PERFORMANCE ANALYSIS OF SOLAR ASSISTED AIR CONDITIONING SYSTEM USING CARBON DIOXIDE AS REFRIGERANT

Olusola Bamisile[1], Ferdinard Dika[2], Mustafa Dagbasi[3], Serkan Abbasoglu[4]
1,2,3,4 Energy System Engineering, Cyprus International University, Haspolat-Lefkosa, Mersin 10, Turkey.
Corresponding author: Olusola Bamisile, e-mail: boomfem@gmail.com

REFERENCE NO
ACON-01

Keywords:
Air conditioning, solar energy, performance, energy saving

ABSTRACT

The aim of this study was to model an air conditioning system that brings about effective cooling and reduce fossil fuel consumption with solar energy as an alternative source of energy. The objective of the study is to design a system with high COP, low usage of electricity and to integrate solar energy into AC systems. A hybrid solar assisted air conditioning system is designed to produce 30-kW cooling capacity and R744 (CO_2) is used as refrigerant. The effect of discharge pressure on the performance of the system is studied. The sub-cool temperature, evaporating temperature (5 °C), and suction gas return temperature (12°C) are kept constant for the four different discharge pressures considered. The cooling gas temperature is set at 25 °C, and the discharge pressure includes 80, 85, 90, and 95 bars. Copeland Scroll software is used for the simulation. A pressure-enthalpy graph is also used to deduce each enthalpy point, while numerical methods were used in making other calculations. From the result of the study, it is observed that a higher COP is achieved with the use of solar assisted systems. As much as 46% of electricity requirements will be save using solar input at compressor stage.

1. INTRODUCTION

Renewable energy sources (RES) can be simply explained as a viable resource available over the long-term goal at a reasonable cost. The diverse use of RES in energy supply selections, both for developed and developing countries, decreases dependency on fossil fuels. RE resources contributed just about 19% of the world energy consumptions in 2012 and about 22% of the electricity generation in 2013 [1]. Solar energy being the most abundant energy source on this planet is affordable. It also has the ability to meet household as well as commercial/industrial needs [2]. Solar energy technologies can deliver the energy needed in buildings both for industrial, residential and non-residential, thus including HVAC, domestic hot water, electricity and lighting [3]. Solar energy technologies can be used in most places for all energy demand of buildings [4]. One of the major setbacks encountered in using solar energy is the intermittency and its variation with weather conditions. Using renewable energy is one of the most promising means of meeting the energy demand as well as reducing this greenhouse gas emission. The high solar insolation period coincides with the hot summer time when solar air conditioning systems are constantly used for cooling purposes. Therefore, the use of solar assisted air conditioning systems is of great importance in this part of the world as it decreases the use and consumption of the electricity. Switching to the use of solar as a renewable energy to bring about comfort in the society, reduces the burden on the utility grids system [5].

As energy consumption is one of the growing concerns of the 21st century [6], the society is faced with high energy prices and of course a growing concern on energy related environmental issues. Heating Ventilation and Air Conditioning (HVAC) systems are installed in a building to provide the occupants heating/cooling comfort. HVAC systems has component arrangement which gives healthy environment and increases productivity of occupants. These components are arranged in a way to either bring cooling/heating process, humidification and dehumidification, delivering the conditioned air which contains some outdoor air, to the conditioned space. The increasing growth of this energy consumption, which results in a higher unavoidable greenhouse gas emission, is one of the main causes of global warming [7]. One of the major components that consumes energy in a building structure is the HVAC system [8]. Generally, introduction of an air conditioning system that is thermally driven is not unachievable. These processes use heat in form to assist the production of the cooling or heating process. One of the most important uses of air conditioning systems is its application in providing comfort in most building. In extremely hot climates, air conditioning systems are used to remove the generated heat and provide cool air to the building [9]. Nowadays, ACs which enable chilling and dehumidification have become essential in residential, commercial and industrial processes [10]. The demand for electricity during summer period is increasing because of the usage of appliances for comfort cooling or air conditioning. Electric energy obtained from fossil fuels also increase emission of CO_2 which leads to the global warming and environmental pollution [11].

