28.3422\left(\frac{\overline{H}}{\overline{H}_0}\right)^2 - 31.4546\left(\frac{\overline{H}}{\overline{H}_0}\right)^3 + 46.4421\left(\frac{\overline{H}}{\overline{H}_0}\right)^4 \qquad (2\text{-}5)$$

Where:

$\overline{H}_d$ = the monthly average diffuse radiation on a horizontal surface, (MJ/m^{2}day)

$\overline{H}_0$ = the monthly average daily extraterrestrial radiation on a horizontal surface, (MJ/m^{2}day)

The ratio of the average daily beam radiation on a tilted surface to that on a horizontal surface for the month $\overline{R}_b$ is determined by the following equation: (Duffie and Beckman. 1991: 109)

$$\overline{R}_b = \frac{\cos(\phi-\beta)\cos\delta\sin\omega'_S + (\pi/180)\omega'_S\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega_S + (\pi/180)\omega_S\sin\phi\sin\delta} \qquad (2\text{-}6)$$

Where:

ω_s' =the sunset hour angle for a tilted surface for the mean day of the month given by the following equation:

$$\omega_s' = \min\begin{bmatrix}\cos^{-1}(-\tan\phi\tan\delta) \\ \cos^{-1}(-\tan(\phi-\beta)\tan\delta\end{bmatrix} \text{(Degrees)} \qquad (2\text{-}7)$$

Silapakorn University of Thailand performed a study to measure the total radiation for each province and sub-province region on Thailand. The data was collected by satellite over a one-year period, and the data for Phitsanulok region is shown in Table.

Table 2 The monthly Average Daily Radiation on a horizontal surface

Measure Monthly Average Daily Radiation on a Flat Plate in Phitsanulok, $\overline{H}$ (MJ/m^2)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aus	Sep	Oct	Nov	Dec	Avg
Naresuan	16.1	17.9	20.1	21.4	22.1	21.0	18.6	21.0	18.3	17.5	15.7	15.7	18.6

Evacuated Heat Pipe Solar Collector

The high temperature operation of Evacuated Heat Pipe Tubes (EHPT) and their very low radiant heat losses make them ideal for solar water heating, solar space heating, desiccant air conditioning, thermal driven cooling and industrial process heating applications. The tubular, iron free cover glass tube and vacuum within protect the absorber coating and all structure materials from corrosion and adverse weather conditions. The vacuum tube envelope minimizes heat loss and ensures high collector durability and steady performance. Evacuated Heat Pipe Solar Collectors (tubes) operate differently than the other collectors available on the market. These solar collectors consist of a heat pipe inside a vacuum sealed tube, as shown Figure 1.

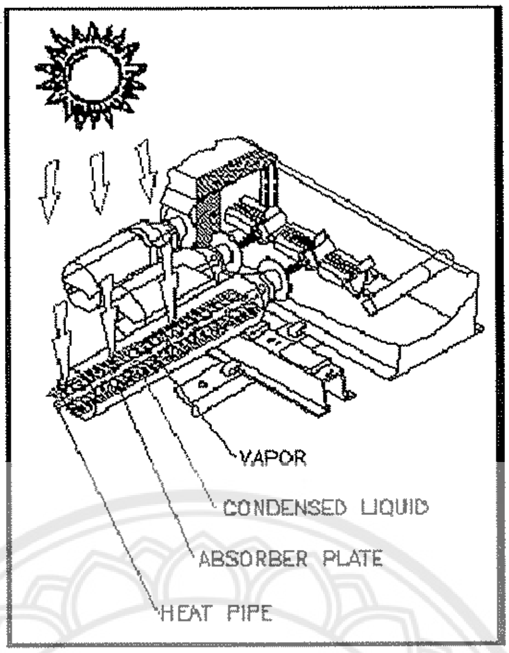

Figure 1 Schematic of Evacuated Heat Pipe Tubes

The heat pipe is an evaporating-condensing device for rapid heat transfer. The latent heat of vaporization is transferred by means of evaporating a water-based liquid in the solar heat inlet region, and condensing its vapor in the discharge region. The heat source is the absorber plate that is continuously bonded to the heat pipe. The condenser (heat discharge region of the heat pipe) is in direct contact with a manifold, which serves as a heat exchange/sink. In addition, the heat pipe has a diode function; i. e. heat transfer is always in one direction - from absorber to the manifold (thus collector to storage tank) and never the reverse.

