Annex 3

Technical and Economical Study on Solar Thermal Cooling

IR. LEONG SIEW MENG, P. ENG, GREEN TECH SOLUTIONS, INC.

1. Introduction

Most of the Association of Southeast Asian Nations (ASEAN) have hot and humid climates. Due to the climatic conditions and the demand for thermal comfort, energy consumption for air conditioning in buildings takes up the largest share in the energy requirements of buildings. As the region's economic activities and population increase, the demand for energy consumption for buildings in ASEAN countries will increase. ASEAN countries like most other countries in the world are diversifying and decarbonising energy supply. Such a trend and a reduction on the reliance on fossil fuels stems from the region's quest for improvement in energy security, an increase in renewable energy for greater sustainability, and a reduction in greenhouse gas emissions while meeting the demand for improvement in standards of living and hence, thermal comfort. Therefore, using solar thermal cooling, one of the renewable energy options, will improve the stability of electricity grids by reducing electrical energy consumption and peak power demand.[1]

This study explores the indicative viability of harnessing solar energy to supplement the generation of chilled water through solar thermal hybrid chiller systems and solar photovoltaic (PV) hybrid chiller systems.

2. Solar Energy

There is an abundance of solar energy in varying degrees in a typical hot and humid climate. The International Energy Agency (IEA) reported in 2015 that the estimated total capacity of solar thermal collectors in operation worldwide by the end of 2014 was 406 GW_{th} or 580 million square metres of collector area. This corresponds to an annual collector yield of 341 TWh, which is equivalent to savings of 36.7 million tons of oil and 118.6 million tons of CO_2.[2] Compared with other forms of renewable energy, solar heating's contribution in meeting global energy demand is, besides the traditional renewable energies like biomass and hydropower, second only to wind power (at 735 TWh).[2] In terms of installed capacity, solar thermal leads, wind power is second at 370 GW_{el}, and photovoltaic is third at 177 GW_{el}.[2]

Solar energy is harnessed in essentially two ways for useful applications – 1) capturing light rays of solar energy through solar PV panels for electricity generation; 2) harnessing solar thermal energy through solar collectors for the production of hot water for heating purposes and, alternatively, for the generation of chilled water through absorption chillers for air-conditioning purposes.

Solar PV electricity generation has been promoted and implemented in the region. Production of hot water through solar collectors for process heating and shower purposes is also fairly well established in the region. However, production of hot water for the purpose of generating chilled water for the air-conditioning systems in buildings has yet to be nurtured into market acceptance.

By comparison, solar PV electricity generation is more straightforward, but only less than 35 percent of the available solar energy is harnessed for conversion to electricity, whereas the remaining 65 percent is converted to the non-useful heating of solar PV panels.[3] On the other hand, a solar thermal cooling system is capable of absorbing more than 95 percent of incident solar radiation[3], depending on the medium used in the system. Therefore, it may be worthwhile to consider harnessing solar thermal energy for the generation of chilled water.

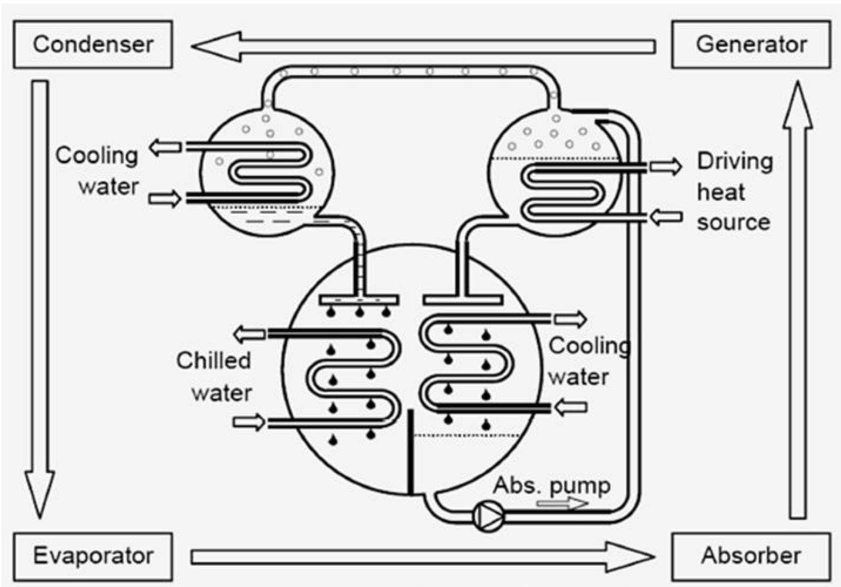
However, in terms of real-world application, solar thermal cooling system is unable to cope with daily cooling load requirements because of the limitations of solar cooling systems. The following sections will outline the basic working principles of solar thermal cooling and will discuss the merits and limitations of solar thermal cooling systems.

