EFFICIENT METHOD TO COOL THE DATA CENTER USING SOLAR ENERGY

by

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To my family, Professor and friends

I am here and I could do this only because of you all

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ABSTRACT

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Solar energy is the only source which is abundantly available and which can be used to power a cooling system that is based on absorption cycle.

Solar cooling system can be used to provide refrigeration for food and medicines and comfort cooling also. Such systems are specifically applicable to the large applications having large cooling loads for particularly big periods of a year. Peak demand for the cooling of a building and the highest availability of solar radiation are in similar phase, which makes solar cooling of any building a potential energy source and also a green solution.

In this project, The Lithium bromide-water absorption cycle is used because of its lower operating temperature. By considering it as a working fluid a solar absorption refrigeration is designed to cool the datacenter with respect to the weather condition of Texas state. The system is designed in such way that the usage of electricity can be totally eliminated in the sunny days and partially eliminated in the winter, when the solar energy is not available at its full intensity.

Regular vapor-compression cooling systems are expensive as they are powered by electricity and are dependent on fossil fuels. Dropping the use of such systems will also help in reducing their effect on Ozone layer depletion and Global warming.

Now-a-days, absorption chillers deliver almost 50% of the worldwide commercial cooling load. This green solution of solar powered air conditioning system together with thermal storage will help in reducing total electricity consumed and increasing the overall cooling capacity of the system.

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CHAPTER 1

INTRODUCTION

This paper provides a case study to cool a datacenter using solar energy as a primary source of energy.

The aim in writing this paper is to reduce the cost of cooling a datacenter by reducing the consumption of electricity. This system will also be helpful in reducing the usage of vapor-compression air conditioning cycle, which in turn helps in reducing their effect on the Ozone layer depletion and Global Warming. Solar Energy is the primary energy source. Li-Br is the absorber and water is refrigerant in this system. The basic idea is derived by the case study of the university datacenter.

LiBr-water cycle is much suitable with solar applications as the operating temperature is lower. The proof that shows the efficiency of this system includes the whole calculation of solar radiation available for whole year, AC generated by the solar during the day time and total AC required by datacenter for 24 hours.

Chapter 2 introduces the solar energy, various methods for solar energy collections with the types of collectors and their properties. It also describes the solar absorption air-conditioning system with the required temperature conditions.

Chapter 3 deals with the case study, which includes the basic environmental conditions, system description, chiller design conditions, results using system integration and global warming impact estimation. The system description explains the flow rate calculations, heat calculation and estimated hourly solar radiation. System integration will explain two cases for the result: 1. Best case (summer) and 2. Worst case (winter). Furthermore, global warming impact estimation compares three kinds of systems which will result in best TWEI system.

Chapter 4 mentions challenges and barriers for this particular system with the consideration of cost for the particular system.

Finally, chapter 5 concludes the entire research work, which will provide the details about the overall efficiency of the designed system with the pros and cons of the same by comparing it with the traditional system.

CHAPTER 2

SOLAR ENERGY AND ABSORPTION REFRIGERATION SYSTEM

2.1 Solar energy

2.1.1 History

Solar energy is an inexhaustible source of energy. The conversion of solar energy in to the heat was the first discovery in 1767 by a Swiss Scientist named Horace de Saussure. He built the first solar collector, which was later utilized to heat water as well as to cook the food. The commercial patent for this water heater went to the Clarence Kemp in 1891. Furthermore, this water heater was sold to some California executives and finally they are installed in the 1/3rd of the homes in Pasadena in 1897.

Electricity production using solar energy was the second discovery by a French physicist named Edmund Becquerel. In 1839, he realized the effect called photovoltaic effect which can be produced by the suns energy. In 1880's, selenium photovoltaic were developed, which were able to convert light into electricity with the efficiency of 1-2%, but the theory of this conversion was still in dark. Lately, in 1900's, Albert Einstein gave an explanation for this effect and won the Nobel Prize for the same.

In 1908, William Bailey of Carnegie Steel Company made a collector with a copper coil inside the insulated box. Before mid 1950's, Bell Telephone Labs achieved 4% and later 11% efficiency using silicon PV cells. This gave speed to the solar power inventions. Furthermore, photovoltaic came in to the use for the space programs in late 1950's and 1960's. The PV cells were selected for the space application as they were light weight, rugged and were able to meet the electricity requirement [1].

Figure 2.1. First PV cell used in space.

But the cells were not practically usable on the earth as the cost of making them was too high. Fossil fuel is the cheaper and easier source for getting the energy in comparison of the solar energy. Therefore, fossil fuel was the versatile source of energy in those times. However, in last few decades, the energy demand is increased with the increase in the environmental problems and decrease in the fossil fuel sources, which leads world towards the usage of alternative energy options.

