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Design, fabrication and performance analysis of solar PV air conditioning system

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Abstract- The demand of air conditioning is increasing due to the effect of climate change and global warming. If we still rely on the conventional electric air conditioning but electricity is generated from fossil fuels, the greenhouse gas emission would continuously worsen global warming; in turn the demand of air conditioning would be further increasing. In subtropical cities, air conditioning is a standard provision for buildings. However, air conditioning would commonly take up half of building electricity consumption. In the present work a portable air conditioning system is fabricated taking into account an indoor room.

Index Terms- Portable ac, heat load, performance analysis

I. Introduction

Air conditioning is defined as the simultaneous processing of temperature, humidity, purification and distribution of air current in compliance with the requirement of space needing air conditioning. In general, air conditioning which also can be known as refrigeration is defined as any process of heat removal. To produce the process, it requires energy. Energy is the primary and most universal measure of all kinds of work by human beings and nature. Energy is a crucial input in the process of economic, social and industrial development. Day by day the energy consumption is increasing very rapidly. The rate of energy consumption is increasing. Supply is depleting resulting in inflation and energy shortage. This is called the energy crisis.

According to law of conservation of energy "energy can neither be created nor be destroyed but can be transformed from one form to another form. Energy can be transported from one place to another place." Alternative or non-conventional or renewable energy resources are very essential to develop for future energy requirements. The energy demand increases day by day because of increase in population, industrialization and transportation etc.

A. *Principle of air conditioning*

The vapour-compression process uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Figure 1 depicts a typical, single-stage vapour-compression system. All such systems have four components:a compressor, a condenser, a thermal expansion valve (also called a throttle valve or metering device), and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapour and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapour is then in the thermodynamic state known as a superheated vapour and it is at a temperature and pressure at which it can be condensed with either cooling water or cooling air. That hot vapour is routed through a condenser where it is cooled and condensed into a liquid by flowing through a coil or tubes with cool water or cool air flowing across the coil or tubes. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by either the water or the air (whichever may be the case). The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid and vapour refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated.

The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapour mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature. The evaporator is where the circulating refrigerant absorbs and removes heat which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser. To complete the refrigeration cycle, the refrigerant vapour from the evaporator is again a saturated vapour and is routed back into the compressor.

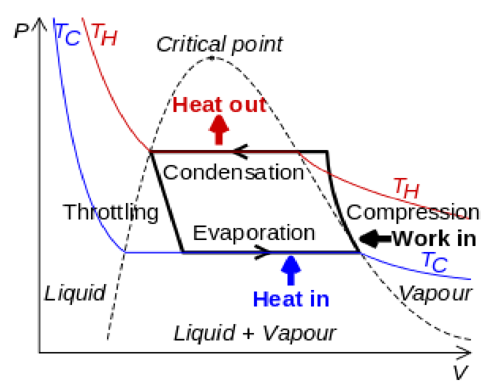

Fig 1 Pressure-volume diagram for a typical refrigeration cycle

B. Main components of air conditioning system Compressor

Compressor is electrically operated can be described as the heart of air conditioning system as it pump refrigerant throughout the system. The main function of a compressor is to compress refrigerant vapour to a high pressure, making it hot for the circulation process of the refrigerant. The compressor we are using for this project is hermitically reciprocating compressor. In hermetic compressors, the motor and the compressor are enclosed in the same housing to prevent refrigerant leakage. The housing has welded connections for refrigerant inlet and outlet and for power input socket. As a result of this, there is virtually no possibility of refrigerant leakage from the compressor. Hermetic compressors are almost universally used in small systems such as domestic refrigerators, water coolers, air conditioners etc, where efficiency is not as important as customer convenience (due to absence of continuous maintenance). In addition to this, the use of hermetic compressors is ideal in systems, which use capillary tubes as expansion devices and are critically charged systems.