Furthermore, conventional air conditioning systems has great impact on global warming and ozone depletion based on the use of fluorinated gases (refrigerants) such as hydrochlorofluorocarbon (HCFC) and chlorofluorocarbon (CFC). The latter effect is thousand times much greater than what is produced by CO_2. From the end of 18th century to the beginning of 19th century, CO_2 was the prime choice as refrigerant that was used in any type of compressed refrigerating machines. In the early days of refrigeration, the two main refrigerants used were the carbon dioxide and ammonia. The latter was problematic as it releases some toxic substances and thus pollute the atmosphere. On the other hand, extremely high pressure (30 to 200 bars) is required for carbon dioxide to work efficiently. One of the problems encountered with the use of CO_2 is the high pressure and temperature demand of the refrigerant, which in turn stresses the compressor to consume higher power. The high temperature requirement of the CO_2 may be utilized to produce heating effect for domestic purposes.

Maintaining appropriate temperature, air motion, and air circulation are the basis of a comfortable indoor environment. This comfortable environment is obtained by using HVAC systems. HVAC systems account for at least 60% of the world total building energy consumed and this calls for a sustainable and steady solutions for the systems. The focal objective of this study is to see how to minimise the energy consumption by shifting towards natural viable renewable sources while maintaining the required comfort level of a structure or building. HVAC systems are delivered so as to meet the specification of comfort, cost, efficiency and aesthetic appeal. A sustainable system adds to the complexity of designing an HVAC system. Over the last two decades the world at large (especially developing countries) has been characterized with inadequate steady electricity supply and high consumption of electricity, if available, for cooling of various buildings, organizations and establishments during the hot season. This study is projected in establishing the facts that the natural source of energy like sun can be used to achieve comfort cooling and hence reduce the cost and pollution of all other sources of energy in the production of electricity for comfort cooling purposes. The aim of this work is to focus on the design of a (HVAC) system that achieves effective cooling and reduce fossil fuel consumption by using solar energy as an alternative source of energy. The objective of the research includes; the design an AC system with high COP, design a system with low usage of electricity in assisting the system, integrate solar energy into HVAC systems and investigate the effect of some parameters on the performance.

2. METHODOLOGY

Solar assisted air conditioning system also known as Hybrid Solar Air Conditioner (HSAC) has been used for comfort cooling with different technological approaches. It is found to be a suitable solution to energy peak load demand for air conditioning system during summer period. This section presents the design methodology of a 30-kW HSAC system with the use of R744 (CO_2) as the refrigerant. The solar radiation during summer period is sufficient to power the system and meet the cooling requirement. In this research, the parameters of the refrigeration cycle are kept constant except the condensing pressure which is varied and the COPs are calculated using EES (Engineering Equation Solver) and Copeland Scroll software. This design is not location restricted as it is designed to fit into any region with moderate or high solar radiation during summer period. In this study, much concentration is on the performance of the system and the energy saved by the design with its technical details.

2.1 Design Approach

In the design of solar assisted air conditioning system, it is important to consider the right components and also the cooling requirement. The type of air conditioning system, the meteorological data and the solar collector to be used are important factors that determines the performance, durability and the life span of this system. The effect of discharge pressure on performance (while all other parameters are constant) will be studied. The sub cool temperature (exit from condenser), evaporating temperature and suction gas return temperature (before entering the compressor) are kept constant for the four-different discharge (condensing) pressures considered.

The solar assistance is considered to be applied at constant volume heating following the pressurization by the compressor. In all the four cases considered (four different condensing pressures), the compressor work was reduced (lower discharge pressure than condenser pressure) and the discharge from the compressor was heated at constant volume by the solar collectors. The discharge temperature from the solar heating section was fixed to be 100°C at all cases.

2.2 Components Selection

Copeland Scroll software is used for the performance analysis and sizing. It should be noted that the software has pre-programmed suitable components based on the inputted design parameters. For this section the major components that are considered includes; compressor, solar energy collector, condenser, expansion valve and evaporator.

