LOCALIZED COOLING – DESIGN OF SINGLE BED AIR CONDITIONING SYSTEM

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Abstract*— Air conditioning is the science and practices of creating a controlled climate in indoor spaces. In air conditioning applications vapour compression refrigeration systems are most commonly used in all capacity air conditioning systems. This paper gives an air conditioning system based on localized cooling concept. This system is same as that of conventional air conditioning systems. During sleeping hours we are using air conditioning system to cool the entire room but our requirement is to get the cooling comfort only at the sleeping space. Hence instead of cooling entire room, we are cooling the sleeping space according to the cooling comfort. Due to calculating the cooling load only for the sleeping space, it is very less than cooling load of the entire room. Hence the cooling load is reduced and instead of installing large (more than 1-1.5 TR) capacity air conditioning units, small capacity air conditioning units (less than 0.5TR) can also serves the purpose. Manufacturing cost of these small units is less as compared to conventional units. Running cost also reduced and significant amount of energy can be saved. This cooling space is covered with heat insulating curtains to reduce the cooling loss and having better coefficient of performance of the system.

***Index Terms*— localized cooling, cooling load, Compressor capacity, Hub ratio.**

I. INTRODUCTION

The control of indoor climate is an important industry throughout the world. The science and practice of creating a controlled climate in indoor spaces is called as air conditioning. A human being spends approximately one-third of his/her life in sleep. Sleep can help people overcome tiredness and is very important to one’s memory. Therefore, in order to improve sleep quality for increasing the work or study efficiency at daytime, air conditioning (AC) serves to maintain not an appropriate indoor working thermal environment at daytime as well as nighttime [1]. This has been demonstrated in a survey on the situations of sleeping thermal environment and the use of air conditioning in bedrooms in residential buildings. The survey results revealed that up to 68% of the respondents would leave their room air conditioners (RACs) on during sleep. However, energy will have to be considered to maintain a suitable level of indoor thermal comfort and air quality. Therefore, it is necessary to develop novel air conditioning systems for sleeping environments, so as to lower energy consumption while maintaining a suitable level of indoor thermal comfort and indoor air quality [2]. With the use of localized cooling of single bed air conditioner, cooling load is reduced, due to which low capacity air conditioning system can also work efficiently. The cost of electricity required to run the air conditioning system is reduced. This type of system is useful in the domestic, hotels etc. [3].

II. NEED OF LOCALIZED COOLING

The localized cooling concept is innovated for minimizing the energy consumption of air conditioning system. At the time of sleeping human needs cooling comfort only at the sleeping space. In localized cooling only the sleeping space is cooled instead of entire room. Hence the cooling load is reduced; hence low capacity air conditioning system can serve the purpose. But minimum 1 ton air conditioning system is available in the market. Hence by using localized cooling we can develop air conditioning system of 0.5 ton for single bed air conditioning system, which gives us less initial as well as running cost and. This type of air conditioning units can improve the energy efficiency.

III. REFRIGERANT

In vapour compression refrigeration system most vital component is refrigerant. Refrigerant takes directly part in heat exchange. Refrigerant R22 is selected because it has high latent heat of vaporization 216 kJ/kg K at -15^{0}c. It has lowest temperature -40^{0}C at above atmospheric pressure. The R22 is a man-made refrigerant developed for a refrigeration installation that need a low evaporating temperature, as in fast freezing units which maintain a temperature of -29 ^{0}c to -40 ^{0}c. It has been successfully used in air conditioning units and in a household refrigerator. It is not necessary to use R22 at below atmospheric pressure in order to maintain low temperature. The boiling point of R22 is -41^{0}C at atmospheric pressure. The freezing temperature of R22 is -160^{0}C. It has latent heat 218 kJ/kg K at -15^{0}C. The normal head pressure at 30^{0}c is 10.88 bar. This refrigerant is stable and is non-toxic, non-corrosive and non-flammable. The evaporator pressure of this refrigerant at -15^{0}C is 1.92 bars. Since water mixes better with R22 than R12 by a ratio of 3:1 therefore dryers should be used to remove most of the moisture to keep water to a minimum. This refrigerant has good solubility in oil down to -9^{0}C. The cylinder color code for this refrigerant is green.[4]

IV. PROPOSED SET UP DIAGRAM

The following Fig.1 shows the proposed plan of the set up.