Condenser and Evaporator

Condensers and evaporators are basically heat exchangers in which the refrigerant undergoes a phase change. Next to compressors, proper design and selection of condensers and evaporators is very important for satisfactory performance of any refrigeration system. Since both condensers and evaporators are essentially heat exchangers, they have many things in common as far as the design of these components is concerned. However, differences exists as far as the heat transfer phenomena is concerned. In condensers the refrigerant vapour condenses by rejecting heat to an external fluid, which acts as a heat sink. In evaporators, the liquid refrigerant evaporates by extracting heat from an external fluid (low temperature heat source). The external fluid may not undergo phase change, for example if the system is used for sensibly cooling water, air or some other fluid. There are many refrigeration and air conditioning applications, where the external fluid also undergoes phase change. For example, in a typical summer air conditioning system, the moist air is dehumidified by condensing water vapour and then, removing the condensed liquid water.

Expansion Device

An expansion device is another basic component of a refrigeration system. The basic functions of an expansion device used in refrigeration systems are to:

1. Reduce pressure from condenser pressure to evaporator pressure.

2. Regulate the refrigerant flow from the high-pressure liquid line into the evaporator at a rate equal to the evaporation rate in the evaporator.

Solar Panel

Solar panel refers to a panel designed to absorb the sun's rays as a source of energy for generating electricity or heating.Solar panel refers either to a photovoltaic module, a solar thermal energy panel, or a set of solar photovoltaic (PV) modules electrically connected and mounted on a supporting structure. A PV module is a packaged, connected assembly of solar cells. Solar Photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. Electrical connections are made in series to achieve a desired output voltage and/or in parallel to provide a desired current capability. A photovoltaic system typically includes a panel or an array of solar modules, a solar inverter, and sometimes a battery and/or solar tracker and interconnection wiring.

Charge Controller

Charge controllers are sold to consumers as separate devices, often in conjunction with solar or wind power generators, for uses such as boat, and off-the-grid home battery storage systems. In solar applications, charge controllers may also be called charge regulator. Some charge controllers / charge regulators have additional features, such as a low voltage disconnect (LDV), a separate circuit which powers down the load when the batteries become overly discharged (some battery chemistries are such that over-discharge can ruin the battery).

Battery

An electric battery is a device consisting of two or more electrochemical cells that convert stored chemical energy into electrical energy. Each cell has a positive terminal, or cathode, and a negative terminal, or anode. The terminal marked positive is at a higher electrical potential energy than is the terminal marked negative. The terminal marked positive is the source of electrons that when connected to an external circuit will flow and deliver energy to an external device. When a battery is connected to an external circuit, electrolytes are able to move as ions within, allowing the chemical reactions to be completed at the separate terminals and so deliver energy to the external circuit.

Inverter

A solar inverter, or PV inverter, or Solar converter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network.

In a photovoltaic system, allowing the use of ordinary AC-powered equipment. Solar inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection.

DESIGN ANALYSIS

Heat load calculation

DOOR SIDE WALL

Door side wall =105"x84"/144=61.25 sq. ft.

Area of door =36"x82"/144=20.5 sq. ft.

Total Wall area =61.25-20.5=47.75 sq. ft.

Q of door,Q1=U x A x T

=0.52x20.5x10=106.6 B.T.U

Q of door,Q2=U x Ax T

=0.24x40.75x10=97.8 B.T.U

Total Q of door side wall=Q1+Q2

=106.6+97.8=204.4 B.T.U

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PLANE WALL
Area of plane wall (other side) =(84”x100”)x2=16800/144=116.66 sq. ft.
Q of wall=0.24x116.66x10=279.98 B.T.U

WINDOW SIDE WALL
Area of wall=105”x84”/144=61.25 sq. ft.
Area of window=39”x58”/144=15.70sq. ft.
Total area of wall=61.25-15.70=45.55 sq. ft.
Q of window,Q1=U x A x T
=1.13x15.70x10=177.41B.T.U
Q of wall,Q2= U x A x T=0.36x45.55x10=163.98B.T.U
Total Q=177.41+163.98=341.39 B.T.U
TOTAL HEAT LOAD OF THE ROOM
=Door side wall + plane wall + window side wall
=204.4+279.9+341.39
=825.774 B.T.U
=825.774/12000=0.068 BTU per hr.
For 8 hr. working of A.C =0.068x8
=0.55 ton