Tests conducted by Florida Solar Energy Center of USA (FSEC Solar Collector Test Report No. 97005, May 1998) yield to the following thermal performance equations

Linear fit: [1]

$$\eta = 0.82 - 2.19 (T_m - T_a)/G \qquad (2\text{-}8)$$

Second order fit:

$$\eta = 0.81 - 1.23 (T_m - T_a)/G - 0.0122\, G\, [(T_m - T_a)/G]^2 \qquad (2\text{-}9)$$

Where:

T_m = mean collector temperature, $(T_{outlet} + T_{inlet})/^2$(°C)

T_a = ambient air temperature, (°C)

G = Solar irradiance, (W/m^2)

These test results are shown in the following figure 2: [1] (G= 800 W/ m^2)

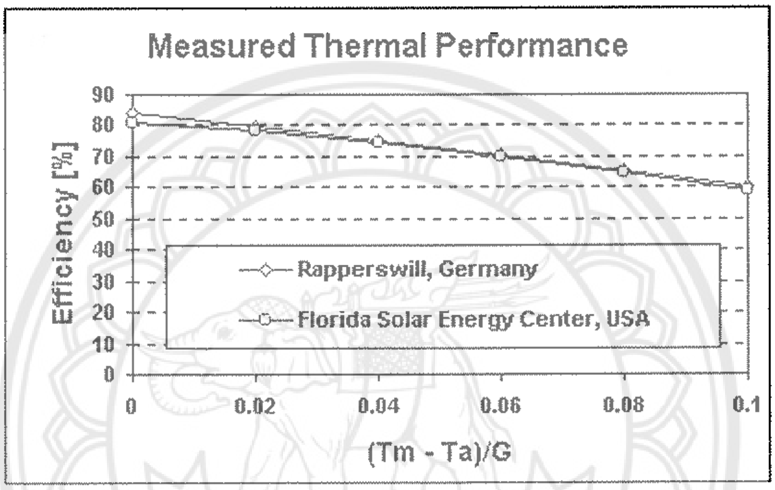

Figure 2 Test results of National and International authorities.

In this work the Thermomax evacuated solar collectors was referenced. The Thermomax collectors are tested by European and North American authorities. The test results of Institute SPF at the Hochschul Rapperswil of Switzerland is in very good agreement with the above of performance test reported.[1]

The practical efficiency of collectors was yielded from mass flow principle:

$$\eta = \frac{Q_u}{A_c I_T} \tag{2-10}$$

Where:

Q_u = useful energy,(KJ)

A_c = area of collectors,(m^2)

I_T = Irradiation on a titled plane, (kW/ m^2)

Technologies for solar-driven cooling

The solar cooling systems under consideration are generally divided into two main categories

1. Closed cycle.
2. Open cycle.

Closed-cycle systems

These types of systems are based mainly on the absorption cycle, which constitutes, thermodynamically, of a heat engine driving a heat pump. In its simplest, single-effect configuration, an absorption system employs a refrigerant expanding from a condenser to an evaporator through a throttle, in much the same way as in the conventional vapor compression system. A second working fluid, the absorbent is employed, which absorbs refrigerant vapor from the evaporator at low pressure, and desorbs into the condenser at high pressure, when heat is supplied to the generator.

The absorption system is hence a heat-driven heat pump; the heat may come from a variety of sources, including solar, waste heat and the like. The system operates between two pressure levels, and interacts with heat sources/sinks at three temperature levels: The low temperature cooling in the evaporator; the intermediate temperature heat rejection in the absorber and condenser; and the high temperature (solar) heat supply in the generator. A variety of working fluids have been proposed; the two most common absorbent–refrigerant pairs are: LiBr–water and water–ammonia.

A key figure to describe the performance of a thermally-driven chiller is the thermal Coefficient of Performance (COP), defined as the produced cold per unit of driving heat. Single-effect absorption systems are limited in COP to about 0.7 for LiBr–water and to 0.6 for ammonia–water. These systems need, however, high temperature collectors, such as evacuated tube or concentrating collectors. The higher cost of the cooling machine and the solar collector should hence be considered.