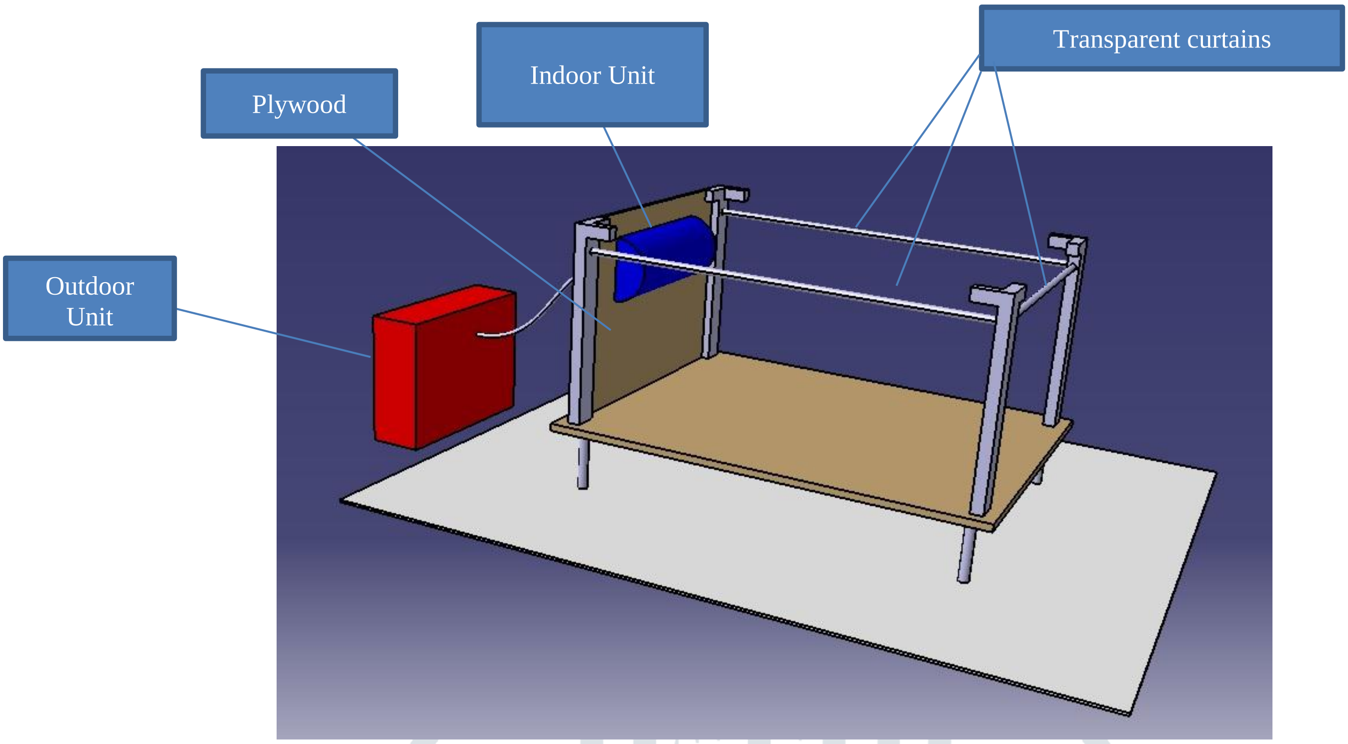

Fig. 1 Proposed Set Up

V. COOLING LOAD CALCULATIONS

The acceptable thermal comfort to 80% often people in a space. This "comfort zone" and the associated assumptions are defined by ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy. Determining the desired condition of the space is the first step in estimating the cooling and heating loads for the space. In this clinic, we will choose 78ºF [25.6ºC] dry-bulb temperature and 50% relative humidity (A) as the desired indoor condition during the cooling season.

