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ScienceDirect
Procedia Earth and Planetary Science 11 (2015) 361 – 367
Procedia
Earth and Planetary Science

Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources (GCPF2015)

A Review on Solar Powered Air Conditioning System

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Abstract

The twenty first century is rapidly becoming the perfect energy storm, modern society is faced with volatile energy prices and growing environmental concerns as well as energy supply and security issues. One of the greatest challenges facing mankind in the twenty first century is energy. Fossil fuels such as coal, petroleum and natural gas have been the main energy resources for everything vital for human society. The burning of fossil fuels has caused and is causing damage to the environment of earth. By 2050 the demand for energy could double or even triple as the global population grows and developing countries expand their economies. This has already raised concerns over potential supply difficulties, depletion of energy resources and expediting environmental impacts like ozone layer depletion, global warming and climate change etc. The most abundant energy resource available to human society is solar energy. The utilization of solar energy is as old as human history. Among various types of renewable energy resources, solar energy is the least utilized. Air conditioning is essential for maintaining thermal comfort in indoor environments, particularly for hot and humid climates. Today, air conditioning comprising cooling and dehumidification has become a necessity in commercial and residential buildings and industrial processes. During the summer, the demand for electricity greatly increases because of the extensive use of air-conditioning systems. This is a source of major problems in the country's electricity supply and contributes to an increase of CO_2 emissions causing the environmental pollution and global warming. On the other hand, vapour compression air conditioning systems have impacts on stratospheric ozone depletion because of the chlorofluorocarbons (CFC) and the hydro fluorocarbon (HCFC) refrigerants. The use of solar energy to drive cooling cycles is attractive since the cooling load is roughly in phase with solar energy availability. To cool with solar thermal energy, one solution is to use an absorption chillier using water and lithium bromide solution. Solar air conditioning systems help to minimize fossil fuel energy use. Among the evolving energy efficient air conditioning technologies are liquid desiccant air conditioning (LDAC) systems, which have showed promising performance during the past decades and are believed to be a strong competitor with the widely used conventional air conditioning systems (CAC). Desiccant evaporation cooling technology is environmental friendly and can be used to condition the indoor environment of buildings. Unlike conventional air conditioning systems, the desiccant air conditioning systems can be driven by low grade heat sources such as solar energy and industrial waste heat. In this study, a focus is made on reduction in Air Conditioning capacity, fuel savings and emission reductions attainable through the use of solar energy.

Peer-review under responsibility of organizing committee of the Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources.

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doi:10.1016/j.proeps.2015.06.073

Keywords: Solar Energy, Desiccant Air Conditioning System, Humidification and Dehumidification, Conventional Air Conditioning;

1. Introduction

As a kind of renewable energy, solar energy is paid more and more attention in the world. Solar system can be classified into two categories; those are thermal systems which convert solar energy to thermal energy and photovoltaic systems which convert solar energy to electrical energy. However, more solar radiation which falling on photovoltaic cells is not converted to electricity, but either reflected or converted to thermal energy. This method leads to a drop of electricity conversion efficiency due to an increase in the photovoltaic cells working temperature.

In the past century, scientific community has devoted much effort to procure energy sustainability of housing in two main directions; those are reducing external energy supply and using renewable energy for the remaining. In both ways, solar resources are gaining popularity because they increase energy independence and sustainability at the same time offering nearly zero impact to the environment.

The modern comfort living conditions are achieved at the cost of vast energy resources. Global warming and ozone depletion and the escalating costs of fossil fuels over the last few years to the design and control of building energy systems. Solar energy is abundant and clean, it is meaningful to substitute solar energy for conventional energy. Solar energy therefore has an important role to play in the building energy systems.

The increasing scarcity and cost of fossil fuels and incentives to reduce greenhouse gas emissions have led to a growing interest in solar energy. Solar energy is widely affordable and has the capability to meet household demand over the year. Unfortunately, its intermittency and variability with weather conditions, time and seasons lead to a mismatch between heating demand and solar energy availability.