The US Department of Energy had installed and tested approximately 3000 PV cells during 1973 1974. By the later time in 1970s, there were lots of investments done in PV industries by the government and energy companies. That accelerated the usage of solar technologies in the industry.

There are only two forms in which solar energy can be used, which are thermal and photovoltaic. Thermal conversion includes conversion of light into heat by concentrating it and producing electricity using steam generator or engines. That heat can be used to heat the water, dry crops, generating the electricity, to warm building

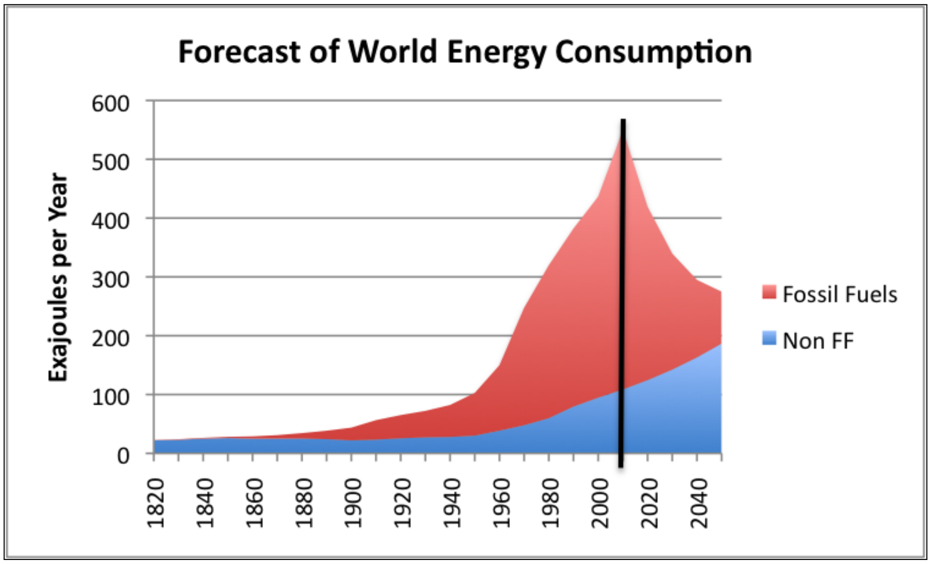

Figure 2.2. World energy consumption scenario.

and also to destroy the dangerous wastes. However, photovoltaic generate electricity directly from the light without using any extra components. The photovoltaic are composed of silicon, which is easily available from the Earths crust. When light strikes the semiconductor material, electric current is generated, which will in turn generates power. Panel is formed of module and module is form of wired cells, which is the smallest unit of the whole system [2].

2.1.2 Global potential energy- solar energy

Solar Energy depends on the nuclear fusion power which converts hydrogen in to the helium. Sun generates sufficient energy in just a minute to provide the worlds total energy requirement for the entire year which is almost 174 Petawatts (PW). From which, almost 70% of energy is absorbed by clouds, land and oceans and approximately and the other is reflected back to the space. The amount of solar energy absorbed by this land, clouds and ocean is around 3850000 Exajoules per year, from which approximately 3,000 EJ is captured by photosynthesis (in biomass) every year. However, the energy available from biomass is around 100-300 EJ/year. Moreover, the solar energy reaching Earths surface in one year is almost twice of the Earths all non-renewable energy sources such as oil, coal, gas, uranium.

