AIRCONDITIONING IN TRANSPORTATION

A Dissertation Submitted
in
Partial Fulfilment of the Requirements
for
The Degree of Master of Engineering
in
Applied Thermodynamics (Refrigeration & Air Conditioning

BY

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CERTIFICATE

Certified that the dissertation entitled " AIR CONDITIONING IN TRANSPORTATION " which is being submitted by Shri S.D. Thakur, in partial fulfilment for the award of the Degree of Master of Engineering in Applied Thermodynamics (Refrigeration and Air-conditioning) of University of Roorkee is a record of the student's own work carried by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

~~This is further to~~ certify that he has worked for a period of six months from 15th April 1960 to 31st August 1960 and 20th August 1962 to 10th October 1962 for preparing dissertation for Master of Engineering Degree at this University.

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(S.D. Thakur)

C O N T E N T S

Abstract

With the advancement of Scientific and technical knowledge the field of air-conditioning is not only confined to stationary objects but is covering various other aspects also such as in transportion field. This dissertation presents a theoretical and practical approach to the study of air-conditioning in transportation. The subject brings forth many difficult problems, namely source of power, weight, and space. Efforts have been made to reduce these problems, but the ideal solution is still to be found.

Air conditioning teachniques are different for different modes of transportation, hence they have been discussed in seperate chapters. In India, air-conditioning in transportation is still in initial stages but has a great potential for future development .

CHAPTER I GENERAL

1.01 AIR CONDITIONING

The required treatment and handling of air to produce the atmospheric environment, conducive to human comfort or essential to the processing of materials in manufacturing operations, is termed air conditioning. The year round treatment of air may be broadly classified into two types of air conditioning.

a. Comfort air conditioning:- It is meant for producing comfortable environments for human beings and involves winter treatment of air viz. heating and humidification, air cleaning and cooling in summer viz. cooling with dehumidification. The various unwanted elements such as odor, bacteria etc. are removed by absorption steriliza-tion and dilution of the air during the process of cleaning.

b. Industrial air conditioning:- This is required for the storage of some materials and products etc. or in some manufacturing operations of different industries. It is felt essential to maintain proper temperature, humidity and cleanliness in environments otherwise the materials are not well preserved, or else the finished products are not upto quality mark. Industrial air-conditioning may produce comfort conditions for the workers as well.

1.011 REQUIREMENTS

The atmospheric conditions are effected by a number of factors, including:

a. Temperature;
b. Humidity;
c. Air motion;
d. Distribution;
e. Bacteria;
f. Toxic gasses;
g. Dust;
h. Ionization.

Profess of air conditioning, controls simultaneously of atleast first three and preferably all these items. The plant is to provide and to distribute air having satisfactory temperature, humidity and purity. The most comfortable values of temperature humidity and air motion are as follows which must be kept as far as possible within these limits.

Summer	Winter
D.B. 72-78°F	D.B. 70°F
R.H. 55% ± 5 %	R.H. 45%

Air motion in the occupied zone should be from 25 to 40 f.p.m, Air velocity in other places may exceed this limit for proper air distribution.

1.02 NECESSITY OF TRANSPORTATION AIR CONDITIONING

a. In India during Summer days outside temperature rises upto 120°F which is much higher than the normal comfortable limit of 80°F. Further while the vehicle is not in motion the inside temperatures are expected to be higher than 120°, to make to conditions still worse.

b. Open windows pass lot of dust and noise to the inside, which become a great source of nuisance. So it is necessary to close the windows. Therefore for comfortable conditions inside the vehicle proper ventilation and air conditioning of the vehicles will be desirable. If windows are closed in the absence of proper ventilation and air conditioning the odors and inside temperature will rise and inside conditions become intolerable to the occupants.

c. In addition to providing comfort to passangers, air conditioning of vehicles increases the efficiency of the staff, which is evident by a report of Chance-vought Air Craft Corporation of U.S. They observed that their vehicles could make regular trips over a distances of 1443 miles throughout the hot Southern part of the country in 80°% of the time usually taken by air-conditioning the vehicle.

d. Driving the air conditioned vehicles decreases accidents. Two weeks test was conducted by O.A.Suttan Corporation, with two cars, one of them air-conditioned, and the other un-conditioned. These cars were driven daily by two atheletes of identical Weight and size, each 19 years old. The object was to find effect of air-conditioning on driver fatigue. The tests showed that driver of air-conditioned car enjoyed a 16 % increase in depth perception while the driver of the un-conditioned car lost 28% of depth perception. Surveys hasve shown that 41.6% of the all fatal accidents were of non-collision type, involving no other error but poor judgement on the part of the driver. Thus by air conditioning vehicles number of accidents can be decreased.

e. Drivers are able to work longer hours in cool vehicles i.e. they need not stop so often to refresh themselves in air-conditioned restaurants.

f. Air-conditioning provides comfort to the sick in ambulances and a cool ambulance might even help to save life in cases of sun stroke.

g. A special competitive situation also arises between conditioned and un-conditioned vehicles . The former draws more customers than the latter.

Now a days it is found that in large cities, important officies luxurious hotels and cinema halls are all airconditioned hence to keep proper balance, transportation air conditioning has become obvious .

1.03 COMPARISON OF STATIONARY AND TRANSPORT AIR CONDITIONING

Transport	Stationary
a. People seated in vehicles are very close to each other.	They are not so close to each other.

Transport	Stationary
b. Front glass area cannot be completely shaded. Comparatively large proportion of glass area is used.	All glass area can be shaded completely.
c. Interior surfaces are relatively hotter than buildings.	Due to thickness and low conductivity inner wall temperature is lower than inner surfaces of vehicles.
d. Light weight equipment is required because of the ultimate load on engine of the transport. Heavier equipment indirectly increases cost in fuel consumption of vehicle.	Weight is of little consideration unless it is a special case where the equipment is to be installed at higher ups.
e. Space for equipment installation is limited and is too small.	Space for equipment is no headack, unless a very special installation.
f. Equipment should be compact and rigid, because it is subjected to severe vibrations.	Comparatively lesser vibration problems.
g. Vehicle cooling system is required to repeatedly achieve rapid cool down from high temperatures.	The stationary system is required only to maintain temperature at comfort level with only infrequent cool down.
h. Source of power is a great problem.	Power is very easily available and presents no problem.

1.04 MODES OF TRANSPORTATION

a. Automobile

(i) Cars;
(ii) Buses;

b. Railways

c. Marine ships

d. Air-planes.

Air-conditioning of vehicles of all the different transportation stated above will be discussed in the chapters to follow.

CHAPTER II AUTOMOBILE AIRCONDITIONING

(a) Cars.

2.01 HISTORY

Air conditioning a car is not a new idea, various attempts in this direction have been tried in the past. Highway travel becomes next to intolerable in summer at places where adbient temperature goes above 100^{o}F. Primitive cooling methods have been tried at some of these places namely tubes of ice carried on the floor and evaporative coolers have been widely used. Cooled air outlet velocity and volume which are proportional to car velocity are undersirable features of evaporative cooling system. These units are usually installed in car windows without any definite air distribution system so that the outlet velocity on passangers can easily exceed, the desirable limits. Their performance is directly related to the wet bulb temperature of the atmosphere in which the cooler is used. Evaporative cooling is successful only in dry climates having low summer wet bulb temperatures.

Various mechanical refregeration equipments have appeared in late 1930's. Packard motor car company had equiped about 1500 cars between 1939 and 1942 with air conditioning units but the customers acceptance of these cars was mixed. Therefore, sufficient interest in air conditioning could not continue in the post war-cars . Later in 1952 many major car manufacturers, announced that in certain of their 1953 models air conditioning would be available.

Now the public acceptance of air-conditioned car is very good and is very encouraging to the industry. This is evident from the following sale figures:-

Year	Approximate number of units sold
1949-1953	10,500 each year
1953-1954	125,000 each year
1955	225,000
1956	375,00
1962	875,00(Expected)

The demand for air-conditioned cars have ever been on the increase since 1953 because of many worth-while improvements in equipment, which include:

a. Better performance;
b. Increased durability and reliability;
c. Simple installation and maintenance;
d. Lighter weight;
e. Less space required for the equipment.

2.02 SPECIAL FEATURES

The special features, which confront the air-conditioning of cars include the following:

a. Air conditioning system should have sufficient capacity to:

(i) Lower inside car temperature quickly af\ r it has picked up considerable heat while standing in the 'm for some-time.

ii) Quickly cool the car during short ride.

b. The refrigeration load on a vehicle must be automatically controlled, because vehicle might have to operate in sub-zero as well as in torried humid weather.

c. Space available for air conditioning system is at the cost of the premium.

d. Complicated mechanism and controls are needed because the automotive system is confronted with compressor speed variations, in a ratio of about 15 to 1. The operating pressure, back pressure, evaporator pressure and head pressures are subject to about as many combinations as one can imagine. Head pressure depending on the ambient temperature, speed of vehicle and wind direction can vary from 50-350 PSI.

e. Another feature is the weight which is of peramanount importance, because vehicles must be designed to be competitive in performance either with or without refrigeration system. Moreover performance is tied up with ton-miles.

f. The performance of mechanical air-conditioning system is subject to five or six opinions of car occupants, so the system should be designed to adjust the comforts of as many occupants as possible independently. This requires co-ordination of an unlimited number of D.B. temperatures and combinations of air velocity. To this end, control of air stream from which the occupants are to drive their comfort is of major importance.

It is believed that better general comfort and fewer problems will result if the individual driver has only a few simple controls. A properly air conditioned car should have uniform temperature control with a minimum amount of draft.

g. In the stationary installations, there is no variation in outside temperature, but the vehicle has to ply from place to place, hence variation in outside conditions occur. An automobile leaving Simla at 85°F ambient reaches Chandigarh or Ambala at 110 - 115°F temperature. So there is a variation of 30°F in a small journey. One can easily guess the passangers reation to it, hence the temperature difference to be maintained for greatest comfort in automobilies is different from stationary air-conditioning system.

2.03 COOLING CYCLE

Following methods can be used for air conditioning of cars.

a. Tubes of ice carried on floor:- In this method tubes of ice are carried on the floor of car. The air coming in contact with these tubes looses heat and serves to keep the car interior cool. However there is no proper distribution of air inside the car.

b. Evaporative cooling:- Evaporative coolers consisting of filter, mat and air inlet are used. There is arrangement for pouring of water on the mat. The air entering car interior evaporates the water and thus becomes colder in doing so. This cold air does the cooling job inside the car.

c. Mechanical refrigeration:- Described in article 2.0.3 First two methods do not cater fully the requirements on cars hence are not in use.

2.03 MECHANICAL REFRIGERATION

Two systems are prevelant in mechanical refrigeration.

(i) Absorption system:- The absorption system uses heat energy instead of mechanical energy to complete a refrigeration cycle. This system uses gas, kerosene or electric heating elements as a source of heat supply. Since these are not readily available in vehicles and the system further presents operational troubles, so this is not considered as a good system.

(ii) Mechanical Compression: Compression cycle of mechanical refregeration is used to air-condtition the automobiles. All compression systems of refregeration operate in principle, on a refregerant sealed in an air tight and leak proof mechanism. Figure(1) shows a compre-

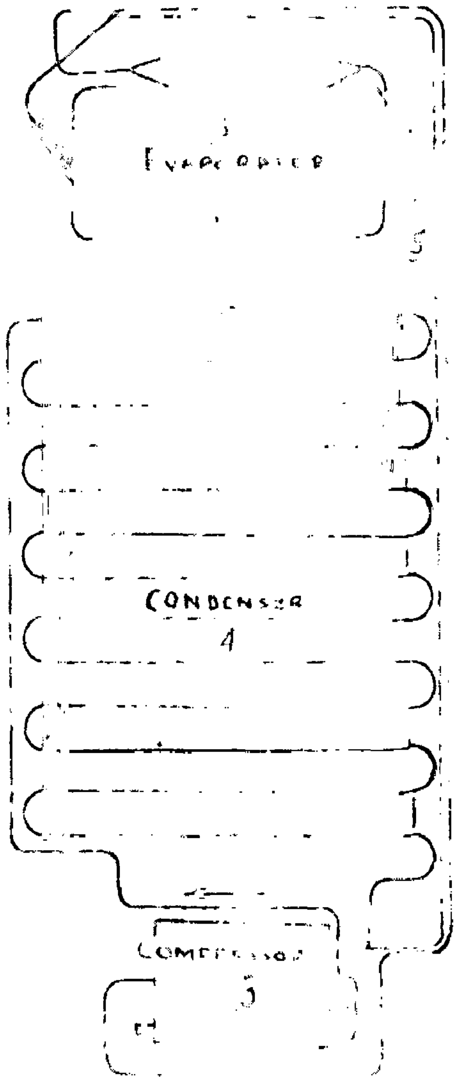


FIG . A COMPRESSION CYCLE

ssion cycle. Basically, liquid evaporates in the cooling unit under low pressure . This pressure will vary depending upon the refrigerant used and the temperatures required. This pressure permits the evaporation to take place at low temperature because as the pressure decreases the boiling temperature also falls. This heat laden gas passes through the suction line 2 to compressor 3 which compresses and discharges it into condenser 4, where it cooles and gives up its latent heat of evaporation under a high pressure and is converted into liquid. The liquid line 5 carries the liquid refrigerant to a restriction called expansion device where the pressure is reduced. The refrigerant then enters the cooling unit and the cycle repeats again.

2.032 CHOICE OR REFRIGERANT

The refrigerant used in any air-conditioning system must have desirable operating and chemical characteristics. Refrigeration equipment of vehicle air-conditioning are subject to severe shocks and vibrations and hence to mechanical failures which may develop leaks. Consequently the hazard of toxic refrigerant must be eliminated. The Freon refrigrants meet all these requirements and hence are exclusively used.

2.04 DESIGN ASPECTS

A set of design conditions and requirements should be established for the Air-conditioning system. An important factor in this direction is the car speed as it effects the following:-

a. Compressor output;
b. Air flow through condenser;
c. Heat gain into the car.

The car air conditioning system should be designed to meet the most severe conditions. The car speed in cities would range from 10 to 25 miles per hour while on highway the speed will be much more, hence city design conditions are more severe than the highway design conditions. Typical design conditions are given below:-

Country	Outside	Inside
U.S.A.	95 D.B.	75 D.B.
	80 W.B.	67 W.B.
India	105 D.B.	80-84 D.B.
	78 W.B.	68-70 W.B.

The departure from usual stationary design conditions where D.B. is 78 is because in the stationary installations, there is some sort of antichamber, such as verandah, while in case of car the occupant is subject to sudden variation from outside to inside conditions which will give a great shock effect, so the design D.B. temperature in vehicles should be higher than the stationary installations, so as to reduce the inside and outside temperature difference to minimum, but it should not be at the cost of comfort to the occupants.

A good unit should be capable of cooling the car temperature from 130 to 85°F within two minutes.

A minimum of 25 cfm per person is required for the control of odors. The noise level caused by the evaporator, blowers etc. should be as low as possible. However greater noise level higher than commercial systems is permitted. This is because far greater noise would accompany with an alternative method of cooling an automobile i.e. keeping windows open. Hence it is felt that air velocities of 1400-1600fpm from discharge grills can be permitted.

The table 1 shows the effect of solar radiation on heat gain on a particular car. The car was painted black and was equiped with solex glass in all windows over the upper third of the wind-shield and rear window.

TABLE NO. I

Element of Heat Gain	% age of Load		Btus / hr.	
	Night	Day	Night	Day
(i) Solar radiation through walls & glass	0	29.4	0	3000
(ii) Normal heat transfer through glass	16.5	11.7	1190	1190
(iii) Normal heat transfer through walls roof and underbody	58.8	41.4	4230	4230
(iv) Air leakage into car	13.6	9.6	980	980
(v) People (Sensible heat only)	11.1	7.9	800	800
Total:	100	100	7200	10200

2.05 LOAD CALCULATIONS

Referegeration load of a car is calculated in the usual way. Some percentage (10 - 15%) of additional load should be included due to following special problems encountered in the car air conditioning.

a. A considerable portion of the accupants body surface is not exposed to direct cooling effect of the cool air stream.

b. Interior volume per person is small. A volume of approximately 107 cft can be occupied by one to six persons in a four door sedan.

c. Due to small space, which requires a high ratio of refrigeration load per cft, the air stream used as direct cooling medium, must be applied with care to avoid passanger discomfort, due to drafts or local over cooling.

d. The car interior is subjected to high radiant heating effects because of a very large ratio of glass surface area, to the total surface area. Some radiant heat is also contributed by the cowl, dash and engine hood.

e. All of the exterior surface of a car is subjected to a high heat load, in the form of radiant heat, from the sun, exhaust system and by conducted heat from the atmosphere and from the engine eompartment.

To meet the design requirements of adequate cooling at low speed, as well as satisfactory performance in cooling down, after the car being parked, approximately 1¼ to 1½ tons of refrigeration should be supplied.

Problems:

A car with six occupants having a body weight of walls and seats equal to 1000 lbs, glass area 20 sq.ft and inside volume 107 cubic feet is to be air-conditioned. Refrigeration load is required assuming glass area is shaded by curtains and average specific heat of car body weight is 0.2 B.T.U'S/lb/F^{0}. Ventilation rate may be taken as 15 cfm per person.

Design conditions

	D.B.	W.B.	Grains per lb	R.H.
Outside	110	80	106	
Inside	80		78	50%

Load Calculations: BTU's per hour

a. Radiation	3000 x 0.35 = 1050		Refer table
b. (i) Transmission in ½ hour	1000x0.2x30x2	= 12000	
(ii) Glass	20x30x1.13	= 678	
c. Ventilation/infilteration	90x30x.1x1.08	= 292	
d. Internal heat due to occupants	6 x 200	= 1200	
e. Internal latent heat due to people	6x180	= 1080	
f. Internal latent heat	90x28x.1x.68	= 158	
Total inside heat		= 16458	

g. Outside sensible heat 90x30x.9x1.08 = 2628

h. Outside latent heat 90x28x.9x.68 = 1362

Total capacity = 20438

$= \frac{20438}{12000}$

= 1.7

= $1\frac{3}{4}$ tons.

2.06 METHODS OF REDUCING LOAD ON EQUIPMENT

Following means can be employed to reduce the load on air-conditioning equipment. These are desired, so as to get the same comfortable conditions by installing plants of lower capacity.

a. Park the car in shade;
b. Use heat absorbing glass, such as solex glass.

The percentage of heat transmission through different types of glasses is shown below:-

Type of glass	Percentage heat transmission
Solex glass	45
Clear Glass	78
Sun shad Solex	20

c. Use of light coloured or more reflective paints, on the exterior surface of a car will reflect solar radiation and will result in cooler surface, thus there will be less conduction of heat into the car.

d. Use of adequate thermal insulation and sealing is important to prevent air infilteration . Because if infilteration is excessive it will increase heat gain.

e. Evaporator weight should be minized as far as possible so that very little capacity is needed to cool this mass.

f. Drive in intermediate gear for longer time when in city traffic. This will speed up both the compressor and engine fan. An increase in the compressor capacity of the order of 50% can be achieved by driving in intermediate gear.

g. For a given capacity, system D.B. and W.B. temperatures will be lower if recriculated air is used instead of fresh outside air. Following table number 2 shows the difference between 100 % recirculated and 100% fresh air.

TABLE NO 2

Conditions of air used	Ambient		Car interior	
	D.B.	W.B.	D.B.	W.B.
A. 100% Fresh Air	102	75	83	66.5
B. 100% Recirculated Air	102	75	80½	62.5
A. 100% Fresh Air	92	82	82.5	69
B. 100% Recirculated Air	92	82	77	61

Calculations made on an overall unit balance indicate that operating with 30% fresh air at 95 D.B.& 78 W.B. the final temperatures would be 3°F D.B.& 4°F W.B.

higher than that with 100 % recirculated air.

h. A high cooling rate is required if the whole body of the car is to be cooled in 15 minutes. This can be shown by the following calculations:-

(i) Approximate mass of body i.e. seats and walls = 1000 lbs.

(ii) Average specific heat = 0.2 BTU'S/lb/OF

To cool from initial temperature of 125°F to a temperature of 75°F	1000 x .2 x (125-75)
The total heat removed	10,000 BTU'S
To perform this cooling in 15 minutes capacity required	$\frac{1000,^{0}x\ 4}{1\ x\ 12000}$
Refrigeration required	3.34 tons

Hence for achieving comfort on short rides it is not possible to cool enough the seats and walls, of the car. Hence we should make provisions for directing high velocity air at relatively low W.B. and D.B. temperatures directly at the occupant giving him a considerable degree of comfort.

2.07 EQUIPMENT SELECTION AND INSTALLATION

Equipment selection and installation are the most important factors. A judicious selection and installation will save lot of troubles during the service and maintenance of the equipment. Following factors should be given a thought before doing the actual job.

COMPRESSER CAPACITIES

Axial-9.20 cu in.   Rotary-7.14 cu. in

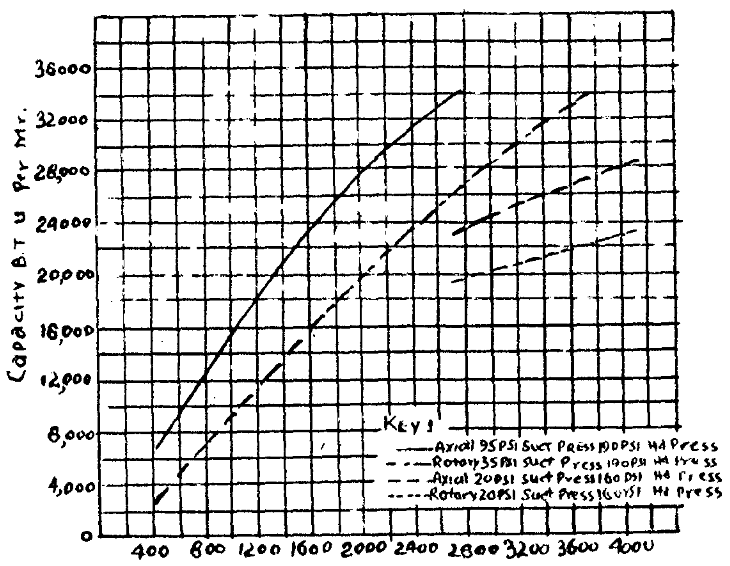
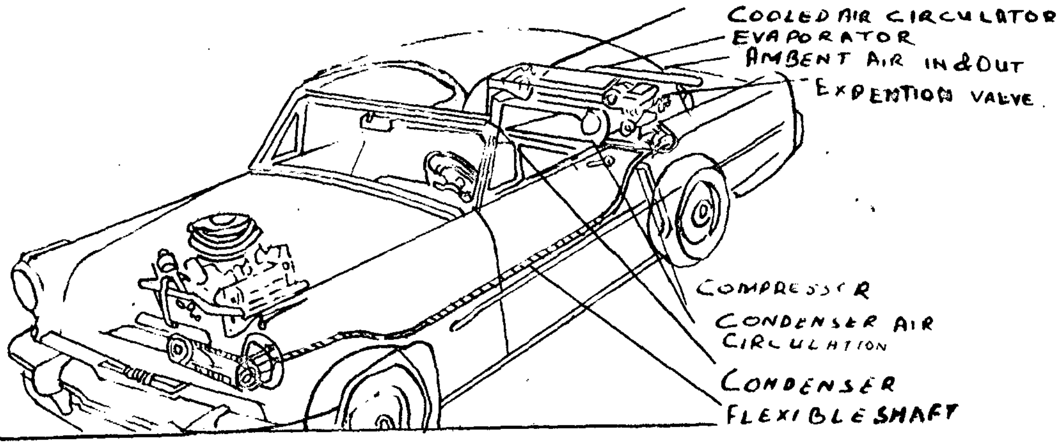


FIG. 2 COMPRESSOR R.P.M



; 3 SELF CONTAINED PACKAGE SYSTEM DRIVEN BY FLEXIBLE SHAFT FROM ENGINE

a. The Condenser of air conditioning unit must not affect the engine cooling system.

b. It must not affect the car performance seriously.

c. It must avoid introduction of objectionable noise.

d. It must eliminate objectionable vibrations.

e. It should not materially increase the car weight. Selection of each element of the vehicle air conditioning system follows.

a. Compressor:- In automobile air conditioning both reciprocating and rotary compressors are used, compressors in use should have following characteristics.

