

Recent Development of Solar Cooling in Hong Kong

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Abstract

With the gradual reduction of available fossil fuel reserves and the impact on the environment of fossil fuel use, renewable energy is becoming increasingly important. Unlike fossil fuels, such as coal and oil, renewable energy will never be run out. It is abundant in the environment and can come from the sun, wind, running water, waves and biomass. Many places worldwide have established government policy in promoting the use of renewable energy. Solar and wind energy, in particular, hold much promise in Hong Kong. Comparing with other renewable energy, solar energy utilization is often the prior across the various measures. It is because the cooling demand of a building is higher when the sunshine is stronger. Solar cooling is able to reduce summer peak electricity demand and to improve the quality of life at the remote area where electricity supply is inadequate. In the tropical area of the Asia Pacific like Hong Kong, air-conditioning is in need all the year round, the use of solar cooling up to now is very occasional. Indeed, solar refrigeration technology with the use of absorption chiller had been developed since 1970s', the technology has been extended to multi-stage systems.

Solar energy research and applications have been receiving increasing attention throughout the world as solar energy is playing a much greater role in the Hong Kong. In this paper, new development, application as well as challenges in solar cooling will also be discussed.

Keywords: Energy, Solar Cooling, Renewable Energy

1. Introduction

Many countries have established a government policy in promoting the use of renewable energy in response to control the deteriorating global warming and urban environment problems, such as urban heat island effect. In Hong Kong Policy Address 2009, Chief Executive suggests promoting green and quality living area, the government who will develop and wider use of renewable energy. In particular, the government will lead to enhance energy efficiency, use clean fuels, rely less on fossil fuel and promote a low carbon economy - an economy based on low energy consumption and low pollution emission, hence, the application of solar energy is positioned the first place in the renewable energy strategy.

In the world commercial market, the solar collectors are overwhelmingly, over 90% is used for water heating [1]. Solar air-conditioning system is considerable a new technology in solar engineering, however, it is particularly suitable used in those lower latitude countries where the solar energy is plentiful and relatively stable like Tunisia. Nevertheless, comparing to the Asian countries in the higher latitudes like Japan and Korea, the drives into solar energy utilization in the warm and hot humid region has been inadequate in the past. Together with the continuous demands on improving the quality of life, especially in the rural and remote area, the outcomes has been increased share of energy consumption in buildings, more than in any other sectors. Because of these, the popularity in solar energy applications in buildings is expected highly effective in reducing the fossil fuel consumptions in the coming 21st century.

The demands as well as the cost of energy are increasing rapidly over the world, particularly in Hong Kong. In fact, more than 20% of energy consumption is used for space conditioning in domestic and commercial buildings which have gained an increasing interest during latest years due to the rising demand for efficient energy use and getting higher comfort standards [2]. The air-conditioning systems use compression machine drive which are energy wasteful and have impacts on the stratospheric ozone depletion due to the chlorofluorocarbons (CFC) and the hydrofluorocarbon (HCFC) refrigerants. They contribute also to the increase of environmental pollution and global warming through releases of refrigerants and greenhouse gases resulting for electricity generation by burning of fossil fuels.

In this respect, international research is moving in two main directions. The first focuses on the building itself, aiming to minimize heat gains through the building envelope and to simultaneously maximize the use of natural heat sinks. Whereas the second is concerned by the development of technologies that can offer reductions in energy consumption, peak electrical demand and energy costs without lowering the desired level of comfort conditions.

Solar cooling is an attractive alternative since it has the advantage of removing the majority of harmful effects of traditional refrigeration machines and that the peaks of requirements in cold coincide most of the time with the availability of the solar radiation. The possible use of solar energy as the main heat input for a cooling system has led to several studies of available cooling technologies. At present, various types of solar-powered systems are available for cooling applications [3]. In Europe, in recent years, more than 50 solar-powered cooling projects in different

climatic zones were surveyed and analysed to identify future needs and evaluate the overall prospects of solar cooling [4]. One wide-spread application of a solar-powered system is for absorption cooling that is largely thermally driven and requires little external work.

People will also understand the cooling demand of a building is higher when the sunshine is much stronger. Solar cooling is able to reduce the peak electricity demand in summer and to improve the quality life at the remote areas where electricity supply is inadequate. In the tropical area of the Asia Pacific though air-conditioning is in need all the year round, the use of solar cooling up to now is very occasional. In this paper, the author will explain the development, application and challenge in adopting absorption solar air-conditioning system in Hong Kong.