3. Solar Thermal Cooling

Solar thermal cooling is based on the application of the absorption cycle instead of the conventional compression cycle in refrigeration. The conventional refrigeration system has four basic functions – evaporation, compression, condensing, and throttling-expansion cycles, whereas the basic solar thermal cooling system or solar thermal absorption refrigeration technology[2] is based on single-effect absorption cycle, which has the following four basic functions:

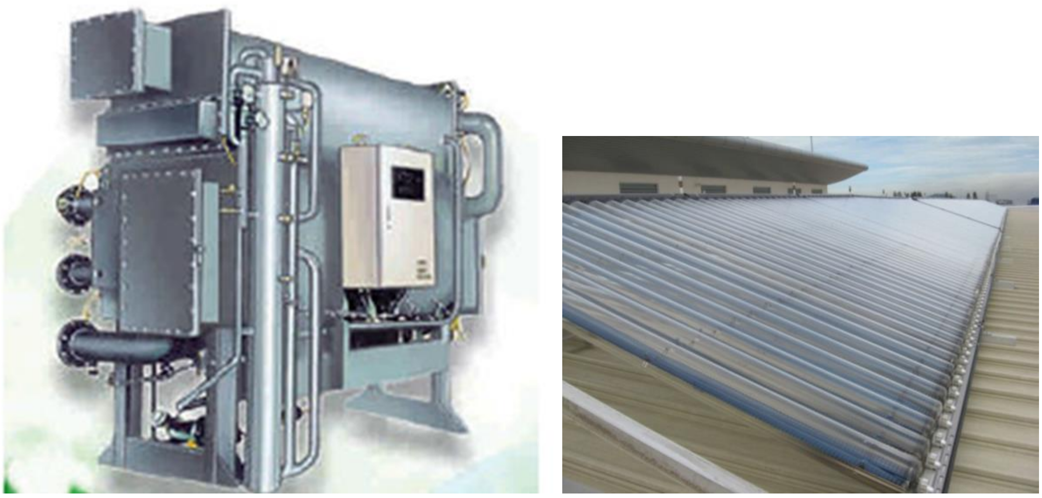
- Evaporation
- Absorption
- Generation
- Condensing

Figure 1. Flow Diagram of Solar Assisted Single-effect LiBr-$H_2$0 Absorption Cycle



Source: Edison Kong, SDC District Cooling Sdn. Bhd.

Figure 2. Absorption Chiller and High-efficiency Evacuated Tube Solar Collectors



Source: Edison Kong, SDC District Cooling Sdn. Bhd.

The main components of a solar thermal cooling system are the absorption chiller and high-efficiency evacuated tube solar collectors, as illustrated in Figure 2. Solar thermal cooling systems have the potential to be used in commercial and office buildings, where the timing of demand for air-conditioning coincides with the greatest availability of solar radiation in hot and humid climates and most cooling is required during the day. In hot and humid climates, air-conditioning takes up the largest share of energy use in buildings. Solar air-conditioning facilities can reduce the peak load demand for electricity and this certainly considerably reduces infrastructure costs; otherwise the transmission and distribution assets need to be sized up to cater for the greater peak electricity demand. This will also result in significant reductions in greenhouse gas (GHG) emissions.

The generation of chilled water from solar thermal cooling systems is subject to weather conditions and sunshine hours, but the latter should have minimal impact in most ASEAN countries where the daylight hours are relatively long. And unlike solar PV, evacuated solar collectors are able to harness solar thermal energy with reasonable efficiency, even in overcast or diffuse sunlight conditions. Nevertheless, solar thermal cooling systems will not be able to function like conventional electric chillers, which can provide relatively quick start-up in the generation of chilled water as required in the morning and in fluctuating cooling load demand scenarios, and of course as required for the cooling load demand at night.