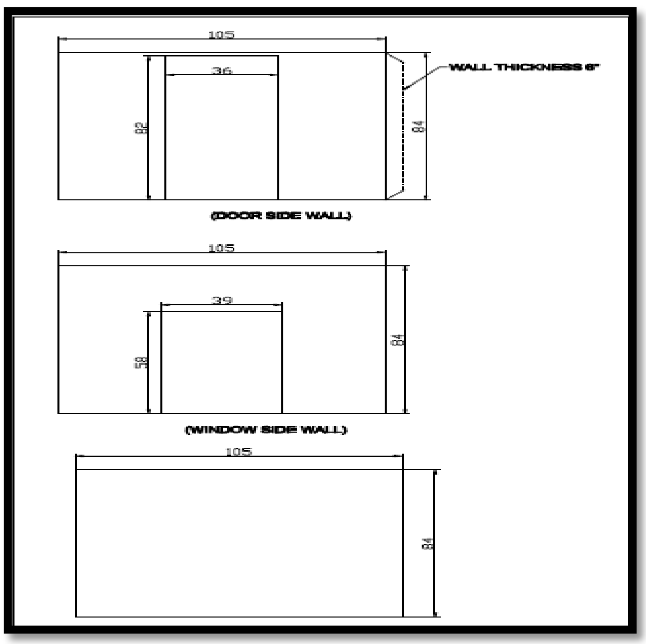


Fig 2 Room Layout

B. Selection of Compressor

Selection of compressor is based on selection of refrigerant.

According to the refrigerant selected the properties of compressor from compressor specification chart is taken. Now, since every company provides its own specification chart for the compressor they manufacture, EMERSON (Chennai) company's compressor is selected.

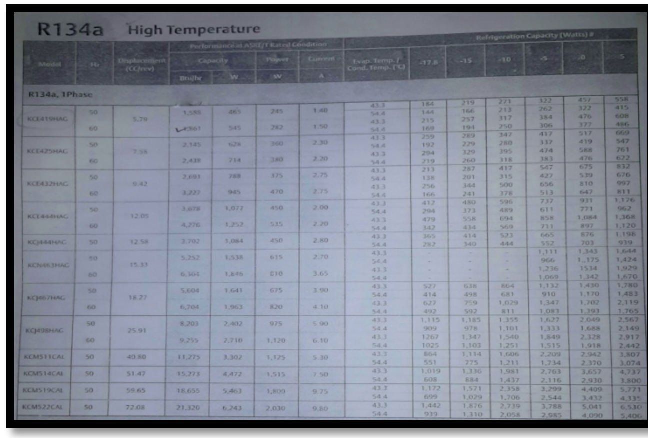


Fig 3 Compressor chart according to refrigeration capacity

The specifications of the compressors are:-
Frequency=50hz
Piston displacement=5.79 cc/rev
Capacity (Cooling watt)=465 watt
Electrical power =245watt
Running Current required for driving the compressor=1.40A
Evaporator temperature from the chart=5^{o}C=T_e
Condenser temperature from the chart=54.4^{o}C= T_c
Refrigeration capacity for T_e and T_c is 415 Watts

C. *Selection of Refrigerant*

Selection of refrigerant for a particular application is based on the following requirements:
i. Thermodynamic properties
ii. Environmental and safety properties, and
iii. Economics

i. Thermodynamic properties
NBP = -26.15^{o}C
h_{fg} at NBP=222.5 kJ/kg
T_{cr}=101.06^{o}C
Cp/Cv = 1.102

ii. Environmental and safety properties

a) Ozone Depletion Potential (ODP): According to the Montreal protocol, the ODP of refrigerants should be zero, i.e., they should be non-ozone depleting substances.

b) Global Warming Potential (GWP):Refrigerants should have as low a GWP value as possible to minimize the problem of global warming. Refrigerants with zero ODP but a high value of GWP are likely to be regulated in future.

iii. Economic properties

The refrigerant used should preferably be inexpensive and easily available.

Refrigerants with zero ODP but a high value of GWP (e.g. R134a) are likely to be regulated in future, hence we have selected R134a as refrigerant. Hence we selected R134a as refrigerant.