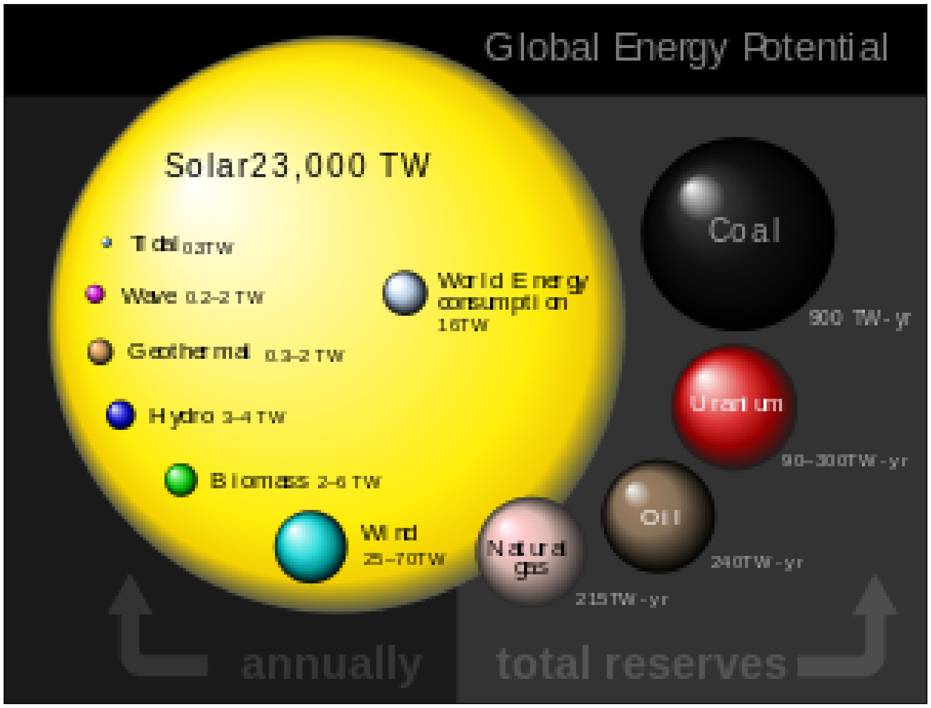

Figure 2.3. Global energy potential.

Solar energy available at particular place can be determined from following three factors:

- Location
- Date
- Time of the day

2.1.3 Utilization of Solar Energy using Solar Collector

The range to utilize solar energy is from domestic uses including water heating using solar collector or attic cooling using solar attic fans to complex applications such as production of electricity using mirrors, boilers/photovoltaic. Solar energy can also be converted in to electrical, chemical and thermal processes which can be finally utilized for power generation, distillation and process heating.

The key component for utilizing solar energy in to different forms is solar collector, which are available in different types according to the temperature required. Solar collector is a device which absorbs solar radiation coming to the Earths surface and converts it in to the required forms such as heat and electricity. This produced heat can be then transferred to the fluids. Finally, this thermal energy can be utilized directly to air-condition a place or can be collected in thermal storage tank for later use at night times when solar energy is not available. Such thermal storage tanks also consist of heating coil to maintain the temperature inside the tank in the case of low solar energy available. Also in the winter time, the water temperature remains too low. In such times, cold water can be directly utilize for the air-conditioning of the room and the heating will be eliminated as solar energy will not be available in enough quantity [3].

There are two types of solar collectors available as follows:

- Concentrating collectors: such collectors are sun trackers in most cases; consist of concave reflecting surfaces to concentrate solar beams to a particularly small area to increase the radiation flux by number of times. There are several techniques used to concentrate the solar rays which can be characterized in five different methods such as Fresnel lenses with solar tracking, holographic tuning, luminescent solar collector, electro wetting and luminescent solar laser (Figure 2.4).

Figure 2.4. Concentrating solar collector.

- Non-concentrating collectors: such collectors consist of fix intercepting and absorbing areas. In this type of collector, the whole solar panel absorbs the light. The flat plate collectors and evacuated tube collectors are the example of non-concentrating collectors.

Figure 2.5. Non-concentrating solar collector.

Table 2.1. Important properties of solar collector

Motion	Collector type	Absorber	Concentration ratio	Temperature
Two-axis tracking	Heliostate field collector	Point	300-1500	150-2000
	Parabolic dish collector	Point	600-2000	100-500
Single axis tracking	Parabolic trough collector	Tubular	10-85	60-400
	Cylindrical trough collector	Tubular	15-50	60-300
	Linear fresnel reflector	Tubular	10-40	60-250
	Compound parabolic collector	Tubular	5-15	60-300
stationary	Evacuated tube collector	Flat	1	50-200
	Flat plate collector	Flat	1	30-80

2.2 Solar Absorption Air-Conditioning system

In traditional absorption air conditioning cycle the key component is fossil fuel fired unit, whereas in solar absorption air conditioning system solar collectors are the key component to supply energy to the generator. The heat generated by the sun can be used directly in to the absorption unit or can be collected first in to the thermal storage tank and then supplied to the absorption unit. The thermal storage tank is a better option for practical purposes as it can be helpful to avoid the intermittent nature of the solar energy. Also, this stored heat can be utilized at night time when the solar energy is not available. Furthermore, such tanks are designed with the heating devices to heat the fluid inside the tank in the case of low solar energy available. Thus, thermal storage tanks are better option in comparison of the direct usage of the solar energy. Buffer tank is recommended if the storage tanks are not available.

There are several cases when solar energy is not available because of the bad weather conditions. As a solution multiple heat sources can be used in combination with the solar heat. These alternatives can be used after careful evaluation of specific needs and requirements.

Table 2.2. Absorption chillers with heat source requirements

Type	COP	Source temperature(^{o} C)	Solar collector matched
Single effect	0.75	98^{o}C hot water	Evacuated tube collector
Double effect	1.4	180^{o}C hot water	Compound parabolic collector
Triple effect	1.8	250^{o}C at 40 bar	Parabolic trough collector

Solar absorption air conditioning system can be categorized in to several options as follow:

- Using fossil fuel or waste heat as a secondary source by keeping the solar energy as a primary source.
- Onsite power with cogeneration.
- Using auxiliary heater as secondary source by keeping the solar energy as a primary source.