(i) Positive lubrications;
(ii)Endurance capacity to withstand high speed driving i.e. upto 5000 rpm.
(iii)Sufficient capacity at relatively low speeds.
(iv) Perfect balance of receprocating and rotary parts.

An interesting innovation in compressor design was the introduction of axial compressor by the Frigidaire devision of General Motors Comp. in1955. Comparative performance of two units is shown in the Fig-2,a graph between compressor speed in R.P.M. and output capacity in B.T.U's per hour. They manufactured rotary and axial units which were fitted with an electro-magnetic clutch to disconnect the compressor when refrigeration is not needed. It could also cycle the compressor for any one operation of automatic capacity control, maintenance of car internal temperature and prevention of frosting of evaporator.

There can be several location in the car from where the compressor may be coupled to power source. The most popular location is the car engine, where necessary power is obtained with the help of belts directly connected to the crank-shaft. The main problems in this location are Small Space, effect on engine balance and the wide speed range between compressor and engine.

Other possibilities of compressor location are the transmission and rear axel, at these locations the space is more limited and some complicated and specially designed power takeoff mechanism, will be required which will naturally be more expensive then simple belt. So the most logical location is the car engine. The compressor may be driven with one or more belts from some rotating part of the car engine, eliminating as for as possible the above mentioned problems.

b.Evaporator:- Some of the characteristics essential for selection of evaporators are:-

(i) The evaporator must not freeze when working at its maximum capacity.

(ii) The car designers do not leave any space for evaporator, so it must be very compact.

(iii) It must be rugged.

(iv) High and efficient heat transfer suffaces are required on both liquid and air side. The efficiency on air side permits an overall reduction in size with maximum air flow, thus reducing the current consumption in the fan to move the air.

(v) It must be capable of getting rid of the water which is condensed from the air and must not plug up by the dirt and dust. The evaporator can be easily located either in the rear or in the front end of the car.

In the rear end system it is located in the luggage compartment. In the other case it is located near engine under the hood. However this system requires careful design to fit the equipment into a very limited space.

c. Fans:- Fan required to circulate the air through evaporator and through the occupied space of the car involves no problem. Fans are usually operated by Squirrelcage type electric motors which receive the power from the regular automotive electrical system. Current consumption is relatively small viz about 9-10 amperes at 12 volts.

The fan may be mounted on the inside or outside of the evaporator housing.

d. Condenser:- The condenser itself does not offer any fundamental problem. Some of the factors to be considered while using the condenser in an automobile are, Shape Size, and

Placement.

The requirements of a condenser are:-

(i) Its interferance, with the cooling system of car, must be as minimum as possible.

(ii) Rise of temperature of air to the radiator should also be minimum.

The major problem of condenser is the provision of ample air, for proper performance, while the car is standing. This has been overcome by proper physical design and placement, of the condenser by proper shrouding of the radiator fan, increase of fan speed, size or number of blades, or by combination of these.

Present trend in design is the thin condenser covering the full frontage area, and to combine the liquid refrigerant filter, dehydrator and receiver with condenser, as one assembly to simplify installation and eliminate number of fittings required thus reducing assembly cost.

Condenser is to be air cooled and this requires the location of the condenser in a steam of air provided either by fan or by car motion. The most apparent location is in front of the engine radiator. A large proportion of cooling systems to date have their condenser located infront of the radiator. Alternative location for condenser would involve the use of separate fans to induce the air flow. One possibility for condenser location is to place it just in front of th- radiator but below the radiator in horizontal position. Here it will not preheat the air and probably would not effect the air volume appreciably. The receiver can usually be located without difficulty under the car in the trunk or perhaps under a fender.

2.08 POWER REQUIREMENT AND SOURCE

Power must be available for the working of air conditioning system components viz. compressor, condenser fan and the air circulating fan. This power must be reliable and dependable. The power source for compressor in an automobile is the car engine and fans are driven by car electrical system.

The refrigeration compressor can be driven by a belt from the motor car. However the refrigeration compressor operates practically on constant speed in use, while the automobile motor runs at widely varying speeds. This variable speed produces one of themajor problems of automobile air conditioning design. Various solutions to thisproblem have been tried. Magnetic drives and clutches, hydraulic drive with high speed modulating valves and even a separate gasoline engine driven compressor have been tried. Experimental work is still undergoing, for compressor power source. Within limits compressor capacity directly varies with speed, from refrigeration point of view this produces two problems.

a. Inability to produce enough refrigeration capacity at low car speeds.

b. Excess capacity at high car speeds which throws the compressor and evaporator capacities out of balance so the evaporator freezes.

On the current automobile air-conditioning systems, the compressor is directly driven from the crankshaft by a belt drive, with appropriate speed ratios obtained by pulley sizing. The speed of the car compressor freely vary with that of the car. Variation of capacity due to variation in speed is controlled on several systems, now in use, by refrigerant by pass controls inserted in the refrigeration system. Capacity control is also obtained by use of electro-magnetic clutch which starts or stops the compressor by thermostate or mannual control. Both these controls are used to prevent icing of the evaporator the later stops the compressor when icing is imminent.

Depending on power source different types of equipment arrangements may be obtained as discussed in next article.

2.09 EQUIPMENT ARRANGEMENT

a. Packaged Unit:- The whole of the unit including compressor condenser, evaporator, condenser fan and cool air circulating fan is located in the luggage compartment of the vehicle. The compressor is driven by a belt driven countershaft from the main engine, as shown in fig.-3.

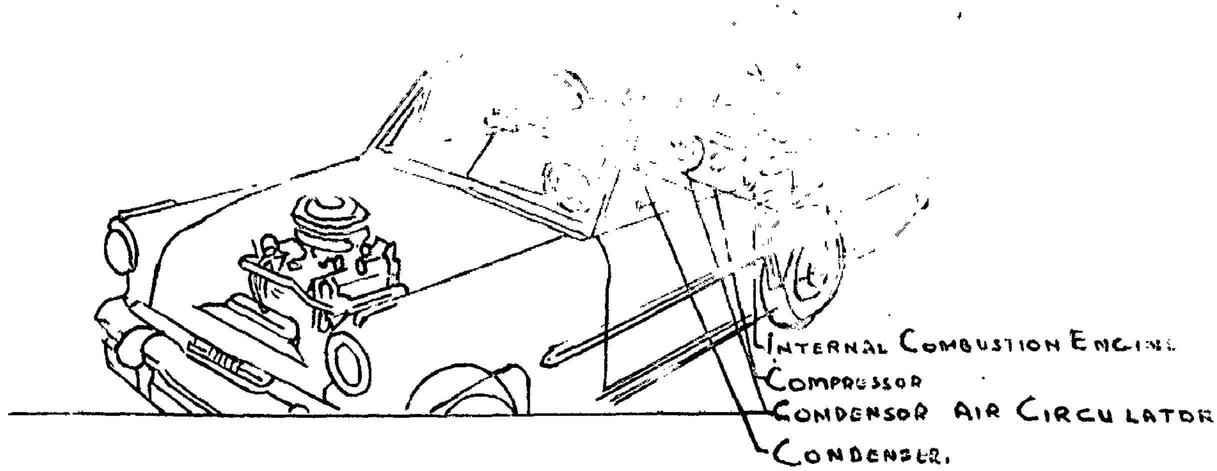


FIG.4 SELF CONTAIND SYSTEM WHICH INCLUDES AUXILIARY GASOLINE ENGINE FOR POWER

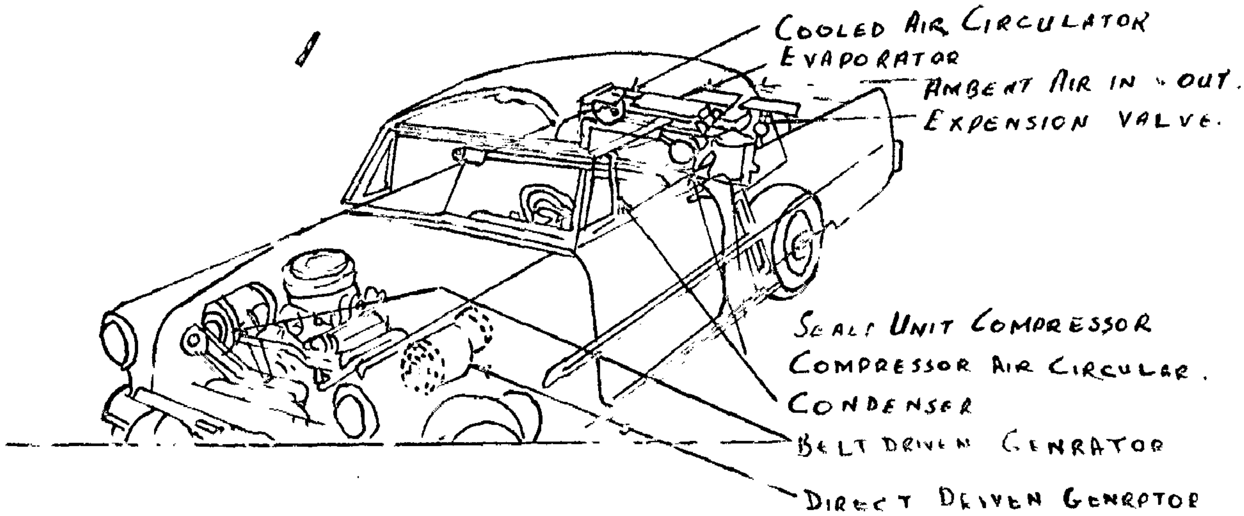


FIG. 5 PACKAGED SYSTEM ELECTRICALLY POWERED FROM OVERSIZE ENGINE GENERATOR

The following are the advantages of this system:-

(i) Relatively easier to install and free from leaks

(ii) Refrigeration system is self-contained.

(iii) By locating the unit within the trunk compartment a more desirable weight distribution is achieved.

At the same time the disadvantages are:-

(i) Complications arise for providing condenser intake air and discharge openings. These are provided either in the fender walls, base pans or trunk lids.

(ii) The drive unit is costly.

b. Packaged unit:- This packaged unit shown in figure 4 includes the complete refrigeration system and separate gas engine for driving the same. It is also located in the luggage compartment. It has separate engine drive. The advantages are:-

(i) Easy to install and replace;

(ii) This is a completely self-contained portable unit.

The dis-advantages are:-

(i) Non availability of small gasoline engines for this unit;

(ii) Small gasoline engines existing in this system are too noisy and produce excessive vibrations.

(iii) Relatively short life of engine.

(iv) Increased cost of unit due to separate engine drive.

(v) Substantial modification of vehicle is necessary for adequate air virculation of condenser and heat rejected by separate engine.

c. Hermetically sealed packaged unit:-(Electricity driven absorption system) In this catagory there are two types :-

(i) A self contained fully sealed air conditioning system shown in figure 5 receives its electric power from an oversized engine driven generator.

The advantages are, this is most clean, and is least subject to mechanical failure. The demerit of the system is the high cost.

(ii) Absorption system employing either engine exhaust heat or separate heater for the boiler have been proposed. Such a system is nice to contemplate.

d. Air expansion refrigeration system:- The refrigerant used in this case is air itself. The equipment required include compressor, condenser and air cooler. This system is relatively service free, but cost of operation and noise are high.

e. Conventional car cooling system:- Conventional mechanical refrigeration systems which are being offered are of two types.

(i) Rear end system:- This is an early comfort cooling system, installed in an automobile as shown in figure 6, is still being used. The compressor, condenser and some other components are mounted under the hood in the engine

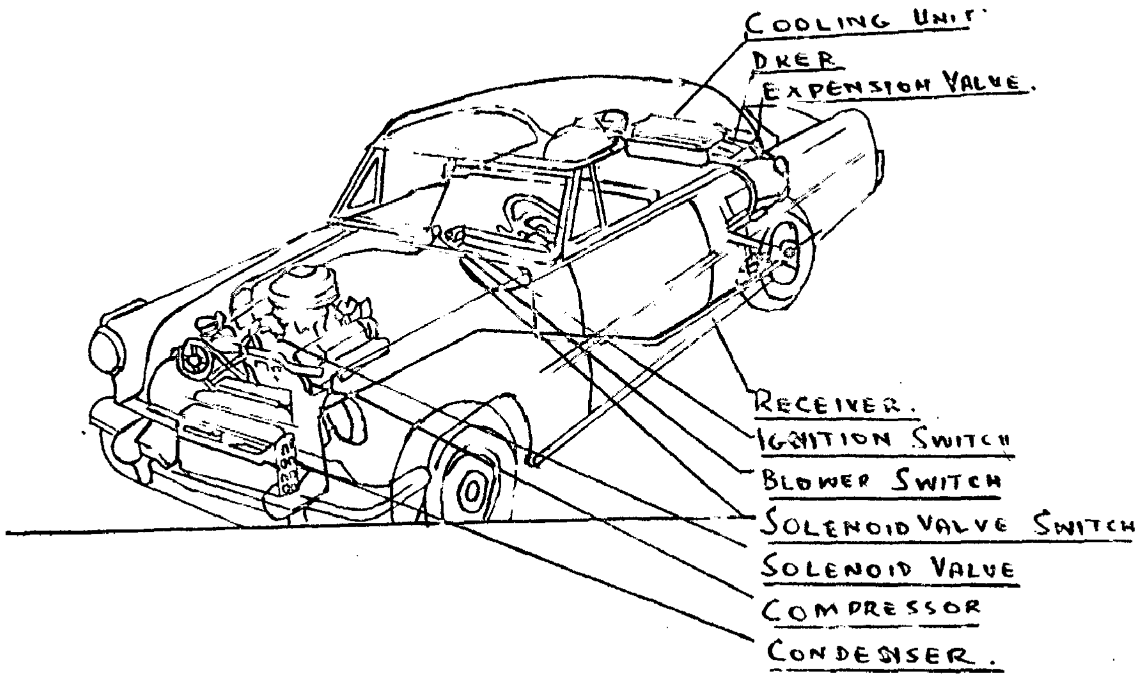


FIG 6 A CONVENTIONAL AUTO AIR CONDITIONING SYSTEM WITH ENGINE DRIVEN COMPRESSOR

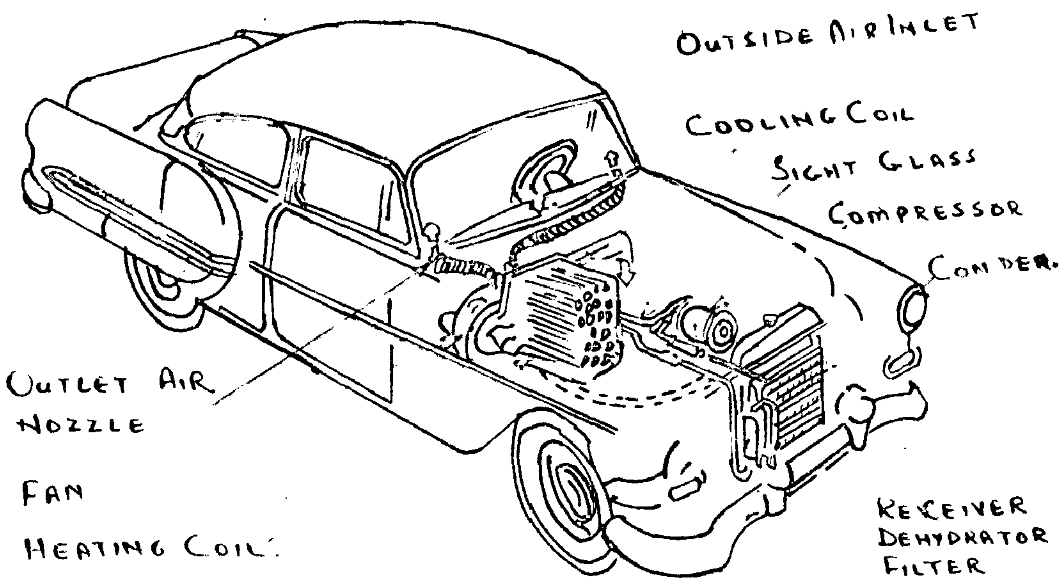


FIG. 7 TYPICAL FRONT END SYSTEM.

compartment. The cooling unit (evaporator, expansion valve, air circulating fans filters etc.) is loacated in the rear luggage compartment. They are connected by copper refrigerant lines running along the car frame below the body. Cooled air is introduced into the occupied space through openings in the rear package shelf above the cooling unit.

(ii) Front end system:- This system has all the components mounted ahead of the front seat as shown in the figure7. It differs in two ways with the previous system.

(i) All the components mounted under the hood ahead of the firewall with openings through the firewall to introduce the cool air.

(ii) The compressor, condenser and some other componants under the hood, with cooling unit and its associated components mounted on the other side of the fire wall in the occupied space.

Following are the advantages of this system:-

(i) It reduces refrigerating piping by eliminating rear end lines.

(ii) Cost, weight and volume reduction is possible compared to rear end mounted evaporator systems having more elaborate air distribution.

(iii) Concentration of all components at one place.

(iv) System is charged and sealed in the factory.

(v) Limited movement of components possible without opening system.

(vi) Simpler assembly line installations in the car plant.

(vii) Conforms to general trend of the refrigeration industry towards package system.

2.10 AIR DISTRIBUTION

The characteristics of a good air distribution are:-

(i) It should avoid stagnant pockets.

(ii) It should give a feeling of air movement.

(iii) Cool air should not strike the occupants directly.

The distribution of air within the automobile body offers several unusual problems. The space is confined, the seats present restriction to air flow, the low foof accelerates the possibility of draft. Another major problem of air distribution is to keep the cool air discharged from system, away from the glass surfaces of the car to avoid exterior condensation. Desirable air velocity over an individual for summer comfort is from 25-40 fpm. Very careful control of air distribution system is therefore necessary, so as to keep it close to this limit, when the supplied air volume is quite low as shown by the following table 3.

TABLE 3 COMPARATIVE AIR DELIVERY CHART

	Volume of space CFT.	No. of occupants.	cft space per person	Ton ref.	cft per ton	Air-delivery volume	Ratio space to delivery minute.
Wind Units I.H.P.	3400	56	567	0.76	4480	300	11.3
R.R. Coach	5000	56	89	7.5	667	2400	2.1
Automobile	160	5	32	1.25	128	300	0.53

The prevalent air distribution systems are:-

a. Ram Action Distribution:- In this air distribution system, only 20% fresh air is admitted. The air is distributed through openings in the instrument panel, either vertically or horizontally. Return air is taken at floor level to the blower inlet. Good cool air distribution has been worked out through the discharge grills or nozzles with the addition of directional finss in conjuction with the hinged cover to give satisfactory control vertically or horizontally. Cool air is disch-arged near the roof at low velocity. This cool blanket of air descends slowly over the occupants . This combination of components for air-conditioning lowers the car temperatures to a comfortable level in approximating four minutes.

b. Rear deck system:- Typical rear deck air distribution systems are:-

(i) Introduction of cool air into the car through openings in the rear package shelf. The air is directed along the roof by means of van-es, allowing it to diffuse down over the occupants. Return air is taken through an opening in the centre of the package-shelf.

(ii) Duct distribution:- The air is carried in transparent plastic ducts from package-shelf to the ducts located above the doors of the car. The ducts are provided with adjustable grills permitting the cool air to be mannually adjusted in both volume and direction to suit the

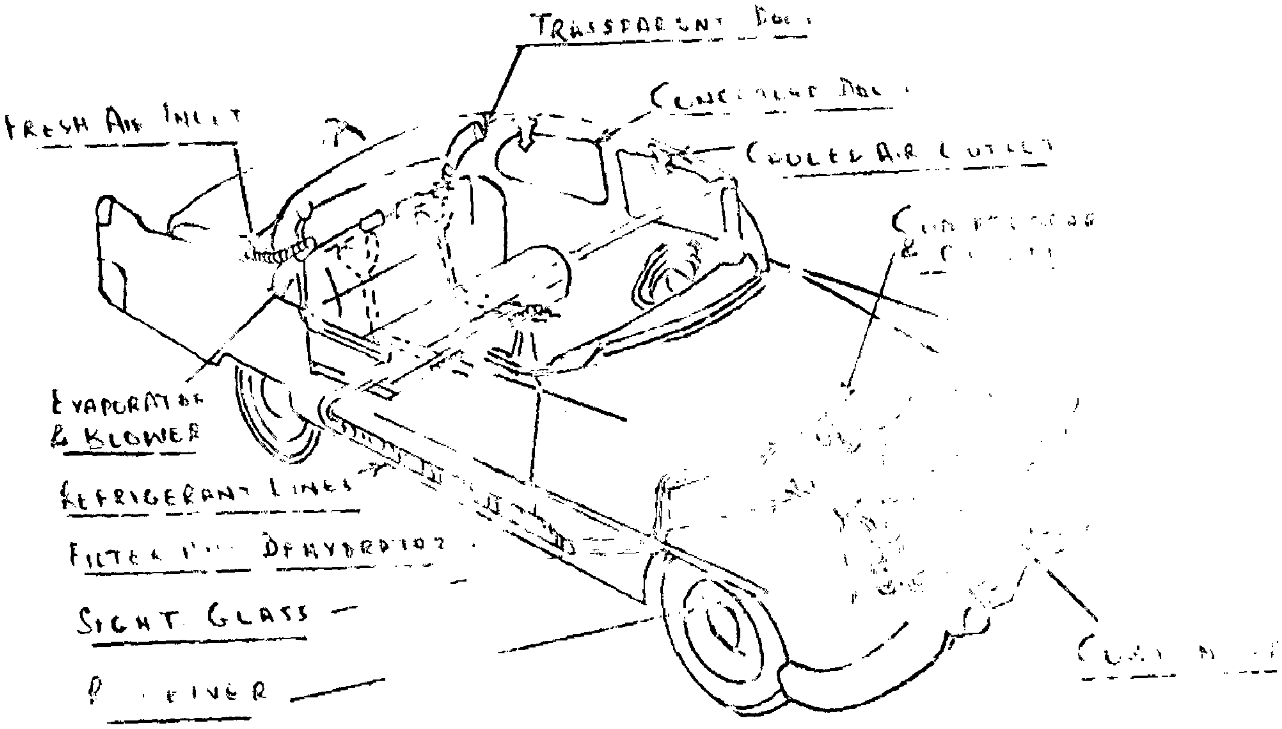
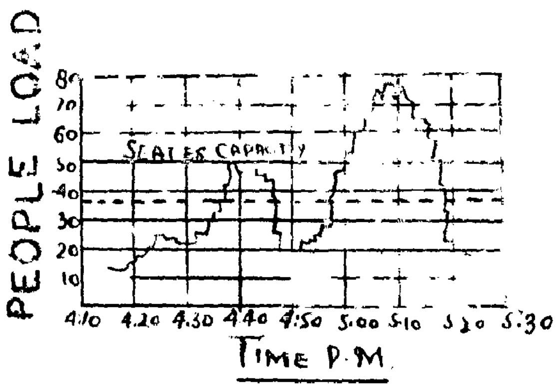


FIG. 8 TYPICAL REAR END SYSTEM WITH DUCT AIR DISTRIBUTION & AIR RETURN UNDER REAR SEAT



PASSENGER LOAD IN A 36 PASSENGER URBAN COACH DURING THE EVENING RUSH PERIOD IN A SOUTHERN CITY.

occupants. Air is returned to the cooling unit through openings below the rear seat as shown in fig. 8.