Copeland 4MTL-12X [INV] compressor is selected based on its best-in-class performance and durability in CO_2 (R744) Transcritical applications. Stream series of four cylinders CO_2 compressor is an ideal solution for the selected refrigerant (R744) with booster systems and medium temperature. A pressure of 135 bars and below is the characterized design feature for this compressor and refrigerant flow has been optimized for maximum performance. The compressor is equipped with CoreSense™ technology which can diagnose system related problems.

A water-cooled condenser is selected considering the design of the system. Water will be used to cool the system step wisely. An expansion valve is used to regulate the flow of the refrigerant and make the drop of the pressure of the refrigerant from the condensing pressure to the evaporation pressure. A 30-kW and above evaporator suitable for R744 refrigerant is selected for this design. The solar thermal collector is chosen based on the 30-kW capacity of the design to give additional heat input to the system so that it will reduce the electricity consumption of the compressor. A collector with evacuated tubes will be used for this design.

2.3 Operating Parameters of the Air Conditioner

System with Refrigerant R744

A Pressure-Enthalpy (p-h) graph for refrigerant R744 is used to analyse the systems performance with and without solar assistance. Coefficient of performance (COP) is calculated using the data extracted from this graph. This graph (Fig. 1) consists of a pressure, and enthalpy axis, and includes lines of constant entropy, constant volume and constant temperatures. It also shows the freezing line, the triple point and the liquid, vapour and mixed regions. The reference state for the graph includes; h = 200.0 kJ/kg and s = 1.00 kJ/(kg.K) for saturated liquid at 0^0C. This was extracted from 2013 ASHRAE Handbook- Fundamental (SI) [12].

Table I: Parameters

Cooling Requirement	30.0 kWh
Discharge abs pressure bar	80, 85, 90 and 95
Evaporating temperature	5^oC
Suction Gas Return	12^oC
Cool Gas Temperature	25^oC

A Pressure-Enthalpy (p-h) graph for refrigerant R744 is used to analyse the systems performance with and without solar assistance. Coefficient of performance (COP) is calculated using the data extracted from this graph. This graph (Fig. 1) consists of a pressure, and enthalpy axis, and includes lines of constant entropy, constant volume and constant temperatures. It also shows the freezing line, the triple point and the liquid, vapour and mixed regions. The reference state for the graph includes; h = 200.0 kJ/kg and s = 1.00 kJ/(kg.K) for saturated liquid at 0^0C. This was extracted from 2013 ASHRAE Handbook- Fundamental (SI) [12].

2.3 System Configuration and Description

The basic system is without the solar input section, where the refrigerant is compressed to a very high pressure and temperature before condensing. The cooled and liquefied refrigerant in the condenser is passed through the expansion valve which help in regulating the flow and dropping the pressure from condensing pressure to the evaporating pressure. The main steps of the basic refrigeration cycle, with reference to the p-h chart (fig 1) is; 1-3 compression, 2-3 compression (without solar input), 4-5 condensation, 5-6 thermal expansion, 6-1 evaporation.

The solar assisted air conditioning system basically includes an extra main component; the solar heater. In this system, the refrigerant outlet from the compressor is channelled to pass through the solar vacuum tube collectors. The solar energy heats up the refrigerant at a constant volume, thus increasing the pressure and temperature of the refrigerant. The super-heated refrigerant leaves the solar collector at 100 °C and enters into a heat exchanger (a first step of condenser). The heat of refrigerant initially at 100^oC is utilised to heat up domestic water for the building. The domestic water will be heated to 45^oC, while the refrigerant is cooled to 50°C. The refrigerant leaving this heat exchanger will enter into a water-cooled condenser where it will be cooled down to 25^oC. The thermal expansion is now introduced to the system to help drop the pressure from condensing pressure to the evaporating pressure of the system. The main steps of the solar assisted refrigeration cycle, with reference to the p-h chart (fig 1) is; 1-2 compression, 2-4 solar input, 4 -4_1 heat used for domestic water heating, 4-5 condensing in water cooled condenser, 5-6 Expansion valve, 6-1 Evaporation.