Air conditioning systems are installed in buildings to provide the occupants with healthy and productive environments. Considerable amount of energy is consumed in the operation of the widely used energy inefficient conventional air conditioning systems, which leads to several environmental problems that are related to energy production such as air pollution, global warming and acid precipitation.

From recent studies, those buildings are responsible for the consumption of around 40% of the primary energy consumption and the emission of nearly 33% of the green house gases in the world.

An air conditioning system consists of components and equipment arranged in sequential order to heat or cool, humidify or dehumidify, clean and purify, attenuate objectionable equipment noise, transport the conditioned outdoor air and recirculate air to the conditioned space and control and maintain an indoor or enclosed environment at optimum energy use.

Most of the air conditioning systems perform the following functions:

a. Provide the cooling and heating energy required
b. Condition the supply air, heat or cool, humidify or dehumidify, clean and purify and attenuate any objectionable noise produced by these systems
c. Distribute the conditioned air, containing sufficient outdoor air, to the conditioned space.
d. Control and maintain the indoor environmental parameters such as temperature, humidity, cleanliness, air movement, sound level and pressure differential between the conditioned space and surrounding within predetermined limits.

1.1. Applications of air conditioning system

a. Institutional buildings, such as schools, colleges, universities, libraries, hospitals and nursing homes, museums, indoor stadiums, cinema theatres..... etc.
b. Commercial buildings, such as offices, stores and shopping centres, supermarkets, department stores, restaurants and others.

c. Residential buildings, including hotels, motels, single family and multifamily low rise buildings of three or fewer stories above grade
d. Manufacturing buildings, which manufacture and store products for examples medicines
e. The transportation sectors like Automobiles, aircraft, railroad cars, buses and cruising ships.... etc

Air conditioning systems are mainly for the occupant's health and comfort. They are often called comfort air conditioning systems.

1.2. Principle of air conditioning system

Figure 1 shows the window mounted air conditioning system. The cabinet is divided into indoor and outdoor compartments which are separated by insulated wall to reduce the heat transfer. The DX coil and indoor fan are in the indoor compartment. The outdoor compartment contains the compressors, condensers, outdoor fan, capillary tube and fan motor. The fan motor often has a double ended shaft which drives both fans at a time.

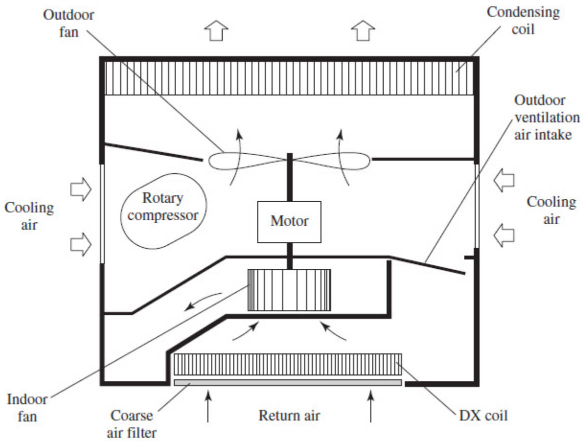

Fig. 1. Window mounted air conditioning

Return air from the conditioned space flows through a coarse air filter and is cooled and dehumidified in a DX coil and then enters the inlet of the indoor fan. In a room air conditioner, the indoor fan is a forward curved centrifugal fan. The conditioned air is pressurised in the impeller and forced through the air passage that leads to the supply grille. The conditioned air is then supplied to the conditioned space to offset the space cooling load.

Outdoor air is extracted by the propeller fan and forced through the condensing coils, in which hot gaseous refrigerant is condensed to liquid refrigerant. During condensation, condensing heat is released to the outside through the cooling air. A portion of outdoor ventilation air is extracted by the indoor fan and mixed with the return air. The opening of the outdoor ventilation air intake is adjustable.