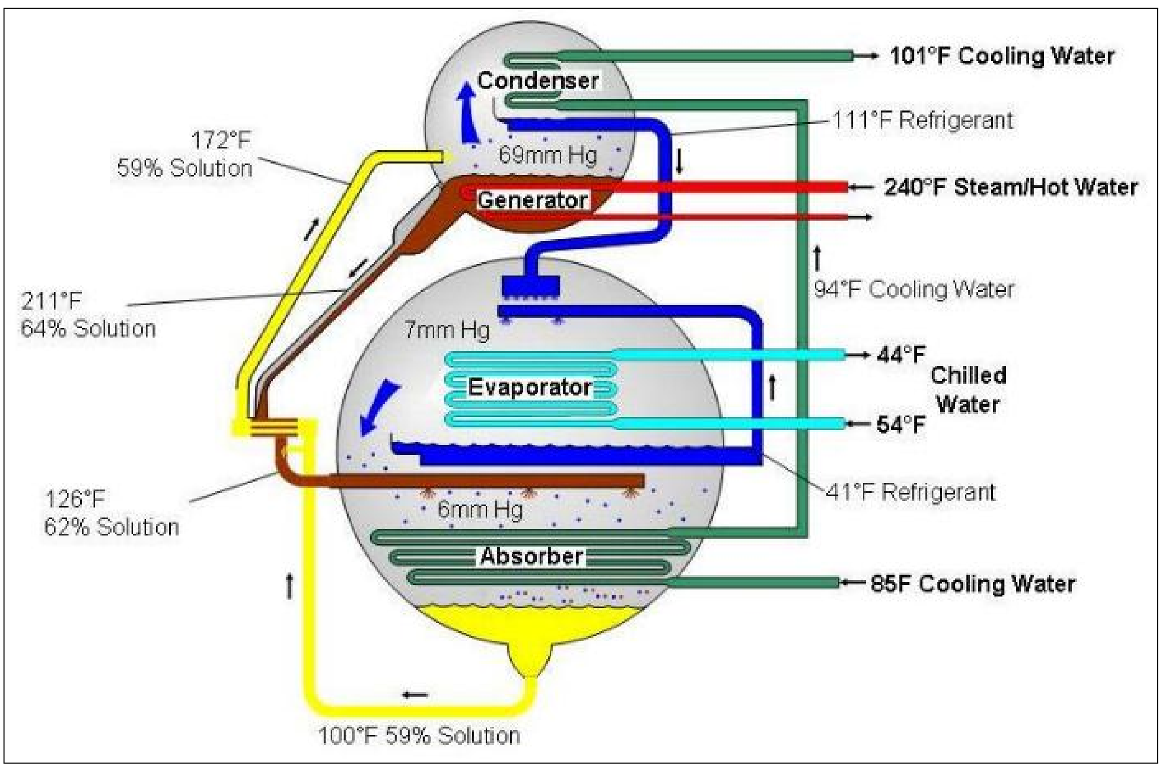

Figure 2.6. Absorption Air-Conditioning System.

Figure 2.6 describes about the complete absorption refrigeration cycle, in which LiBr-H_2O is used as a main fluid. The other possible fluid is H_2O-NH_3. However, LiBr-H_2O used in most cases as its COP is higher in comparison with the other fluids.

CHAPTER 3

CASE STUDY

3.1 System description

The datacenter considered for this case study is a small datacenter under the authority of University of Texas at Arlington, United Status having air conditioning load of 41 TR in its peak hours. This case study consists of the analysis of the suitability of LiBr absorption chiller, which will be operating by hot water generated by the solar collector. Evacuated tube solar collectors are used to produce the hot water to utilize it as a primary heat source.

Total area available on the roof of the building is 6,900 m^2, however out of all this area only 29% area is required for the installation of solar panel that is 2000 m^2. Evacuated tubes are used as they can produce temperature between 75^oC to 120^oC [4].

3.2 Basic parameters

3.2.1 Environmental conditions:

1. Outdoor Air (ASHRAE 1%)

   Design DB temperature: 37.77 ^{o}C (100 ^{o}F) DB

   Design WB temperature: 25.5 ^{o}C (78 ^{o}F); for cooling towers selection

2. Solar Radiation Data

Table 3.1. Monthly Averaged Direct Normal Radiation ($kWh/m^2/day$)

Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Avg
3.06	3.89	4.82	5.4	5.91	6.61	6.77	6.28	5.24	4.51	3.34	2.73	4.88

Table 3.2. Monthly Averaged Daylight Hours (hours)

Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Avg
5.3	5.6	6.61	6.9	7.25	9.16	10.16	9.6	7.6	6.9	5.8	5.16	7.17

3.3 System Calculations

Area available for the installation of the solar panel is 2000 m^2. Hot water required by chiller is at temperature of 98 ^oC. Heat generated using this system can be calculated as follows. AP-30 is considered for this case study as it has maximum number of heat pipes to absorb solar radiations and also suitable for commercial uses as it is able to generate water at boiling temperature. AP-30 consists of 30 heat pipe in one system. We require 3 systems connected in series to produce required temperature. This will generate required temperature by consuming very small area [5].