2.11 CAPACITY CONTROLS

Automatic air conditioning controls may be divided into four catagories:-

a. Refrigerant flow control.

b. Air temperature control.

c. Air distribution control.

d. Air Volume control.

a & b. Refrigerant flow and air temperature control:- For automobile air-conditioning system the liquid refrigerant control is best met by a thermostatic expansion valve. Manual control is completely undesirable, float values are not used due to instability in normal automobile operation. The automatic expansion valve and capillary tube do not provide the flexibility required therefore thermostatic valves with or without equilizer lines are used depending on individual system. In some systems control valve, in the refrigerant circuit is provided to prevent icing of evaporator and to offset compressor variable speed for controlling the system capacity. The function of this valve is to by-pass hot discharge gas from compressor into the suction side of the system and thus prevent liquid refrigerant, from evaporating and producing further cooling, until it is required. Controls used may be :-

(i) Solenoid valves electricially actuated by a thermostat.

(ii) Pressure actuated valves, modulated by evaporator pressure.

(iii) Valves actuated by thermostatic bulb incorporated in the valve.

c. Air distribution control:- In the confined area of a passanger carbody rapid change, in temperature must occur, to afford adequate comfort. Air valves which control the amount of outside air or recirculated air are manually comtrolled to give maximum refrigeration when needed, with minimum dust, outside odor or freshness in car as desired. These valves may be controlled by some type of vacuum diaphrams or servodevices.

d. Air volume control:- The blower is usually operated, on two or three speeds through toggle switches, push buttons or levers. A single speed motor with resistors in the line is usually used to obtain speed control. This is a wasteful speed control. Therefore two speed windings are often used to make more efficient use of generating capacity.

These controls are usually located near the steering column. Simplicity is of utmost importance so that average mechanically minded individual can operate them with ease and understanding.

CHAPTER II AUTOMOBILE AIRCONDITIONING

(b) Buses

2.12 HISTORY

The public acceptance of air conditioning has now been extended to include motor coaches of city and intercity type. Competition from other forms of transportation is continually growing and all operators, are sensing the necessity of making their vehicles, more attractive to travelling public. Air conditioning of course is one of the many improvements which are offered for this purpose and as such has to compete with other refinements. A complete and fully equipped coach, is a very carefully planned and specialized affair, with very detail aimed at profitable operation. This includes those things, necessary to attract patronage, but each refinement is balanced against operating cost per passanger mile and has to prove, its value as a profit maker.

The ideal motor coach is that in which every cubic foot of space, is available for revenue and is so planned, that it is the best balance between the passanger capacity, luggage space, freight space and air-conditioning equipment space.

In 1934 Yellow Truck and Coach manufacturing company took first active step towards air conditioning motor coaches. Their first installation, was a four cylinder engine installed in the rear of bus which was used as power source. They performed series of tests, but the results were inconclusive.

Next they designed an air-conditioning system with high side in the rear luggage compartment and low side kept on the top of the roof. This was put into actual service,to know the reactions of passangers and operators. The laters opinion was discouraging. The job was impracticable due to high cost for profitable operation and loss of valuable luggage space.

They then tried ice, in 1936 they put two coaches in service with ice cooling. The results were unsuccessful and the project was abandoned. The hindrance for air conditioning was the construction of the coaches. In those days motor coaches were of the chassis type, with engine infront and a separate wooden body in the rear, hence there was no space available under the floor for air conditioning equipment.

In 1937 the change over to intergral type coaches was underway. In this design the body was the basic structure. The engine was tucked away in the back end and the absence of frame and drive line permitted liberal sized compartments under the floor, which can be used for air conditioning system.

The first batch of air-conditioned coaches 25 in number were produced in 1938. A total of about 700 were on the road in U.S.A. at the break of II World War. In 1952 there were 4000 air-conditioned buses in service and cooling is a must in the summer on most of intercity bus lines. The number of air-conditioned coaches are ever on the increase, since then.

2.13 SPECIAL PROBLEMS

Special requirements for bus airconditioning equipment, need special attention and consideration, these requirements are of less improtance in other applications of such equipment. These requirements are as under:-

a. Weight:- Various states have authority to restrict the built weight and size of a coach. They also determine safety features of vehicles using their highways. Therefore weight and size factors are of considerable importance because of the prevailing transport rules in various states. Average gross loaded weight of a 35-37 passanger bus is 26,000 pounds. In most of the states the law is not strictly in force, but where it is it means reduction in pay load by the installation of the air-conditioning equipment. In some cases it becomes essential to reduce the number of passangers. Where the state laws limit the weight per wheel or per axel in that case, the weight distribution of air-conditioning equipment becomes very important.

Installation of air-conditioning equipment is at the cost of revenue, so the weight of equipment must be reduced as far as possible.

b. Bus construction:- There has been a continous trend towards construction of larger and heavior vehicles, from the operators side. While it might appear, that in larger size coaches, more space would be avialble for air-conditioning, but the opposite seems true. Because the larger size coach means the possibility of adding features such as snack bars, toilet-room,radio's , television and other comforts and conveniences in addition to air conditioning. A larger passanger capacity also requires more luggage space. All these factors tend to reduce the space for air conditioning equipment.

The body must be made air-tight to prevent excessive air leakage. It must also be insulated and the roof may be painted in such a way so as to reflect sun-light. To reduce cooling load and keep inside atmosphere clean, permanent closed windows are necessary.

People travel on buses because it affords greater opportunity for sightseeing. Therefore it is essential that large windows be provided. For above reason it is not desirable to request the passangers to keep the shades drawn. Therefore, it is essential to keep it view when calculating the solar heat load.

2.016 POWER REQUIREMENTS

Auxiliary power requirement is a problem with mo-tor coaches. The present electrical systems have reached their saturation limit, because in all new models there is increase in electric load for lighting and other features. Similarly in new models the horse power is also being increased regularly, this increase in horse power is made use for acceleration, hill climbing and in general to keep up highway traffic and to meet schedule timing.

One may think on the lines that ample horse power is available in the propelling engines to cop with the [illegible]ll increase, which may range between 7 to 20 B.H.P. for vari[illegible] requirements. The electrical requirements may vary from 1000 to 1500 watts when electric blowers are used. In this context one thing must not be forgotten that air-conditioning is a continous load and is constant for all the speeds of the vehicle. The constant power requirement penalizes the top performance of the vehicle considerably. Even if the required power is available in the properling engine there arise other problems i.e. running air-conditioning properly, during idling as well as under all road speed conditions. Therefore it is necessary that some means of constant speed or constant power output be incorporated. This drive has the advantage of making for a minimum of mechanical parts and therefore results in a arrangements requiring a minimum of maintenance. This drive cannot be used on city buses, because they have idle speed at least 30% of operating time, comparing advantages and disadvantages the drive has practical use in air-conditioning systems on buses.

The alternative method of obtaining power is by installing a separate engine for the air-conditioning system. This method is being adopted by Punjab Roadways for air-conditioning their buses.

The advantages of this method are, greater efficiency, easier control and full output can be obtained at all road speeds, while disadvantages are that it requires additional space and maintenance.

There is no particular cost advantage between the two methods. However operating costs may differ in case the propelling engine is of Diesel type and auxiliary engine is of gosoline. It is certainly more convenient to use the same fuel in both the engines. This avoids negligence on the part of the operators, in the former type one fine morning there may be Diesel instead of gasoline in the auxiliary engine. There might be some fuel tax saving because of difference of taxes imposed on two types of fuels. All these factors must be considered for the source of power for the air-conditioning system.

The operation of separate engine at a constant speed and constant throttle is a severe type of operation. For satisfactory engine performance following conditions should be observed:-

a. The engine should have at least 25% power margin over maximum horse power demand output.

b. Stellite faced exhaust valves should be used to eliminate effects of lead deposits and resist burning and sealing of exhause valves.

c. The gasoline used should be of good quality to avoid deposits of lead on spark plugs.

d. As far as possible constant load on the engine should be avoided.

e. The engine cooling water should be maintained at 150°F.

The use of electric power for driving compressor is the ideal operation for the air-conditioning system. This can be controlled with great ease, but is restricted to trackless trolly operations as it is not possible to use the necessary horse-power motor on a bus. For selection of motor on trolly bus, investigations should be made of the conditions of low voltage, because during rush hours there are large voltage drops.

2.14 BUS HEATING

The heat for heating of passanger coaches is obtained from the engine coolant. The engine coolant liquid is passed through the finned coils, over which the air is blown. The warm air thus obtained is distributed throughout the passanger space by means of ducts and outlets. In some designs the finned coils are located on the floor, to increase effectiveness. Heaters have been used, to raise the coolant temperature for obtaining maximum engine operating efficiency and to provide enough heat for the bus heating system.

2.15 COOLING METHODS

Various methods tried and used for a air-conditioning buses are follows:-

a. Mechanical compression system.

b. Absorption system.

The obious choice for bus air-conditioning system is mechanical compression refreigeration system and is exclusively used. The refrigerant used is mostly freon 12, because of its properties. It is nontoxic and non-irritating, there are more chances of leakage of refrigerant in the bus air-conditioning system than stationary one due to vibrations, so is preferred.

The absorption system has been a subject of discu--ssion in automative circles because of its attractive features. It requires low grade energy which can be supplied from the rejected heat of the propulsion engine. However the development of system has not progressed to the point where it can be seriously considered for bus use.

2.16 DESIGN ASPECTS AND EQUIPMENT SELECTION

Following paragraphs describe the design aspects and equipment selection for Air-conditioning systems installed on buses.

a. Design problems:- The designer of air-conditioning coaches faces many problems such as limitations of space, weight and cost. The other difficulties are capacity requirements, seviceability, air distribution and control. As far as heat gain calculations and general method of attack are concerned the problems are similar to the stationary air-conditioning systems. The problems become more difficult and complex due to the limitations mentioned and the relative severe service conditions, the equipment receives, as compared to stationary equipment.

(i) The equipment is continously under road shock and vibrations.

(ii) It operates over a long period per day in comparison with usual commercial equipment.

(iii) Ambient condition fluctuations are comparatively more, the altitudes may vary from sea level to 10,000 feet. The temperature may vary from very humid locations at 92-94^{o}F maximum to very dry conditions at 115-120^{o}F maximum because the buses are to run from place to place to cover distances.

(iv) The equipment is continously subjected to dust and dirt. The extreme demands on equipment must be met with air quantities evaporator, condenser surfaces , and filter areas etc. The size of the equipment should be smaller, than the usual for commercial use. Another factor to be noted is that the speeds of fans and other rotating equipments, must be high because there is no limitation on the noise level, but it should not be objectionable.

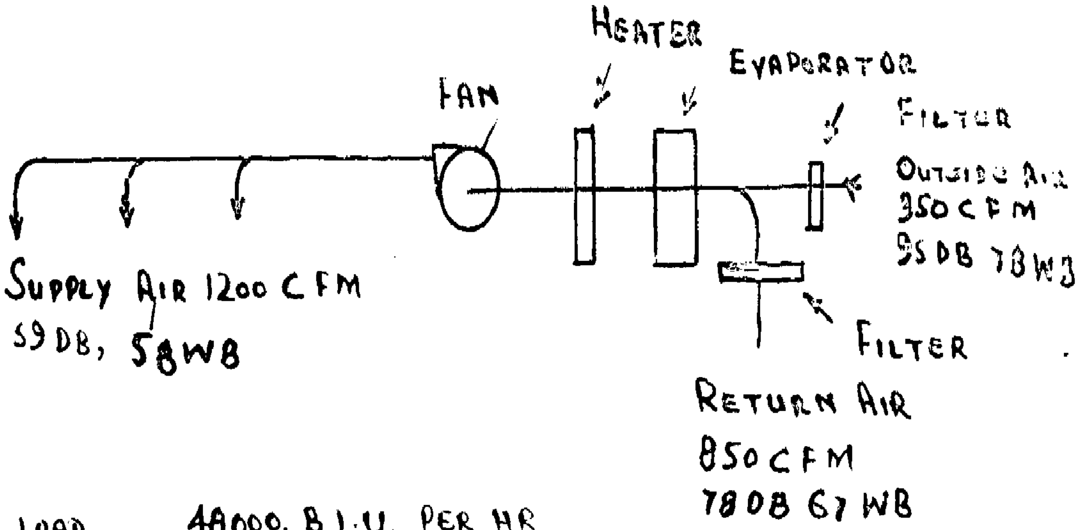
The air-conditioned bus is a luxury coach so smoking is allowed, hence a minimum of 15 cfm per person is the ventilation air required for keeping the air pure. This value is governed by the state laws and is to be used accordingly.

For common type of buses the capacity varies from 3 to 9 tons. The capacity worked out for Punjab roadways 22 sector bus is 2-5 tons, the equipment can take up load up to 4.5 tons. The circulating air is generally kept the maximum, which will handle the tonnage required without objectionable inefficiency.

Most of these problems do not appear in city buses but here the standees capacity is more than double the normal capacity as shown in fig 9. The door remains almost open throughout the operation time. Moreover the space capacity is so designed that it leave no space for equipment and luggage.

(v) The construction of body should be such that it keeps the load and air infilteration to the bare minimum.

The body must be well insulated with vermin and fire proof insulation. The space for insulation is between



LOAD 48,000 BTU PER HR.
SH. FACTOR .75
APPARATUS DEW POINT 57 F.

SUCTION PRESSOR 40 PSI
HEAD PRESSOR 160 PSI

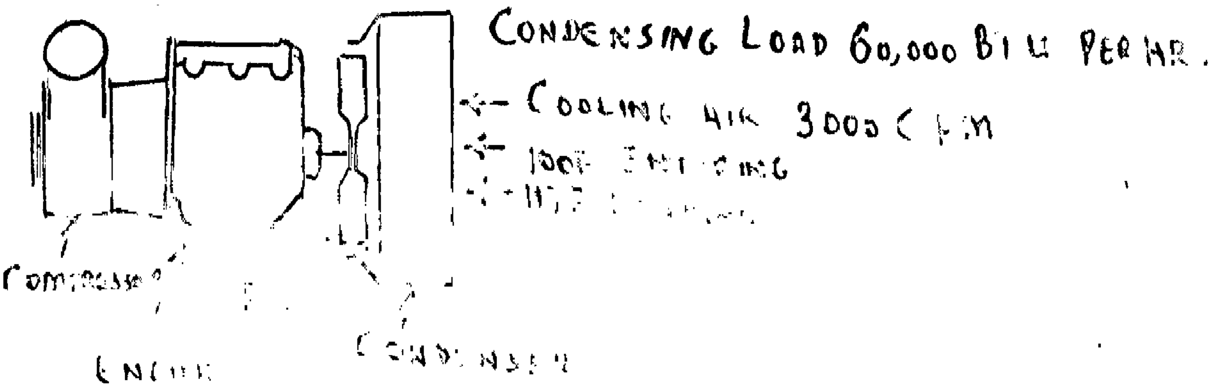


FIG 10 DESIGN CONDITIONS ON AN AVERAGE 40 PASSENGER INTERCITY BUS

inner and outer panels of the bus body. The floor is made of plywood with linoleum covering and should have minimum equivalent of 3/8" layer of cork. The body should be painted in such a manner that sun is reflected back. Design conditions commonly attained in the average 40 passanger intercity bus are shown in figure 10.

Various componants of air conditioning systems can be selected as under:-

(i) Condenser:- Water spray evaporative condenser have been tried, but they offer problems of additional maintenance and water tank load. In regions where water is not favourable there arises problems of scale formation on condenser coils.

Due to the above difficulties these have not been favourably accepted, therefore the best obious choice is the air cooled condensers. They present their own problems such as the presure around the vehicle may vary from positive to negative, so that the fan may not be able to handle these pressures at one time or the other. Copper coils are used for condensers. The aluminium coils due to their weight saving may be used but they require more space due to their low heat transfer efficiency.

(ii) Compressor:- The compressor must be designed to be fairly efficient and trouble free, under all conditions, of variable speeds, low and high pressure. The requirements of a compressor are:-

1. Moving parts must be balanced for all speeds.
2. Regardless of speed the volumetric efficiency must stay upto a certain minimum.
3. Heavy duty crank shaft seals.

Compressors used may be rotary or reciprocating. Generally high speed compressors operating safely upto 2500 rpm of reciprocating type are used. There is a considerable weight reduction due to recent development of aluminium alloy crankcase. The displacement can be varied automatically to suit the refrigeration demand by cylinder unloaders. They have replaced the conventronal cast iron compressors and contribute to the efficient functioning of the equipment.

(iii)<u>Evaporators:-</u> The evaporator of the automotive conditioner is of finned direct- expansion type, and is controlled by a thermostatic expansion valve. The suction pressure becomes excessive when the evaporator is located on the roof and is parked in sun. So some form of suction pressure controller should be inserted. For this reason it is desirable that expansion valve, of limited gas discharge type, designed to limit the maximum evaporator pressure to 55 PSI may be used. The material used is copper for the evaporator coils but aluminium coils are receiving experimental considerations but have not been adopted uptil now.

2.17 EQUIPMENT ARRANGEMENT

The main consideration for equipment locations are:-

a. Easy replacement.
b. The elements should be easily accessible for maintenance.

Therefore equipment arrangement is mainly according to the bus design. The high side equipment are located under the floor keeping in view the space available and the weight distribution on the wheel or axels. The low side equipment i.e. evaporator may also be located under the floor, but the problems of entrance of ventilation air and connecting it with ducts for supply crop in. This problem has been successfully tackled in some bus designs. The consideration for locations of low side are weight distribution, space available, entrance of ventilation air and connection with supply ducts. The alternative location would be above the driver seat, which has the advantage of simplicity of ducting. This design has been adopted by Punjab Roadways. The other locations can be overhead in the rear or underneath the rear settee.

2.18 AIR DISTRIBUTION

The air distribution system in a bus air-conditioning system is comfronted with problems of high occupant density and low ceiling height. It is a quite difficult to maintain uniform temperature and air motion, which are the essential factors of a good air distribution.

The distribution system may be downward type. The ducts may be located on two sides or in the ceiling, the return can be taken at the floor level. Usually perforated ducts in the ceiling for supply of conditioned air, are used and they are good solution of the problems encountered. These ducts introduce the air at many places over the passangers, complete and rapid diffusion is accomplished. The return may be had at the floor level on one end under or near the evaporator.

Careful attention should be paid to the driver comfort. Additional spot cooling should be provided to him, which is to be controlled by the driver himself at his will.

2.19 CONTROLS

The most vunerable part of an air conditioning system are its controls proper controls are as important as the system itself. The controls used should be automatic, manual controls are avoided because of uncertainty and inefficiency. It is not conducive to the passangers good will if the air-conditioning system, fails after a couple of hundred miles from garage on a hot day. The cause of failure may be as simple, as a direct contact of a switch. Therefore it is essential and important for the designer to have as few controls as possible and the controls should be simple, consistent and reliable.

Humidity can be controlled by a thermostate, sensitive to sensible temperature. This either controls the reheat coil or increases the evaporator by-pass factor. In general these controls have been found adequate but still humidistate is used for closer control of humidity. A recent development is the drum switch powered by a thermal element which may be designed to set up any desired sequence of operations from cooling to heating depending upon the inside temperature.

Freezing of evaporator can be avoided in two ways. One method is to unload the compressor on a low suction pressure. This is achieved by a by-pass circuit around the compressor and is controlled by a valve similar in design to a constant pressure expansion valve.

The other way is to stop the compressor instead of unloading it on low suction pressures. This can be used in a separate engine drive only. A pressure-state in the suction line opens the ignition switch when the pressure falls below 24 P.S.I. in the suction line.

A pressure-state and a solinoid valve are inserted in the liquid line to control the head pressure of the compressor. It is designed so that when the head pressure reaches above 250 P.S.I. the pressurestate opens the circuit to the solinoid valve, causing it to shut off the flow of refrigrant to the evaporator, when the head pressure falls below 215 P.S.I it closes the circuit, allowing the system to come to normal.

Safety devices on separate engine drive are provided to warn the drive against high coolant temperature and low oil pressure.

As a protection against the dangers of an explosion in the event of fire a fusible plug at the receiver is desirable.

2.20 SAFETY REQUIREMENT

The society of automotive engineers made certain safety recommendations regarding air-conditioning of buses in 1953. These are as follows:-

a. In automobile air conditioning installations, there should be some temperature and pressure sensitive valves.

b. Each unit must be plainly marked as to the type of refrigerant used.

c. Always wear goggles when working on any part of the air-conditioning system containing refrigerant.

d. Keep your face away from any fitting when it is to be disconnected.

e. Close the shut off valves before disconnecting lines or fittings.

f. Never weld or solder refrigerant lines to avoid dangerous explosion but instead use blow torch.

g. Do not leave refrigerant drums exposed to direct sun or carry them in a passanger car.

2.21 SERVICE AND MAINTENANCE

The designers of automobile air-conditioning system must not forget, the problems of service and maintenance, because they are very important. A bus represents a large investment and only when on road it is earning a return. Operating schedules allow only a minimum time, for allowance from maintenance point of view the package units and separate engine drive are preferable because of following reasons:-

(i) The package unit can be easily replaced with the new one and the unit out of order can be serviced in the workshop resulting in economy.

(ii) In case a stand by unit is not available the vehicle can proceed on its trip without air conditioning system, while in the other case the servicing of air conditioning system ties up the vehicle also with itself.

(iii) With equipment in its present stage of development more service is required on the power source than on the air-conditioning equipment itself. The self contained idea is equally advantageous here also and it is quicker and better to replace the engine, than it is to tinker, with one built into the coach.

There has been various attempts to standardize equipment on automobiles. This will reduce the manufacturing cost, but its practical problems may put obstacles in its way.