Cooling Load Calculations

Considering a bed having following dimensions

Length = 6ft, Width = 4ft height above sleeping surface = 4ft

Table No. 1 Heat Gain Sources

Sr. No.	Heat Gain through/due to	Sensible Heat (W)	Latent Heat(W)
1	Left Surface	157.74	-
2	Right Surface	157.74	-
3	Front Surface	105.21	-
4	Back Surface	71.62	-
5	Top Surface	210.80	-
6	Floor Surface	71.88	-
7	Infiltration Surface	2.59	2.97
8	Persons (2No)	133.40	110.2
9	Light	10	-
	Total	1009.47	113.2

Total heat gain inside room = Total sensible heat gain + Total latent heat gain

= 1009.47 + 113.2 = 1122.69 W = 0.321 TR= 3850Btu

Room sensible heat factor $= \frac{\text{Room Sensible Heat}}{\text{Room Sensible Heat+Room Latent Heat}} = \frac{1009.47}{1009.47+113.2} = 0.89$

Mass of supplied air $= \frac{RSH+RLH}{h2-h4} = \frac{981.71+110.2}{51.6-43.2}$ =0.13 kg/ sec

Load on coil = m_a (h_3- h_4) = 0.13 (57-45.2) = 1.534 kW

Load on coil= 0.438 TR

Components of air conditioning system

1. **Compressor**
   Compressor is basic part of refrigeration system. Compressor compresses the refrigerant from evaporation pressure to the condensing pressure. In this set up we are using hermetically sealed compressor of 0.5 ton capacity. These types of compressors eliminate the use of crankshaft seal which is necessary in ordinary compressors in order to prevent the leakage of refrigerant. Hermetically sealed compressors are normally used in small to medium capacity refrigeration system for all refrigerants. These hermetic units having some advantages such as no leakage of refrigerant, compact, less noise and etc.[4].
2. **Condenser**
   Condenser a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. Condenser is one type of heat exchanger used for rejecting heat to the cooling medium. Here in this set up we are using air cooled

condenser because of its advantages over water cooled condenser. It required air which is abundantly available in atmosphere. Fouling problem is reduced, cost of condenser reduces. Hence we are using fin tube type air cooled condenser[4].

3. **Expansion devices**
Expansion devices are used to expand the refrigerant from condensing pressure to evaporating pressure with stages . One expansion devices used is capillary tube and other one is expansion valve[4].

4. **Evaporator**
Here in this study we are going to use two evaporators in series with different capacities of evaporator at different temperature. Two bare tube type evaporators are used with different evaporator coil length[4].

VI. DESIGN AND SELECTION OF COMPONENTS

The last decade has been radical changes in the selection and uses of refrigerants, mainly in response to the environmental issues of holes and the ozone layer and global warming or greenhouse effect. Previously there had not been much discussion about the choice of refrigerant, as the majority of applications could be met by the well-known and well –tested fluids, R11, R22, R502 and ammonia (R717). While selecting the refrigerant all the physical as well as chemical properties of refrigerants are taken into the consideration. At the time of selection we have to know that condensing pressure and evaporating temperature that is temperature range of application. We are also considering the condensing as well as evaporating temperature and their corresponding pressures. Before selection of compressor and condenser we should know the refrigerant. Hence by studying all the aspects of the system and all refrigerant properties we are selected R 22 as a refrigerant.

Table 2- Refrigerant Selection

Refrigerant	Evaporating pressure at -15^0C in bar	Condensing Pressure at 30^0C in bar	Specific volume (m^3/kg)	Latent heat of Vaporisation
R717	2.36	11.67	0.51	1316.5
R744	22.90	71.93	0.0167	274
R134a	1.63	7.70	0.121	209.5
R404a	3.70	14.272	0.0156	143.68
R12	1.8260	7.4490	0.0910	
R22	2.96	12.03	0.078	218.1

Compressor is basic part of any refrigeration system. In other words we call it as heart of refrigeration system. Now days various type of compressor are used in refrigeration industry for operation. A compressor is the most important and often the costliest component (typically 30 to 40 percent of total cost) of any vapour compression refrigeration system (VCRS). The function of a compressor in a vapour compression refrigeration system is to continuously draw the refrigerant vapour from the evaporator, so that a low pressure and low temperature can be maintained in the evaporator at which the refrigerant can boil extracting heat from the refrigerated space. The compressor then has to raise the pressure of the refrigerant to a level at which it can condense by rejecting heat to the cooling medium in the condenser. Refrigerants are classified by considering various factors such as based on working principle.

