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Review on Solar Assisted Air Conditioning for Hospitals Isolation Units

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ABSTRACT

Hospitals and hospital special units for example operation theatres, isolation units, laboratories are not like any other commercial property as they are required to operate special HVAC systems. To build an effective HVAC system design to enhance the air quality in the healthcare facilities is a great challenge. Indoor air Quality (IAQ) is more critical in healthcare facilities due to the hazardous microbial and chemical agents present and the increased susceptibility of the patients and health care staff. In certain areas, air handling unit dampers are forced to be fully open to allow for 100% of air extraction and, hypo filters are used in conjunction with dampers to ensure the quality of air during twenty four working hours seven days a week. Using no recycled air means more energy, more money and more gas emissions. Solar air conditioning systems can be constructed in a way that eliminates the need for refrigerants such as, Chlorofluorocarbon (CFC) and hydrochlorofluorocarbons (HCFC). Solar cooling systems are a nice tool for the exploitation of solar energy. They have the advantage of using absolutely harmless working fluids such as water, or a salt solution. They are energy efficient and environmentally safe. They can be used either as stand-alone systems or with conventional AC, to improve the indoor air quality of all types of buildings. The main goal is to utilize ‘‘zero emissions’’ technologies in order to reduce energy consumption as well as the CO2 emissions.

Keywords: Solar Energy, HVAC, Isolation units, Zero Emissions.

INTRODUCTION

Air conditioning (AC) is one of the major consumers of electrical energy in many parts of the world today and already its effects can cause energy shortages nationwide. The demand can be expected to increase because of changing working times, and increased comfort expectations due to the effects of global warming. Air conditioning systems in use are most often built around vapour compression systems driven by grid electricity. However, generating electricity today, as well as the refrigerants being used in traditional vapour compression systems has a negative impact on the environment. During the summer the demand for electricity increases dramatically because of the extensive use of heating ventilation air conditioning (HVAC) systems, which increases the peak electric load, causing major problems in the national electric supply system. In some countries, for example New Zealand, the energy shortage is worse during dry years as a result of incapability of the hydroelectric power stations to operate. The total energy demand increases by 3%–4% per year, which corresponds to an annual increase of electric energy consumption. [1]. Acknowledging that global warming is the number one environmental threat; due to gas emission, this puts a serious pressure on mankind to reduce carbon dioxide emission. Further more, high fuel prices force decision makers and world leaders to adopt and encourage renewable energy resources. The use of solar cell assisted air conditioning in hospitals is a very attractive option especially in tropical areas where there is sunny weather throughout the year. Savings in fuel and reducing gas emissions has become an important milestone for all mankind. Solar air conditioning will be a way to reduce the demand for electricity which means less demand for fuel and coal. In addition, many solar air conditioning systems are constructed in a way that eliminate the need for CFC, HCFC or HFC refrigerants. Alternatives to use solar energy is waste heat from different industrial process such as refineries, garbage treatment facilities etc. Even driving the air conditioning system directly from fossil fuel might, in some cases be more environmentally friendly than using electricity [2]. Energy costs, for example, which typically represent up to three percent of a hospital’s operating budget, can be reduced easily by 20% to 25% according to *Peter Glynn, Former CEO, Kingston General Hospital, Canada [3].* Almost all health care organizations treat energy costs as ongoing, uncontrollable costs extracted from core funding. By reducing energy costs, hospitals can keep more money for core funding and increase their discretionary spending [3].

A poorly maintained air conditioning system can occasionally promote the growth and spread of microorganisms and fungus but as long as the air conditioner is kept clean these health hazards can be avoided. Conversely, air conditioning, including filtration, humidification, cooling, disinfection, can be used to provide a clean, safe, hypo allergic atmosphere in hospital operating rooms and other environments where an appropriate atmosphere is critical to patient safety and well-being. Air conditioning can have a positive effect on sufferers of allergies and asthma [4]. Solar air conditioning uses harmless cooling fluids (water generally) and near zero primary energy cost compared to traditional systems [5]. A review of solar assisted air conditioning systems for implementation into hospitals special units is presented in this study. Both technical and economic feasibility compared to only grid connected air conditioning systems are discussed.