2. Outline of Paper

A brief description of energy use in Asia Pacific nations and its electricity consumption from 1997 to 2007 are presented in Chapter 3. In Chapter 4, a weather data obtained from Hong Kong Observatory is analyzed and the result is also described in this Chapter. Also, working mechanism of solar collector is introduced in Chapter 5. In the next chapters, basic principle of absorption cycle used in air-conditioning system is outlined. Based on the available technology in the industry, utilization of solar cooling with absorption refrigeration is detailed and its potential benefits are explained in Chapter 7 and 8 respectively. In Chapter 9 and 10, the paper is summarized current development of solar absorption system and further work is suggested.

3. Energy Use in Asia Pacific Nations

Generally energy consumption in the world is keeping continually growing in almost all its forms. There is no sign for this trend to reverse. From 1970 to 2000 the primary energy consumption increased from 4,900 to 8,752 million tons of oil equivalent in the world, which was an increase of 79% in 20 years. It is worth notice that within the Asia Pacific, the rate of increase of primary energy consumption in the warm and hot climate region was on the high side. Figure 1 shows the trend of energy consumption in various locations in 1997 to 2007 in the world. The rate of increase in China, Republic of Korea and Chinese Taipei were respectively 189%, 85% and 70%. China is much higher than the overall increase rate of the region. In Asia Pacific, the increase rate, no doubt, is a parameter closely related to the affluence and the economic growth of a region. It is well known fact that the industrial productivity as well as the city modernization consumes energy in various forms, such as higher growth in Gross National Product (GNP) or Gross Domestic Product (GDP) will result higher energy consumption. Yet, the consumption is also a reflection of the energy policy of a nation in response to the global challenges and responsibility in fighting against excessive carbon dioxide (CO₂) emissions and industrial wastes as the key elements leading to global warming and environmental deterioration. It is a challenge of the fast-developing Asia Pacific region to achieve a high economic growth with less energy consumption as well as pollution emission.

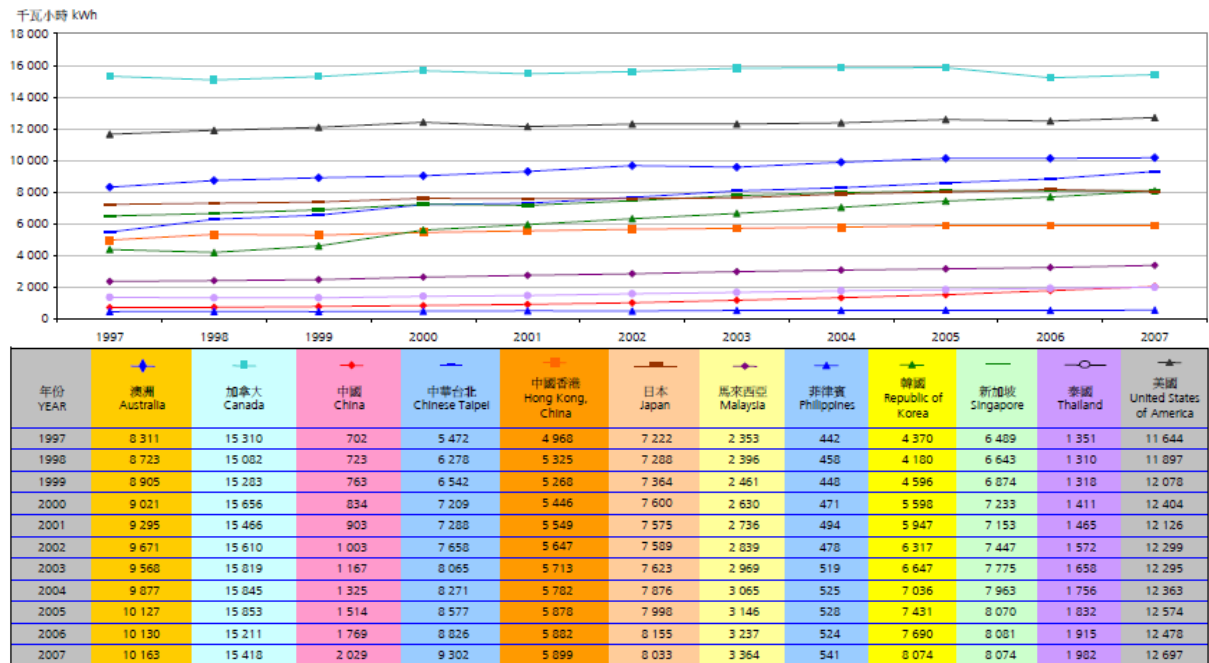


Figure 1 – Electricity consumption per capita (Unit: kWh)
(Source: APEC Energy Statistics 2007) [2]

For the case of Hong Kong, it increased 19% energy consumption from 1997 to 2007. According to current updated date made by Electrical and Mechanical Services Department, over 20% and 24% of energy were used for air-conditioning in domestic and commercial segment respectively, which was the major contributor in total power consumption in 2008 [2].