Selection of compressor is done according to the cooling load, refrigerant, condensing and evaporation pressure. By studying all these parameters we are selecting a hermetically sealed Emerson make compressor KCE461HAE. For KCE461HAE compressor various parameters are mentioned on website. For selected compressor and design requirements of system, P-h chart is plotted as shown in Fig.2

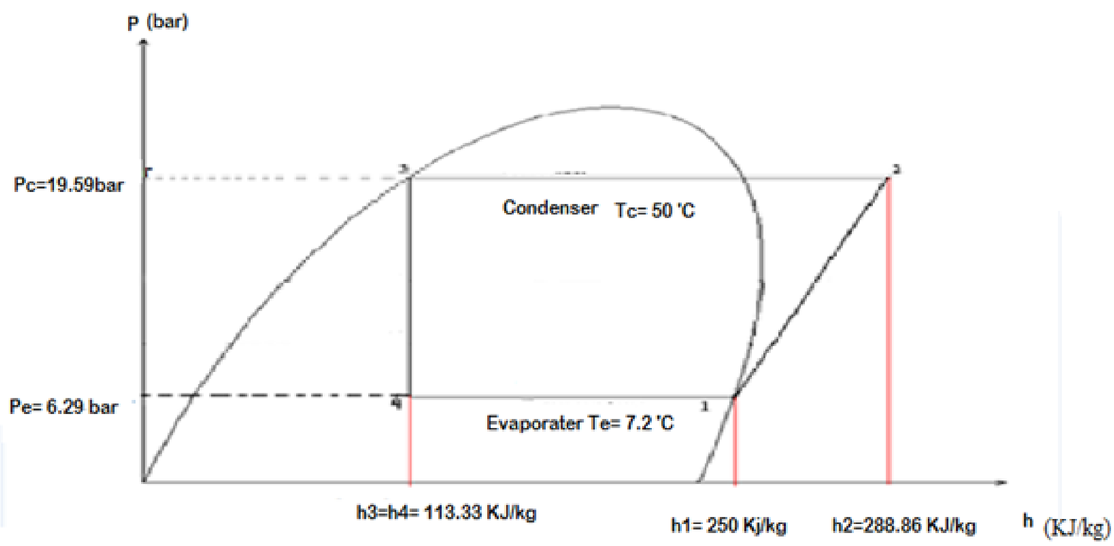

Fig. 2 P-h chart for R-22

From Fig. 2 following parameters are calculated

h_1=250 KJ/kg h_2= 288.86 KJ/kg

h_3 =h_4=113.33 KJ/kg

Condensing Temperature T_c= 50°C Evaporating Temperature T_e = 7.2°C

Condensing pressure P_c= 19.59 bar Evaporating pressure P_e= 6.29 bar

Table 3-Compressor Parameter Summary (Making of compressor Emerson)

Parameters	Capacity (Btu)	Power (Watt)	Current (Amp)	Evaporating Temperature (°C)	Condensing Temperature (°C)	Suction Pressure (bar)	Discharge Pressure (bar)	Refrigerant
KCE461HAE	5200	675	3.1	7.2	50	4.83	19.69	R 22

Condenser

Condenser is one of the main parts of refrigerating system which is required to reject heat to the atmosphere by convection. Condenser is heat transfer surface like evaporator. In condenser copper tube transfer heat of refrigerant to the aluminum fins/foils which is cooled or rejected by with the help of fan. The condenser load is the total heat rejected at the condenser. It includes both the heat absorbed and the energy equivalent of the work of compression in compressor, as shown in Fig.3[4]

Advantages of air cooled condenser

1. Air-cooled condensers are cooled by ambient air and no water is required.
2. There is also no need for a cooling tower and condenser water pump.
3. There no handling problem with air cooled condenser.
4. No problem with disposing used air as like water cooled condenser.
5. Fouling factor has less effect.
6. Maintenance cost is low.[4]

For selection of condenser following parameters are considered

1) Cooling capacity

The amount of heat rejected by condenser to the surrounding medium is called as cooling capacity of condenser The amount of heat rejected include heat absorb in evaporator and work done by compressor. Air cooled condenser is at Available in various sizes from less than 1 kw to 500 kw or more according to heat rejection capacity.