2.21 THE TROUBLE SHOOTING CHART OF AUTOMOBILE AIR CONDITIONING

Trouble	Cause	Indications	Remedy
a. System will	i. Low charge	i. Sigh gauge	i. Check for

not produce sufficient cooling at discharge side of blower	of refrigerant.	will show bubbles & low pressure gauge will show excessively low readings.	leaks & charge system until bubbles disappear & pressure returns to normal.
	(ii)Defective expansion valve.	(ii)Excessively high & excessively low readings.	(ii)Pump system down and replace expansion valve.
	(iii)Obstruction in air circulating system.	(iii)Blower will not circulate correct amount of air.	(iii)Check & clean air filter check for blocked grills on rear seat package, check flexible air ducts for tears or restriction.
	(iv)Defective modulating valve	(iv)High pressure reading below normal low pressure reading above normal.	(iv) Replace valve.
b. Unit will produce no refrig.	(i)Loose or broken drive belt.	(i)Pressure readings will be same on both the high & low pressure gauges at any engine speed.	(i) Tighten or replace belt.
	(ii)Inoperative valves in compressor.	(ii)Pressure readings will vary only slightly on both sides at any engine speed.	(ii)Replace compressor(note check expansion valve to make sure it is not stuck in the open position.
	(iii)Break in any part of closed refrigeration system.	(iii) No pressure in any part of system.	(iii)Replace defective part install new dehydrator.

c. Compressor is noisy.	(i) High pressure valve is shut off.	(i) High pressure gauge reading excessively high & compressure knocks noticeably.	(i) Open valve immediately.
	(ii) Insufficient comp. lubricating oil.	(ii) Comp. crank case becomes excessively hot & noisy.	(ii) Check system for oil leaks. Correct leak or replace defective part. Refill with special comp. oil.
	(iii) Loose or worn parts in compressor.	(iii) Noisy operation.	(iii) Replace compressor.
	(iv) High charge of refrigerant.	(iv) High pressure gauge will show excessively high readings.	(iv) Release pressure through pressure test gauge manifold until pressure becomes normal.
d. There is no air circulation at blower outlet or blower operation is intermetant.	(i) Blower motors have short or open field or armature windings electrical connections are loose or disconnected electrical wiring is shorted or open or panel switches or inoperative. Burned out fuse.	(i) Blower motors operate intermet antly or will not operate at all.	(i) Check refreigeration electrical system repair or replace defective parts. Replace fuse.

CHAPTER III RAILROAD AIRCONDITIONING

3.01 SHORT HISTORY

The Baltimore and Ohio Railroad in U.S.A. started experimenting with the possibilities of Air Conditioningin the year 1884. The first experiment was to build a huge ice box on the head end of a car fitted with air ducts, so that the Car's motion caught up some ofthe breeze it created and carried it back over the ice, through the ducts and into the car proper. This method was stopped due to frequent stops and the inability to cool the car while it was standing still.

In 1925 another type of installation was made on the car using electric fans and a pump but it required more current than the generators on the cars at that time could supply.

In 1929 another experiment was made by Baltimore and Ohio Railroad with Amonia refrigerant, using a compressor driven by electric motor. While Ammonia did a fair job of cooling, the vibration of the car's equipment etc. caused too many leaks. It did prove however that air conditioning on Rai-road cars could be accomplished. In 1930, Methyle Chloride was tried and it was abandoned on account of the effects from leaks etc.

Then on May 4,1931 the first completely Air-conditioning train in history, the Baltimire and Ohio "Columbian" was put into service from New-york to Washington, mark-ing the begining of a vast improvement in Railroad passanger comfort. The equipment used Ammonia as refrigerant and compressor were driven with gasoline engine, however later the gasoline engine proved to be a headache.

On April 20,1932 ' National Limited ', New-york to St.-Loins became the first long distance, sleeping car train, that was completely equipped with Air-conditioning to be operated on any Railroad . Refrigerant used was Freon.

In 1957, 16000 cars were on the railroad and operated satisfactorily, since then they are on the increase.

3.02 SPECIAL FEATURES

When an air conditioning equipment is to be provided and installed in a railway car many problems crop in and their solution is not always satisfactory,the problem include those of :-

a. Power supply

b. Space and weight restrictions.

c. Air Distribution.

d. Heavy ventilatin load requiring high capacity heating and cooling system.

e. Heat loss from high speed and poor insulation.

f. Solar radiation and window area.

g. Changing locality with resulting change in temperature.

h. Altitude changes.

i. Human heat load variation in comparative small location.

j. Human element in operation of equipment.

In modren light weight cars space and weight are important factors, because of their ultimate affect on the economy of vehicle. They have direct bearing on capacity for passangers and luggage of the car. The material used for equipment should be light weight and compact, so as to withstand the severe and hard service to which they are subjected. Power requirement will be discussed in article 3.04.

Since the range for comfort of passangers is so broad that it is not feasible to set the air temperature and humidity to a particular value to maintain comfort conditions for all. It will therefore be not necessary and appropriate to aim at accurately maintaining conditions of temperature and humidity. The various air-conditioning requirements for railway carriage are as follows:-

(i) Ventilation:- Average car contains approximately 5000 CFT (70.8' x 9.8' x 7.5') which is being conaminated by the occupants who are continually liberating heat, moisture, carbon dioxide odors and other organic matter in breathing. The heat and moisture can be handled by the cooling and dehumidyying apparatus, but others can be handled only by proper ventilation.

The total amount of air to be supplied to the car interior for maintaining desired conditions, has to be calculated on the basis of psychrometry and the heat gain and loss from the car, but it varies with types of cars. A portion of air has to be drawn from the outside and its quantity will depend on the ventilation requirements as discussed above, normally 10 to 15 CFT of fresh air should be circulated per person.

In the average car of the size given above 2000 to 2500 CFT of conditioned air are delivered out of which 25% should be the fresh air and remainder may be the recirculated air.

(ii) Air Cleaning:- It is natural to expect sufficient amount of dirt and dust in any vehicular system, it is apparent that fresh air and also the recirculated air should be cleaned, properly by passing through suitable filters. Usually 4" thick filters made of mineral wool, hemp, spun glass or cloth are used at the fresh air grille and 2" thick filters are used in the return air inlet.

(iii) Temp. and Humidity:- As it has already been pointed out that in comfort air-conditioning no close control of temp. and humidity is maintained. The inside temp. is generally kept about 20°F below in summer and 25°F above in winter than the outside temperature. Permissible humidity variation is 5% .

In medium seasons vantilating fans are used and the conditioning plant is not put into operation.

(iv) Air Motion:- In heating the air gives up heat and in cooling it absorbs heat. Therefore if uniform conditions are to be obtained the air must be properly distributed throughout the space served. This is necessary in order that the heat either be properly supplied or removed and it is necessary to prevant the concentration of moisture, odors toxic gases etc. in various locations.

The velocity of air in the occupied zone is important as it must never be such as to produce objectionable drafts. The Air velocity in the occupied zone should not exceed 25 to 40 f.p.m. in summer and winter installations and should be just enough to give a pleasant feeling. In case of cars velocity is kept 60 f.p.m. which is the most favourable one. Hence the inlets must be designed in such a way as to achieve the best results. The velocity above occupied zone may be higher.

3.03 CAR HEATING

Passanger cars are heated by using split system consisting of an overhead air circulating system with heating coils and floor heaters. The floor heaters used are generally finned tubes. Low pressure steam is used as the heating medium, in the convectors and radiators. Depending on the heating requirements, the steam may be either drawn from the locomotive or from a separate boiler, which may be mounted in a corner of the car. Separate boiler is used when the heating requirements are high.

The finned tubing at the floor must have sufficient capacity to off set effects of cold walls and windows during normal operation, and to heat the entire car to a minimum temperature of 60°F during standby when the over head system is not operating. The maximum capacity varies with car construction and design temperatures, but is approximately 90,000 B.T.U's per hour.

The overhead heating coil must have sufficient capacity to heat the outside air brought into the car for ventilation and to supply approximately 20 per cent of the internal heat loss of the car so as to permit supply of floor heat at all times at an output that will not be objectionable to passangers sitting near it.

Heating of rail cars is not a problem in our country where the average out door temperature during winter is about 40°F. The reverse cycle heating can easily be employed for heating purposes. This can be accomplished by installing suitable valves in the suction and discharge line of the summer air conditioning equipment to interchange the functions of condenser and cooling coil.

3.04 COOLING SYSTEM

Of the basic systems capable of providing cooling adaptable to railway car air conditioning are:-

a. Steam ejector.

b. Mechanical compression.

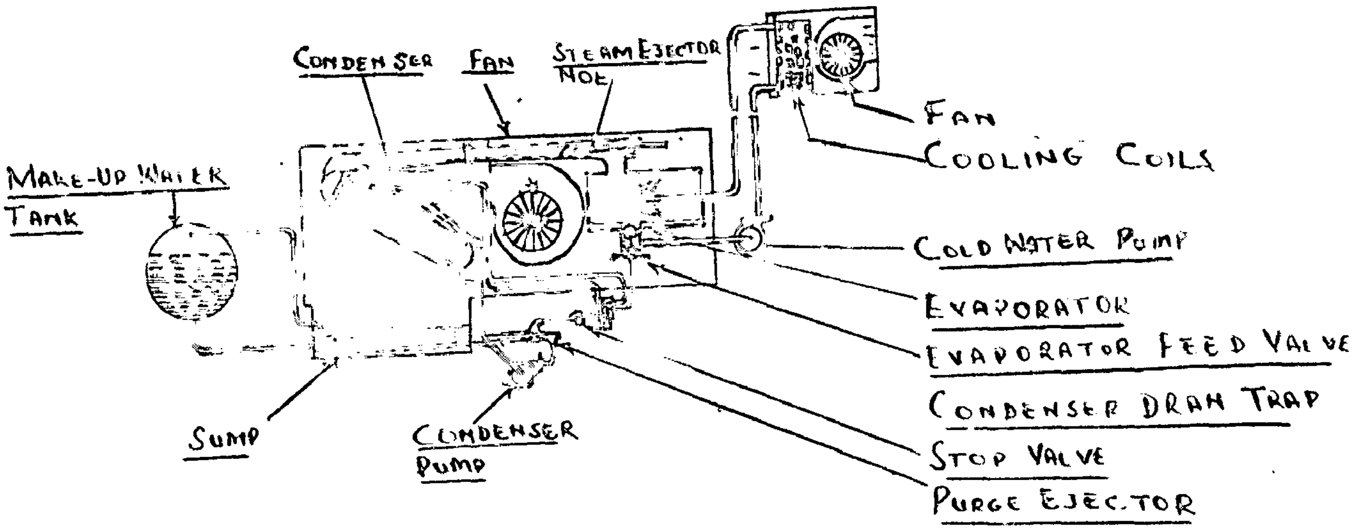


FIG. 11 STEAM JET SYSTEM DIAGRAME OF OPERATION WITH UNDER FRAME REFRIGERATING & ROOF MOUNTED AIR CONDITIONING UNIT.

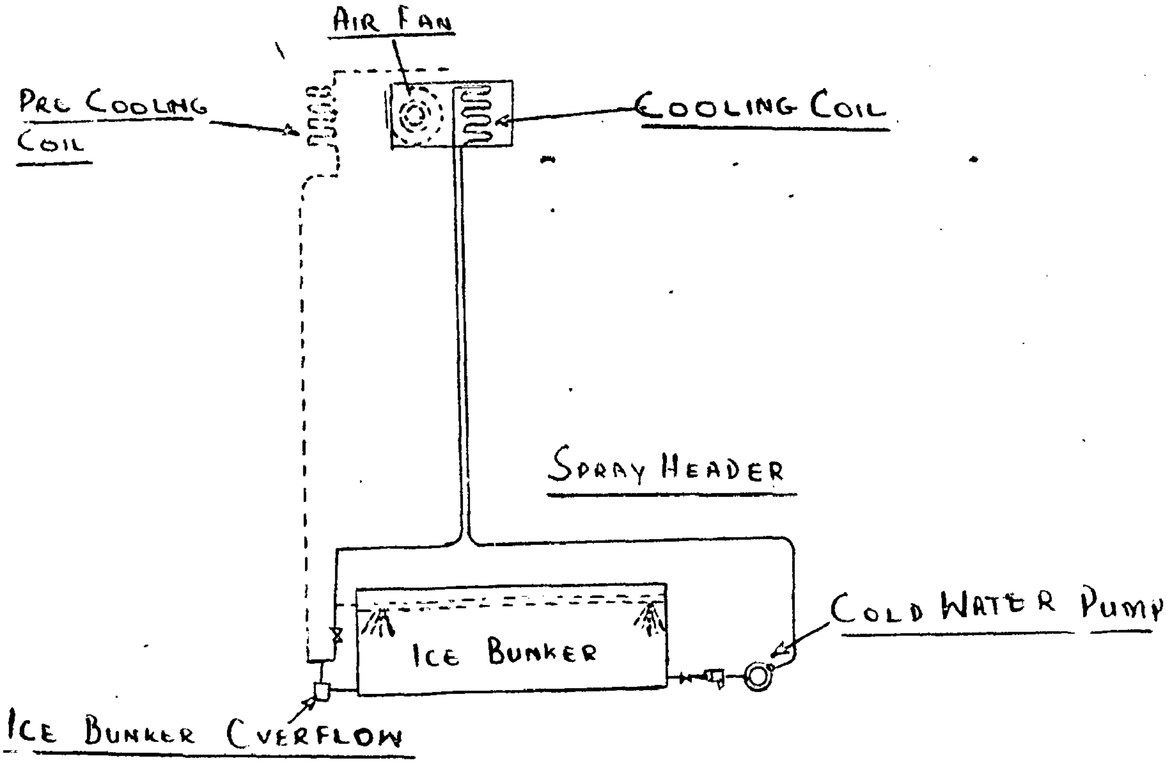


FIG. 12 COOLING SYSTEM USING WATER ICE AS THE REFRIGERANT.

(i) Compressor driven directly from car axle through a speed control.

(ii)With compressor driven by an I.C.engine using bottled liquified petrolimum gas for feul.

(iii)With compressor driven by an electric motor by power obtained from movement of car.

c. Water Ice.

d. Other Systems.

a. Steam Ejector:- The steam ejector system shown in fig.11 utilizes steam taken from the locomotive through the train line passing through an ejector which is connected to a flash tank or evaporator, evaporating a part of the water in the flash tank at low pressure and temperature and cooling the remaining water in the evaporator. The steam and vapor are compressed in the ejector to a pressure at which they can be condensed by the surface condenser to which they pass from ejector. The condenser is cooled by the combined action of a water spray and an air blast. The condenser temperature therefore is controlled by atmospheric wet bulb temperature.

Air is purged from the condenser by a water ejector operated by condenser spray water which is pumped through the purge ejector before going to sprays. Enough of the condensed steam and vapor from condenser is automatically returned to the evaporator to make up the amount evaporated in the evaporator and the remainder is used in the condenser cooling system.

A circulating pump takes the cooled water from the evaporator and circulates it through the cooling coils of Air-Conditioning units.

b. <u>Mechanical Compression:</u>- In the mechanical compression system the refrigerant gas which has absorbed heat from the air passing through the cooling coil in the air conditioning unit is compressed to a relatively high pressure in the compressor from which it is discharged to an air cooled condenser where the heat is extracted and the gas liquified passing to a stage reservoir. The low pressure maintained in the evaporator by the action of the compressor combined with the pressure in the condenser forces liquid refrigerant to the expansion valve at the cooling coil. The expansion valve permits liquid passage into the cooling coil. The expansion of this liquid to a gas at the low pressure existing in the cooling coil extracts heat from air passing over the coil. This type of compression system is used with either of the three types of drives mentioned before.

c. <u>Water Ice:</u>- With the water ice system shown in fig.12, water is stored in a bunker underneath the car to furnish cooling for the air conditioning unit. A motor driven pump circulates water cooled by the ice through the cooling coil in the air conditioning unit and the warmed water as it returns from the cooling coil is sprayed over the ice in the bunkers where its temperature is again lowered.

Two methods have been employed with the ice system for controlling car temperature. In the one the thermostate starts and stops the circulating water pump and controls the circulation of the water through cooling coil.

In the other method the pump is running continuously and the thermostate controls by pass valves which either direct the return water from the cooling coil to the spray in the ice bunker or totally or partially by-passes the spray and returns the water from the coil direct to the pump suction, with the result that the temperature of the water circulating through the coil is modified to suit the cooling requirements.

Apart from the above systems adopted for cooling packaged air conditioners of 8 to 10 Tons capacity can also be installed in the Railway carriages. These air conditioners are self contained units and are similar to residential window type of air conditioners.

3.05 POWER SUPPLY

The power supply is governed not solely by the air-conditioning load but the total connected load which includes

a. Incandescent lamp load.

b. Electrical Water coolers.

c. Water circulating Pump motor.

d. And motor alternator where cars are equipped with flourescent lights radio tape recorder or similar equipment. Cars usually are equipped with connectors so that in case of generator or battery failure power may be obtained from adjacent cars.

In an unconditioned car the power is supplied by storage batteries with generators. For an air conditioned coach the load is increased by 1 k.w. for mechanical refrijeration.

Usually three methods of power supply are adopted which are:-

(i) Direct drive compressor.

(ii) Electric drive compressor.

(iii) Internal combustion Engine drive.

(i) The compressor is directly driven from the car axle with a speed control device to maintain a uniform compressor speed. This control is a speed governed electric induction clutch, which automatically holds the compressor to a constant speed after a certain train speed has been reached and starts and stops the condensing unit under the control of car thermostate.

The clutch shaft is placed longitudinally of the car it is driven from the car axle by means of V-belts and level gears. The compressor and fan shaft are parallel to the clutch shaft and are driven from it by V-belts.

The compressor and condenser fan are so designed that they will operate properly when their direction of rotation is reversed by change in direction of the car move-

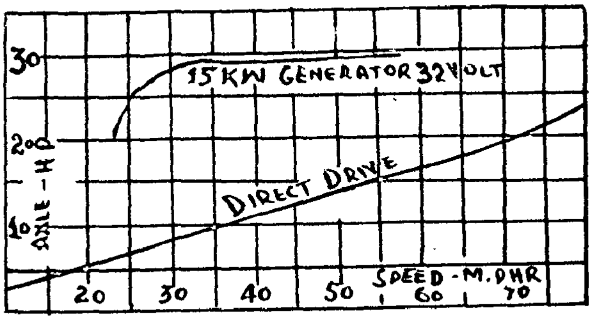


FIG. 13 RELATION OF POWER TAKEN FROM A LOCOMOTIVE FOR PUTTING A GENERATOR MOTOR BATTERY DRIVE & FOR A PULL MAN DIRECT DRIVE.

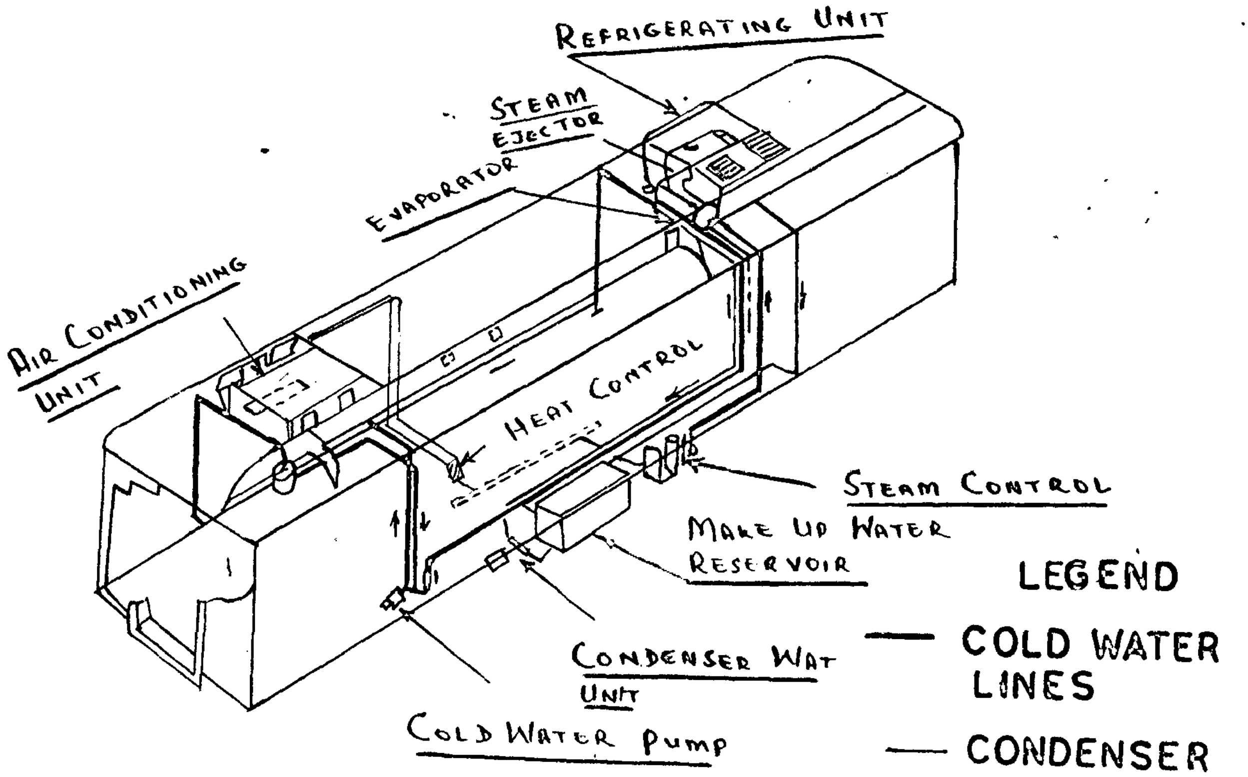


FIG. 14 INSTALLATION OF STEAM EJECTOR EQUIPMENT ON CAR

ment.

With this type of drive no cooling is obtained when the car is stationary and the amount is reduced when the car runs below 20 miles per hour.

An auxiliary motor can be connected to the driven member of the speed control to operate the compressor and condenser when the car is stationary for a considerable period but this is not useable for the usual station stops.

(ii) Electric drive compressor:- With this system a direct current motor is used to drive the compressor. This motor obtains its current supply directly from an axle driven generator when the car is moved at speeds over 25 miles per hour and from a storage battery charged by the generator at speeds under 25 m.p.h. or when the car is standing as shown in fig.13. For precooling at terminals the compressor motor may take its power supply from this storage battery in which case a relatively large capacity battery must be used or the driving motor may be designed to operate on either direct or alternating current so that when the car is standing in a yard or station it may utilize an external source of alternating current. In that case a smaller battery may suffice to operate the equipment during low speed or at station stops.

(iii) Internal Combustion Engine drive:- With a mechanical system using the internal combustion engine drive an engine especially developed to operate on a liquified petrolium gas or fuel is belted direct to the compressor and no power for the compressor is taken from the car axle.

The condensor may be air cooled by a fan driven from the engine shaft or by a fan with electric motor drive. The condensing unit is embodied in on assembly, current for air conditioning unit fan motor and condenser fan motor if used is obtained from the car electric system. Control of the car temperature is by means of control ofthe engine speed through the suction pressure of compressor.

The air conditioning unit may be single coil or divided coil type.

The fuel used is liquid propane carried in cylinders underneath the car. Automatic valves are provided to prevent excape of fuel in case of breakage of piping.

Diesel type engines are also used for this type of equipment.

3.06 DESIGN ASPECTS

Early application of air conditioning equipment to passanger cars was done in a rather hapazard manner due to the necessity of fitting the equipment into available existing space in cars not designed for use of air conditioning equipment.

With the advent of light weight cars, it was necessary to develop certain basic design specifications to cover average operating conditions as applied to Railway Passanger carrying car. Briefly for a particular car conditions are as under:-

Outside temperature conditions 95 DB 78^{0}WB

Inside car temperature 75^{0}FDB 50% R.H.

Air volume for ventilation not less than 25% of total air volume calculated heat gains :-

Sensible 49,600 BTU/hour

Latent 12,400 "

These are the specific average operating conditions governing the basic specifications. Many railroads operate through territories where this average prevails, this is particularly true of the roads of the Eastern and Southern sections of the U.S.A.