4. Climate and Energy Considerations in Hong Kong

Solar intensity on surfaces varies with geographical and environmental conditions. The availability is limited to the daytime, and may not be in line with the energy demands in buildings, such as for space conditioning. In many applications, such as in solar energy technologies, an accurate climatic database is needed. In these applications, the accuracy of solar radiation and ambient air temperature are crucial. Hong Kong has a sub-tropical climate characterized by a relatively high level of the solar resource at the country side. It is located at 22°18' latitude and 114°10' longitude and received an annual average of 1.29MWh/m² (4.65GJ/m²) global horizontal radiation. It receives an average of 12.82MJ/m²/day with a total insolation period of 1,800 hours per year [5].

Both the increase in the concentration of suspended particulates and the increase in cloud amount would reduce the amount of solar radiation reaching the surface. The amount of solar radiation reaching the surface is recorded continuously by thermoelectric pyranometers from the Hong Kong Observatory's King's Park Weather Station. Between 1958 and 2010, there has been a clear, broad falling trend. For the whole period, regression result indicates that the annual mean daily global solar radiation decreased at a linear rate of 0.77 MJ/m² per decade (see Figure 2).

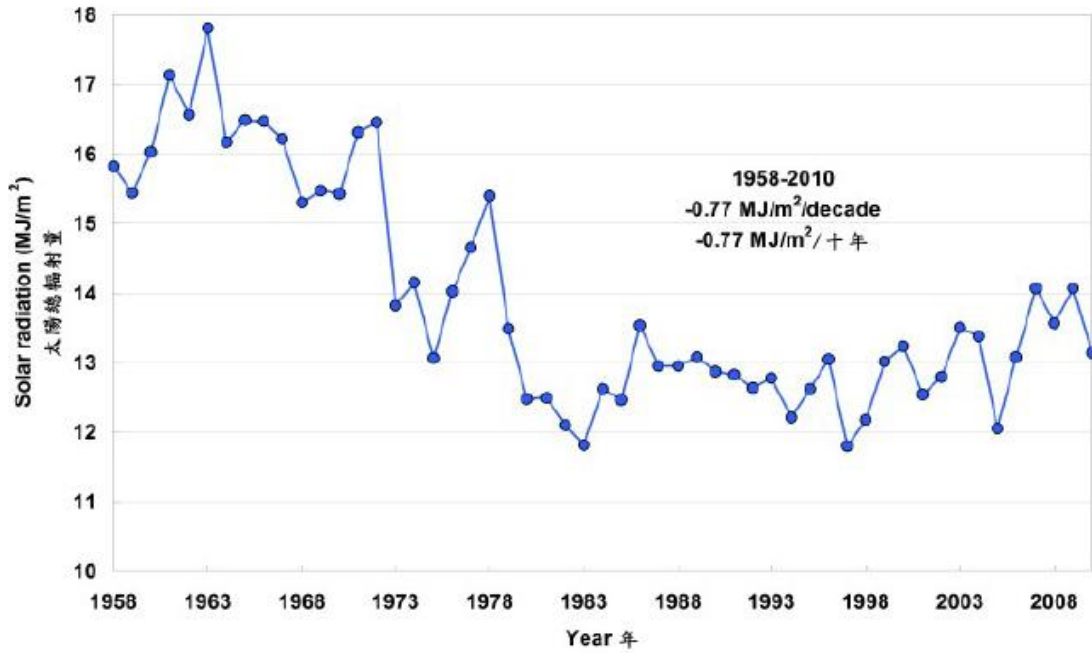


Figure 2 – Annual mean daily total global solar radiation at King’s Park (1958-2010) (Source: Hong Kong Observatory)

Solar irradiation data gathered by King's Park Weather Station over the past 14 years (1997 to 2010) were derived in Table 1. In given data shown that solar irradiation was average 13.03 MJ/m²/day in the past. It would be higher in July, average 17.05 MJ/m²/day to be gained daily.