3.3.1 Flow rate calculation:

- Total area available on the roof for installation of solar panel = 2000 m^2
- Number of panel that can be installed = 2000/18 = 111 panels
- Area for 1 system = 6 m^2
- Total area for 3 systems = 18 m^2
- Flow rate per section = 1.8 m^3/hr
- Flow rate for 111 system = 1.8 x 111 = 199.8 m^3/hr

3.3.2 Heat calculation:

- System Efficiency = 85%
- Annual Averaged direct normal radiations = 4.88 kWh/ m^2/day
- Contour aperture area for 1 system = 3.979 m^2
- Average total heat generated = 4.88 x 3.979 x 3 x 111 x 0.85 = 5496.12 kWh/day

3.3.3 Estimated hourly solar radiations with system integrations:

There are two possible cases for the whole year. 1 Best case and 2 Worst case. Summer will provide result for the best case as it is the only time when maximum solar radiations are available. However, there are several days in the winter when there is no solar radiations are available for the generation of the hot water. Therefore, winter is considered for the worst case possible. This paper consists of the overall analysis for the summer and winter using hourly solar radiation available on the hottest day and coldest day of the year, to provide the overall efficiency of the system. The solar data considered for this case study is from 1990.

Furthermore, the system is integrated with the AC current to get the result about how much external energy is required during both period of time. Thermal storage tank is the best option to replace this AC current as such tanks are combination of insulated tank and heating devices. Therefore, using this heating device, the temperature of water inside the tank can be maintained in the worst case also. Hence, thermal storage tank is the best alternative for the AC current to eliminate the total use of the electricity [6].

1. Summer (Best case)

   following table 3.3, gives the detail about the solar radiation on hourly bases for the entire day and figure 3.1 gives the graphical representation of the same.

Table 3.3. Estimated hourly solar radiations (Best case)

Hr	Solar radiation (kW)	Hr	Solar radiation (kW)
1	0	13	1283
2	0	14	1253
3	0	15	1152
4	0	16	989
5	0	17	773
6	41	18	520
7	205	19	248
8	479	20	59
9	736	21	0
10	958	22	0
11	1130	23	0
12	1241	24	0

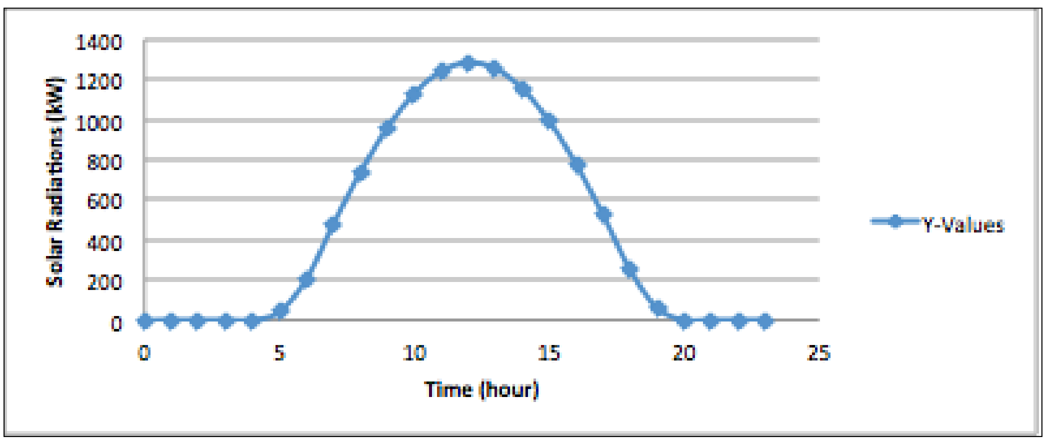

Figure 3.1. Average hourly solar radiations estimate (kW).

There is no solar radiation at night time. Therefore, to get the rough estimation of the amount of electricity required in sun depleting hours system integration is necessary. System integration will provide rough estimation about amount of solar energy generated and compares it with the total requirement of the same during 24hours.