Calculations

The actual COP of the system without solar assistance is obtained with the help of Copeland Scroll software. For the case with solar assistance the compressor efficiency (isentropic efficiency) was considered to be the same. COP after inputting a solar system is calculated using EES. Before the COP with the solar assistance can be calculated it is important to calculate enthalpy h_3 (enthalpy of gas exiting the compressor in the case without solar assistance) and this is calculated with equation 1 below.

$$\dot{m}(h_3 - h_1) = W_e \tag{1}$$

where:
W_e: Power Input (kW)
$\dot{m}$: Mass Flow rate (kg/s)
h_3: Enthalpy at point 3 (using Fig. 1 as an example)
h_1: Enthalpy at point 1 (using Fig. 1 as an example)

Therefore, the COP_e (without solar assistance) and COP_s (with solar assistance) are calculated using equation 2 and equation 3 below:

$$COP_e = \frac{h_1 - h_6}{h_3 - h_1} \qquad (2)$$

$$COP_s = \frac{h_1 - h_6}{h_2 - h_1} \qquad (3)$$

where h_1 to h_6 are enthalpies at points 1 to 6 as shown in the sample chart above (fig 1).
The heat input, power input (for solar assisted case) and saved energy are all calculated using the formula used are given in equations (4) - (6). The solar system that will be used in assisting the air conditioning system is designed with respect to the result gotten from solar input calculations. The energy saved for this study is paramount as this will help to know the possible fossil fuel saving and the GHG emission saved by the system.

Solar heat Input,

$$Q_s = \dot{m}(h_4 - h_2) \qquad (4)$$

Power Input when solar assisted),

$$W_s = \dot{m}(h_2 - h_1) \qquad (5)$$

Saved Electrical power,

$$W_a = \dot{m}(h_3 - h_2) \qquad (6)$$

A comparison graph is drawn to compare the 3 different COPs. The saved energy comparison will also be displayed using table to intrinsically check the accuracy of all the calculations.
Heat for domestic hot water (with solar assistance),

$$Q_d = \dot{m}(h_4 - h_{4'}) \qquad (7)$$

where $h_{4'}$ is the enthalpy of hot water at 50°C

Domestic water heating may be introduced into the design especially in the case solar assisted design. It is worth noting that, the exit temperature of the refrigerant from the solar collectors is at 100°C and domestic hot water may easily be produced at temperatures around 50°C.