Railroads operating west of Missipi river are confronted with the problem of operating air conditioning equipment under conditions that differ widely from the normal on which the original specifications are based. e.g. variation in altitude and the outside relative humidity may vary from 30 to 85 % D.B. may vary from normal of 80 or 90 to 120 or 130^{0} with road bed temperature exceeding 150^{0}F during summer.

In order to meet the conditions imposed by various types of cars and the varied service conditions the designer of Railway passanger car air-conditioning equipment must be prepared to recommend the air conditioning system best suited to particular application.

Consideration must be given to the design of air-filtering equipment not only for the car body but also for condensers during travel through desert areas. Similarly temperature control must be designed to function properly and maintain normal conditions within the car regardless of the outside climatic conditions.

The utmost in comfort is the new thought in the passanger car design and the designer of the modern passanger car is as much concerned with this feature as he is with safety and maintenance which were formerly his most significant problems. Again in the design of new air conditioned passanger cars insulation and sound absorbing materials play a very important part. The selection of insulation is a question of economic importance and must be considered from all possible view points. The thickness and the kind of insulation selected for the lowest ultimate cost rather than the lowest initial cost. The insulation must be light weight easily applied and the comparatively inexpensive.

3.07 LOAD CALCULATIONS

For designing a suitable air conditioning system of a Railway car accurate load calculations as in the case of buildings cannot be made due to many variable factors. Hence basing upon the practical experience only approximate load calculations can be obtained . The total capacity of machine depends upon many factors, such as:

a. Size.
b. Type of construction of car.
c. Thickness and kind of insulation used.
d. Amount of heat produced within the car by lights and motors.
e. Occupancy.
f. Infilteration etc.

Refrigeration load may be calculated in the similar manner as done in case of automobiles. It has been estimated that the refrigeration capacity of a normal carriage of about 7000 sq.ft. floor area with normal insulation and 70 persons seating is about 8 to 10 tons. In winter season with an average outside temperature of 30°F the heat required to be supplied is oftheorder of 8000 BTU's hour.

Comparison of road and laboratory tests show that heat gain of a Refrigerated Trailor was significantly greater during road operations than under stationery laboratory conditions for the same ambient temperature and humidity.This increase ranged from about 20 to 30 % for the three trailors at ambient conditions of 100°F and 50% R.H. Since these ambient conditions were not attained during road tests.This comparison is based on extrapolation of the observed data to the standard laboratory test conditions. The extrapolated heat gain values of the three trailors for these conditions ranged from 9,000 to 12,600 B.T.U's/hour for a road speed of 50 m.p.h.

The increase in heat gain on the road was due principally to air leakage into trailor construction under the impact pressure of the air against the front of the trailor. Additional small increases were caused by solar radiation and the movement of air heated by engine under the floor.

From these tests it is concluded that some percentage say 20 to 25 of the total load should be added to the load calculated in order to get the actual load for the air-conditioning system.

3.08 EQUIPMENT ARRANGEMENT

An arrangement of equipment in an air-conditioning system for subway cars of Hudson and Manhattan system developed by the Trane Company. The equipment arrangement for other types of system will be dealt subsequently.

Compression system:- The air-conditioning system for each car consists of a compressor, a condensor and two cooling coils. Both compressor and condensor are mounted underneath the car and the cooling units are installed overhead, one at each end of the car so that no space is taken from passanger area. Air from the cooling unit is directed towards the centre of the cars. Each cooling unit contains a coil which is split horizontally into two equal sections. Each coil section is provided with a thermostatic expansion valve and a solnoid liquid valve. Each cooling unit has electric heating unit which is also split into two equal sections.

In each car the solinoid valves of the two upper coils sections are electically connected. Each pair of solinoid valves is controlled by a relay which in turn activated by a two-step thermostate.

<u>Steam Ejector:-</u> The refrigerating unit of the steam ejector system which contains the condenser, fans, fan motor, condenser water spray evaporator and steam ejector is shown in fig. 14.

3.09 SYSTEM SELECTION

With regard to choice of a particular type of system various application requiremnts must be taken into account, considering the applicability to existing equipment the direct drive mechanical compression system would probably in most cases be found the easiest to apply, as the only space required under the car is that for the compressor-condenser unit plus a small control box with no additional electrical wiring except that for control and standby motor.

Where hold-over refrigeration is used additional piping and wiring are required as well as the space for the hold-over tank and pump.

Next in order of simplicity of application is the steam ejector system using the under frame refrigeration unit.

The direct drive mechanical system using the hold-over feature, mechanical system with compressor driven by electric motor and power obtained from movements of car and the water ice system are generally about on a par as regards ease of application. Factors effecting selection are:-

a. <u>Weight:-</u> From standpoint of weight the overall advantage is with the water ice system. The additional weight added per car will be from 3500 to 6000 depending on capacity of the ice bunker used. With the bunker fully loaded with ice the weight may be from 7000 to 11000 lbs.

The added weight of the direct drive mechanical system without the hold over arrangement will be approximately 6000 lbs. and with hold over about 7500 lbs.

The weight of the mechanical system with electric drive, including weight due to larger axle generators and storage batteries will be in the neighbourhood of 8000 lbs.

The steam ejector will run from 7000 to 9000 lbs depending on the type of installation.

b. <u>Reliability:-</u> From the stand point of reliability the inherent design of the ice system places it first. With the exception of thermostatic control which is practically common to all systems it has only two moving parts the circulating pump and blower fan which require only proper lubrication and the ordinary maintenance required by any small motor. About the only other source of potential trouble is the clogging up of the circulating pump or sprays by the refuse coming from the ice melled in the bunker. A properly designed stainer in the pump suction line regular and frequent cleaning of the stainer with a reasonable precaution against loading dirty ice will effectively remove trouble from this source.

The reliability of ice system is of course based on an ample and available source of ice.

The mechanical compression system is rather complicated and contains several potential sources of trouble. The drive either electrical or direct mechanical presents a problem and many of the troubles experienced with mechanical system originated at the drive.

Freon gas is difficult to hold and more or less trouble is experienced with refrigerant leaks in piping around expansion valves and at compressor shafts seals.

All of these features have been improved and a high degree of reliability can now be obtained with the mechanical system.

The reliability of steam ejector system is basically about on a par with water ice system.

c. Power requirements:- Power required for water ice system is about 30 ampere at 30 volts it has decided advantage.

For steam ejector power required is about 100 amperes at 30 volts plus a steam consumption of 200 to 250 lbs/car/ hour.

Power requirements for mechanical compression systems is about the same as for steam ejector later has the advantage that large power consumed taken in the form of steam is directly from the locamotive boiler. So it does not effect the handling capacity of locomotive.

The compressor system using electric drive with large storage battery for standby power will impose on average electrical load taking into consideration power required for compressor plus power for recharging standly storage battery of approximately 12 K.W.

All the three systems will give the same results as far as air conditioning within the car are concerned and the final choice generally depends on the adoptability to the work required in view of conditions on any particular run, plus cost of application and overall costs.

d. Operating limitations:- The ice system presents a considerable problem with respect to storing and handling of ice if a large number of cars are in volved and for long runs introduces the problem of re-icing enroute.

Mechanical compressor system using A.C./D.C. motors for standby power for precooling may in some cases not be advisable, owing to the high cost of equiping yards and teminals with the necessary power outlets.

Where extremely high outside air dry bulb tempera- ture are met with as on the desert runs in the western states the compression system is handicapped by excessive head pressures resulting from high condenser temperature.

The steam ejector system operates without such handicap as its condenser temperature is determined by the W.B.T. of the outside air which under desert conditions does not reach high values. In some cases the steam ejector system cannot be used owing to peculiar operating conditions involved, where electric locomotives are employed and city regulations which prohibit firing of the oil fired heating boiler on electric locomotives with certain limits. It can thus be seen that no set rule can be laid down as to which of the various systems is preferable but that all conditions must be carefully considered and the choice made with reference to the particular ones under which the equipment is to operate.

e. <u>Cost Question</u>:-

Method	Approximate cost per car	Remarks
(i) Ice System	£ 2000-4000	Depending on ice bunker installed capacity.
(ii) Compression system i. Electric Drive	£ 6000-9000	
	£ 8000-9000	
(iii) Steam ejector system.	£ 8000-9000	

It is difficult as yet to get reliable figures for the cost of operation and maintenance. The cost of operation of ice system will be the highest, while the cost of maintenance is the lowest. Operating costs for the ice system will very widely depending on the cost of ice and the length of run.

Generally speaking it would be fo'nd considering overall costs, depending on the cost of ice, the balancing point for ice verses mechanical compressor systems would be on runs of from 5 to 8 hours per day.

The cost of oper'tion ofthe steam ejector system is about on par with the operating cost of a mechanical compressor system. While the maintenance of steam ejector system will be less than the electromechanical and some what more than ice.

Mechanical refrigeration is preferred over others for the following reasons:-

(i) Cost of actual refrigeration.

(ii) Fever car overhauls:- The damaging and corrossive effects of salt and water ice are eliminated. The life of cars will probably be increased by 10 to 12 years.

(iii) Reduction of way damage:- Besides damage to the car itself, drip water from the salt and ice has destructive corrosive effects on metal on the right of way such as rails, switches, bridges etc. little imagination is needed to see that this is worth considering even though such surveys cannot be accurately estimated or compiled.

(iv) More useable revenue producing space:- The space used above the car frame for mechanical equipment and the additional space occupied by heavier insulation are less than that occupied by the two ice bunkers. The most recent mechanical cars provide approximately 20 % greater revenue load space.

(v) <u>Operating savings</u>:- When full trains of mechanical cars can be used, there will be no loss of time caused by switching cars to icing stations and icing them, thereby providing greater availability for the cars. It may even result in fewer cars needed to provide the required service.

(vi) <u>Better Insulation protection</u>:- Cars using compression system will not damage the insulation, while in case other systems, The insulation gets deteriorated because of wetting.

3.10 AIR DISTRIBUTION

Air distribution in a passanger car would seem to be a simple process, but when it is necessary to balance the distribution in a car to $1\frac{1}{2}^{o}$F temperature variation. It is not so simple. The fan delivers from 1400 to 2200 c.f.m. 25 % fresh air and 75% recirculated, chair cars, lounges and dinners use diffuser type units and the variation of opening, control the distribution. In cars having separate rooms the air vave type delivery is used and the hall way is used as a return passage with air exhausting through grills in the lower portion of the doors.

With the advent of high speed trains the problem of some what constant pressure within the cars has become a serious problem. Baffles or scoops are installed infront of the fresh air intake on the roof of some cars to get the air into the intake when this is done the pressure will increase slightly at high speed. On the Santa Fe Railroad 15 cars were tested with a load over the fresh air intake and a scoop which in reality is a flat with 5^{0} angle catering at the centre of the hood, forcing the air into the hood, tests have shown it to be satisfactory upto 80 m.p.h. If the pressure is not maintained within the car, the doors will not stay closed dirt will seep in around doors and windows are very annoying result. Water will flow back in the toilets when flushed.

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CHAPTER IV MARINE SHIP AIRCONDITIONING

4.01 HISTORY

Technical literature from 1830 to 1860 was full of proposals for marine air-conditioning. In those days hot air-engine of Ericson, Frachot and Lamoine was used as power source in air-conditioning installation, it showed poor performance due to high tonnage.

In the period from 1830 to 1933 the marine air-conditioning has passed through many installations such as Allen Dense air machine, clothel Methyle chloride equipment, convential compressor using carbon dioxide and Freons. Freon 12 refrigerant in conventional compression was used by U.S. Navy in 1933 but the speed remained limited to 600 r.p.m. In 1947 this restriction of 600 r.p.m. was removed.

Since 1947 there have been many developments in the use of materials for equipment and air-conditioning in marine ships has increased tremendously.

4.02 REQUIREMENTS

All types of air-conditioning equipment on marine installations must meet the following requirements:-

a. Maximum reliability.

b. Maximum accessibility for inspection,maintenance and repair.

c. Maximum operating and maintenance economy.

d. Maximum inter-changeability of componants and parts.

e. Satisfactory operation when permanently inclined at 15 Deg, or rolling upto 45 Deg to each side or when pitching 10 Deg.

f. Operating Time:- Marine plants run intermittantly depending upon type of ship and service, the working of summer air-conditioning plants vary from 1000 to 4000 hours. In short plants may run from 15 to 40% of the ships voyage.

g. Size:- The size of the equipment and its auxiliary units should be as small as possible. These units are located at such places which can be used for passangers hence revenue of the ship is effected by the size of the equipment

h. Weight:- Light and compact equipment should be used. There should be balance between cost and weight of equipment. The use of very costly and light weight equipment is not recommended. The weight effects the stability of ship and performance of propelling engine depending on location.

4.03 COOLING SYSTEM

Marine air-conditioning cooling systems are:-

a. Air Cycles:- These air cycles use air as its refrigerant and are described in article.

b. Mechanical Refrigeration:-

(i) Vapor Campression:- The conventional compression system uses Carbon dioxide, Ammonia or Freons as refrigerants depending on their properties and particular use.

(ii)Absorption system:- Lithium bromide absorption type plant is used in some navel vessels.

4.04 CHOICE OF SYSTEM

Each ton of dead weight in the ship requires a certain amount of power from propelling engine. This also effects the centre of gravity of the ship and the propelling energy due to its location. Therefore air cycle is prefered over the conventional compression system.

There are other factors, also to be considered,the type of the energy for running refrigerating unit,type of propelling machinery and the fuel used .

There is yet another consideration, that of safety for passangers and crew. Danger from Carbon dioxide,Ammonia Freons has been reduced considerably still they are poisonous explosive, and decompose over a flame. Keeping this in view air cycle is recommended particularly for accommodation air-conditioning.

There are secondary advantages of air cycle cooling.

(i) Its working pressure are very low.

(ii) There is no leakage problem.

(iii)Secondary refrigerants are not needed.

(iv) Equipment for air regrigeration can be manufactured from ordinary metal, while ammonia and Freon require special quality metals.

(v) Air units are serviced with parts normally stocked on board ship, on the other hand Freon and Ammonia devices require large quantities of special oils and refrigerants not ordinarily carried on ship.

When a plant is designed for very high efficiency, good degree of flexibility and lightness, some practical applications have shown that the best results may be obtained by using both air and condensing fluid refrigerating units. A high rate and short working time aircycle unit can be used to bring the conditions in the shortest time to a comfortable level, then a low rate long working time condensing unit plant can be used to maintain and control the temperature for the best conditions.

4.05 EQUIPMENT DESIGN SELECTION AND LOCATION :

Air conditioning plants are generally located on the top side and their weight and size are practically proportionate. Individual elements selection follows:-

Condensers:- Condensers when used with sea water require radical changes in design from those suitable for fresh water. The natural crrosive effect of sea water and the added erosive effect of the minute particles of entrained air require special materials and restrictions on water velocities. 70-30 copper nickle tubes and tube sheets seamless brass shells were used. The water velocity at inlet flange was limited to 6½ feet per second. Presently material used is

90-10 copper nickle. This affords a substantial saving in cost of material with improved heat transfer co-efficient Air-cooled condensers are limited to units under 2.H.P., they introduce additional ventilation capacity.

Compressors:- The materials and design of compressors vary slightly, from convential direct connected units, built for commercial use. Thus full advantage is taken of the experience of manufacturers in the development of compressors. It is also desirable from production point of view to be able to use compressors from manufacturers standard lines. To make the units suitable for marine service only minor details have been changed. High speed compressors generally 50 tons or under are used. In naval installation compressors are located in various compartments to minimize the effect of battle damage.

Cooling Coils:- Cooling coils are made from copper tubing, tinned on the outside. These are located on the bulk-head or side-walls of the compartment. While direct-expansion cooling coils have been used in thepast, future installations will generally favour distribution system employing chilled water. There will be some exceptions to this trend for example in an installation having small capacity direct-expansion coils will be preferred. The inside temperature for comfort conditions is about 72^{o}F and these coils require greater capacity for dehumidifications because of ambient conditions. Therefore selection will be based on these factors and capacity of refrigeration system.

4.05 CONTROLS

Fully automatic control is provided for air-conditioning plant,individual room control is maintained by one or more thermostates, controlling liquid solinoid valves in coil circuit. Thermostates are adjusted for a differatial of $\pm$ 3 F°.

In the compressor room automatic control feature consist of a high pressure cut-out, a low pressure cu-out, a water failure switch and magnetic starters for compressor and pump motors.

4.07 MAINTENANCE AND SERVICE

The proper maintenance of shipboard refrigerating and air-conditioning plants require certain basic parts to be carried on each vessel for emergency repairs, for replenishment of these parts, additional stocks of these must be maintained at numerous supply and repair bases, on board tenders and repair ships. To maintain such stocks involves not only problems of storage and transportation but serious production difficulties for the manufacturers.

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CHAPTER V AIRPLANE AIRCONDITIONING

5.01

The field of air-conditioning now covers the air-conditioning of commercial and military airplanes. The compressed ventilation air which is supplied during flight for cabin pressurization is cooled and dehumidified. To avoid the unbearable conditions the ventilation air supplied to the cockpit of high speed military fighters is also refrigerated. The cooling of cabin can be achieved by either of the following methods.

a. By portable refrigeration units.

b. By central cooling system which can be connected to the cabin by flexible ducts.

c. By the refrigeration unit installed in the plane.

5.02 HISTORY

The first transport aircraft was air-conditioned in 1939, with recirculation fan and heated cabin wall panels. The poineer in this field were the Lock-Heed constellation. As a result of war time development programs, it was found that with a small expenditure of weight and space, an air cycle refrigeration can be used. Vapor compression system was used, in the original design.

5.03 NECESSITY

There has been a common misconception even among the engineers that there is no need of refrigeration in air-conditioning of air-planes. This is approximately true in case of unpressurized air planes by flying them at high attitudes and avoiding excessive ambient temperatures, but is not at all true in case of pressurised planes. During hot summer days at a attitude of 7000 feet the ambient temperature is 75°F, but this does not in any way mean that the cabin can be maintained at 75°F, without removal of heat due to following reasons:-

a. There are internal sources of heat namely occupants, solar radiation through transparent surfaces and electrical devices etc.

b. The difference between static and total temperature. There is a rise in temperature due to stoping (relative to air plane). This factor amounts 2°F in airplanes having climb speed between 110 to 120 m.p.h. In the high climb speeds of present day air-planes this may be between 5 to 6°F while in level flight it can increase to 15 to 20° F. This effect is present in both the air i.e. stopped and in the boundary layer, which envelops the entire external surface. Hence at 7000 feet on a summer day the cabin temperature would range between 80 to 95°F, where the cabin temperature is higher than the ambient, insultation of fuselage wall will be disadvantageous.

c. Another important factor to be considered is the time elapsed between terminal point of take off and the corresponding ground maneovering time after landing. This

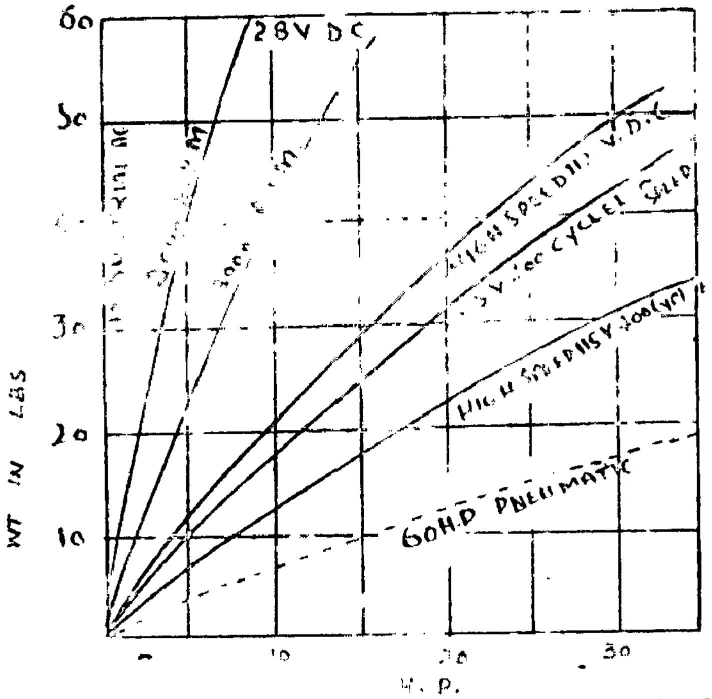


FIG.15 WT COMPARISON OF A.C.& D.C. ELECTRICAL MOTORS

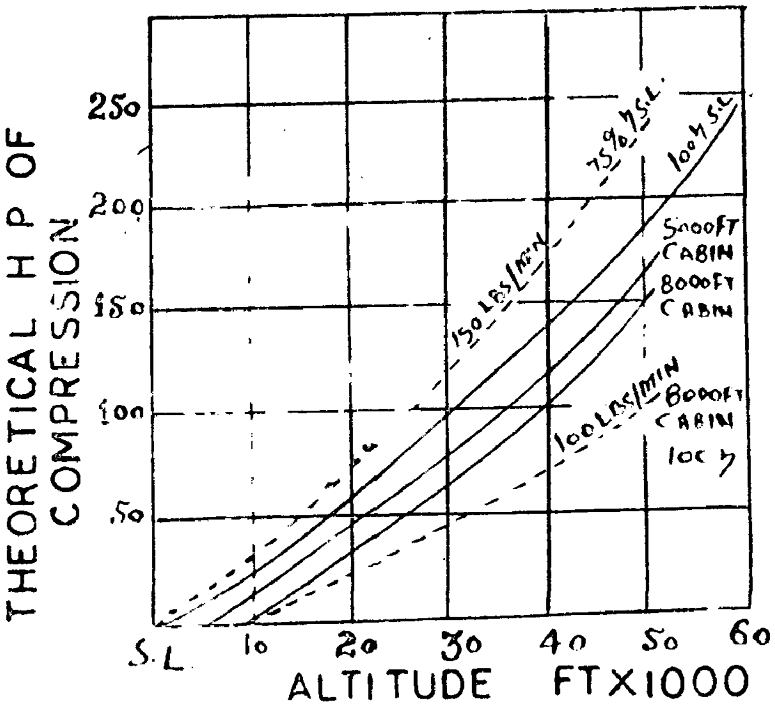


FIG.16 H.P. REQUIRED TO PRESSURISE THE CABIN OF A 100 SEATER AIRCRAFT

time varies from 5 to 30 minutes. In planes in which pressurization begins at take-off all the above factors apply, the other consideration to be included in this case is supercharging of cabin. Its effect is based on two factors.

(i) Air enters the cabin at somewhat higher temperature than ambient, even if high effective after-coolers are used.

(ii) Elimination of large ventilation flow rates.

5.04 GENERAL REQUIREMENTS

An air conditioning system is required to ensure that all aircraft equipment and componants are maintained at the most favourable and correct conditions. It is also to ensure that they operate efficiently. The general requirements of an air-conditioning system include.

a. Weight saving:- This is an important requirement. Light weight equipment should be used so as to carry the minimum possible weight on the aircraft. Some designers are clinging to the 28 Volt D.C. electrical system, instead of changing over to 400 cycle A.C. One of the advantages of A.C. system is that it is free from commutation troubles. The performance and weight comparison of A.C. and D.C. motors are shown in figure 15. The curves show the changes of weight of different types of electric motors. Reviewing the overall situation D.C. system installation is 30% heavier than A.C. system. It is worth mentioning that the electric starter weights achieved in the figure and D.C. motors, as owing to the characteristics of squirel cage motors, no saving can be made with A.C. types.