NOMENCLATURE

Symbols	Units	Description
COP_{Conv}		Conventional Coefficient of performance
$COP_{thermal}$		Thermal Coefficient of performance
COP_{solar}		Solar Coefficient of performance
Qc	Kw	Cooling Capacity
Qh	Kw	Heating Capacity
Qr	Kw	Rejected Capacity
P_{el}	Kw	Electric input Power e
m_c	m3/h	Water flow ratw of the cooling tower
m_{CT}	m3/h	Water flow rate of the cooling tower
C_p	C	Specific heat of water
θi (t)	C	Temperature at the local i and time t
C_S	$	Caost of installed sollar equipment
C_A	$/$m^2$	Coast of equipment area
A_C	m^2	Collector area
C_E	$	Equipment coast independent of A_C
YC	$	Yearly Coast
F_e	$	Fuel expences insert
Mg	$	Mortgage payment
Ptax	$	Property Tax
Gg&t	$	Goverment grants and income tax savings
$I_{tx,saving}$	$	Income tax savings
E_t	$	Effective tax rate
Ip	$	Interest payment
Fe	$	Fuel expenses
Pe	$	Paractice energy coast
dp	$	Depreciation
N	year	Period
i		Rate per period
d		Fraction per time period
Ei	$	Energy inflatation

HOSPITALS AIR-CONDITIONING REQUIRMENTS

Preventing microbes, fungus, and viruses' contaminations transport through hospital air conditioning system is the optimum priority for the designe engineers. Proper air conditioning systems are helpful in the prevention and treatment of diseases. The factors that affect air conditioning design in hospital facilities are: a) recycle air movement between various departments. b) a very active function for ventilation and filtration to dilute and remove contaminants in the form of airborne microorganisms, viruses, odour, hazardous chemicals and radioactive substances. c) various temperature and humidity requirements for various areas [6].

HOSPITALS INDOOR AIR QUALITY

Indoor air quality is determined by a constantly changing interaction of complex factors that affect the types, levels and importance of pollutants in the indoor environment. It is a major concern to hospitals, building managers, patients and employees because it affects the health, comfort, disease transmissions and productivity of the building occupants for example any infected patient can transmit the same disease to another room or department occupant, those occupant could be a doctor, patient, etc, due to the use of recycled air. The quality of the indoor air is expressed as the extent to which human requirements are met. By definition, an *acceptable indoor air quality* is defined as air in which there are no known contaminants at harmful levels. The quality of the indoor air depends on both the quality of the outdoor air and on the strength of emissions from indoor sources. To satisfy comfort needs, indoor spaces must receive a quantity of tempered outdoor air and a sufficient quantity of clean air to create an acceptable indoor air quality. Similarly, to satisfy health ventilation needs, indoor spaces must receive air that is free from hazardous chemical or microbiological contaminants. Indoor air quality is influenced by changes in building operation, occupant activity and outdoor climate [7]. There is no tolerance towards hospitals indoor air quality, there is no room for human risk as a strong opourtunity for contemenations due to the surrounding atmosphere or as a result of chemicals excessive usage in hospitals laboratories, operation theatres and isolation units. The requirements of fully extracted air in certain hospital departments are an expensive necessary procedure to insure patients and staff ocupancy safety. Air conditioning system economisers are always based on the use of recycle and treated air, this function requires less energy to recool the same air and reuse it again. As some hospital departments do not permit the use of recycled air it can make the whole air conditioning process expensive to operate in comparison to regular systems in commercial sites where there are no internal contamination threats.

WHY SOLAR COOLING?

During the summer the demand for electricity increases because of the extensive use of HVAC systems, which increase the peak electric load, causing major problems in the electric supply. The energy shortage is worse during 'dry' years because of the inability of the hydroelectric power stations to function and cover part of the peak load. The use of solar energy to drive cooling cycles for space conditioning of most buildings is an attractive concept, since the cooling load coincides generally with solar energy availability and therefore cooling requirements of a building are roughly in phase with the solar incidence. Solar cooling systems have the advantage of using absolutely harmless working fluids such as water, or solutions of certain salts. They are energy efficient and environmentally safe. They can be used, either as stand-alone systems or with conventional air conditioning, to improve the indoor air quality of all types of buildings. The main goal is to utilize "zero emission" technologies to reduce energy consumption and CO_2 emissions [5]. The schematic diagram of a solar air conditioning system is shown in figure 1.