Month	January	February	March	April	May	June
Monthly averaged daily horizontal solar irradiation (MJ/m ² /day)	10.24	10.25	10.93	12.16	14.44	13.64

Month	July	August	September	October	November	December
Monthly averaged daily horizontal solar irradiation (MJ/m ² /day)	17.05	15.48	14.67	14.04	12.44	11.02

Table 1 – Average solar irradiation data from 1997 to 2010 in Hong Kong

For the case of Hong Kong, the sun position is shifted to the north between the 4th of June and the 9th of July. Within this 36-day period, it is the north facade rather than the south facade that will receive direct solar radiation. This bears the implication that for a low-latitude region in the northern hemisphere, a South-facing wall may not receive the highest solar radiation over a year. Simulation studies have been evaluated the best positions of the solar panels in South China region were performed by The City University of Hong Kong since 1991. They find that the direct beam component accounts for a very small proportion as low as 25% of the global

insolation throughout the year except summer. During summer, the proportion of direct beam is between 50% and 60%. Overall, the annual proportion of the direct beam component is relatively low, say less than 50%. They suggest that solar concentrator technology is unlikely to be effective for Hong Kong [1].

The performance of a solar cooling air-conditioning system depends on the cooling capacity profile over the day and the weather conditions. For design of any solar energy installation, an important design parameter is the daily mean solar irradiation for each month of the year. The weather data gathered by Hong Kong Observatory in 2010 is tabulated in Table 2 and illustrated in Figure 3.

Month	Mean Temperature (°C)	Mean Relative Humidity (%)	Total Bright Sunshine (hours)	Mean Daily Global Solar Radiation (MJ/m ²)	Mean Amount of Cloud (%)
January	16.8	80	108.7	9.25	73
February	17.9	88	31.8	6.32	88
March	20.2	80	110.1	11.10	73
April	21.0	87	49.2	9.53	84
May	25.6	86	112.1	14.10	77
June	27.1	85	92.5	12.94	81
July	29.2	81	247.8	20.99	69
August	28.8	81	213.4	18.69	67
September	28.0	83	179.9	15.54	70
October	24.8	72	165.5	13.49	67
November	21.2	74	212.5	13.70	51
December	18.1	66	185.8	12.03	45

Table 2 - Hong Kong weather data in 2010

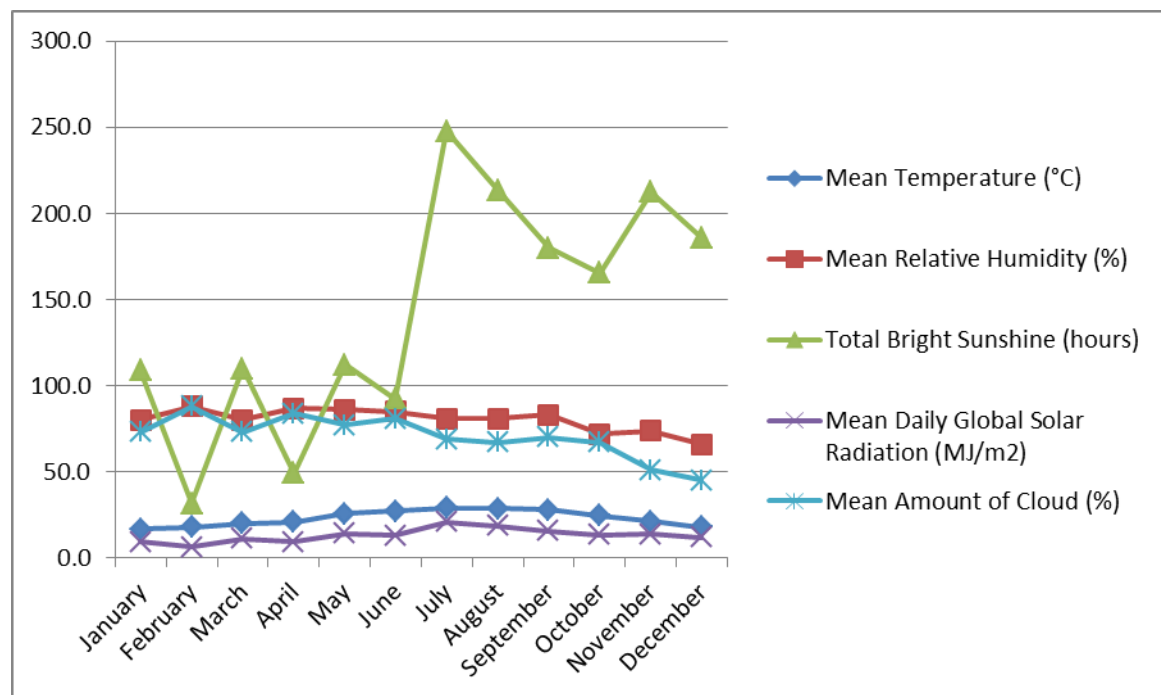


Figure 3 - Hong Kong weather data in 2010

In fact, Hong Kong enjoys a significant amount of direct sunlight year-round, and its wintertime heating requirements are moderate. This offers a good opportunity for using solar systems to achieve thermal comfort at low energy cost as well as reduce CO₂ emissions, provide that an appropriate design of the building envelope is adopted.