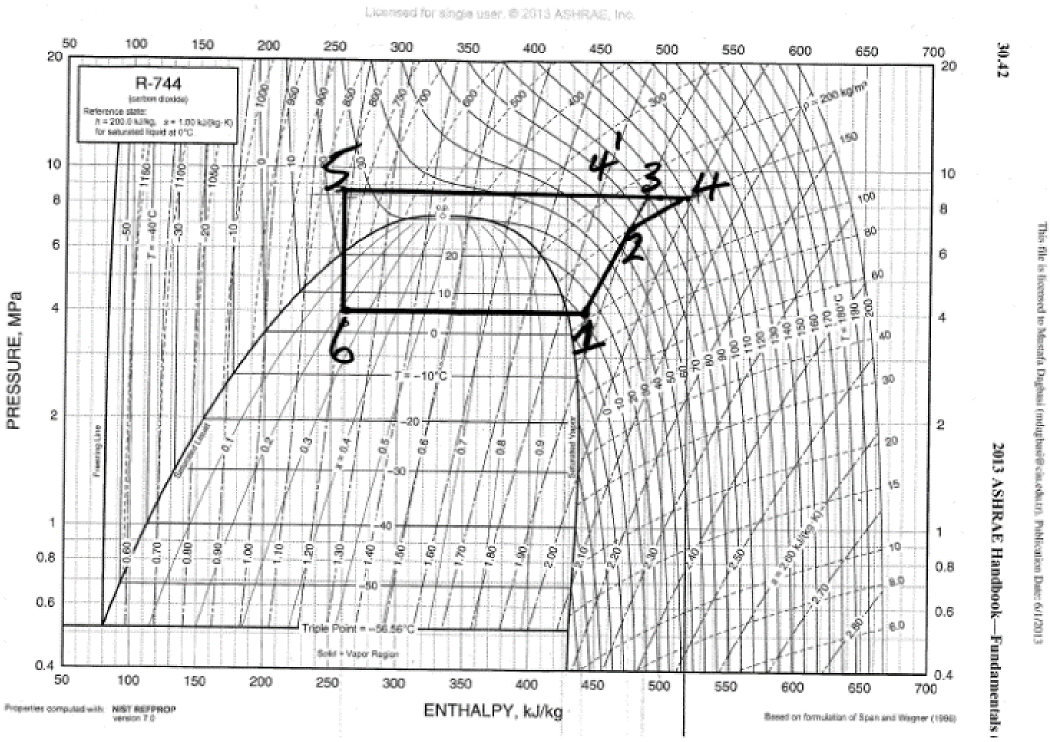

Fig. 1 Pressure-enthalpy graph showing different points

3. RESULTS AND DISCUSSIONS

The results obtained from the use of solar energy to assist air conditioning system for different condensing pressures (80, 85, 90 and 95) is presented in this section. The cooling requirement for this design is 30.00 kWh, evaporating temperature is set 5^{o}C while the suction gas return is 12^{o}C and the cooling gas temperature is 25^{o}C. The graph is drawn in such a way that 1-3 represents the compressing region, 2-4 is solar input, 4-5 is the condensing region, 5-6 is the thermal expansion device and 6-1 is the evaporator.

The processes involved in the solar assisted air condition cycle are explained with the help of graph (fig 1). The process from 1-3 indicates the compressor work where the refrigerant is compressed to the point where the solar assistance comes in. 2-4 indicates the solar heat input to the refrigerant at constant volume. The process 4 -41 indicates the first part of condensing (high temperature) where the heat is used to heat up domestic water, and process 4-5 indicates the condensation in a water-cooled heat exchanger. The refrigerant at the exit of the condenser is in the liquid, usually sub cooled by a few degrees below saturation temperature. Process 5-6 the expansion process where the refrigerant pressure is dropped to evaporating pressure. The flow of refrigerant is also controlled by the expansion valve. The process 6-1 indicates the evaporator section of the graph where the refrigerant evaporates into the compressor and the system goes on and on.

Equations 1 to 8 are stated in the methodology section are inputted into EES and used for the calculations. The result from all the calculation are shown in a table for simplicity and clarity. This table also includes the simulation results obtained from Copeland software. The results are discussed in detail below.

3.1 COPs

Three different kind of COPs are gotten from the results in this study. The conventional COP_e is obtained with the use of Copeland software while the COP with solar assistance, COPs were calculated using p-h diagrams. From table II, it is observed that the COPs and COP_e follows the same trend. As the pressure of the system is increased, the COPs and COP_e are decreasing. Also, the difference between the COPs for the conventional case and (COP_E) and solar assisted case are decreasing with the increase of condensing pressure. From the result, it is clearly seen that a higher COP is achieved with the use of solar assisted systems. The decrease in the difference of COPs and COP_e at higher pressures may be partly attributed to the limitation of refrigerant temperature (100°C) at the exit from the solar heater. This limit is set due to the performance of the solar vacuum tubes.

Table II: Analysis and Simulation result summary

	Pressure(bar)	**80**	**85**	**90**	**95**
Software Result	Power Input (kW)	7.71	8.07	8.63	9.41
	Capacity (kW)	30	30.50	30.20	30.80
	Mass Flow (g/s)	169.0	170	166.0	168.0
	Isentropic Efficiency (%)	63.09	66.29	65.75	65.51
	Heat Rejection (kW)	37.40	38.20	38.40	39.80
	COP	3.90	3.78	3.50	3.28
Enthalpy readings from Graph	h1 (kJ/kg)	440	440	440	440
	h2 (kJ/kg)	470	475	484	490
	h3 (kJ/kg)	487	488	495	498
	h4 (kJ/kg)	520	518	512	518
	h4I (kJ/kg)	438	428	414	416
	h5 (kJ/kg)	267	260	252	256
	h6 (kJ/kg)	267	260	252	256
Numerical Analysis	COPE	3.68	3.55	3.42	3.17
	COPS	5.77	5.14	4.27	3.68
	Heat Input	8.45	7.31	4.65	4.70
	Power Input for Solar (kW)	5.07	5.95	7.30	8.40
	Saved Powera (kW)	2.87	2.21	1.83	1.34
	Saved Powerb (kW)	2.64	2.12	1.33	1.01
	Domestic Heat Supply (kW)	13.86	15.3	16.27	17.14