The ability to tap the engine compressor for cabin pressurization and pnuematic driven auxiliaries obviously represents a major step forward in weight reduction as shown in figure 15.

b. Safety considerations:- In modern high altitude flight safety is one of the major requirements. The question is that how many safeguards should be there, in a pressure cabin system. Camet has two sets of series discharge valves and then these are paralleled by a safety valve as a final safeguard. It is obvious that such a system would be heavier and complicated than it would seem at first necessary but is required to ensure maximum safety. Priority should be given to ensure safety than to reduce weight.

Americans say that emergency oxygen should be there when the aircraft is flying at 45000 ft. they do not rely on the pressurization system.

Russians have installed oxygen in their latest aircrafts for passangers only sufficient to cover the short time from high altitudes to 10,000 feet on the assumption that they will still have a sufficient fuel to reach an emergency airport at resulting reduced range of the aircraft.

Britishers say that cabin design pressure should allow 10 % air leakage over the required supply for the aircraft.

c. <u>Passanger comfort</u>:- In the present day aeroplanes due to rising competition passangers will take the plane providing maximum comforts so this requirement has great influence on the revenue, therefore attention must be paid in this direction. In the field of aircraft conditioning passanger comfort arises in many ways of which, two are worth mentioning.

(i) It is desirable to recirculate the cabin air because recirculation ensures saving in power, but it may make the air stuffy. In total air requirement of 2 lbs/person/min., should the air be 100 % outside or 50% . It is recommended that minimum quantity of outside air for cabin pressurization should be used. The recirculated air should be adequately purified. It can be stated that the air tapped from an engine is equivalent to a loss of power of 2 H.P. Such a statement is a vague one, depending on ones own basis of comparison.

(ii) Prior to take off while the aircraft is loading or taxing the cabin conditions are unbearable. The vapor cycle cooling is added to the aircraft. It reduces the humidity within the aircraft and is more efficient than ground cooling truck. It provides the cooling required while standing, taking off and during flight where necessary.

d. Power and air supply:- Horse power required for pressurization of 100 seator aircraft is shown in figure 16. The indication is that in case heavy engine driven cabin compressors must be used then it must be ensured that actual H.P. required is used. Horse power absorbed during take-off can be reduced by two speed gear box as shown in figure 17. The early comet aircraft was designed with three stage compressor which required 250 H.P. at sea level. The design involved problems namely free-wheel variable speed,hydraulic coupling with problems of heat transfer.

It is generally considered that where engine bleed is available this gives a much simpler cabin pressurization source, eliminating maintenance troubles. It is well worth, in the face of small increase in fuel consumption by the engine. Now that hydromechanical and air turbine devices are available it is accepted that all future aircrafts will change over to A.C. drive. Power for compressors in mechanical refrigeration system is supplied from engine generators and for air cycles it is taken from air turbines.

5.05 COOLING METHODS

There are two main cooling systems available namely air cooling cycles using air as refrigerant and vapor compression system in which some other refrigerant other than air is used.

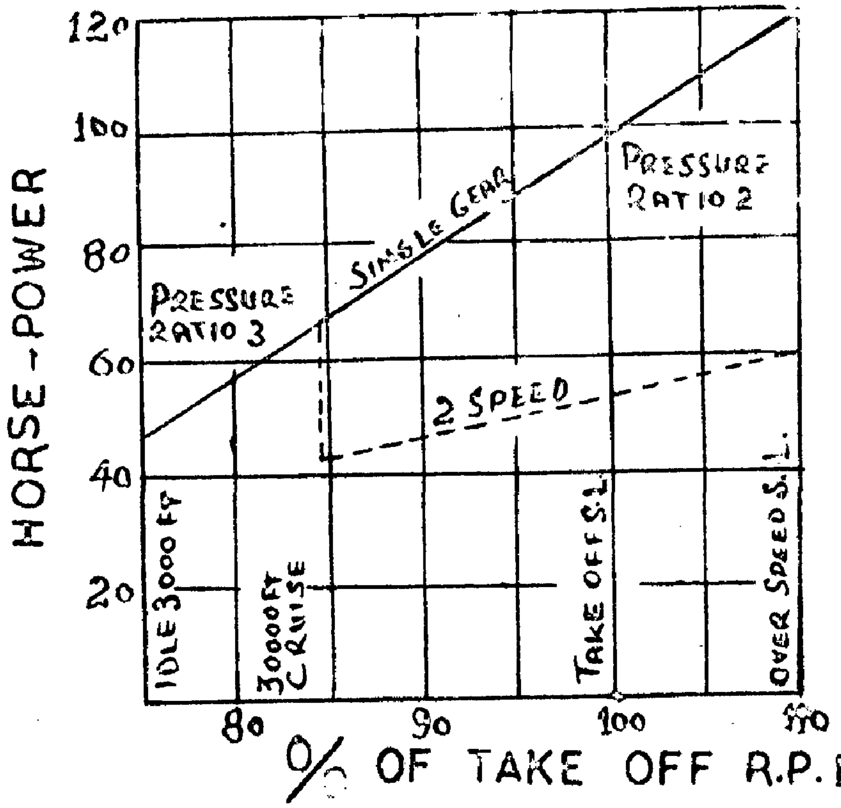


FIG. 17 H.P. REQUIREMENTS FOR ENGINE DRIVEN SUPERCHARGERS.

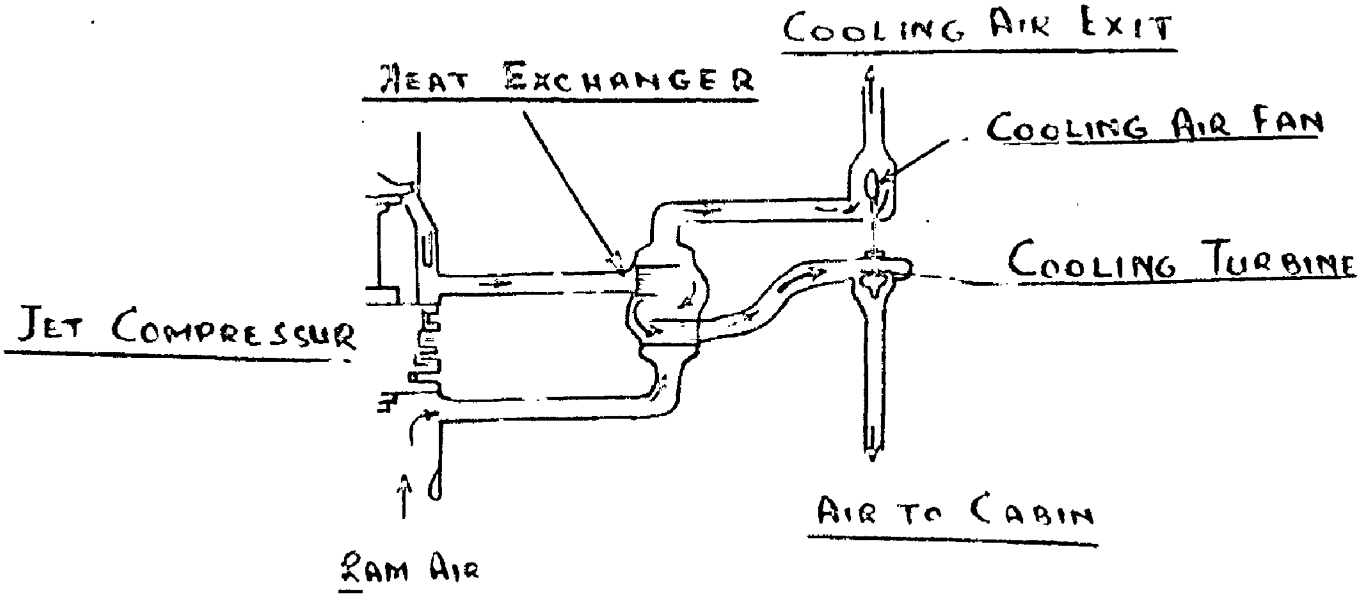


FIG.18 SIMPLE AIR CYCLE COOLING SYSTEM

a. Air cooling cycle systems:- There exist six cycles of t is type given as under:-

(i) Simple air cooling cycle:- Air is bled from a compression source in this case compression source is a jet engine. To remove majority of heat of compression the bled air is passed through a intercooler. Then the air is expanded in an air turbine for extraction of result energy from the air, since turbine at reduced temperature is available for coöling . The air for removal of heat of compressor is drawn from outside by means of a fan,which is driven by power supplied from cooling turbine. The cycle is shown in figure 18.

The capacity depends on the available ratio of inlet to out-let pressure of cooling turbine . In commercial applications this ratio is limited and scope of this type of cooling is limited but in military application because of increase of jet engine performance the capacity is quite adequate.

(ii) Boot-strap cycle:- Figure 19 shows a Boot-strap air cycle. This is a modification of simple air cycle. The air from the engine driven blowers is further compressed by a compressor to raise the pressure. This compressor drive receives its power from the turbine. The compressed air is then passed thro gh an intercooler, this intercooler eliminates the heat gain during second stage of compression. Then the air is passed through the cooling turbine. Because of second stage compression a sufficient high pressure ratio across the

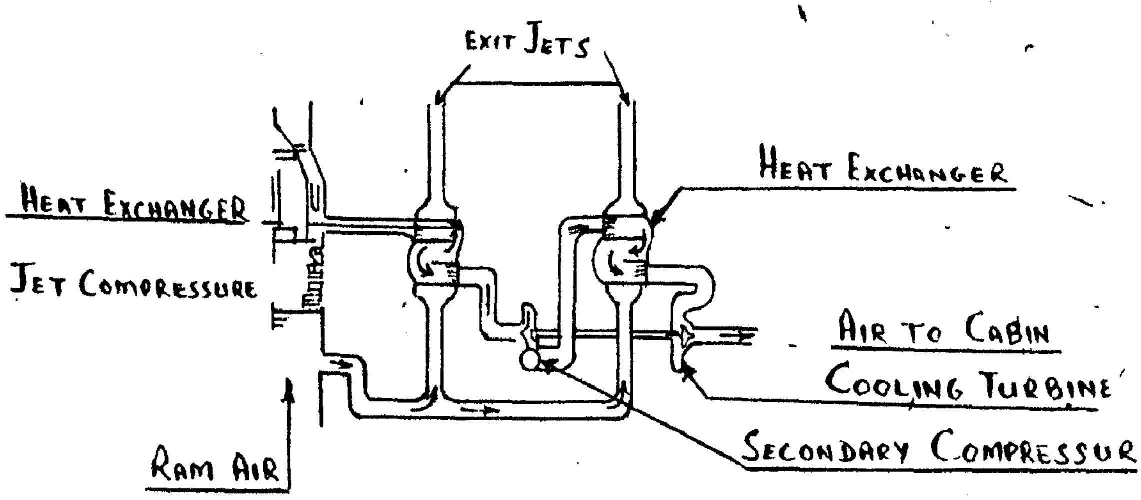


FIG 19. BOOTSTRAP COOLING CYCLE

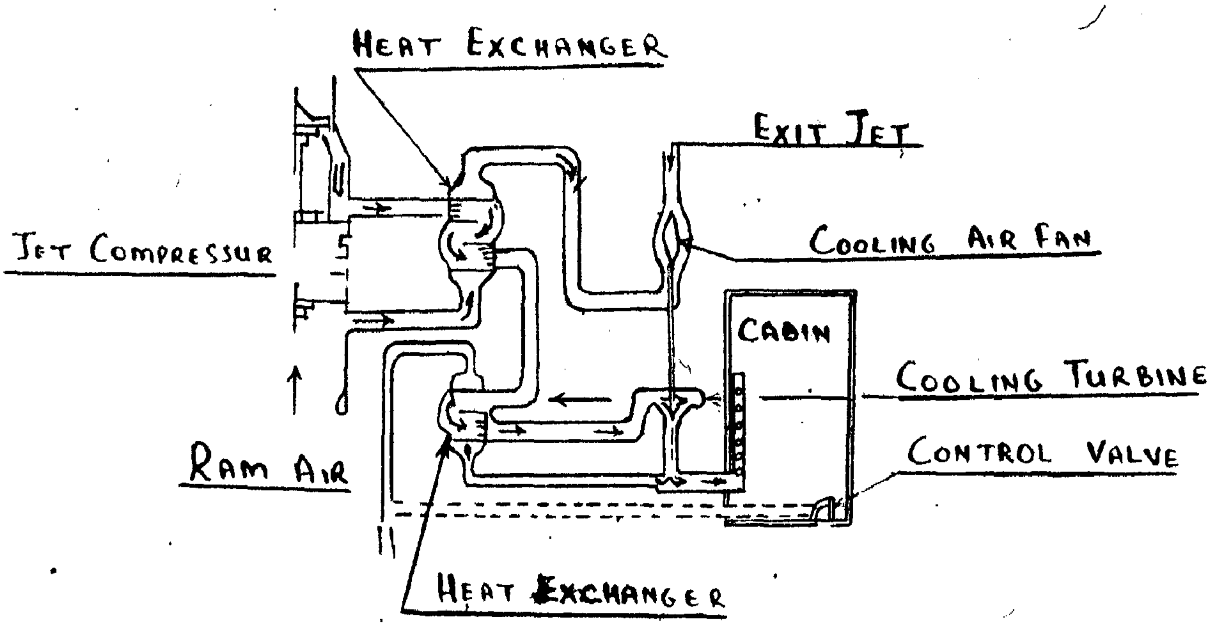


FIG.20 REGENERATIVE COOLING SYSTEM

cooling turbine is achieved giving a much greater temperature drop across the turbine. The refrigeration is brought about fundamentally by the work done by the turbine in driving the compressor.

A precooler is of course used between the engine driven blower and compressor. Both the precooler and inter-cooler are cooled by the ram air. The disadvantage of ram cooling of heat exchangers is that very little cooling can be obtained when the air-craft is stationary. There is a limit to the amount of cooling that can be applied by such a system due to:-

(i) Frosting of the air outlet ducts, if turbine outlet temperature is taken to the freezing point.

(ii) Problems of water separation.

(iii) The minimum pressure ratio consistent with cabin pressurization and cooling needs should be used if the engine drive compressor horse power is not to become excessive.

(iii) <u>Regenerative cycle:</u>- In regenerative cycle system cabin air is bled from the engine compressor and passes through an air to air heat exchanger then through the turbine of the cold air unit and finally into the cabin. The discharge air from cabin is not thrown overboard, but is passed through the heat exchanger and is finally discharged through a nozzle to obtain the maximum use of the energy left. Figure 20

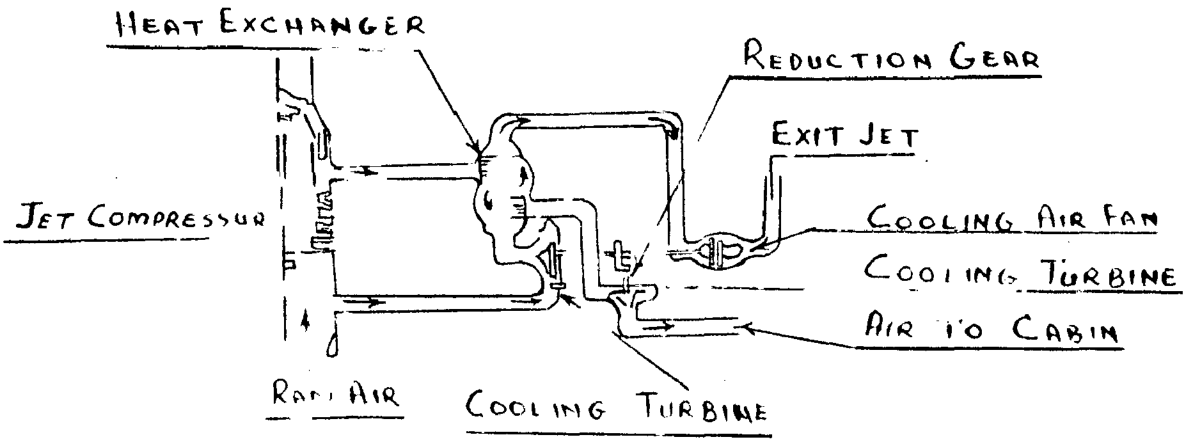


FIG 21. REDUCED AMBIENT COOLING SYSTEM

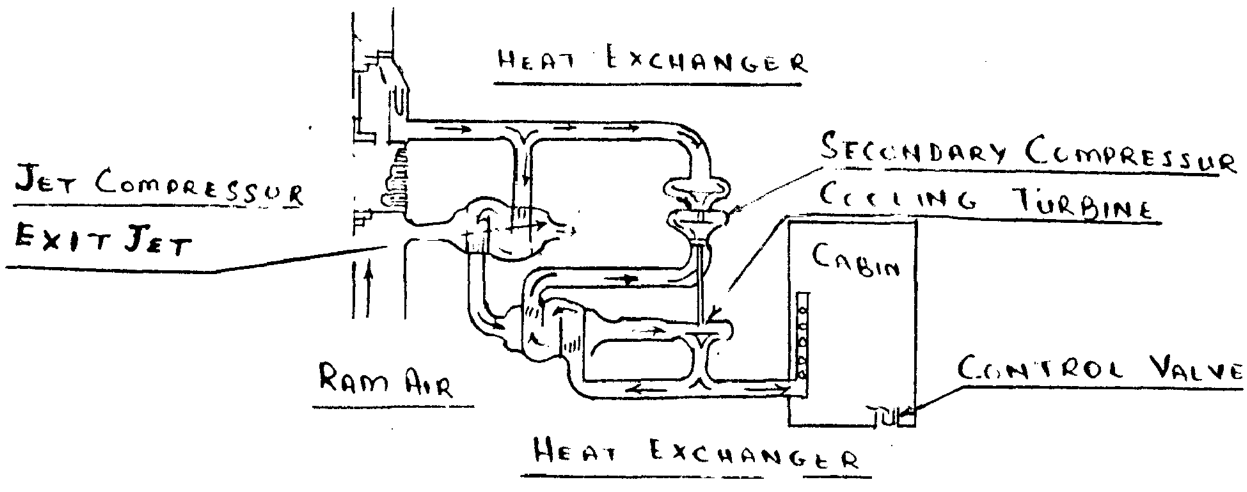


FIG 22. SHOESTRING COOLING SYSTEM

shows the layout of this system, for a given temperature and pressure of the air bled from engine all available energy is extracted from the air before it is finally thrown overboard, and also ram heat exchanger losses are eliminated. This system is particularly applicable to small military aircrafts.

(iv) Reduced ambient system:- It employes two expansion turbines one in the cabin air stream and one in the cooling air. The turbine in cooling air side is located, up-stream of the heat exchanger and operates from the pressure ratio made available by the ram air pressure, on the inlet side and suction of the fan located down stream of the heat exchanger. Both turbines are connected to the shaft driving the fan therefore the fan must absorb the power generated by two turbines, turbine in cooling air passage permits cooling of the bleed air to temperature below effective ambient temperature and thus a much lower final temperature from the cabin air turbine discharge. This system fig.21 shows most promise for application involving exceptionally high speed air-craft, where ram air temperature is too high to accomplish the necessary cooling in the exchanger, in order to achieve final temperature from the cabin air turbine.

(v) Shoe string system:- This system is similar in certain respect to both the regenerative and Boot-strap systems. A portion of the cooled air from the turbine is utilized as cooling air for a secondary heat exchanger,instead of being spilled over board, as the case of the true regenra-tive, it is recompressed by a compressor driven by the turbine and fed back into the engine air bleed system. This cycle is shown in fig.22.

(vi) <u>Simple evaporative cooling system:</u>- Cooling by evaporation involves an evaporator following the heat exchanger in a simple air cycle system. This has theoretical advantage for supersonic airplanes.

5.06 CHOICE OF COOLING SYSTEM

The following factors must be kept in view, while selecting the cooling system for an aircraft application.

a. The weight of the equipment should be as light as possible.

b. The size of the equipment for the system should be small and compact in nature.

c. Refrigeration equipment should be of such a nature that it can be quickly removed, as a unit in winter season, so that during winter operations a negligible weight penality will be charged to the system. This also permits easy excess to the equipment for maintenance and service.

d. Minimum cabin dry bulb is to be kept 60^{o}F and R.H. 50% .

e. Refrigeration system should be capable of delivering the required capacity in flight or on the ground as long as both out board engine are operating at 1200 r.p.m.

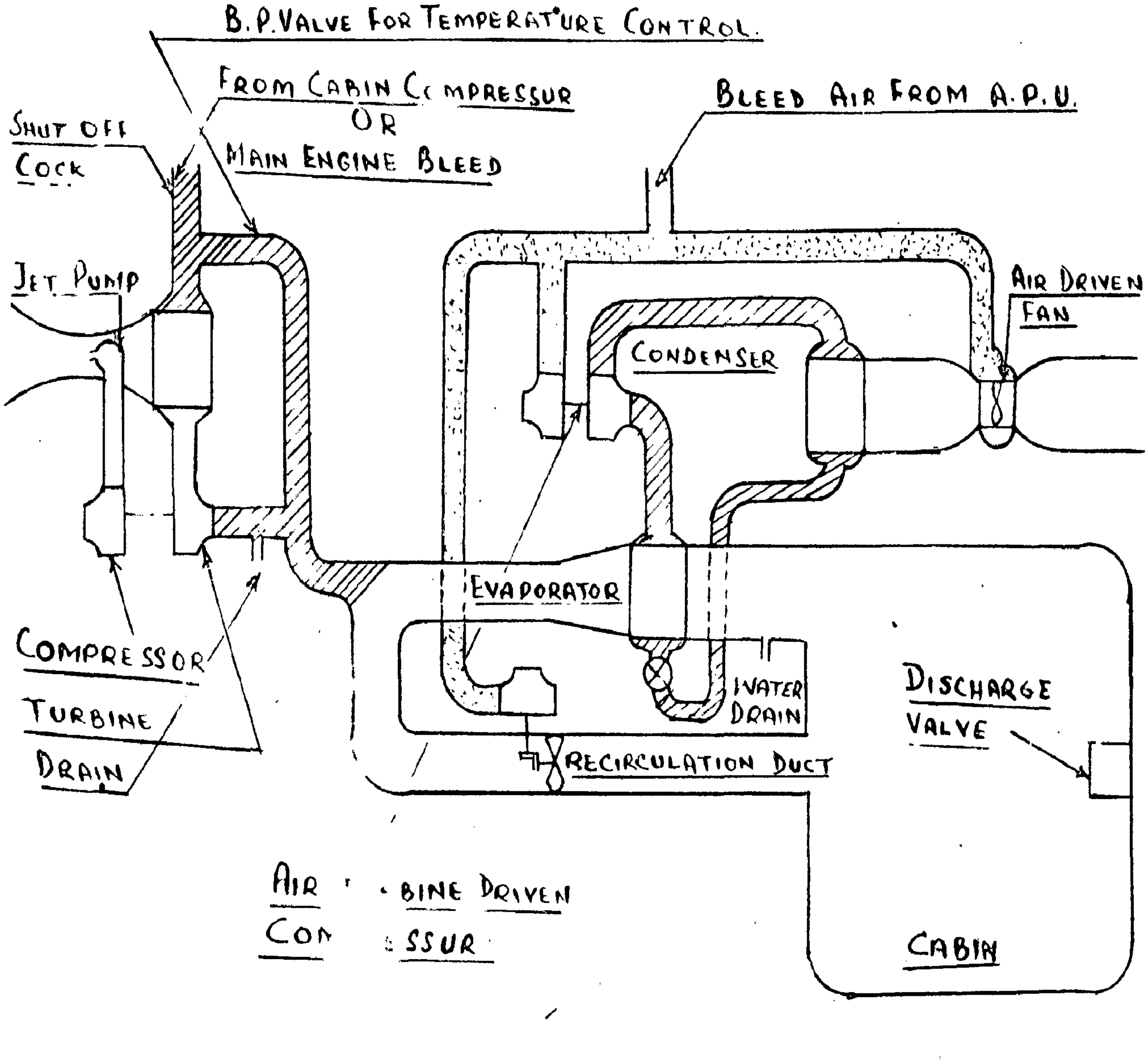


FIG 23 VAPOUR CYCLE COOLING SYSTEM

i.e. it should be adequate for all altitudes from sea level to the crusing altitude of aircraft.