5. Solar Collectors

A solar energy system is to collect solar radiation and convert it into useful thermal energy. System performance depends on several factors, including availability of solar energy, the ambient air temperature, the characteristics of the energy requirement, and especially the thermal characteristics of the solar system itself. Solar collection systems for heating or cooling are usually classified as passive or active. Passive systems collect and distribute solar energy without the use of an auxiliary energy sources. They are dependent upon building design and the thermal characteristics of the materials used. Active systems consist of components which are to a large extent independent of the building design and often require an auxiliary energy source for transporting the solar energy collected to its point of use. Active systems are more easily applied to existing buildings.

Collectors may also be classified as flat-plate or concentrating. Concentrating collectors use mirrored surfaces or lenses to focus the collected solar energy on smaller areas to obtain higher working temperatures. Flat-plate collectors may be used for water heating and most space-heating applications. High-performance flat-plate or concentrating collectors are generally required for cooling applications since higher temperatures are needed to drive absorption-type cooling units.

The flat-plate collector consists of an absorber plate, cover glass, insulation, and housing as illustrated in Figure 4. The absorber plate is usually made of copper and coated to increase the absorption of solar radiation. The cover glasses are used to reduce convection and re-radiation losses from the absorber. The working fluid such as water, ethylene, glycol, air etc. is circulated in a serpentine fashion through the absorber plate to carry out the solar energy to its point of use. The temperature of the working fluid in a flat-plate collector may range from 30 to 90°C, depending on the type of collector and the application. The collection efficiency of flat-plate collectors varies with design, orientation, time of day, and the temperature of the working fluid.

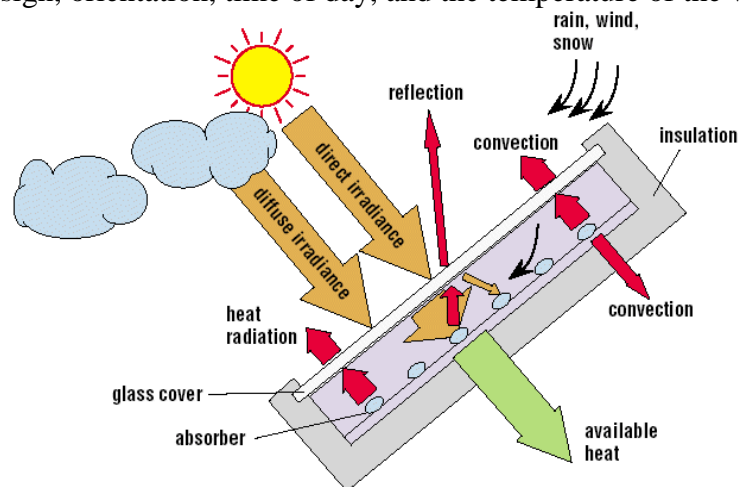


Figure 4 – Flat-plate collector

(Sources: <http://www.volker-quaschnig.de/articles/fundamentals4/index.php>)

6. Absorption Cycle

Among solar cooling technologies, there is the absorption cooling. The absorption cycle is a process by which refrigeration effect is produced through the use of two fluids and some quantity of heat input, rather than electrical input as in the more familiar vapour compression cycle. Both vapour compression and absorption refrigeration cycles accomplish the removal of heat through the evaporation of a refrigerant at a low pressure and the rejection of heat through the condensation at a higher pressure. The method of creating the pressure difference and circulating the refrigerant is the primary difference between the two cycles. The vapour compression cycle employs a mechanical compressor to create the pressure differences necessary to circulate the refrigerant. In the absorption system, an absorbent is used to circulate the refrigerant. Because the temperature requirements for the cycle fall into the low moderate temperature range, and there is significant potential for electrical energy savings, absorption would seem to be a good prospect for solar energy application. The most common combinations of fluids include lithium bromide (LiBr-H₂O) where water vapour is the refrigerant and ammonia-water (H₂O-NH₃) systems where ammonia is the refrigerant. An absorption air-conditioning system basically consists of evaporator, condenser, generator, absorber and solution heat exchanger as shown in Figure 5. A quantity of heat Q_{gen} supplied in the generator section is added to the working fluid solution at a relatively high temperature. This heat causes the refrigerant to be boiled out of the solution in a distillation process. The vapour that results passes into the condenser section where a cooling medium is used to condense the vapour back to a liquid state, delivering an amount of heat Q_{con} at an intermediate temperature. The liquid then flows down through an expansion valve (or say throttling valve) to the evaporator section where it passes over tubes containing the fluid to be cooled. By maintaining a low pressure in the absorber-evaporator shell, the working fluid evaporates by means of a quantity of heat Q_{eva} at a low temperature. This evaporation causes the working fluid to absorb heat from the medium to be cooled, thus, lowering its temperature. The vapourized working fluid then passes into the absorber section where it is absorbed by the solution coming from the generator. Finally, the solution leaving the absorber is pre-heated in the solution heat exchanger and pass to the generator section to repeat the cycle. Figure 5 shows a diagram of absorption cycle.