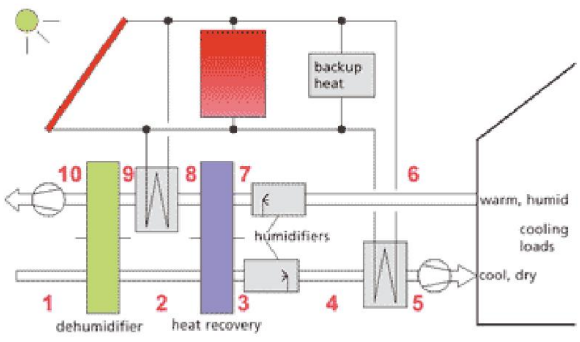

Figure 1: Schematic of solarair conditioning [5].

COEFFICIENT OF PERFORMANCE (COP)

A key figure describing the efficiency of a thermally driven chiller is the thermal coefficient of performance (COP_{conv}), defined as the fraction of heat rejected from the chilled water cycle ('delivered cold') and the required driving heat, for conventional air conditioning units coefficeint of performance is given by equation 1 [10].

$$COP_{conv} = \frac{Qc}{P_{el}} \quad (1)$$

A key figure describing the efficiency of a thermally driven chiller is the thermal coefficient of performance ($COP_{thermal}$), defined as the fractionof heat rejected from the chilled water cycle ('delivered cold') and the required driving heat given by equation 2.

$$COP_{thermal} = \frac{Qc}{Qh} \quad (2)$$

A realistic comparison of different technologies thus requires the consideration of the total energy input for heat as well as for pumps, fans, etc. It has to be noted that the smaller the *COP*, the more heat input is required and the more heat has to be removed by the cooling tower. Vice versa, a high *COP* value is of advantage in reducing both heat input and electric power for the pumps in the heating cycle and in the re-cooling cycle.

EXISTING SOLAR COOLING TECHNOLOGIES

Cooling can be obtained from many different ways. The majority of them have a direct or indirect origin with the sun, such as fossil fuels. The expression "solar cooling" is usually restricted to when the solar radiation is the direct agent of cooling. In order to evaluate the potential of the different solar cooling systems, a classification has been made by Best and Ortega [8]. In solar assisted air conditioning systems, solar heat is required to drive the cooling process. Thus, solar assisted air conditioning systems operated so far may be classified into two types: closed systems and open system, where closed system these are thermally driven chillers which provide chilled water, that is either used in air handling units to supply conditioned air (cooled, dehumidified) or that is distributed via a chilled water network to the designated rooms to operate decentralized room installations, e.g. fan coils. Market available machines for this purpose are absorption chillers (most common) and adsorption chillers (a few hundred machines worldwide, but of rising interest in solar assisted air conditioning). Open systems; allows complete air conditioning by supplying cooled and dehumidified air according to the comfort conditions. The "refrigerant" is always water, since it is in direct contact with the atmosphere. Most common systems are desiccant cooling systems that use a rotating dehumidification wheel with solidsorbent [5]. According to [13], it has been possible to calculate the COP of the chiller based on the available temperature and flow measurements according the following formulas:

$$COP_{solar} = \frac{Qc}{Qh} = \frac{Qc}{Qr - Qc} \quad (3)$$

$$COP_{solar} = \frac{1}{\left(\frac{Qr}{Qc} - 1\right)} \quad (4)$$

Where

$$Qc = m_c C_p \left(\theta_2(t) - \theta_3(t)\right) \quad (5)$$

And

$$Qr = m_{CT} C_p \left(\theta_4(t) - \theta_5(t)\right) \quad (6)$$

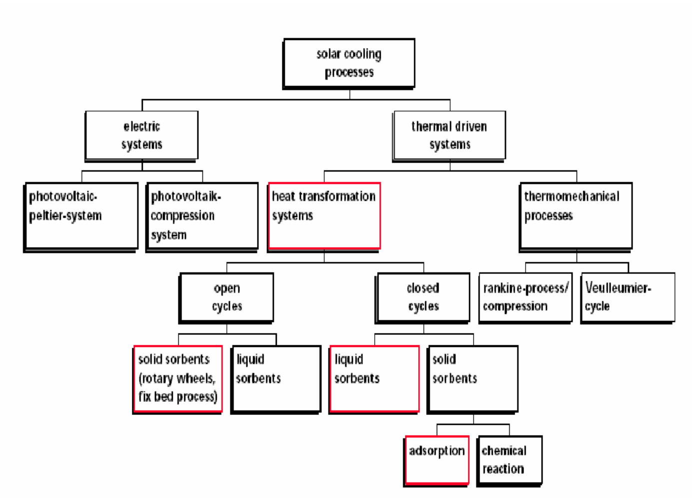

Figure 2. Overview of solar cooling methods [9]

PHOTOVOLTAIC AIR CONDITIONING

Photovoltaic can provide the power for any type of electrically powered cooling be it conventional compressor-based or adsorption/absorption-based, though the most common implementation is with compressors which are the least efficient form of electrical cooling methods [12]. However, due to high cost, low efficiency and subsequently high price of PV electricity conversion, such systems are not cost effective.

ABSORPTION COOLING

Absorption chillers offer an exciting alternative to conventional compression chillers, since their main energy input is heat instead of mechanical power. Figure 3 shows the schematic of an absorbtion cycle. Absorption chillers come in a large variety of models and types, frequently requiring heat in the form of water vapour, or even direct fire. Applications with vapour frequently fit most waste heat rejection found in industrial processes such as combination heat and power. The COP is defined as in compression chillers but with the driving heat replacing the mechanical/electrical input. Traditionally absorption chillers are large machines with a large cooling capacity. Absorption chillers work much like conventional compression chillers, except that there is no mechanical compressor. Instead, the vaporised refrigerant leaves the evaporator to the absorber where it is diluted by a solution. The liquid solution is then pumped (pumps are more efficient than compressors), and then regenerated with heat (in the generator), so that the refrigerant is vaporised again, at a higher pressure and temperature. It then goes to the condenser to release the contained waste heat. Typically for chilled water temperatures less than 5°C, ammonia is used as the refrigerant and water as the absorber. For typical air-conditioning applications (chilled water above 5°C), the combination of water as refrigerant and lithium bromide (LiBr) as absorbent is more popular, while chillers using Ammonia as absorbent are more suited for industrial refrigeration, producing chilled water down to –10ºC [7]. The condenser's heat rejection is again critical to the COP of the chiller.

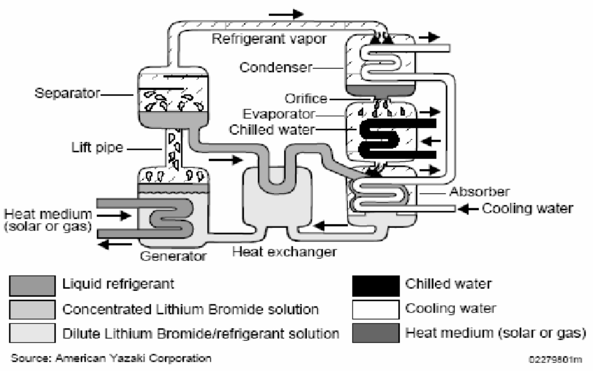

Figure 3. Absorption cycles [14].