Table 1
Selection for the size of condenser, evaporator and expansion valve

Parameters	R134a	
Ambient Temperature(^{0}c)	35	43
Suction Pressure (bar)	1.2 to 1.3	2 to 2.2
Discharge Pressure (bar)	11 to 12	12.7 to13.7
Return Gas Temperature(^{o}c)	16	21
Top Shell Temperature(^{0}c)	43 to 60	49 to 71

Table 2
System Operating Parameters

R134a Models	KCE419HAG
Condenser Size(inch) (length x height) 3/8" O.D tube 10-12 FPI	9 x 9 x 2 Rows
Condenser fan motor	1/83 HP x 1350 rpm
Evaporator size O.D tube(inch)x length(ft)	5/16 x 30
Condenser fan	8"dia
Capillary tube	0.004" x 10 ft x 1NO

Fabrication of air conditioner

A. Body of the AC

1. Base- It is provided with four number of rollers for movement.
2. Frame- It is a riveted frame, separated into two half segments.

The lower half contains equipments

- Compressor
- Condenser
- Condenser Blower

The upper half has components

- Evaporator

The Panel Board On Top Consists Of

- A Temperature Indicator
- Two Pressure Gauges - High Pressure and Low Pressure
- Energy Meter
- Sensor Device

B. Materials used with specifications

Compressor
Refrigerant-R134a
Purchased from –Matsuchita Electric Industrial Co. Ltd.
Phase –single
200/220V , 50Hz
Serial No.-P21L C0003636
Made in MALAYSIA

Condenser
Length-45ft
Diameter-10mm
Fin-110

Compactly fixed with in a15×15.5×5 inch 24 SWG GP sheet metal box. Along with both sides, fixed with a 20 SWG 12.5×9×2.5 inch 306SS compact box. In both SS compact boxes, there are 2 numbers of each box, 450mm size copper tube brazed with each other for inlet of sub cooling air and outlet of condensing air. There is a 15.5×5×2.5 inch condensate water drain set fixed at the side of condenser, made by GP sheet, the collected water automatically evaporates.

Strainer- 5/8 diameter copper strainer. It filters the refrigerant, for any impurities.
Capillary tube - diameter-0.050mm 30inch (2 pieces)
Evaporator- Length- 27.2,Diameter-10mm,Fin-110
High pressure gauge 0-500psi
Connector size - ¼ inch
Low pressure gauge 0-220psi