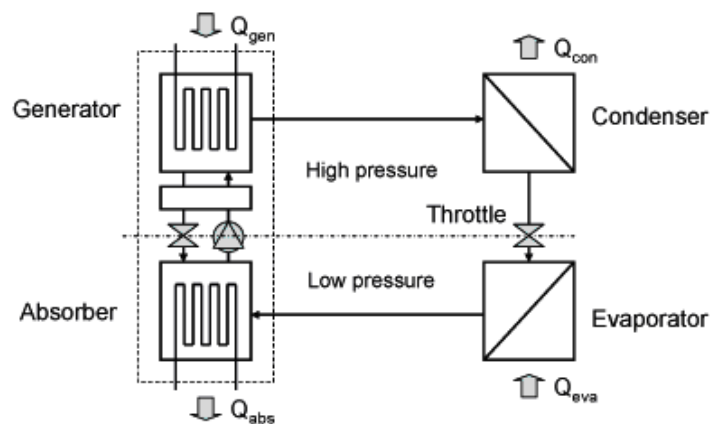


Figure 5 – Diagram of absorption cycle

(Source: http://www.arsenal.ac.at/topics/topics_therm_acs_pro_en.html)

It is possible to calculate heat balance for the whole cycle according to following equation.

In the absorber:

Heat of entering water vapour + heat of entering solution – heat of leaving solution = heat to be removed at absorber

In the generator:

Heat of leaving water vapour + heat of leaving solution – heat of entering solution = heat to be supplied to generator

In the condenser:

Heat of entering water – heat of leaving liquid = heat to be removed at condenser

7. Solar Cooling with Absorption Refrigeration

Absorption chillers differ from compression chillers at all they use a thermal compressor instead of a mechanical one. The cooling part of the absorption chiller is no different from conventional compression chiller. The necessary compression of the cooling medium to the condenser pressure is performed by the thermal compressor. Figure 6 shows a schematic diagram of ammonia absorption refrigeration system by using of solar energy.