Most solar-powered absorption cooling projects to-date have utilized single-effect systems, with low-temperature solar collectors. Developments in gas-fired absorption systems in recent years. For LiBr–water chillers, have made available in the market double-effect systems with COP in the range 1.0–1.2. Triple-effect systems are still under development but close to the market, with COP of about 1.7. These systems may be adapted to and employed in a solar-powered installation with high temperature solar collectors. Fig 3 compares the performance of several multi-effects chillers, showing the COP as a function of the solar heat supply temperature for typical single-, double-and triple-effect chillers with the same component size and under the same operating conditions. The corresponding Carnot performance curve is also shown for comparison.[1]

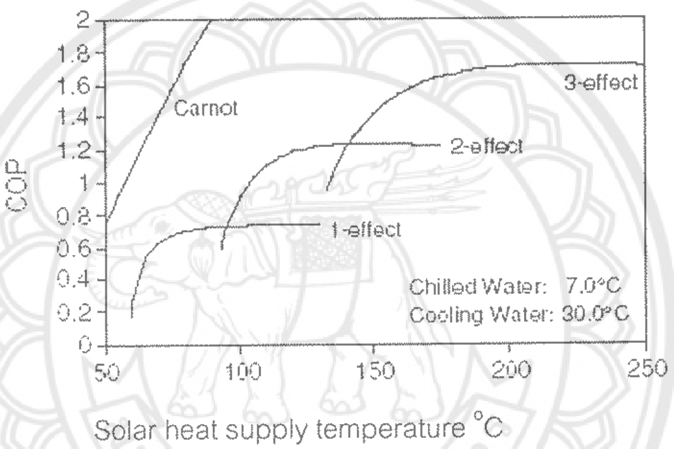

Figure 3 Coefficient of Performance (COP) as a function of (solar) heat supply Temperature for single -,double - and triple-effect LiBr–water absorption chillers.

The single-effect system gives best results in the temperature range 80–100 C; for a higher supply temperature, it is worth switching to a double effect system, up to about 160C, and then to a triple-effect. An advantage of LiBr–water system is in the high boiling point distance between the refrigerant and solvent, so when the refrigerant is expelled from the solution, pure refrigerant vapor develops.

Adsorption chillers working with solid sorption materials are also available. The main difference compared to the absorption systems is that two or more absorbers are necessary in order to provide continuous operation. Adsorption systems allow for somewhat lower driving temperatures but have a somewhat lower COP compared to absorption systems under the same conditions. The simplicity of the process, the wide range of heating temperatures and other advantages such as noiseless operation could lead to a large number of small solar assisted air conditioning applications. Further research and development work on small-size adsorption machines is necessary in order to reduce their volume and increase the power density.

Open-cycle systems

Desiccant systems are essentially open sorption cycles, utilizing water as the refrigerant in direct contact with air. The desiccant (absorbent) can be either solid or liquid and is used to facilitate the exchange of sensible and latent heat of the conditioned air stream. The term 'open' is used to indicate that the refrigerant is discarded from the system after providing the cooling effect and new refrigerant is supplied in its place in an open-ended loop.

In this type of systems the process air is treated in a dehumidifier and goes through several additional stages before being supplied to the conditioned space. The absorbent is regenerated with ambient or exhaust air heated to the required temperature by the solar heat source. Most desiccant systems presently use a solid sorption material such as silica gel. Since the solid desiccant cannot be circulated by pumping, these systems usually employ a rotary bed carrying the absorbent material, referred to as a 'desiccant wheel', to allow continuous operation.

Systems employing liquid sorption materials are less widespread but also available. They have several advantages such as the ability to contain, pump and filter the desiccant, cool during absorption and heat during adsorptions, the possibility of energy storage by means of concentrated hygroscopic solutions.

Of the various continuous absorption solar air conditioning systems, LiBr-H_2O and H_2O-NH_3 are the major working pairs employed in these systems. It is reported that LiBr-H_2O has a higher COP than that of the other working fluids. Though it has a limited range of operation due to the onset of crystallization occurring at the point of the recuperation discharge into the absorber which would stop solution flow through the device. However its low cost and excellent performance make it the favorable candidate for use in solar cooling cycles. For these reasons, the lithium bromide-water system is considered to be better suited for most solar-absorption air conditioning applications.