2) Temperature difference

The heat transfer capacity of condenser greatly depends on the temperature difference between condensing medium and vapour refrigerant. As the temperature difference increases the heat transfer rate increase and therefore condenser capacity is increases. Most of air cooled condenser is design to operate temperature difference 14^0C.

3) Refrigerant

Since property of refrigerant is differ so condensing and evaporative temperature depend upon the refrigerant used. So during selection of compressor and condenser the refrigerant must be known.

4) Altitude

In air cooled condenser air is used as condensing medium as altitude increases air density decreases so the cooling capacity of condenser reduces at same volume of air flow rate. Hence the proper correction factor in change in its altitude must be used while calculating heat rejection rate which decides size of condenser.[4]

By considering all these parameters and our requirement we designed a air cooled condenser of specifications given below [4].

For designing the condenser following parameters must be known:

Condenser heat rejection (Q_c) = 3.64 kW

Mass flow of refrigerant through the condenser,

m_r= 1.2 kg/min= 0.02 kg/sec

Condenser inlet temperature = T_{ci} =70°C

Condenser outlet temperature = T_{co} = 50°C

Air inlet temperature = T_{ai} =30°C

Air outlet temperature = T_{ao} = 35°C

By calculating all the parameters of fin tube type air cooled condenser [5] we get,

Face area a_f = 0.09985 and no. of rows = 3

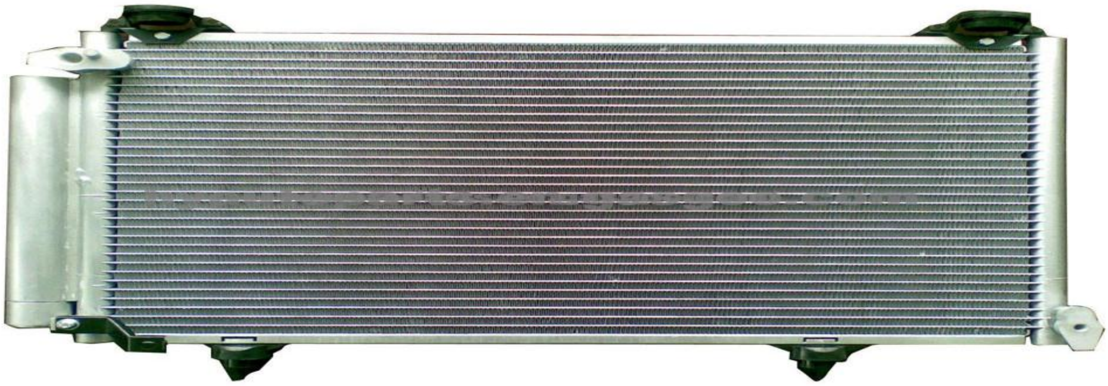

Fig.3 Condenser

Here it is air cooled condenser with fan connected so called as forced convention air cooled condenser axial fan is selected according to condenser load and requirement of condenser axial fan is selected from manufactures chart with calculating volume flow rate. Axial fans which are normally related with characteristics hub ratio. Hub ratio is the ratio of outer hub diameter to the diameter of impeller.[4]

$$R_{Hub} = \text{Hub Diameter/ diameter of impeller}$$

Higher hub ratio which means greater conversion of velocity pressure to static pressure and also capacity and total pressure of axial fans can be increased by raising their rotating speed or through there adjustment of blade pitch angle to higher value . It is used for fans that are directly by motor without using belts [4].

Condenser load (by calculations) =3.64 KW

$$Q = m\,C_p\,(^\wedge T)$$
$$3.64 \times 10^3 = m \times 1.005 \times 10^3 \times 5$$
$$m = 0.7243 \text{ Kg}$$
$$\rho = m/v$$
$$1.15 = 0.7243/V$$
$$V = 1827.37 \text{ m}^3/\text{hr.}$$

For requirement of above volume flow of air from axial fan catalogue fan model selected is 4E300.