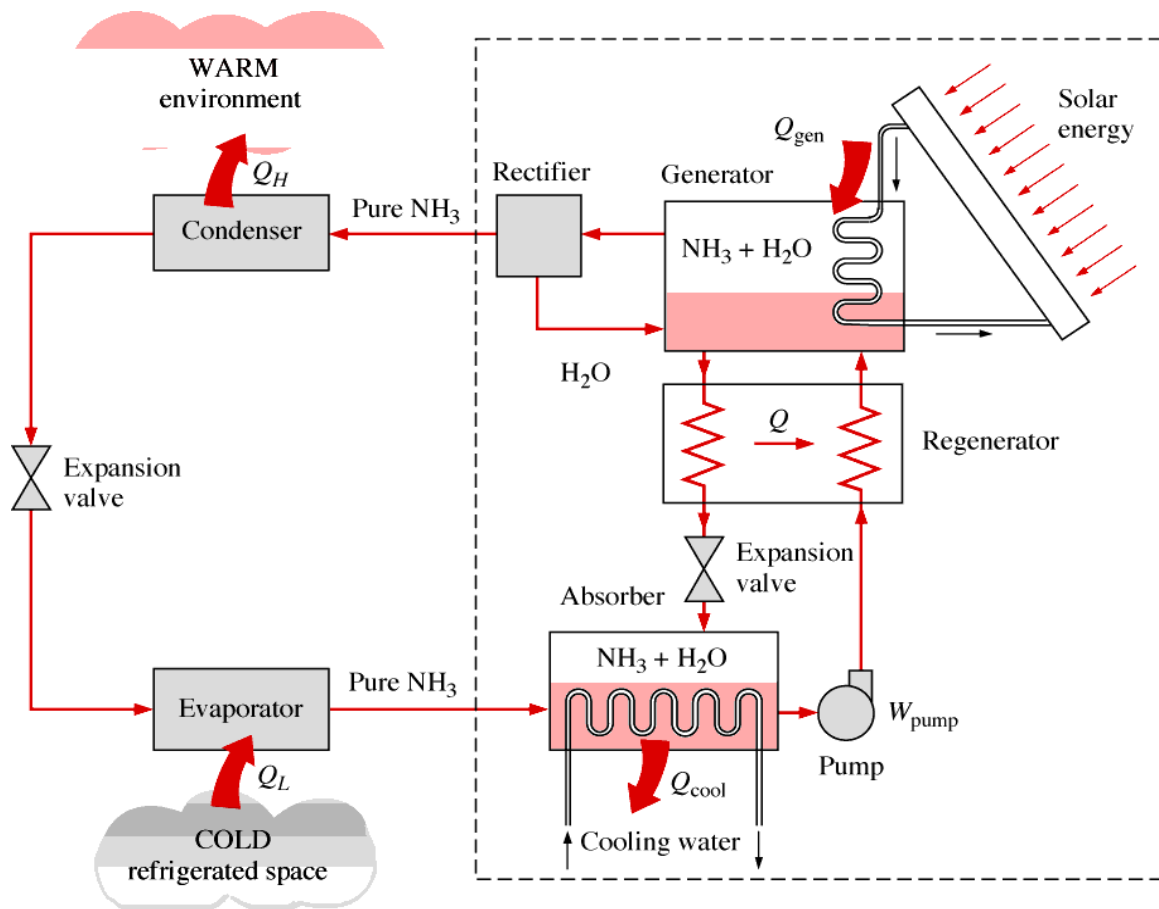


Figure 6 - Ammonia absorption refrigeration system by using of solar energy.

Absorption machines are commercially available today in two basic configurations. For applications above 0°C, such as primarily air conditioning, the cycle uses LiBr-H₂O as the absorbent and water as the refrigerant. For applications below 0°C, H₂O-NH₃ cycle is employed with ammonia as the refrigerant and water as the absorbent. Absorption machines based on LiBr-H₂O are typically configured as water chillers for air-conditioning systems in large buildings. Machines are available in sizes ranging from 35 to 5,200kW. The coefficient of performance (COP) of these machines, defined as the refrigeration capacity divided by the driving heat input, typically varies over the range of COP between 0.7 and 1.2 depending on the particular cycle configuration [6]. H₂O-NH₃ is an absorption fluid which utilizes ammonia as the refrigerant. Thus, the role of water is distinctly different in H₂O-NH₃ and LiBr-H₂O systems.

One advantage of ammonia as refrigerant is that the allowable refrigeration temperature is much lower as the freezing temperature of ammonia is 77.7°C. However, the toxicity of ammonia is a factor that has limited its use to well-ventilated areas. Machines are available in capacity ranging from 10 to 90kW with COP typically around 0.5 [6]. Of the various continuous absorption solar air-conditioning systems, LiBr-H₂O and H₂O-NH₃ are the major working pairs employed in these systems. It is reported that LiBr-H₂O 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 solution discharge into the absorber resulting stop solution flow through the device, its low cost and excellent performance make it the favourable candidate for use in solar cooling system. For these reasons, the LiBr-H₂O system is considered to be better suited for most solar-absorption air-conditioning applications [7].

Apart from the electrical power requirements of the solution pump, the absorption chiller is driven only by thermal energy. However, the energy requirement of the solution pump is very low, with approximately 0.5 to 2% of the refrigerating capacity achieved in the vaporized. The efficiency of the absorption chiller is usually improved by installing a solvent heat exchanger as shown in Figure 5. This is arranged so that the rich, cold solution after the absorber and the warm, depleted solution after the generator flow in opposite directions through the heat exchanger. This makes possible savings on the thermal heat in the generator and on cooling water in the absorber.

8. Potential Benefits of Solar Absorption System

The use of solar energy for cooling purposes presents the advantage that the resource contributing to supply the demand of the building sector, which is an important energy sector, with renewable energy sources. Availability is apparently almost in phase with the energy demand. Absorption cooling requires a thermal energy supply, such as solar energy. Hence, as the power peak and overall energy demand for cooling are high in many regions, solar absorption cooling systems justify the installation of much larger solar collector surfaces than in only heating applications, because of the significant improvement in their annually utilization factor. Therefore, solar absorption cooling systems, besides allowing to partially covering with solar energy the building cooling energy demand due to their higher installed solar collector surface also permit to have higher solar contributions. This leads to a significant

increase in the renewable energy fraction of the building sector energy demand and facilitates the development of the potential solar collector surface. In addition, utilizing solar energy that would otherwise be unused greatly increases the cost-effectiveness of the systems, compared to consuming electricity directly. Also, absorption system has several non-energy benefits over conventional electric systems including:

- ◆ To eliminate the use of CFC and HCFC refrigerants;
- ◆ To provide quiet and vibration-free operation;
- ◆ Lower pressure systems so that no large rotating components involved;
- ◆ High reliability; and
- ◆ Low maintenance required.