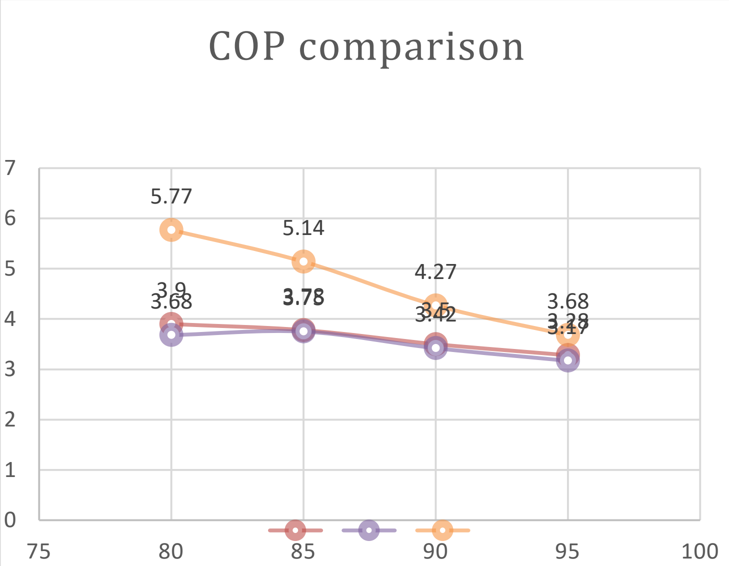

Fig. 2 COP Comparison chart

3.2 Solar Power and Heat Input

The solar power (heat input rate) requirement for the system follows a decreasing trend with the increase of the condensing pressure.

3.3 Energy/Emission/Fossil Fuel Saving

It will be incomplete if the environmental impact of this study is not considered. The power saved with this design is calculated using equation (6) and equation (7) and the result is shown in Table II. The energy saved can easily be estimated by considering the total working hours of the system in a specific time frame.

Table III: Emission Factor table

Emission factors for #6 fuel oil	GHG Gases	CO2	0.263 kg/kWh
		NO_X	0.743 g/kWh
		SO_X	1.47 g/kWh
Fossil fuel savings	Fuel used in generating 1 kWh of electricity (with 33% overall system efficiency)	Coal	1.05 pounds (477 grams)
		Natural Gas	10.1 cubic feet (0.286 m^3)
		Petroleum	0.073 gallons (0.276 litres)

GHG emission is one of the important factors taken into consideration in any energy related design. Nowadays a design must consider various options to save fossil fuel and therefore reduce those emissions harmful to the environment especially for the future generations. According to Olusola et al. (2016) [13], the emission factor for #6 fuel oil is as stated in table III. These values are used in calculating the emission and fossil fuel saving for this study and the result is presented in table IV.

Table IV: Emission and Fossil Fuel Savings

Condensing Pressure (bar)	Power Saved (kW)	Emission Savings			Fossil Fuel Savings		
		CO2 (kg/h)	NOX (g/h)	SOX (g/h)	Coal kg/hr	Petroleum Lt/hr	Natural m3/hr
80	.87	0.755	2.132	4.219	1.368	0.792	.821
85	2.21	0.581	1.642	3.249	1.054	0.610	0.632
90	1.83	0.481	1.360	2.690	0.873	0.505	0.523
95	1.34	0.352	0.996	1.970	0.639	0.370	0.383

CDD=1251-degree days (based on T_i = 25ºC)

q = the cooling capacity of the system,

q = 30kw (based on T_o = 40ºC

Where T_i and T_o refers to indoor and outdoor design temperatures for the cooling capacity calculations.