Table 3.4. Estimated hourly air-conditioning

Hr	AC Load	AC by Solar	AC by TES	Hr	AC Load	AC by Solar	AC by TES
1	41	0	41	13	41	266	-225
2	41	0	41	14	41	260	-219
3	41	0	41	15	41	239	-198
4	41	0	41	16	41	205	-164
5	41	0	41	17	41	160	-119
6	41	9	32	18	41	108	-67
7	41	43	-2	19	41	51	-10
8	41	99	-58	20	41	12	29
9	41	153	-112	21	41	0	41
10	41	199	-158	22	41	0	41
11	41	235	-194	23	41	0	41
12	41	258	-217	24	41	0	41

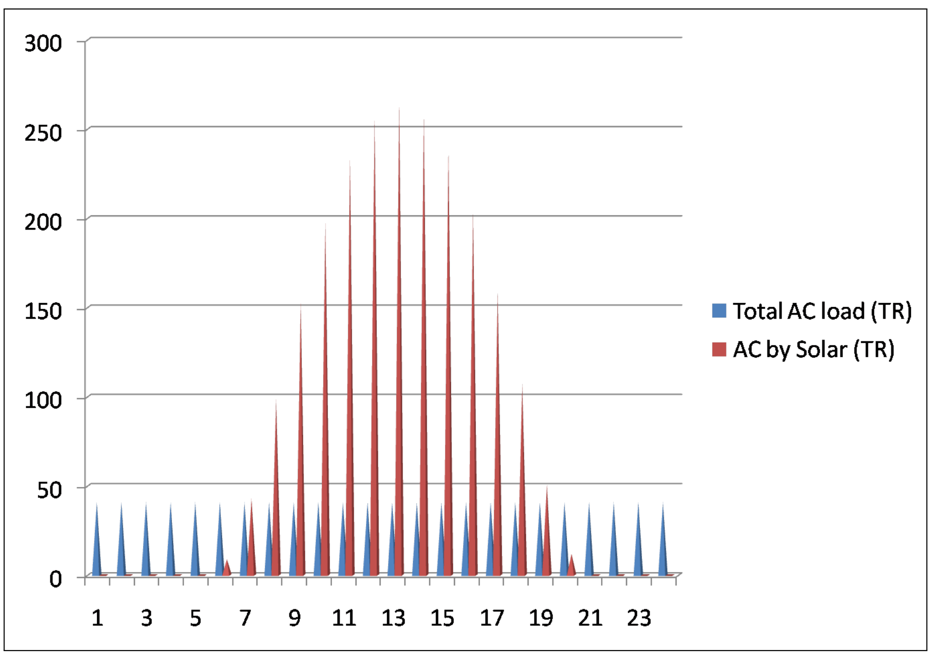

Figure 3.2. Comparison of building air-conditioning load and solar conditioning available.

As shown in table 3.4, The available solar radiations can produce 266 TR of air conditioning at peak solar radiations. The air-conditioning load of the building is estimated to be 41 TR at this time. The surplus cooling produced can be stored in thermal storage tank for use in sun depleting hours.

Total AC by solar in 24 hours = 2297 TR

Actual requirement of AC during 24 hours including both systems = 984 TR

Therefore, the above table shows that the solar energy in the day time only can generate enough cooling for 24 hours. Thermal storage tank utilization makes the whole system 100% efficient in summer time.

The same procedure can be governed for the worst case that is for winter timings. Since, there are many days in the winter, when solar radiations are not available, storage tank is considered to generate the hot water. Such tanks are designed with the heating facility to maintain temperature in cold weather [5]. The coldest day of the year 1990 is considered for the calculation of soar conditioning availability.

2. Winter (worst case)

   There is no solar radiation at night time and very less amount of radiation in day times. The radiation available in day is almost half of the solar radiation available in summer.

Therefore, to get the rough estimation of the amount of electricity required in sun depleting hours system integration is necessary. System integration will provide rough estimation about amount of solar energy generated and compares it with the total requirement of the same during 24hours.

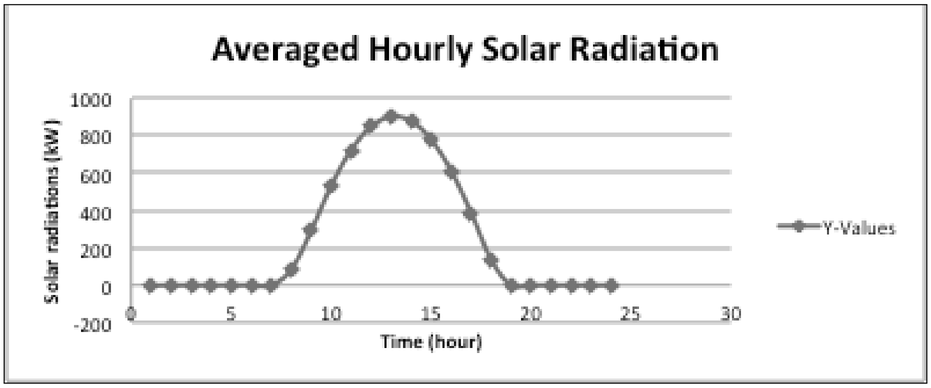

Figure 3.3. Average hourly solar radiations estimate (kW).