Therefore, despite the advantages of providing thermal cooling by harnessing the free solar energy source, it is necessary to consider the solar thermal hybrid chiller system, which is a solar thermal cooling system combined with a conventional electric chiller, to address the limitations of using only a solar thermal cooling system. A solar thermal hybrid chiller system captures the best of both solar thermal and electric usage by installing an absorption chiller as the main equipment in the solar air-conditioning system in parallel with an electric vapour compression system. This system is hereafter referred to as Option 1. The second option (Option 2) is to install a solar PV hybrid chiller system, which comprises of a solar PV system and conventional electric chiller.

4. Economic Comparisons

Having identified two possible options of harnessing solar energy for air conditioning in buildings, two case studies in economic comparisons of the additional investments that would be incurred in various configurations of solar thermal hybrid chiller systems and solar PV hybrid chiller systems were conducted. These two case studies were based on hypothetical installation and operational costs in Malaysia, and simulation of various configurations and refrigeration capacities. The objective of these case studies was to obtain an indication of economic viability of the two possible options discussed above for the harnessing of solar energy in generating chilled water for air conditioning in buildings. To make an economic comparison of these two options, the refrigeration capacity of the respective chillers were made identical. The capacities of the electric chiller, solar thermal chiller system, and solar PV system in various configurations were arbitrarily selected.

4.1. Option 1 – Solar Thermal Hybrid Chiller System

Table 1 summarises an economic comparison of additional investments in various configurations of a solar thermal hybrid chiller system, based on estimated equipment costs, operational costs, and electricity tariff C2 (medium voltage peak/off-peak commercial tariff) in Malaysia.

Table 1. Economic Comparison of Additional Investments in Various Configurations of a Solar Thermal Hybrid Chiller System

Electric Chiller	90 RT	235 RT	175 RT	350 RT	250 RT
Solar Thermal Chiller System	50 RT	75 RT	135 RT	150 RT	250 RT
Additional Investment (RM)	630,000	982,500	1,690,100	1,788,000	2,587,500
Additional Annual O&M Costs (RM)	14,700	22,050	37,989	39,195	60,938
Energy Saving (kWh)	113,278	172,288	311,360	340,502	578,336
Net Energy Cost Saving (RM)	39,251	53,772	99,066	116,192	202,143
% Energy Saving	16.7	13.9	25.1	16.0	27.1
Simple Payback Period (years)	16.1	18.3	17.1	15.4	12.8
IRR	2%	1%	2%	3%	5%

RT = refrigeration ton; RM = ringgit; kWh = kilowatt-hour.
Source: Analysed by Ir. Leong Siew Meng under the guidance of Shigeru Kimura, based on inputs from Solar District Cooling Sdn. Bhd.

Table 1 shows some interesting findings. The higher share of a solar thermal chiller system in refrigeration capacity provides greater energy saving potentials (>27 percent for large refrigeration capacity), which seems to be more economically viable than the lower capacity of a solar thermal chiller system. However, the overall viability of installing a solar thermal hybrid chiller system is still low with a relatively low internal rate of return (IRR) and a relatively long payback period. It should be noted that the estimated net energy cost savings were based on the Malaysian electricity tariff, which contains energy subsidies from the Malaysian government. Therefore, the IRR and payback period will improve in countries with high energy costs and no energy subsidies.

4.2. Option 2 – Solar PV Hybrid Chiller System

Table 2 summarises an economic comparison of additional investments in various configurations of a solar PV hybrid chiller system.

It shows some interesting findings. The energy saving potentials of a solar PV hybrid chiller system do not appear to be as high as that of Option 1. The energy savings in the solar PV hybrid chiller system are due to the electricity generation by the solar PV system to supplement the electricity needed to operate the electric chiller. The energy savings estimated in Option 2 did not take account of the degradation factor, which is prevalent in solar PV panels. Therefore, the energy saving potential of Option 1 is more promising.