Scientists and engineers are trying to develop more efficient air conditioning systems that are capable of achieving good indoor air quality with low energy consumption rates and air pollution emissions. Among the evolving energy efficient air conditioning technologies are liquid desiccant air conditioning (LDAC) systems, which have showed promising performance during the past decades and are believed to be a strong competitor with the widely used conventional air conditioning systems (CAC).

The air handling in air conditioning systems was moist because of the dehumidification process in summer, so bacteria were easily propagated and developed. In addition, the air humidity in moist central air conditioning systems is seldom controlled. This causes people to feel uncomfortable in such air conditioning rooms. Solar energy driven liquid desiccant cooling air conditioning systems (LDCS) can improve indoor air quality and reduce electrical energy consumption and have been regarded highly by researchers and engineers in recent years.

The desiccant based air conditioning system comes to be one of the prospective alternatives for the traditional vapour compression air conditioning systems.

1.3. Literature review

Ahmed H Abdel Salam and Carey J Simonson (2014) proposed a membrane liquid desiccant air conditioning (M-LDAC) system modelled using the TRNSYS building energy simulation software. The four air conditioning systems investigated in this study are evaluated from technical, environmental and economic points of views. They found that, the energy consumption of the systems with an ERV increases as the exhaust airflow decreases. Energy consumptions of the CAC-ERV increases by 11% and M-LDAC-ERV increases by 6% when $R_{exhaust}$ decreases from 1 to 0.6. When M-LDAC system is used CO_2 emissions decrease by 19% compared to CAC system and CO_2 reduction goes to 31% when ERV used at $R_{exhaust}$ equal to unity in the M-LDAC system. It was found that the electrical, thermal and total COPs of the M-LDAC system are 3.45, 1.95 and 0.68 respectively. In their simulation results, the M-LDAC system is a promising system from technical environmental and economic point of views. More energy savings can be achieved through the integration of an energy recovery ventilator, a solar thermal system or a heat pump with the proposed M-LDAC system.

Balghouthi M et al (2008) did computer model and simulations using the TRNSYS and EES programs with meteorological data. The system optimized for a typical building of 150 m^2 area consists of a water lithium bromide absorption chiller of a capacity of 11 kW, a 30 m^2 flat plate collector area tilted 35^0 from the horizontal and 800 l hot water storage tank. The simulation results show that, absorption solar air conditioning systems are suitable under Tunisian conditions.

Elsherbini A L and Maheshwari G P (2010) they found that the theoretical increase in the coefficient of performance (COP) due to shading is within 2.5%, this small improvement in ideal efficiency decreases at higher ambient temperatures, when enhancements to efficiency are more needed. The actual efficiency improvement due to shading is not expected to exceed 1% and the daily energy savings will be lower.

Guo J and Shen H G (2009) studied a lumped method combined with dynamic model and investigated the performance and solar fraction of a solar ejector refrigeration system (SERS) using R134a. They found that, during the office working time, i.e. 9:00 a.m. to 5:00 p.m. the average COP and the average solar fraction of the system were 0.48 and 0.82 when the operating conditions are: generator temperature is 85^0C and evaporator temperature is 8^0C and condenser temperature varying with ambient temperature. This system can save up to 80% of electrical energy when compared with traditional compressor based air conditioning.