Following points are in favor of air cycle system:-

(i) It uses air as a refrigerant hence saving in cost compared to vapor cycle.

(ii) Air cycle systems can be used as a cooling system alone or as a pressureization system. It can also be used for both cooling as well as presurization of cabin,while vapor cycle can be used only as a cooling cycle.

(iii) Air cycle systems have definite weight and size advantage over vapor cycle.

(iv) Refrigerant leakage is also infavour of air cycle.

In the light of above facts when a fully developed air cycle system is in existance why to use a vapor cycle layout shown in fig.23 for the air conditioning of air crafts is answered in the following points:-

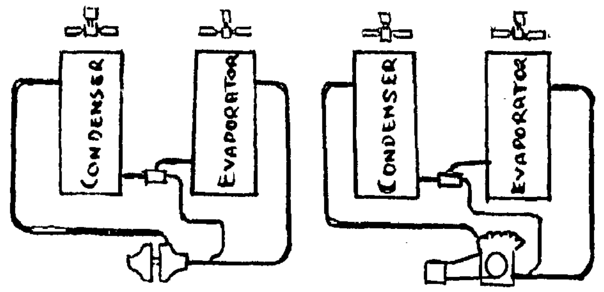
(i) It has been established that power required in vapor refrigeration system is less than required for the corresponding air cycle system. The power is drived from the aircraft's power plant thus the power required for refrigeration system effects the performance of aeroplanes.

Air research manufacturing to report AAc 1709-R Engineering analysis-Air conditioning system Jet transport air craft states that approximately 1000 lbs. of fuel would be required to provide the necessary power for an air cycle refrigeration system for a 6 hour flight of Jet transport. The power requirement of the air cycle systems is three or more times than that required for vapor cycle system, a substantial saving results in the cost of fuel or more important the pay load of air-plane is increased.

(ii) Another disadvantage of air cycle cooling system is that it cannot normally produce the required cooling when the aeroplane is parked, with engines off on the loading ramp. In Bootstrap system if fans are installed for heat exchangers then the air cycle equipment loses much of its weight advantage.

(iii) There is yet another problem of humidity, in air cycle cooling systems. On a humid day the air contains 120-130 grains/lb dry air. The design expansion ratio of the air turbine must be limited so that frost does not develop and clog the turbine under these humid conditions. If this is done, then most of the cooling effect produced goes for condensing the moisture out of the air turbine. Exhaust moisture separtors are required to eleminate the condensed moisture, the use of separators depreciates, the weight and simplicity advantages inherent to air cooling cycle.

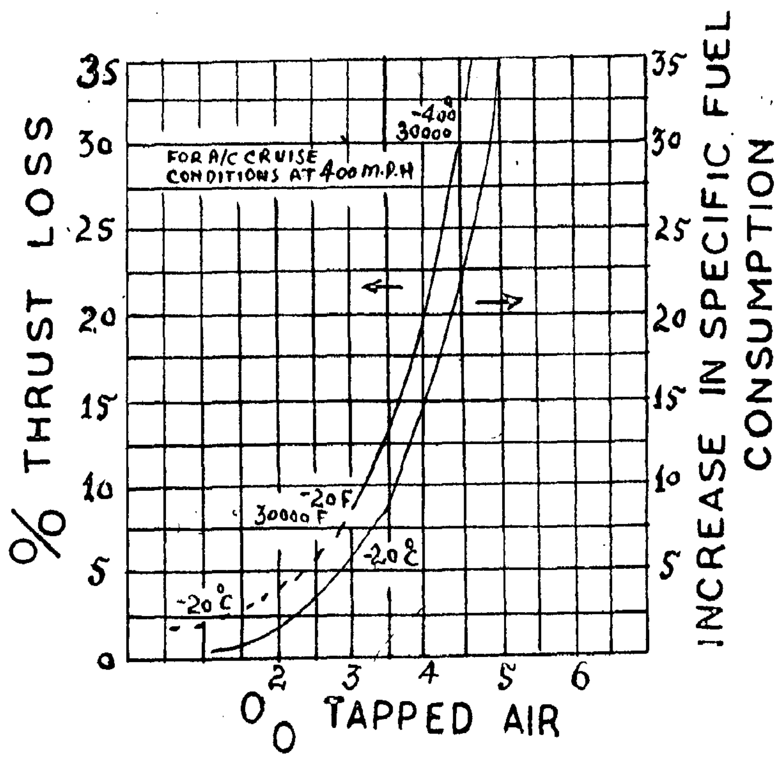
Hence it is concluded that vapor compression cycle is preferable to air cycle cooling systems. The recent weight reductions obtained in both centrifugal and reciprocating compressor systems have made the use of vapor cycle



12 TON CENTRIFUGAL SYSTEM, WEIGHT 150 LBS.

6 TON RECIPROCATING SYSTEM, WEIGHT 240 LBS.

FIG.24 WEIGHT COMPARISON OF VAPOUR CYCLE SYSTEM



ASSESSED % BLEED FOR ENGINE ANTICING
S L 30000 FT 500 MPH LETDOWN CASE

FIG 25 LOSS OF THRUST DUE TO BLEEDING AIR FROM COMPRESSOR system much more attractive. The weight comparison of two types is shown in figure 24.

The ground power requirements for such systems however severely strain the existing equipment. Hence it is possible to consider the use of auxiliary power units(A.P.U.).

Fig.25 shows the loss of thrust due to bleeding air from compressor.When bleed air is available it is possible with an air born A.P.U. to replace the heavy electrical starting by low pressure (45 P.S.I.) air turbine starting. The weight reduction is sufficient to cover the installed weight of A.P.U. therefore.

(i)Provides the bleed air for engine starting.

(ii)Provides bleed air for driving the vapor cycle compressor.

(iii)It can drive any emergency equipment required.

(iv) It makes the unit independent of ground starting trucks.

(v) It provides emergency power at high altitudes though not normally used above 10,000 feet this being decided by the cooling requirements.

<u>Weight comparison for 100 seator air-craft.</u>

System details	Jet engine with bleed	Jet engine with no bleed. 28 V.D.C. Electric.
(i)Cabin pressure system	50	50
(ii)Heat exchangers	100 Primary	200 Primary & secondary

(iii)	Air cycle refrigeration	40 Turbojet	45 Boot strap.
(iv)	Vapor cycle system	149 Turbine air driven	240 Reciprocating.
(v)	Engine starting	104 air Turbine bleed.	28 volt D.C. Motor
(vi)	A.P.U. GTCP-85 40 K.V.A.	215 & 80 alternator	Nil 140 D.C. generator.
(vii)	Installations	125	Nil
(viii)	Engine driven compressors	Nil	200(2Nos.)
	Total weight in lbs.	863	1275
(ix)	Cooling tonnage	Air cycle 18	18
		Vapor cycle 12	6
(x)	Ground cooling	self contained	from ground truck

The above analysis will favour jet engine bleed case.

5.07 DESIGN CONSIDERATIONS

Air travel is a superior means of travel,the air-conditioning equipment must therefore produce conditions in commercial passanger planes under all conditions better or at least comparable to other compititive forms of travel. In designing and selection of equipment consideration should be given for making the equipment light and compact. The other conditions which must be provided and maintained by the equipment are as under:-

a. Temperature:- The temperature coditions to be provided and maintained at various places and instruments of the airplane are:-

(i) Cabin temperature is variable from 60 to 80^{o}F, but should not vary once set by more than 2½^{o}F normally this temperature is kept 73 to 75^{o}F.

(ii) Maximum cabin in-let temperature should be 212 F.

(iii) In an ambient of -65^{o} F the passangers and crew temperature should not be below 60^{o}F. This can be maintained by the use of combustion heaters.

(iv) The cold air discharge temperature shall be controlled to prevent frosting of ducting or freezing of water separators.

(v) The air instruments are to be kept at 40^{o}F.

(vi) Battries to be kept between 40 to 110^{o}F.

(vii) Temperature variation both longitudially and vertically should not exceed 5^{o}F.

b. Humidity:- The relative humidity to be maintained is about 50% and there should be some means to add moisture under high altitude conditions and to remove the moisture under high humidity low altitudes to prevent fogging.

c. Pressure requirements:- Government reg lations limit the rate of change of cabin pressures, which can be imposed upon the passangers. Reduction of cabin pressure with increase in altitude is held to a minimum by compression of ventilating air. The structural design of plane limits the pressurization to 5 or 6 per sq.inch internal pressure above the pressure surrounding the cabin. This pressurization permits maintaining sea level pressure at 12000 ft. The control of cabin pressure should be automatic and should require minimum attention of crew. The outlets are to be located and designed in such a way that no water enters the cabin in the event of air-craft ditching in the sea.

d. Air flow and ventilation requirements:- The various requirements in this context are as under:-

(i) A normal fresh air flow of 1 lb/minute/passanger is required in cabins which provide 40 to 60 cft per person.

(ii) For adequate temperature distribution additional, 1lb/minute/person recirculated air is required.

(iii) The ventilation rate required for minimum oxygen supplied to passangers in a reduced air pressure cabin is estimated at 5 cfm at 5000 feet to 7 cfm at 8000 feet, but in a unpressurized cabin with no cooling the rate is 3 lbs/minute/person.

(iv) Air motion of about 15 to 25 feet per minute is desirable over the passangers.

Approximately 10 tons of refrigeration capacity is required for proper air conditioning of sixty passanger pressurized cabin of commercial plane during summer flight. The refrigeration capacity needed for proper air conditioning of several types of commercial planes in current use under optimum summer conditions, while grounded at the air ports with full passanger load and exposed to direct sun light is considered to be as under without any allowance for ground cooling.

Plane	No. of passangers	Refrigeration needed.
Stratocriuser	60-75	17
Consellation	43-60	12
DC-6	55-58	12
Covair	40	10
Martin 202	36	10
DC-4	34-50	10
DC-3	21	8

e. <u>Ground cooling:</u>- Ground cooling of an air craft should be available without starting the main engine. This is provided by two means either by a central system supplying cold or hot air to the plane through underground insulated ducts or by a portable truck mounted units using gasoline engine direct expansion freon systems. The portable units are connected with the air craft duct work through flexible ducts. The capacity is about 20 tons. In ground cooling the reduction of the cabin temperature to a desired level should be possible in 30 minutes from that prevailing under maximum outside ambient conditions before loading passangers.

2.08 LOAD CALCULATIONS

a. Cooling Load:- The cooling loads of aircraft structures are calculated in the same way as in the case of ground applications, except for several basic points, these exception points are as under:-

(i) There is no shade on the aircraft which sometimes is present in stationary objects. This results in a constant solar input of about 430 B.T.U's /hr/sq.ft. at about 50,000 ft.

(ii) It is essential to consider the problem of transients, in the heat transmission calculations because of wide variation of outside temperature due to change of velocity of the aircraft.

(iii) The whole of the structure is made of metal frames and skin, it becomes necessary to consider the fin effect.

(iv) The external film co-efficients are much higher and range between 30 to 50 BTUS/Br/Ft^2/F^0. These of-course vary with altitudes.

(v) The personal loads are also included and these are usually computed on the basis of tables available in ASHRAE guide with allowance being made for increased activity level of crew personal.

In addition to above loads we have to take into account other loads as well namely pull-down and defrosting. The transparent areas get iced or frosted when they come down from high to low altitudes in an extremely short time, because in doing so they come in contact from low temperature to high humidity area. The use of thermal means for reducing this frosting perduces a large heat load on cooling system. The pull down load is due to the fact that aircraft is parked frequently in sun. The entire structure of the aircraft reaches a elevated temperature due to solar heat gain. So to remove the stored heat in a reasonable time affects the capacity of the cooling system.

Sample calculations for 100 seator aircraft:-

Jet engine aircraft 200,0000 lbs A.U.W.

530 M.P.H. T.A.S. at altitude 35,000 ft.

Cabin length 110 feet diameter 11 feet.

Passangers 100 crew 6.

Cabin volume 8,800 cubic feet.

External cabin surface area 3163 sq. feet.

Extra cargo space surface area 632 sq.feet.

Rear bulk head 95 sq.feet.

Windows cockpit 20 sq. feet

Forty passanger windows 40 sq.feet.

Skin conductivities BTU's/hr/sq.ft./F^{o}

(i) Cabin wall 0.2

(ii) Cargo skin 0.4

(iii) Rear bulkhead 0.4

(iv) passanger window 0.47

(v) Cockpit window 1.2

Heat transfer for a temperature difference of $10^{o}F$.

Cabin skin	=	3163x0.2x10	=	6326
Cargo skin	=	632x0.4x10	=	2528
Rear Bulkhead	=	95x0.4x10	=	380
Cockpit windows	=	20x1.2x10	=	240
Cabin windows	=	40x0.47x10	=	188
Total			=	9692 or 10,000 BTU's

In addition to this cooling load is due to solar radiation through windows. At very high altitudes the solar radiation is approximately 500 BTU's/hr/sq. ft., at sea level this is about 335 BTU's/hr/sq.ft., due to atmosphere absroption of about 29% . The maximum window area facing sun at any instant would be about 25 sq. feet giving a possible load of 9000 BTU's /hr on ground and 12000 BTU's/hr at crusing flight.

Another load to be considered is the effect of solar radiation on the cabin surface temperature. This can be eliminated altogether by use of special paints. In an ambient temperature of $100^{o}F$ the surface temperature reaches $180^{o}F$ with a dull black surface in regions normal to suns rays.

Certain white paints reflect about 80% of the suns rays with a emissinity factor of 0.9. Thus for a light painted fuselage air-craft it is best to ignore the effect of solar radiation on the surface temperature.

The heat given up by passangers can be taken as 400 BTU's/hour. When standing on ground without the engines running the cabin requires cooling because some air for ventilation must be fed to cabin but it should be kept to a minimum.

It is to be kept in mind that when the passangers are entering an aircraft the effective temperature should not be more than 10°F below that of ambient air to avoid shock. Once they are on board the cooling system should be capable of pulling down, the temperature to a more comfortable level.

Hence the cooling load for steady conditions would be:-

(i) Heat transfer through skin windows and bulk head (½ an hour cooling time)	20000 BTU'S/hr.
(ii) Solar radiation through windows and canopy	9000"
(iii) Passanger heat load	42400"
Total load	71,400 BTU'S/hour

Tons of refrigerations = 71400/1200 = 5.95 tons.

To allow for cooling-down rate, for the aircraft the capacity of refrigeration system should not be less than 10-12 tons.

b. Heating Load:- For heating load the worst condition is the dull weather with a temperature of-85^{0}F ambient at high altitudes. The crusing speed of aircraft corresponds to a kinematic temperature rise of 50^{0}F. If an apparant rise in the ambient is considered as 43^{0}F, it brings the ambient temperature to-42^{0}F. For a cabin temperature of +65^{0}F the temperature difference would be 107^{0}F requiring heating load of 103,600 BTU'S/hour for no passangers, or 63,600 BTU's/hour for full passanger load, with this aircraft the pressure ratio of cabin compressors would not be less than 3.5:1. At normal efficiency of 0.7 this would give a delivery temperature of 227^{0}F. If completely uncooled then 100 pounds air per minute, at this temperature would give a heat input of 23,4000 BTU's/hour to the cabin, more than double the required amount under the coldest possible crusing conditions. Thus under even the coldest crusing flight conditions, the cabin air supply must be partially cooled, by the air turbines and the ram air heat-exchangers. They are never completely by-passed.

Aircraft heating:- On older, non-pressurized planes, the heating system consisted either of a steam boiler and radiator or a single stage or double stage heat-exchanger. Cabin temperature was maintained with the help of face and by-pass dampers.

In the modern aeroplanes the heating system consists of two combustion heaters, each having 100,000 BTU's/hr.

capacity. These heaters keep a plenum chamber at a constant temperature. Air from plenum chamber is then mixed with outside air to maintain desired cabin temperature. All of the warm air is then discharged into the cabin through walls,and by way of outlets located on the floor under the passanger seats. A modulating type controller varies proportions of heated and outside air necessary to maintain desired cabin temperature.

An auxiliary duct running from the plenum chamber is used by the pilot as a source of wind-shield defrosting air.

2.09 CONTROLS

Automatic controls are provided for the following items:-

a. Humidity:- Its a well known fact that a room can be comfortable on separate days with the same dry bulb temperature. This is due to variation of wet bulb temperature, surrounding air velocity and clothing worn by people. The high altitude flight has necessitated the need of addition of moisture to passanger aircraft, air conditioning systems. At 40,000 feet the relative humidity is 1 to 2%,which causes irritation of eyes,nose and throat. 30 gallons of water may be used in 8 hour flight to raise the humidity to 30 % . Venture humidifiers due to their light weight and simplicity as compared with electrically operatored or similar configurations are used. They are advantageous to jet orifices because orifices are prone to blokage troubles . It also B dispenses with the water pumps driven by electricity. The only electricially driven element is solinoid controlled, shutt off valve. The latter can be controlled, by manual switching or automatically by a manual switch. The problem of water removal is divided into two types:-

(i) Wind screen heating and wing anticing;

(ii)Humidity control at ground condition.

(i) Wind screen heating and deicing:- When the external temperature of the aircraft is very low, the passage through high humidity conditions will cause large scale formation of frost, on the aircraft surface. There are two ways to prevent this namely hot air and electrical system.

Warm Air:- The wind screen is made as thin as possible and sand-witch method is used. The external surface being heated by the inner surface. In some cases the cabin air flow is tapped to provide the wind screen heating. The temperature of hot air is to be controlled within limits, because of its effect on strength of the screen. The heat required is about 3000 BTU'S/hour and flow of air about 3 lbs. per sq. foot of wind screen area per minute.

Wing anticing:- The icing of the wing can also be prevented by use of warm air which can be taken from compressor or by tapping the interstage turbine. The maximum temperature of

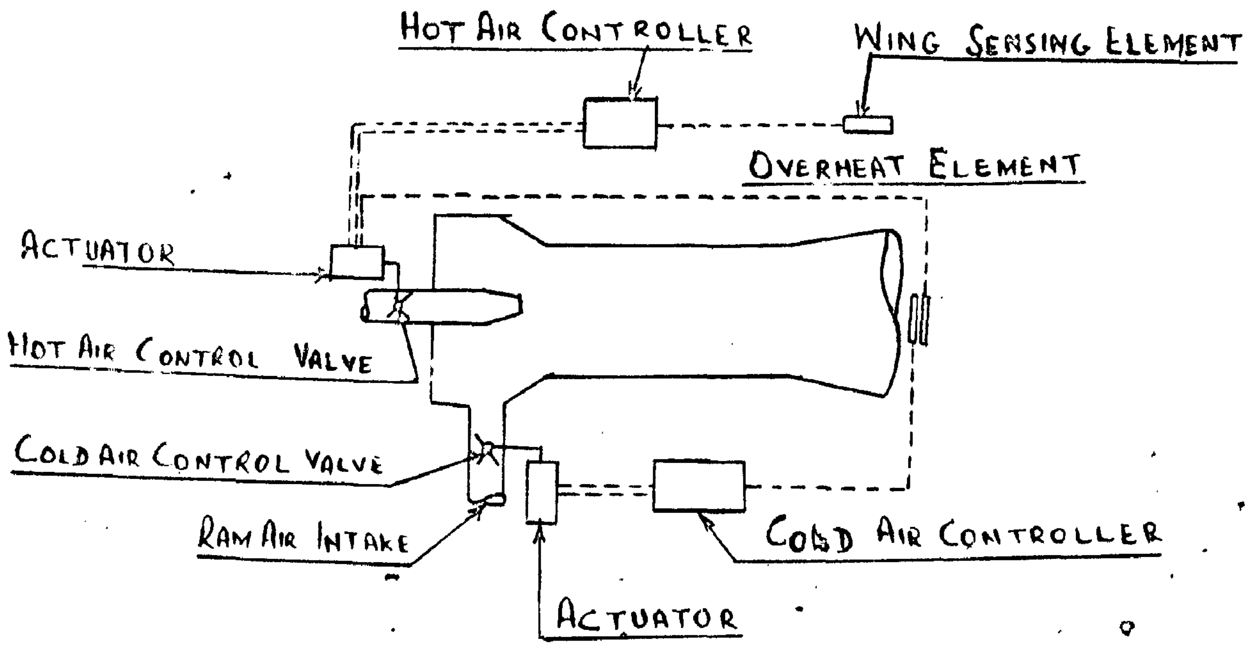


FIG. 26 AIR INJECTOR PUMP

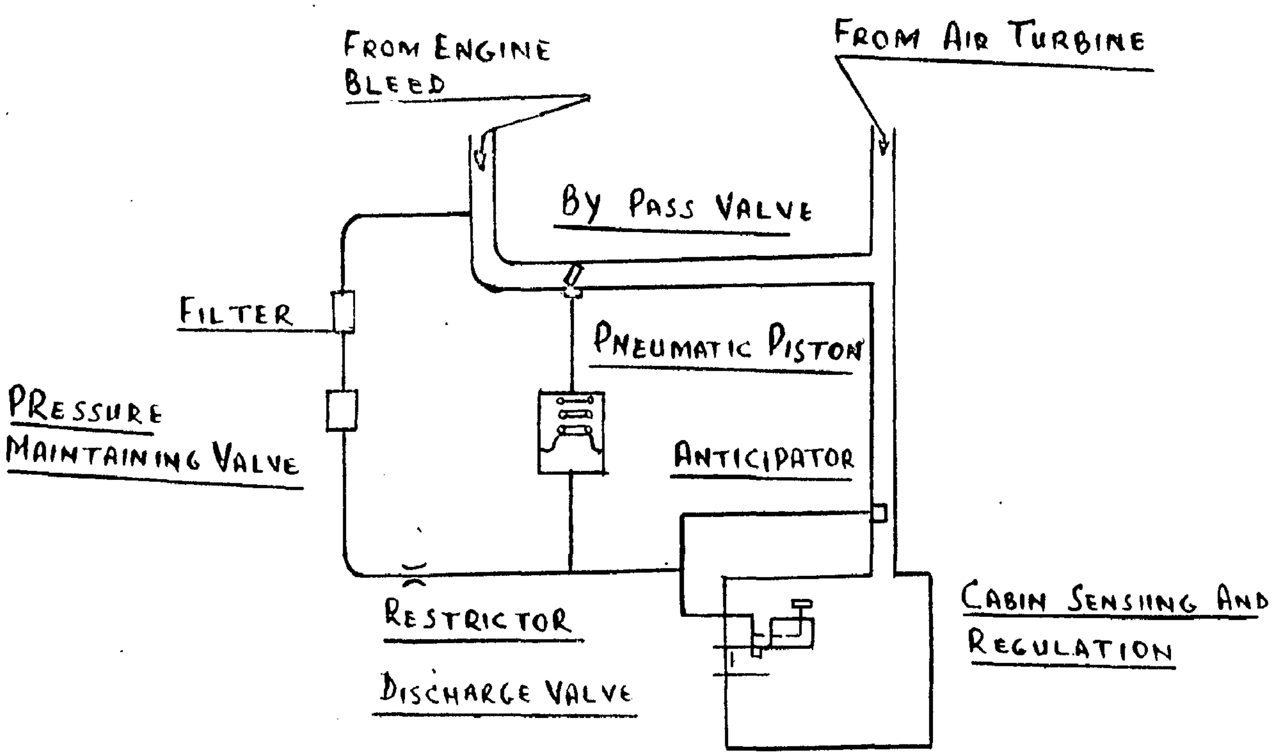


FIG. 27 PNEUMATIC TEMPERATURE CONTROL SYSTEM

the hot air must be controlled, so as not to exceed 180°C. The maximum air temperature can be controlled by an air injector as shown in figure 26. The flow of gas has also to be controlled because it affects the engine thrust.