However, the economic viability of the solar PV hybrid chiller system seems to be better than Option 1. This is the case because the present market scenario favours the solar PV system due to its growing market acceptance and relatively lower costs compared with the solar thermal chiller system.

Table 2. Economic Comparison of Additional Investments in Various Configurations of a Solar PV Hybrid Chiller System

Electric Chiller	90 RT	235 RT	17511.2 RT	350 RT	250 RT
Solar PV System	50 RT (36kW)	75 RT (54kW)	135 RT (97kW)	150 RT (107kW)	250 RT (179kW)
Additional Investment (RM)	292,250	412,875	708,718	883,575	1,276,125
Energy Saving (kWh)	39,325	58,988	106,178	117,975	196,625
% Energy Saving	5.8	4.7	8.5	5.5	9.2
Energy Cost Saving (RM)	27,052	40,578	73,040	81,156	135,260
Simple Payback Period (years)	10.8	10.2	9.7	10.9	9.4
IRR	7%	8%	8%	7%	9%

RT = refrigeration ton; kW = kilowatt; RM = ringgit; kWh = kilowatt-hour.
Source: Analysed by Ir. Leong Siew Meng under the guidance of Shigeru Kimura, based on inputs from Solar District Cooling Sdn. Bhd.

5. Potential Market Outlook

Solar thermal cooling is still a niche technology and its presence is relatively insignificant in ASEAN countries, although the region has excellent solar resources and huge air-conditioning requirements due to climatic conditions, population growth, economic, and urbanisation developments. Based on the current market scenario, multiple market barriers, mostly economic, prevent the technology from achieving market penetration.[5] The following summarises the market barriers:

- Low electricity prices, especially in Malaysia, Indonesia, and Brunei Darussalam
- High capital costs in solar cooling systems
- Low costs in conventional air conditioning for low capacities such as split-unit air conditioners
- High maintenance costs due to lack of trained serviced personnel experienced with solar cooling
- Low number of installed solar cooling systems
- Solar cooling system complexity

However, market potentials and opportunities may be developed under the following scenarios:

- The barriers mentioned in the above are addressed, especially with improvement in the economics of solar cooling systems (lower capital costs, etc.)
- Advancement in the technology, especially with improvement in Coefficient of Performance (COP) of the small to medium capacity of solar cooling systems
- Greater support from governments and vigorous promotion of the technology
- Incentives for peak power savings
- Recognition and incentives for harnessing of solar thermal energy as RE (renewable energy)

- Financing mechanism for solar thermal cooling systems
- Encouragement to building owners to adopt green building certification programmes that give recognition to solar thermal cooling

6. Conclusion

The solar thermal absorption refrigeration technology is not new, but unlike other solar energy systems such as the solar hot water system and solar PV system, it has yet to make major inroads into market acceptance. This study suggests it is technically feasible for the solar thermal hybrid chiller system, comprising of the solar chiller system and the conventional electric chiller, to cater for both the base-load and fluctuating cooling load requirements of a building. However, it is economically unattractive under the present capital and operational cost scenarios in Malaysia, as the IRR is relatively low compared with the alternative option in solar PV hybrid chiller systems. The commercialisation of solar thermal hybrid chiller systems is still in its early stages.

It should be noted that the extent of energy savings achievable by the solar thermal hybrid chiller systems (Option 1) is substantially higher than that of the solar PV hybrid chiller system (Option 2), which is expected as a solar thermal cooling system is capable of absorbing more than 95 percent of incident solar radiation compared with only up to 35 percent of the available solar energy[3] being harnessed for the conversion to electricity in the Option 2 technology.

Based on this study, it is concluded that the solar thermal cooling system is currently not competitive in terms of economic cost compared with the solar PV hybrid system due to its high capital and operation and maintenance costs. However, a solar thermal cooling system can provide greater electricity savings than a solar PV hybrid system. It is apparent from Table 1 that larger commercial installations of solar thermal chiller systems are more viable than smaller units. Market barriers, market potentials, and opportunities are discussed. The main barriers to implementation of solar thermal cooling are essentially economic and concerted efforts by all parties are required to tap into the benefits of solar thermal cooling for the population in hot and humid climates such as those of the ASEAN region.

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