Ha Q P and Vakiloroaya V (2014) studied the performance enhancement and energy efficiency improvement of a new hybrid solar assisted air conditioning system. A single stage vapour compression solar air conditioner consists of six major components; a compressor, a condenser, an expansion device, an evaporator, a solar vacuum collector and a solar storage tank. In this new configuration a bypass line is implemented in the discharge line after the compressor to control the refrigerant mass flow rate via a two way valve while a variable speed drive is connected to the air cooled condenser to adjust the condenser fan air flow rate. From the simulation, they found that the enthalpy of refrigerant entering the expansion valve with and without the new configuration is reduced by 8.5%. Designed at steady state conditions, the compressor power consumption for the system without control and the developed system are 1.45kW and 1.24kW and energy savings is 14%. The average power consumption by using the developed system is 9.7% less than that of the uncontrolled system. The average energy saving potential for the proposed approach for the compressor and condenser fan is 7.1% and 2.6%. Both of compressor and condenser reduction can result ultimately in an increase of COP. The average supply temperature of the developed system is decreased from 13.77^0C to 11.44^0C. The average energy consumption of the newly developed system under control and the original one in summer month power consumption is less than the power usage of the uncontrolled plant. For the closed loop system under control have 7% to 14% electricity consumed by the compressor can be saved using the proposed system under multivariable control as compared to the system without control. They concluded that this new design is promising for improving the system performance while fulfilling the cooling demands as well as achieving high energy efficiency.

Ibrahim I El Sharkawy et al (2014) theoretically investigation on the performance of solar powered silica gel/water based adsorption cooling system working under Middle East region climate conditions. Two bed silica gel/water type adsorption chiller has been used. They found that the maximum cyclic average cooling capacity of the system working under Cairo and Jeddah climate conditions reaches to 14.8 kW and 15.8 kW under Aswan climate conditions. Cooling capacity of the system without hot water buffer storage reaches its maximum at noon and for the system with hot water buffer storage, the maximum cooling capacity value is 13 kW that is achieved at a time interval of 14:00 and 15:00 hours. The system with hot water buffer storage has less fluctuating cooling energy production compared to that of the system without hot water buffer storage.

Lucas M et al (2003) installed a Hydrosolar roof prototype on a laboratory roof at Spain. This building was air conditioned with a water condensed chiller working with the solar roof as a condenser. The total volume occupied by the four cells of the prototype is roughly 6m*6m*1.2m in size. During the summer 2000 the system was monitored to obtain performance data in a real installation and under real conditions. They created CFD model and analysed. From their numerical results and experimental results, they confirmed that, the air mass flow is induced through the channel due to natural and forced convection. Natural convection is produced by the solar radiation heating the plates and forced convection is due to the wind suction effect at the output of the channel. Therefore, the two main meteorological factors that influence the system performance are solar radiation and wind velocity.

Ma Q et al (2006) studied performance of hybrid air conditioning systems and they observed that, the performance of hybride air conditioning system is 44.5% higher than conventional vapour compression refrigeration system at a latent load of 30% and the improvement can be achieved by 73.8% at a latent load of 42%.

Min Tu et al (2010) performed comparison between two novel configurations of liquid desiccant air conditioning system driven by low grade thermal energies.

Moncef Balghouthi et al (2005) studied with the TRNSYS program simulation study of solar powered absorption cooling technology under Tunisian conditions. A number of simulations were carried out in order to optimize the various factors affecting the performance of the system. Their simulation results show that absorption solar air conditions solar air conditioning systems are suitable for Tunisian's conditions.

Sukamongkol Y et al (2010) they conducted an experimental test to investigate validity of a developed simulation model in predicting the dynamic performance of a condenser heat recovery with a hybrid PV/T air heating collector. The thermal energy generated by the system can produce warm dry air as high as 53^0C and 23% relative humidity. 6% of daily electricity can be obtained from the PV/T collector in the system. The use of a hybrid PV/T air heater, incorporated with the heat recovered from the condenser to regenerate the desiccant for dehumidification and save the energy use of the air conditioning system by 18%. They concluded that, the experimental validation results that the developed simulation model is able to predict within acceptable limits of accuracy the performance of a condenser heat recovery with a hybrid PV/T air heater to regenerate desiccant for reducing energy use of an air conditioning room.