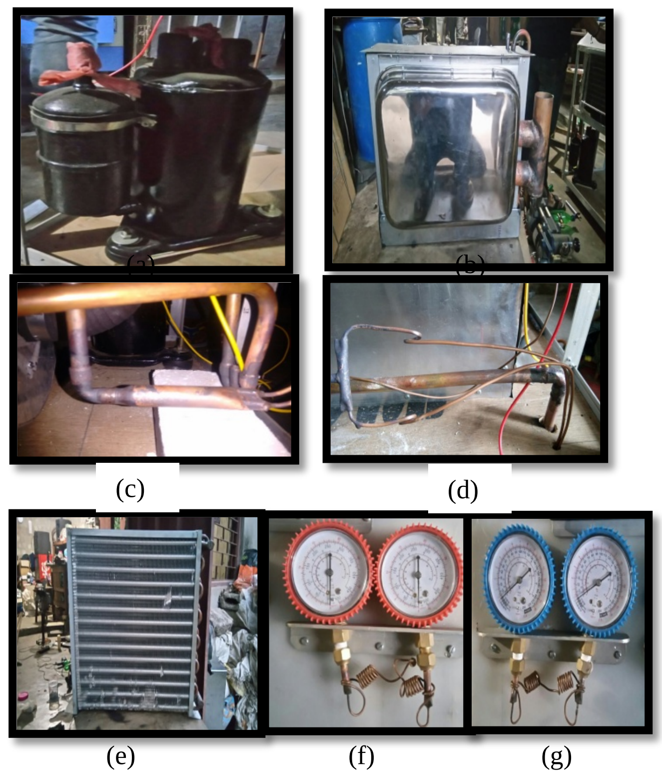


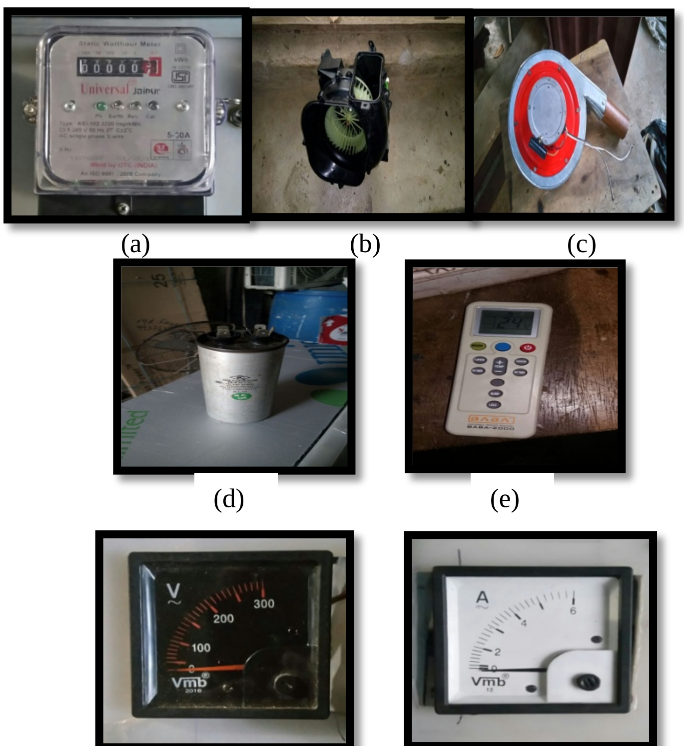
Fig 4 (a) Compressor (b) Condenser (c) Strainer (d) Capillary tube (e) Evaporator (f) High pressure gauge (g) Low pressure gauge

Electrical circuit

Energy meter:brand- universal; capacity-5-30amp, 240v, 50hz, 1ph

Evaporator blower set:
diameter-2inch

height-4×2inch(left & right)
speed-300rpm,12v dc
both side blower section
Condenser blower set:
impellor type
serial no -82150lp
220v ac, 50-60hz
made in japan
Running capacitor:25-30mfd(micro faraday)
Remote controlling system:
company-baba
universal pcb with remote handset controlling system type.
Wires and cables clips:
length-2m
size-2.5mm^2, 3core main cable
hpl cable limited
Voltmeter: size-72 x 72mm volt-0-300volt
Ammeter: Size-72 X 72 Ampere-0-6amp



(a) (b) (c)
(d) (e)
(f) (g)

Fig 5 (a) Energy meter (b) Evaporator blower (c) Condenser blower (d) Capacitor (e) Remote controller (f) Voltmeter (g) Ammeter

PERFORMANCE ANALYSIS
From the p-h chart,
Enthalpies at different points are
h_1=h_4=485 kJ/kg
h_2 = 615 kJ/kg
h_3= 660 kJ/kg
The AC has to develop 0.5 tons of refrigeration.
Q_r (refrigerating effect)
$=h_2-h_1=615-485=130$ kJ/kg
m_r (mass of refrigerant)

$$= \frac{0.5\times3.5}{h2-h1}$$

$$= \frac{1.76}{130} = 0.013 \text{ kg/sec}$$

Power required to run the compressor
p = 0.013(h3-h2)
= 0.013(660-615)
= 0.585 kW
Heat rejected to the condenser
$Q_c= m_r (h_3-h_4)$
= 0.013(660-485)
= 2.275

$$COP = \frac{h_2-h_1}{h_3-h_2} = \frac{615-485}{660-615} = \frac{130}{45} = 2.88$$

Carnot COP=$T_L/(T_H-T_L)$
=(5+273)/(54.4-5)
=5.62

II. CONCLUSION

The portable solar air conditioning system is successfully designed, fabricated and installed in the room. It is made of 0.5 tons. The performance analysis calculation is made to investigate the cooling capacity of the system and provide an efficient minimal power output. Hence regardless of the atmospheric temperature the system can provide adequate cooling for the room it is designed.

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