Effective full capacity working hours (H) of the machine is estimated as:

$$H = CDD * 24 / (T_o - T_i)$$
$$H = 2001\ hrs$$

The electrical energy (Q1) required to operate a standard air conditioning unit is estimated as:

$$Q_1 = 2001 * 30 / 3.2 = 18765 \text{ kWh}$$

where 3.2 is the COP of the standard air conditioner unit.

Heat energy transferred to domestic water (Q_w), for 80 bar condensing pressure, is calculated (assume all water generated is used) as:

$$Q_w = 13.86 \text{ kW} \times H \qquad (8)$$
$$Q_w = 2001 \times 13.86 \text{ kW} = 27742.2 \text{ kWh}$$

Assuming this would have been otherwise supplied by natural gas (NG), whose useful energy content is 14.0 kwh/kg, the annual saved gas quantity is estimated as:

$$m_{(NG)} = 27742.2 / 14.0 = 1982 \text{ kg}$$

The refrigeration system described in this work will consume lower electrical energy as it has a much higher COP. For the case with 80 bar condensing pressure and with solar heat supply, the electrical energy usage is estimated below.

$$E_{e(saved)} = 18765 - (5.07 \times 2001) = 8619.93 \text{ kWh/yr}$$

Assume electrical energy is also produced using NG, total mass of NG saved is estimated as:

$$m_{(NG\ tot)} = m(NG) + Ee(saved) / 7.65 \quad (9)$$

$$m_{(NG\ tot)} = 1982 + 8619.93 / 7.65$$

$$m_{(NG\ tot)} = 3108.8 \text{ kg/year}$$

Where the electrical energy conversion ratio for NG is taken as 7.65 kWh/kg

Carbon Dioxide abated as a result of saved (reduced) NG combustion is estimated to stress the reduction in GHG emission. Combustion of produces 2.75 kg CO2 per kg of NG. Total CO_2 abated is therefore estimated to be 8547 kg C02/yr.

3.4 Heat Energy and Heat Storage Requirement

The solar heat input requirement depends on condensing pressure. Daily solar heat energy input requirement will vary depending on the time of the day and other parameters such as daily temperature variations. Furthermore, the cooling energy requirement of the building varies throughout the day and throughout the cooling season. As a base for calculations, the following equation is used.

$$E_s = Qs\ (t1*f1 + t2*f2 + t3*f3) \quad (10)$$

Where f1· will be a factor for different time periods, t1· hours of the day and Qs is the heat input rate to the refrigeration system. In this work the day will be divided in 3 equal periods each of 8 hours. The factors will indicate the ratio of cooling capacity in a time compared to that of full capacity.

t1 = t2 = t3 = 8 hours
f1 = 1 (full capacity)
f2 = 0.5
f3 = 0.2

Part of the solar energy collected from the sun during sunny hours of the day shall be stored for use at night. The daily solar energy input requirement is calculated below for the case of 80 bar condensing pressure.

The heat energy requirement during a day (24-hour period) is estimated as

$$E_g = 13.86*(t1*f1 + t2*f2 + t3*f3) \quad (11)$$

$$E_s = 13.86*[8*1 + 8*0.5 + 8*0.2]$$

$$E_s = 188.5 \text{ kWh}$$

Part of the solar energy collected from the sun during sunny hours of the day shall be stored for use at night. The heat storage requirement is estimated as:

$$E_g = (t2*f2 + t3*f3)\ Qs \quad (12)$$

$$E_s = [8*0.5 + 8*0.2]\ 13.86$$

$$E_s = 77.62 \text{ kWh}$$

In the cases considered in this study the maximum temperature of the refrigerant gas is limited to 100°C. This requires the heating medium from the solar collectors to be at a higher temperature. Pressurized water at 2.0 bars boil at 120°C, hence is suitable for use as the heat transfer fluid. The energy stored will be at 120°C (in hot tank) and will be cooled down to 105°C (in cold tank); where the cold fluid temperature 105°C is 5°C above the maximum gas temperature in system.