Thosapon Katejanekarn and Kumar S (2008) simulation procedure is used to predict the operating and performance parameters of the system in the form of daily profiles. They found that, the system is reduced the average relative humidity of air is decreased by 15%. The regenerating air coming out of the solar C/R is warmer and drier than the entering ambient air. They studied the system performance with the ventilation air flow rate was varied and they found that, the effectiveness at the ventilation rate of 40, 60 and 80 CFM is decreased by 23%, 45% and 68% when compared with the base 20 CFM. Because, the less contact time between the air and the desiccant inside the dehumidifier. On a daily average, the relative humidity of the delivered air at the ventilation rate of 20, 40, 60 and 80 CFM is 43.12%, 48.49%, 52.83% and 57.15%. This is due to the less moisture removal effectiveness at higher ventilation rates. At the ventilation rate of 40, 60 and 80 CFM, the moisture removal rate is increased by 48%, 58% and 26%, whereas the evaporation rate is increased by 17%, 20% and 6%.

Tingyao chen et al (2007) designed a solar air conditioning system which is independent on design dry bulb and wet bulb temperatures. This design coincident dry bulb and wet bulb temperatures more than 6^0C higher as compared to the newly generated design dry bulb and wet bulb temperature. From this new method they can, when the peak cooling load occurs, HVAC engineers can avoid calculating 24hours cooling loads on one design day in each month of the year. This new method and design weather data allow to determining the peak cooling load for a room or building in any orientation directly, but with a thermal lag less than 1 hour.

Yonggao Yin and Xiaosong Zhang (2010) studied on internally heated and adiabatic regenerators in liquid desiccant air conditioning system. Heat and mass transfer model was used to analyse and compare the performance of internally heated and adiabatic regenerators. They found that, internally heated regenerator is proposed to achieve better regeneration performance when compared to conventional packed regenerator. Internally heated regenerator not only could increase the regenerate rate, but also could exhibit higher energy utilization efficiency. Internally heated regenerator can provide comparable regeneration efficiency and regeneration rate at low desiccant flow rate, so it should be a good alternative to avoid carryover of desiccant droplets. Higher air flow rate would result in a deduction of regeneration thermal efficiency although achieving higher regeneration rate.

Yonggao Yin et al (2007) experimentally studied the dehumidification rate of the air decreases from 0.104 g/sec to 0.073 g/sec when the temperature of the inlet air changes from 29^0C to 34.1^0C. From this experiment, they found that the average mass transfer coefficient of the packing regenerator is 4g/m^2sec. When the desiccant solution mass concentration is 20% and heating temperature is 77.5^0C, the maximum mass transfer coefficient is 7.5 g/m^2sec. In this experiment, the humidity of the inlet air is varied from 11.5 g/kg to 35 g/kg and its temperature is 28.5^0C. The desiccant solution temperatures are in the range from 55^0C to 70^0C. The solution outlet temperatures range between 39.5^0C to 43^0C and the air outlet temperatures range between 32^0C to 35^0C. They found that the dehumidification rate increases obviously with increasing humidity of the inlet air.

The coefficient of performance (COP) of the air conditioning systems varies from 0.7 to 1.2.

2. Conclusions

From the literature review, it is observed that, the energy and water are the basic necessity for all of us to lead a normal life on this beautiful earth. Solar energy technologies and its usage are very important and useful for the developing and under developed countries to sustain their energy needs.

The main motivation for solar cooling systems is the substitution of electricity as the premium energy sources for air conditioning systems by a renewable heat source, i.e. low grade heat from solar collectors.

Solar cooling is a good example of addressing climate changes. Long term data should be used to prove the feasibility of air conditioning systems.

Acknowledgements

Foremost, I am thankful to Professor A.V. Sita Rama Raju, JNT University for his valuable suggestion of reading numerous research publications in the area of solar distillation and to write review papers. I am thankful to Professor K.Vijaya Kumar Reddy and Professor B. Sudheer Prem Kumar, JNT University and my parents for their encouragement in preparing this research paper.

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