Table 3.5. Estimated hourly solar radiations (Worst case)

Hr	Solar radiation (kW)	Hr	Solar radiation (kW)
1	0	13	901
2	0	14	878
3	0	15	778
4	0	16	611
5	0	17	387
6	0	18	136
7	0	19	0
8	83	20	0
9	290	21	0
10	532	22	0
11	722	23	0
12	849	24	0

The available solar radiations can produce 187 TR of air conditioning at peak solar radiations. The air-conditioning load of the building is estimated to be 41 TR at this time. The surplus cooling produced can be stored in thermal storage tank for use in sun depleting hours.

Total AC by solar in 24 hours = 1279 TR

Actual requirement of AC during 24 hours including both systems = 984 TR

Therefore, the above table shows that the solar energy in the day time only can generate enough cooling for 24 hours. Thermal storage tank utilization makes

Table 3.6. Estimated hourly air-conditioning

Hr	AC Load	AC by Solar	AC by TES	Hr	AC Load	AC by Solar	AC by TES
1	41	0	41	13	41	187	-146
2	41	0	41	14	41	182	-141
3	41	0	41	15	41	162	-121
4	41	0	41	16	41	127	-86
5	41	0	41	17	41	80	-39
6	41	0	41	18	41	28	-13
7	41	0	41	19	41	0	41
8	41	17	24	20	41	0	41
9	41	60	-19	21	41	0	41
10	41	110	-69	22	41	0	41
11	41	150	-109	23	41	0	41
12	41	176	-135	24	41	0	41

the whole system 100% efficient in summer time.

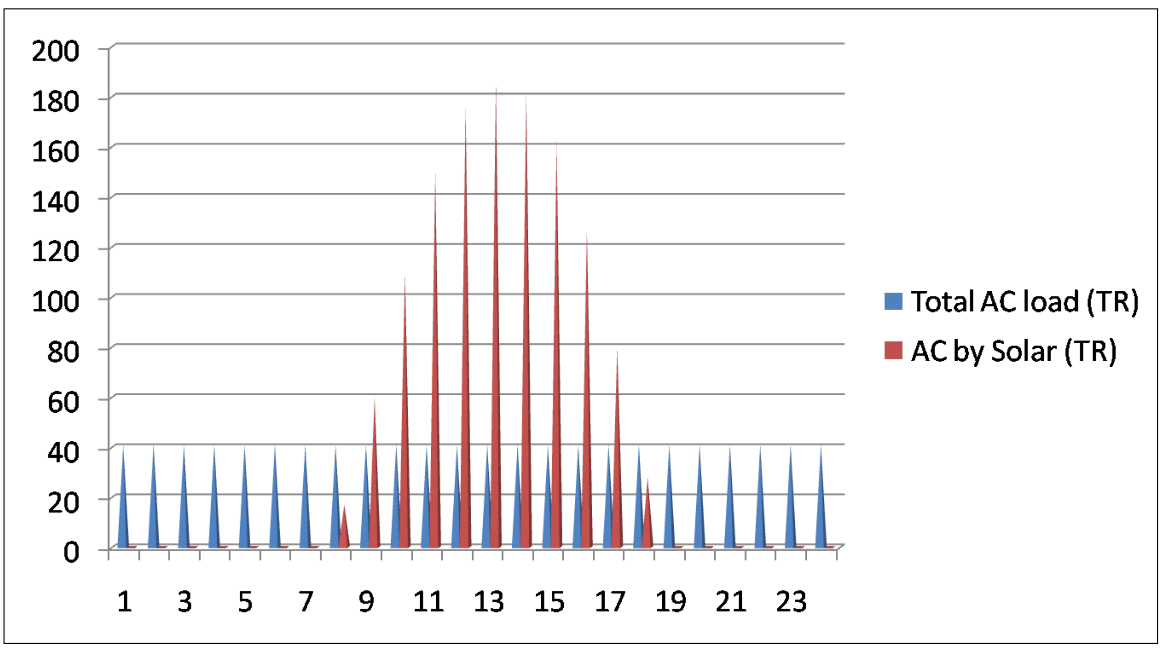

Figure 3.4. Comparison of building air-conditioning load and solar conditioning available.

3.3.4 Chillers

Solar radiation available in both cases can produce maximum 266 TR of air-conditioning at peak hours. Therefore, chiller of 300 TR capacity is selected for this particular case study to generate required hot water [7].