Expansion Device

This system is having very small capacity hence we are using capillary tube as an expansion device. A fine mesh screen is provided at the inlet of the tube in order to protect it from contaminants.

From catalogue, for refrigerant R-22 the suitable size of capillary tube is TC-49.

Mass flow of refrigerant

$$m_r = 0.021 \text{ kg/sec}$$

Volume flow rate (V)

$$V = \frac{\text{mass}}{\text{density}}$$
$$V = 1.6712 \times 10^{-5} \text{ m}^3/\text{sec}$$

Assuming capillary of TC-49

Diameter of tube = 0.005" = 1.2446 mm

But $V = \pi D^2 V_r/4$

$$V_r = 3.4341 \text{ m/s}$$

Now

Reynold's number (R_e)

$$R_e = \frac{4m_1}{\pi D\mu}$$
$$= 101408.71$$

Friction factor (f)

$$f = \frac{0.32}{Re^{0.25}}$$
$$= 0.018$$

Pressure drop (ΔP)

$$\Delta P = Pc - P_e = 1.3473 \text{ MPa}$$
$$h_f = \Delta P/\rho g = 109.296 \text{ m}$$

By Darcy- equation for loss of head due to friction in tube [11],

$$h_f = \frac{4fLV_r^2}{2gD}$$

$$L = 2.9767 \text{ m} = 9.8229 \text{ ft.}$$

Hence length of capillary tube is = L= 2.9767 m = 9.8229 ft

Capillary tube is selected 0.0050 m diameter and 2.9767 m length [6]

Evaporator

Evaporator is component where actual heat is absorbed from evaporated space by refrigerant to cool space which is to be cooled. Here we are using fin tube type evaporators. The finned evaporator consists of bare tube coils over which the metal plates or fins are fastened. The metal fins are constructed of thin sheets of metal having good thermal conductivity. The shape, size or spacing of the fins can be adapted to provide best rate of heat transfer for a given application. Since the fins greatly increase the contact surfaces for heat transfer, therefore finned evaporators are also called extended surface evaporators, as shown in Fig 4[4].

Fig.4 Evaporator

Factor Effecting Heat Transfer Capacity of Evaporator Coil

1) Material

In order to rapid heat transfer in evaporator the material used for construction evaporator coil should be the good conductor. The material which is not affected by the refrigerant must be selected. Iron and steel pipes can also use for all common refrigerants. Brass and copper are used with all refrigerants except ammonia.

2) Temperature difference

Temperature difference between the evaporator and the product to be cooled plays an important role between the heat transfer capacities of the evaporator.

3) Velocity of refrigerant

The velocity of refrigerant flow through coil is increases then the overall heat transfer co-efficient is also increased. But increase velocity causes greater pressure loss into the evaporator which give the more load on the compressor.

4) Thickness of wall

Thicker wall has less heat transfer through the evaporator coil. Since the refrigerant is under pressure in evaporator coil so the evaporator coil should be able to withstand the pressure.

5) Contact surface area

An important factor affecting the evaporator capacity is the contact surface available between the walls of evaporator coil and the medium being cooled. The amount of contact surface, in turn, depends basically on the physical size and shape of the evaporator coil.

Load on the evaporator (Q_e) = 0.5TR = 147 KJ/kg

Mass flow of refrigerant through the evaporator,

m_r= 1.17 kg/min= 0.02 kg/sec

By calculating all the parameters of fin tube type air cooled condenser [5] we get,

Face area a_f = 0.1063 and no. of rows = 2

VII. CONCLUSIONS

This paper explains about the basic design of single bed air conditioning system. There is always need in scientific community to develop energy efficient air conditioning systems. This air conditioning system is design for half ton capacity hermetically sealed compressor which should efficiently operate refrigeration system. The various components of air conditioning system are designed and selected at given condition of temperature range and required refrigerating capacity. The main component selected in system is compressor and designed components are air cooled condenser, expansion device and evaporator. These all component are suitable for developing a single bed air conditioning system according to design condition.

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