ADSORPTION

These chillers are similar to absorption chillers, since both are driven by heat. However, adsorption chillers can be driven by hot water at lower temperatures than absorption chillers, thus benefiting from a better efficiency on the solar collectors system because they are generating water at a lower temperature. The adsorbtion cycles is shown in figure 4. From a physical point of view, both technologies differ significantly since the sorbent used in adsorption is silica gel, a solid that cannot be compressed or pumped. Instead, each compartment containing the solid sorbent is alternately heated and cooled to adsorb and desorb the refrigerant in a periodic process. An adsorption chiller consists of two compartments on which the internal surfaces are covered with silica gel; a highly porous solid that captures water vapour (adsorbs the refrigerant). The same compartment is then heated (regenerated) with the driving hot water at temperatures ranging from 55°C to 95°C. The refrigerant at a higher temperature moves to the condenser where it is condensed, resulting waste heat that must be dissipated. A throttle valve drops the pressure of the condensed water to the level of the evaporator. At that low pressure, it receives enthalpy from the chilled water and evaporates, moving on to the other compartment, with the regenerated silica gel, thus completing the process. A cycle can take around seven minutes and it begins where the refrigerant goes to the evaporator, where it is evaporated with a strong vacuum, and produces chilled water. Then the refrigerant moves to one of the compartments filled with recently regenerated silica gel, where it is adsorbed. Then the cool/ hot water cycle inverts. Now heat is being supplied to the compartment, regenerating the silica gel. Back as in vapour form, the refrigerant is pressurized and goes to the condenser. And in the condenser, chiller condensates releasing waste heat (to be dissipated). The liquid refrigerant is then sprayed back to the evaporator completing the cycle [15].

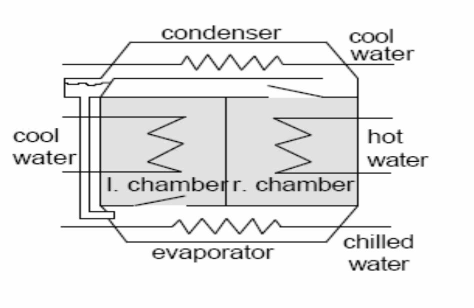

Figure 4. Adsorption cycles [16].

DESICCANT COOLING

In desiccant cooling, the cooling medium is air instead of water as in figure 5. It is usually associated with a double deck air-handling unit, where the inlet air is dehumidified via a desiccant rotating wheel that adsorbs the water, again in silica gel laid in the internal walls of the wheel. The dehumidified inlet air is consequently cooled via a cooling coil, a heat recovery unit or adiabatic cooling system, to a lower temperature close to saturation. Meanwhile the return air from the building is heated through a heating coil (with e.g. solar hot water ranging from 50ºC to 100ºC) regenerating the rotating (6-12 rpm) desiccant wheel.

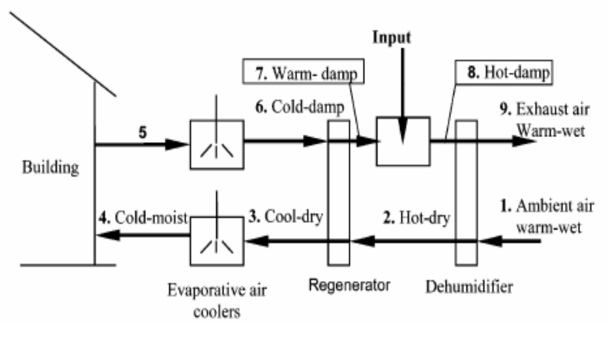

Figure 5. Desiccant cycle [17].

SOLAR COLLECTORS

In solar air-conditioning, all processes involve some sort of regeneration process that is done with solar heat. For close cycle processes (absorption and adsorption), the ideal medium is through solar hot water. In solar assisted air conditioning systems, the difference in the operation of the solar collectors compared to solar thermal collector systems for hot water production is the high temperature level, at which the useful heat has to be provided. For thermally driven chillers, the driving temperature is mainly above 80°C, lowest values are 60°C. For desiccant cooling systems, the driving temperature is above 55°C up to 90°C. Due to the high volume flow rates in the heat supply cycle, an ideal stratification in the hot water storage is difficult and the return temperature to the solar collector is relatively high as well. This causes some restrictions in the selection of the collector type [5].

FINANCIAL PERFORMANCE

The financial performance of solar cell assisted air conditioning must be evaluated to determine whether or not it is providing economically viable services. To do this, operating expenses, current and projected cash flows, including capital expenditures needs to be monitored and assessed. This information is then used to determine the current and projected economic return of the asset or portfolio. Cash Flow analysis can be used to provide a measure of the Net Present Value and the internal rate of return for assets. Solar processes are generally characterised by high investment and low operating cost. The cost of any energy delivery process includes all the items of hardware and labour that are involved in the installation of the equipment, plus the operating expenses. It is vital to determine the primary energy savings and relevant costs for different solar system. The economic analysis methods such as the net present worth, the benefit cost ratio, the rate of return and the payback period are suitable to evaluate single retrofit options. However, life cycle analysis methods are appropriate to select most economic options among multiple retrofit alternatives [18].