Nominal capacity (TR)	Chilled water			Condenser water			Hot water		
	Flow (1/s)	LWT (ºC)	EWT (ºC)	Flow (1/s)	LWT (ºC)	EWT (ºC)	Flow (1/s)	LWT (ºC)	EWT (ºC)
300	95	7	12	198	37.5	32	65	88	98

Figure 3.5. Chiller nominal design conditions.

The chiller of 300 TR requires 181.15 m^3/hr and 1055 kW at 100% capacity operation. This implies that the available flow of 199.8 m^3/hr and 5496.12 kW h/day is sufficient for the chiller operation and system can be run for minimum 5 hours on solar hot water at 100% capacity.

3.4 Global Warming Impact Estimation TEWI Calculations

Total equivalent warming impact (TEWI) is an estimation to determine indirect and direct global warming potential of any equipment. The indirect components are related to the production of CO_2 to power the equipment whereas the direct components are the release of the refrigerant to the atmosphere.

The concept of global warming impact estimation is developed for the comparison of the ability of greenhouse gas to trap the heat in atmosphere with the effect of

CO_2. The value of GWP varies according to the time frame considerations.

TEWI = Direct global warming potential + Indirect global warming potential

Direct global warming potential = [GWP x L x n] + [GWP x m x (1-a)]

Where,

L = leakage rate per year, kg

n = system operating time, years

m = refrigerant charge in the system, kg

a = recycling factor

Indirect global warming potential = n x Eannual x b

Where,

n = system operating time, years

Eannual = energy consumption per year

b = CO_2 emission per kWh energy production, kg

TEWI calculation for the above case study is compared with the typical HFC 134a system and direct fired absorption system in table3.7

Table3.7 shows the difference between all three systems is huge.

Table 3.7. TEWI calculation

Sr No	Parameter	Solar absorption system(LiBr-water)	Direct fired absorption system (LiBr-water)	Vapor compression system(R134a)
1	Capacity	550 TR	550 TR	550 TR
2	Years of operation	25 years	25 years	25 years
3	Operation per year	3600 hrs	3600 hrs	3600 hrs
4	Power consumption	20 kW	20 kW	0.65 kW/TR
5	Refrigerant charge	5000 kg, water	5000 kg, water	550 kg
6	Leakage rate	N/A	N/A	0.5%
7	Recycling factor	N/A	N/A	0.75
8	Co_2 emission	0.65 kg/kWh	0.62 kg/TR-hr	0.65 kg/kWh
9	GWP_{100} for refrigerant	N/A	N/A	1430
10	Direct effect, kg of co_2	0	0	294,940
11	Indirect effect, kg of co_2	965,250	30,660,495	20,913,750
12	Net TEWI, kg of CO_2	965,250	30,660,495	21,208,690

The CO_2 emission for solar absorption system is almost 3% of direct fired double effect absorption chiller and 5% of vapor compression system. Furthermore, it is proved that the major environmental impact is because of the indirect effect only [8].

CHAPTER 4

CHALLENGES

The main two challenges are intermittent nature of solar energy and fossil fuel prices. However, these can be overcome by storage of energy and incentives provided by the government. But, the other challenge is installation cost for the solar energy is 2 to 2.5 times higher than the conventional electric chillers. This can be overcome by lower component cost. It can also be reduced by proper planning and designing of the system. There are some other challenges as follows [9]:

4.1 Technical barriers

Technical barriers include the hardware and software part of the system. Thus, technical barriers can be listed as follows [10]:

1. Lack of small capacity units.
2. Low coefficient of performance
3. Lack of package-solutions for residential and small commercial applications.
4. Lack of skills in the professionals
5. Design of hydraulic system is not yet standardized
6. Lack of proper planning guidelines and simple design tools for the planners.
7. Less number of solar collector available for medium temperature range(100-250^oC), which will drive to double and triple effect chillers.

4.2 Lack of awareness

The technology is still developing, however as the solar cooling system become more standardized, the lack of awareness by the consumers and professionals are becoming the main barriers in the growth [11].

4.3 Cost

The barriers related cost can be listed as follows [12]:

1. Higher investment cost in comparison with the conventional cooling system.
2. It has developed in a very big scale, yet it is not cost effective from a business point of view.
3. Often neglected in financial intensive schemes for solar thermal.

CHAPTER 5

CONCLUSION

With the help of thermal storage tank, solar absorption air-conditioning system can generate 100% building cooling load. The excess heat generated in day time can be utilize during night, evening and early morning using storage tanks.

The payback of this system is dependent only on electricity rates, peak charges and the availability of solar radiations. It is assumed that the payback time will be significantly shorter in future as the fuel prices and electricity charges are increasing. Furthermore, the development and research in solar energy is going on, which will make solar energy cheaper.

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