9. Further Development in Solar Absorption System

Solar absorption system has the potential to play an important role in the development of installed solar thermal collector surface as well as in contributing the supply demand of the building sector, which is an important energy sector with renewable energy sources. However, it still persist some limitations associated to absorption system that may prevent them to develop this technological niche.

- ◆ Relative high capital cost by installing absorption chiller, particularly in the low power range associated with building applications. It is often thought that the costs of solar absorption chillers are dominated by the solar collector field. Solar collector cost reduction is an important point for high solar multiple cooling systems economic viability, but since subsidies currently exist for solar collectors, the main economic constraint in absorption cooling commercial installations is often leading to high absorption system costs.
- ◆ Lack of commercial availability of suitable absorption chillers for solar applications in the power range relevant to applications in the building sector, especially in the small power range which could be used for single family houses only. Even for higher power applications, people still find nowadays situations like the ones experienced at the beginning of absorption solar cooling, when direct fired or vapour fed commercial absorption chillers had to be adapted to operate with solar energy.
- ◆ Retro-fitting of solar absorption cooling system in existing buildings in Hong Kong would be difficult due to space requirements for the solar collector. It is possible to mount solar collectors on a North-facing wall of high-rise building or on balconies. Integration of solar collectors into a building at design stage is relatively straightforward. A typical architectural design approach for high-rise buildings is to build the solar collector integrated into a window shade. For this configuration a large solar array would be mounted on the roof of the building. For large commercial or institutional users such as hospitals and hotels, opportunities for installation of solar water heaters could be more, as there would be relatively more opportunity to retrofit such systems. However, this will need to be evaluated on a site-specific basis.
- ◆ Cooling tower is dependency to dissipate chiller residual energy in most

applications especially in small installations, which to be able to eliminate the additional equipment with its additional costs, energy consumption and additional installation complications. In single effect LiBr-H₂O absorption chillers, cooling tower becomes compulsory in most applications to avoid the salt crystallization problems at the evaporator operating temperatures common in conventional air conditioning distribution systems, such as fan-coils unit. Although, there are alternatives both for the cooling distribution system like radiant floor or wall by using heat dissipating technology that may be applied in some cases to eliminate the need for the cooling tower with current absorption chiller technology, it would be good to have absorption chillers that could work without the cooling tower in any situation.

- ◆ To operate the absorption chiller in limited capability under reversible mood as a heat pump in the heating season, which would allow the use of the same equipment in the heating and the cooling season, improving the economic system performances. Indeed, LiBr-H₂O machines are limited for their operation as heat pumps in the heating season because of the evaporator freezing limit of the working fluid, such as water with low ambient temperatures.
- ◆ Lack of adequate experimental chiller performance characterization out of design conditions and operating data in part load. Unlike in conventional applications, absorption chillers in solar installations work under variable conditions, far from the design point, at part load and even in transient operation. It still becomes sometimes difficult to get from manufacturers an appropriate characterization of their absorption chillers to be evaluated and optimized in solar cooling installations.

10. Conclusion

Although a large potential market exists for this technology, existing solar cooling systems are still not competitive with electricity-driven air-conditioning systems because of their high first costs. Lowering the cost of components and improving their performance could reduce the cost of solar cooling systems and become favor by building owner. Improvements such as reduced collector area because of improved system performance and reduced collector cost will lower the first cost of solar system. Furthermore, the main technical problem of solar refrigeration is that the system is highly dependent upon environmental factors, such as cooling water temperature, air temperature, solar radiation, wind speed and others. On the other hand, its energetic conversion efficiency is low, and from an economic point of view, solar cooling and refrigeration are not competitive with the conventional systems. Moreover, the area that is actually available for solar panel installation would be much smaller in Hong Kong due to many other land uses and constraints. It seems unlikely to be effective in population centre unless the system can be integrated into buildings making use of otherwise alienated space, and have a potential for wide-scale application in Hong Kong.

Finally, solar absorption cooling constitutes an interesting technological alternative to cope with the increasing cooling energy demand with sustainability criteria. It has additional advantages like reducing peak electricity demand in summer and providing

comfortable environment in remote area by using of renewable energy. However, the peculiarities of solar absorption systems require a more detailed evaluation in order to design them properly and evaluate their performances accurately through detailed dynamic simulation of recent commercial installations and studies are required.

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