3.5 Solar Collector Requirements

The solar water collector's efficiency (η_{sol}) and solar system efficiency (η_{sys}) will be taken to be 50% and 75% respectively. The collector surface area will as will be calculated with a factor of safety to supply heat requirement of the system. If and when necessary, the auxiliary system will come into operation to to enable continuous heat supply to the generator of the absorption system.

$$As = Eg * Fs / (Esol * \eta sol * \eta sys) \quad (13)$$

Where:
As = solar collector surface area
Fs = factor of safety 110%

Esol =average solar energy available in hot season, taken as 7.00 kwh/day

ηsol = solar collectors' system efficiency, taken as 75%

ηsys = solar collector efficiency taken as 50%

Eg = heat energy requirement by the generator

For the case of 80 bar condensing pressure, the collector requirement is:

$$As = 188.5 * 1.1 / (7.0 *0 .75 * 0.5)$$

$$As = 79 \text{ m}^2$$

4. CONCLUSIONS

One of the ways to save the world and to tackle the current energy crisis in this age is energy conservation and efficiency. Energy conservation being the cleanest form of energy all over the world, this study proposes a way to save more energy and reducing the HVAC fossil fuel energy requirements of buildings. A solar assisted air conditioning system is designed and the COPs, solar energy input, energy saving, and other related parameters were calculated.

From the results and discussion, it can be concluded that using solar assisted air conditioning systems increases the COP of the system without a change in system performance of the primary object, which is the cooling of the building. This will help to save a lot of energy as the solar system is applied at some points to the system and this will also reduce the energy/electricity cost. About 46% of the required electricity will be saved using solar input at the compressor and up to 100% water heating in during summer period. Implementing this kind of system will also reduce the fossil fuels consumption of the system, thereby reducing GHG emission which has significant impact on countries like USA, UAE etc.

REFERENCE

[1]. REN21, (2016). Renewable 2016: Global Status Report., s.l.: Renewable Energy Policy Network.

[2]. Martinot, E., Chaurey, A., Lew, D., Moreira, J.R. and Wamukonya, N., (2002). Renewable energy markets in developing countries*. Annual Review of Energy and the Environment, 27(1), pp.309-348.

[3]. Pérez-Lombard, L., Ortiz, J., Coronel, J.F. and Maestre, I.R., (2011). A review of HVAC systems requirements in building energy regulations. Energy and Buildings, 43(2), pp.255-268.

[4]. Turner, J.A., (1999). A realizable renewable energy future. Science, 285(5428), pp.687-689.

[5]. Su, W. and Wang, J., (2012). Energy management systems in microgrid operations. The Electricity Journal, 25(8), pp.45-60.

[6]. Chu, S. and Majumdar, A., (2012). Opportunities and challenges for a sustainable energy future. Nature, 488(7411), pp.294-303.

[7]. Weisser, D., (2007). A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. Energy, 32(9), pp.1543-1559.

[8]. Mathews, E.H., Botha, C.P., Arndt, D.C. and Malan, A., (2001). HVAC control strategies to enhance comfort and minimise energy usage. Energy and buildings, 33(8), pp.853-863.

[9]. Dincer, I. and Rosen, M., (2002). Thermal energy storage: systems and applications. John Wiley & Sons.

[10]. Sultan, M., El-Sharkawy, I.I., Miyazaki, T., Saha, B.B. and Koyama, S., (2015). An overview of solid desiccant dehumidification and air conditioning systems. Renewable and Sustainable Energy Reviews, 46, pp.16-29.

[11]. Jacobson, M.Z., (2009). Review of solutions to global warming, air pollution, and energy security. Energy & Environmental Science, 2(2), pp.148-173.

[12]. https://www.ashrae.org/resources--publications/handbook [Accessed, 20/12/2016]

[13]. Olusola Olorunfemi Bamisile, Mustafa Dagbasi and Serkan Abbasoglu, (2016). Economic feasibility of replacing sodium vapor and high pressure mercury vapor bulbs with LEDs for street lighting, ENERGY AND POLICY RESEARCH 2016, VOL. 3, NO. 1, 27–31.

[14]. www.degreedays.net. [Accessed, 25/12/2016]