COST OF SOLAR CELL ASSISTED AIR

The cost of solar process has many important factors to be considered such as collector's storage unit, pumps, blowers, control system, pipes, ducts, heat exchange, and all other equipment associated with solar installations. Installed costs of solar equipment can be shown as the sum of two terms as shown in equation 7, one proportional to collector area and the other independent of collector area. [18].

$$C_S = C_A A_C + C_E \qquad (7)$$

OPERATION COST

These costs are associated with the solar process. It is a continuous cost including a cost of auxiliary energy which feeds pumps; blowers and etc. operation cost more likely to be hit by government tax changes and also subjectes to all interest rates impacts. Here in Australia the government's stimulus packages in some aspects are granted specialy for green projects, these grants involved directly in operation coasts. Source [22] stated that annual cost for sollar and non sollar to meet an energy need can be expressed in equation 8 and 9:

$$\mathrm{YC} = \mathrm{F_e} + \mathrm{Mg} + \mathrm{Mt\,\&\,i} + \mathrm{C,energy} + \mathrm{Ptax} - \mathrm{Gg\,\&\,t} \qquad (8)$$

$$I_{tx.saving} = E_t \begin{pmatrix} Ip + P_{tax} + Fe + \\ Mtci + Pe - dp \end{pmatrix} \qquad (9)$$

With saving concept, it is necessary to estimate the cost of installing a solar system. Thus if there are any difference between solar and non solar system components, that difference in there costs can be increment or decrement to the costs of installing a solar system [18]. Solar saving can be expressed as:

$$\text{Solar saving} = \begin{pmatrix} \text{fuel savings - incremental mortgage payment} \\ \text{- incremental insurance and maintenance} \\ \text{- incrementa conventional energy cost} \\ \text{- incremental property tax} \\ \text{+ income tax savings + goverment grants} \end{pmatrix}$$

PRESENT WORTH FACTOR

Worth factor is defined as the difference between the life cycle cost of a conventional fuel only system and the life cycle cost of the solar plus auxiliary energy system [18]. Present worth factor can be expressed as in equation 11 and 12:

$$PWF(N,i,d) = \sum_{j=1}^{N} \frac{(1+i)^{j-1}}{(1+d)^{j}} \qquad (11)$$

$$= \begin{cases} \dfrac{1}{d-i}\left[1-\left(\dfrac{1+i}{1+i}\right)^{N}\right] \rightarrow i \neq d \\ \dfrac{N}{N+1} \rightarrow i = d \end{cases} \qquad (12)$$

PAY BACK

Several economic criteria have been proposed for evaluating and optimizing solar energy systems, and there is no universal agreement on which should be used [19]. The most common way to evaluate PAYBACK is given by equation 13.

$$PB = \frac{\log\left[\dfrac{C_S}{Ei}\cdot\dfrac{Ei}{100}+1\right]}{\log\left[1+\dfrac{Ei}{100}\right]} \qquad (13)$$

CONCLUSION

Solar cooling has the potential of significantly reducing the electricity consumption by hospitals. Although most of the current solar cooling applications are demonstration projects in nature, the technologies are mature. Research and development activities are concentrated in improving the COP as well as making the equipment smaller in size and more affordable. It is of vital importance to select the right equipment for each application depending on the desired performance specifications. Careful analysis of internal loads is required to size and specify the equipment correctly. Hospital operators and other stakeholders need to break free from considering only the financial payback and embrace the long term benefits of solar cooling that contribute towards energy independence and environmentally friendly goals in a larger scale. Solar assisted air conditioning is a new and growing technology, compared to other fields of solar energy application. The novelty of this technology is reflected by the fact that most of today's realized projects are of demonstration nature and still a lot of additional design and planning effort is required in the implementation phase of such a project. Various technical solutions are possible, depending on the type and use of the building, on boundary conditions like e.g. existing technical infrastructure, and on other like e.g. climate conditions [5].

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