Electrical:- Electric heating elements are embeded in wind screen, wing leading edge pads or similar devices in air intakes or propellers to avoid the frosting.

(ii) The second form of humidity control is associated with ground conditions and is achieved by a vapor cycle refrigeration system. Normally the cabin temperature is reduced by 20°F with corresponding reduction of humidity on the ground.

b. Temperature control:- Temperature in the airplane is controlled by either pneumatically or electrically. The basic principle is the same in both the cases. A sensitive element senses the cabin temperature and transmits it to a by-pass control value, which then operates to correct the cabin temperature. Signal is cancelled after the cabin temperature is established. No signal is sent by the sensitive element when the cabin temperature is within $\pm$ 2°F of the set cabin temperature. The ideal control system would be that which requires very short time. All these systems are closed loop servo-systems which consist of the following:-

(i) The cabin sensing element sends no signal within the variation of $\pm$ $2^{o}F$ cabin temperature.

(ii) Signal is amplified by amplifiers and is passed to the actuator of control valve. This valve should control from full to shut off linearally.

(iii) The actuator is to be designed to make full stroke in 30 seconds.

(iv) For a given aircraft, there is roughly, a ratio of 3 to 1 between duct temperature change to cabin temperature change. Such a system is known as the proportional floating control.

(v) In the absence of anticipating sensing elements stabilized cabin temperature, results after two to three swings, above or below the control position.

(vi) In the presence of anticipator the cabin temperature is brought to its set temperature with little or no over shot, controlling the duct temperature in one swing.

(vii) In order to obtain a correction, proportional to the temperature out of balance, the output characteristics of the controller is made to give a signal proportional to the temperature out of balance and so the series actuator will produce a similar change.

(viii) The element normally calling for temperature correction is cabin element and the anticipator merely provides a correction and cancellation for a change of duct

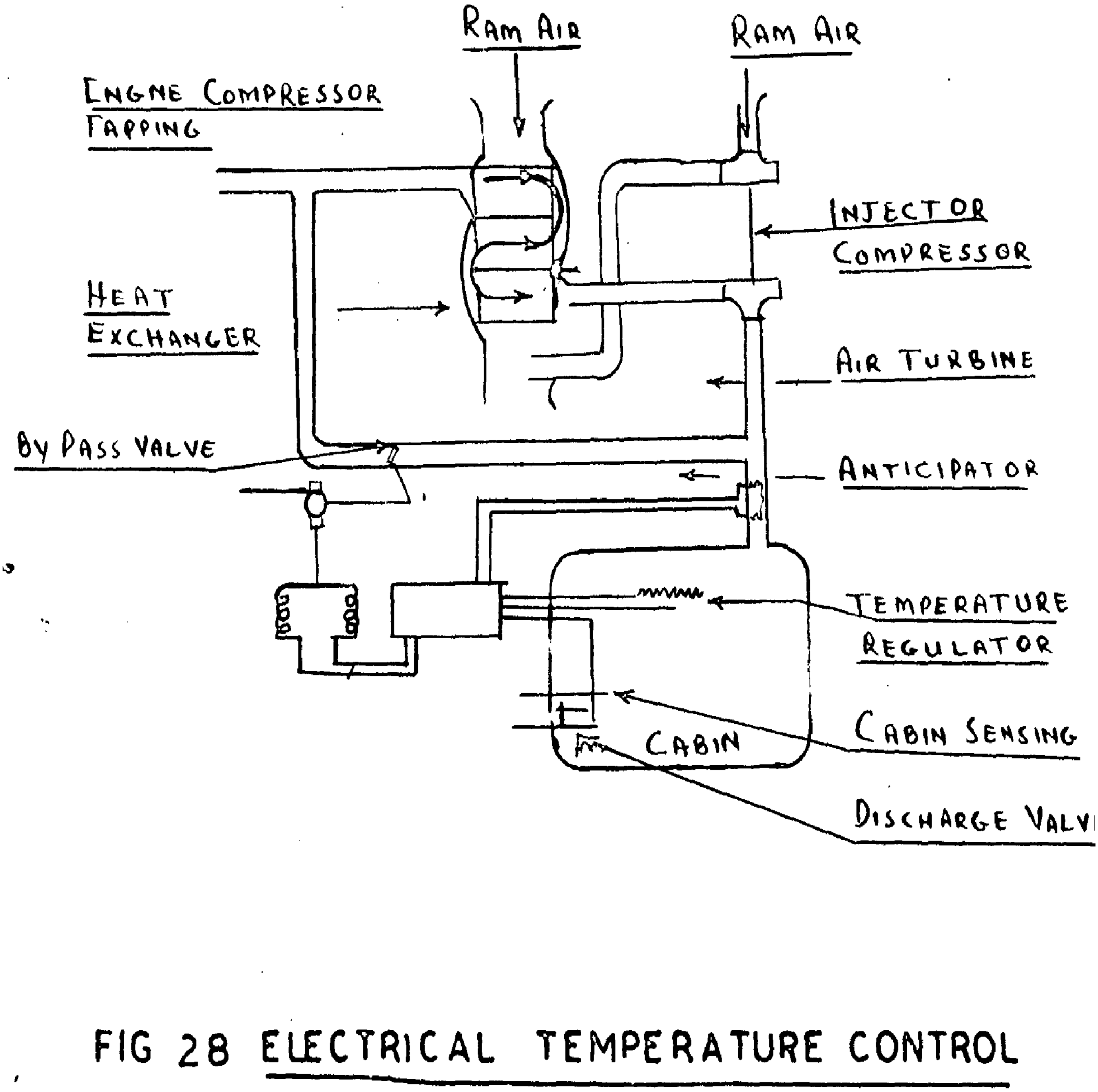


FIG 28 ELECTRICAL TEMPERATURE CONTROL SYSTEM.

temperature resulting from change of engine bleed condition. This in turn will result from variation of engine R.P.M., aircraft altitude or by the initial signal from the cabin element.

(ix) The control valve, must be capable of controlling temperature in less than $1^{o}F$ steps, this means a sensing element with high rate of response, therefore cabin sensing element should be placed in cabin discharge duct, where reasonable velocities exist.

Comparison:- The pneumatic system is lighter than electrical one except where basic pressure available falls below 8 PSI as in the case of engine driven compressors. It becomes very simple where only a duct sensing element is used, in that case pilot has to exercise some control. Pneumatic system is mostly used for military aircrafts while the electrical is used for passanger aircrafts. The two systems are shown in figure 27 & 28 .

c. Air-craft pressurisation control:- The pressure control inside a aircraft, military or passanger is obtained by one or more discharge valves, which receive a signal from the pressure controller, thus restrict the air flow over board the cabin. The amount of air required is not according to the needs of pressurezation, but is according to the cooling and ventilation requirements. The pressure in a cabin or

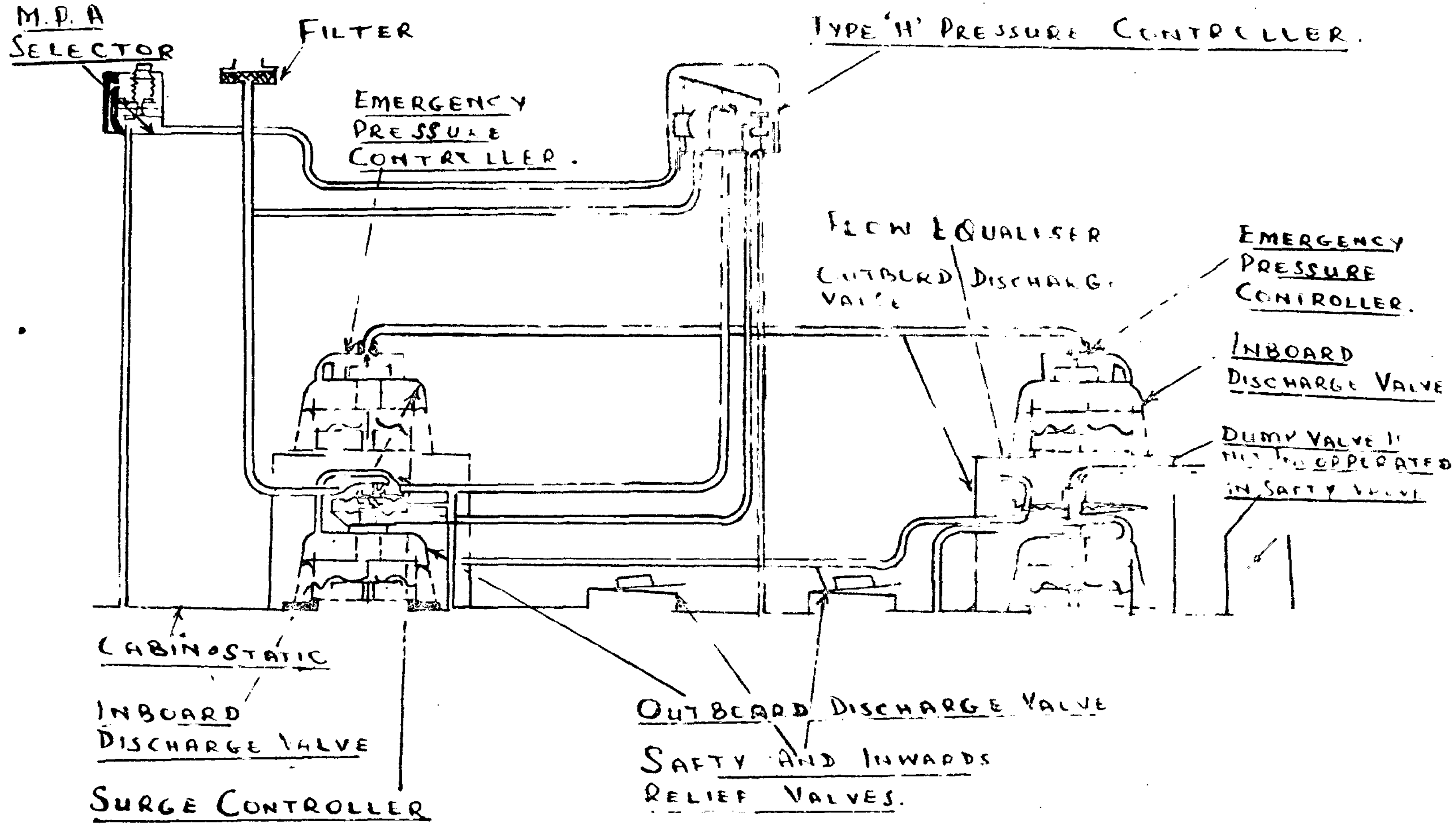


FIG 29 TYPICAL PRESSURISATION SYSTEM FOR A LARGE CIVIL TRANSPORT AIRCRAFT

compartment can be controlled by the amount of inlet air against rate of leak from the compartment, where cooling is ignored or is done by recirculation or where ventilation requirement is low. In civil aircrafts where we have to take into account the age and health standards of passangers, the rate of change agreed is 0.16 lbs/minute to suit all passangers.

A typical control system for a large civil aircraft is shown in figure 29. It consists of a single control unit modulating two discharge valves. For good cabin air distribution and flow equalization the two valves are inter-connected. Similar discharge valves are physically attached on the upstream side of each of these valves. This unit is called the emergency controller. In case of failure emergency unit automatically comes into operation and holds the cabin at a pre-determined pressure. The controller will automatically provide the desired conditions during ascending, descending and cruising flight. The pressure control equipment safety valve etc. should work in close co-ordination for successful system design.

d. Flow control:- The main important characteristics of the flow controllers should be that they are fast in action and sensitive. Flow controllers be of electric or preumatic type.

2.11 AIR DISTRIBUTION

The air distribution system should be designed in such a way that it gives a sense of freshness and air movement in the compartments. Therefore it is essential that during taxying a minimum of 0.5 lbs. per minute per person and during flight for all altitudes 1.2 lbs. per minute per person fresh air should be supplied. The quantity of air entering each compartment should be decided on the basis of its occupancy. The fresh air supply must be entirely uncontaminated.

The conditioned air should enter the passanger compartments, flight deck and so on at roof or luggage level and be taken for recirculation at the floor level. The maximum velocity over passangers should not exceed 40 feet per minute except when cold outlets are being used, but these outlets are provided in positions normally not occupied by passangers.

Cold outlets with noise within acceptable limits should be provided for each passanger individually. The quantity and velocity from these outlets should be adjustable from zero to maximum.

The air from toilets and freight holds must not be recirculated, the pressure in these compartments is kept some what low compared to passanger and crew compartments so as to prevent undesirable odours.

CHAPTER VI PERFORMANCE AND CONCLUSION

Condenser for 4.022 B.T.U/Min Ambient Air 94°F Condenser Temperature 140°F. Finned Plate Construction. Fins .3" x .006". Mean Hydraulic Dia. .0622" Free Area Ratio 562"

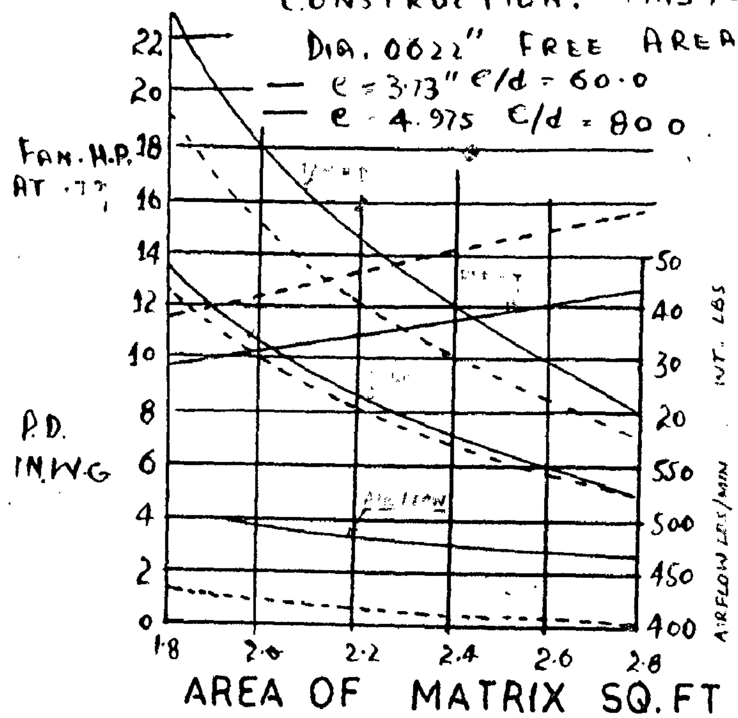
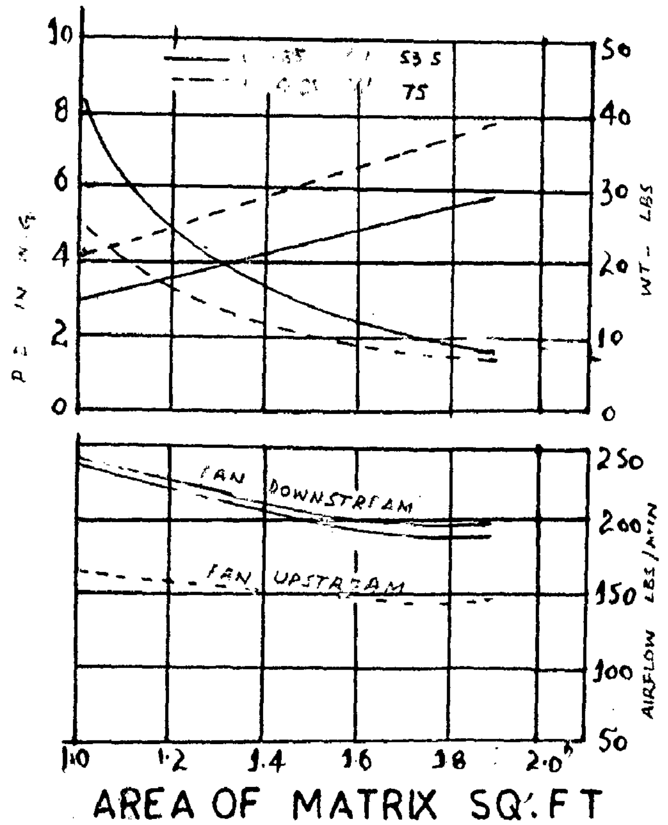


FIG 37 PERFORMANCE CURVES VAPOUR CYCLE CONDENSER



Evaporator 2400 BTUs/min Net Cabin Cooling. Cabin Air 88°F 81 Grains/LB Fans P.D. 10" H_2O. Temperature Rise 5°F Finned Plate Construction:- Fins .3" x .006" Mean Hydraulic Diameter .00622" Free Area Ratio 100.562 Base Mean Temperature 35°F Vaporating 25°F Min

FIG 38

PERMANCE CURVES VAPOUR CYCLE EVAPORATOR

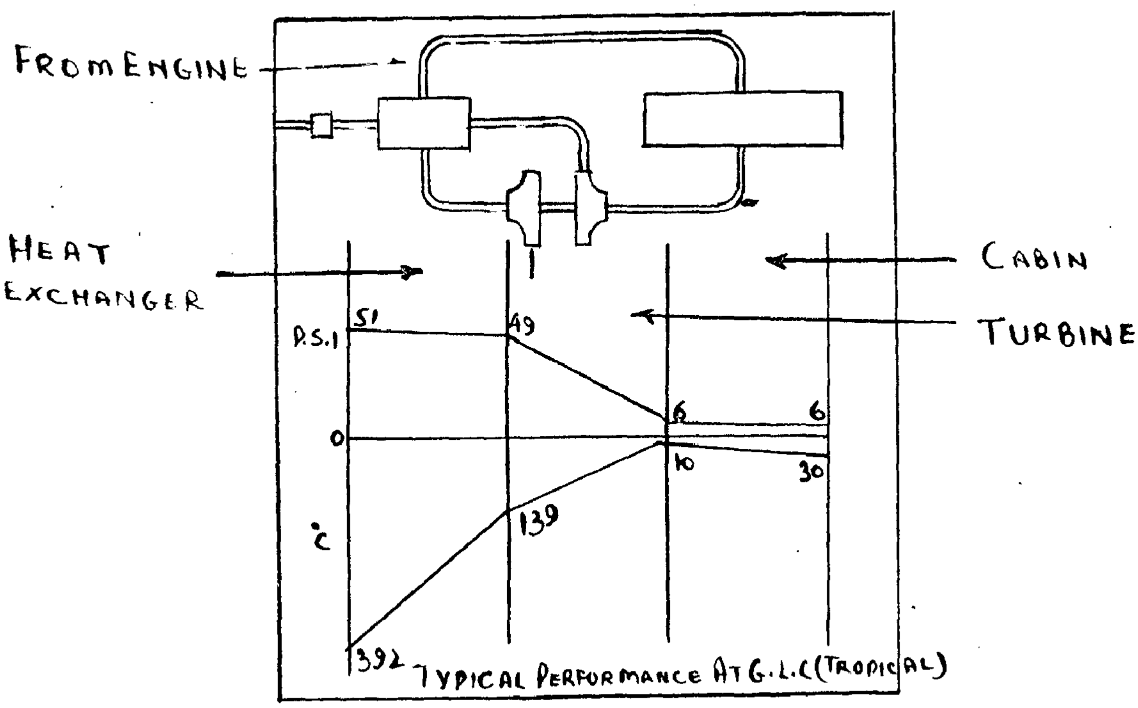


FIG 36 DIAGRAM OF REGNERATIVE CYCLE COLD AIR UNIT & ITS PERFORMANCE

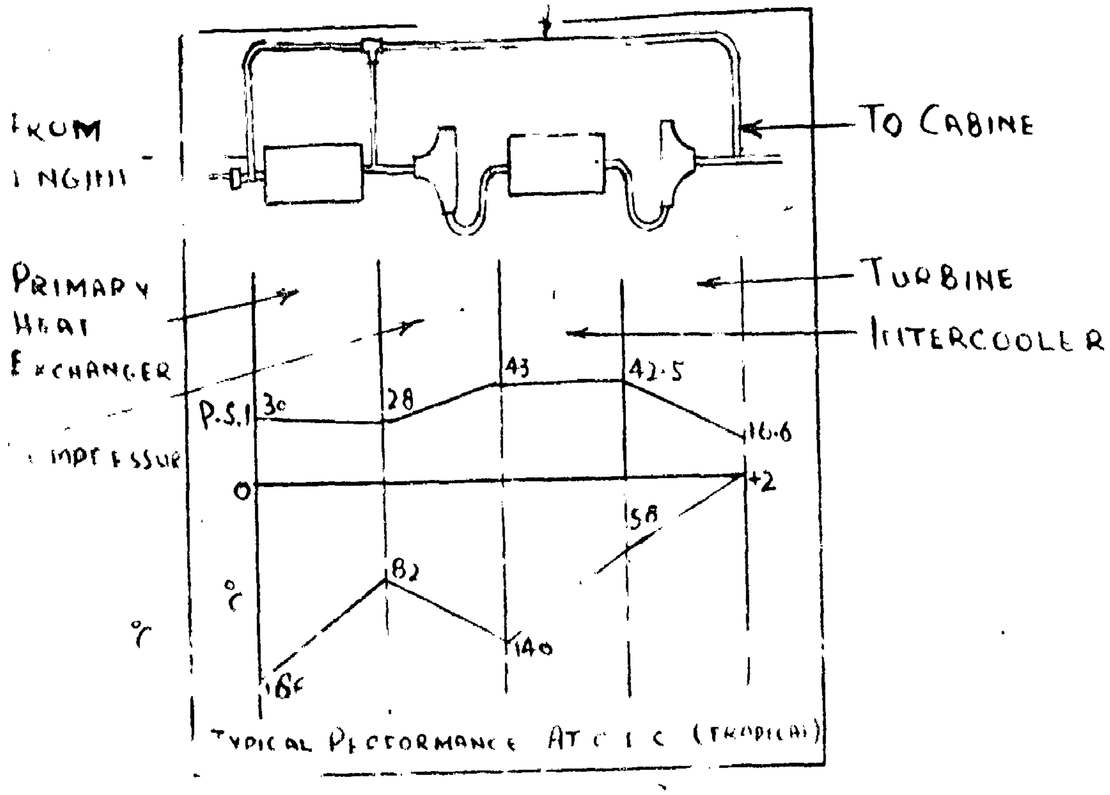


FIG 34 DIAGRAM OF BOOTSTRAP COLD AIR UNITED & ITS PERFORMANCE.

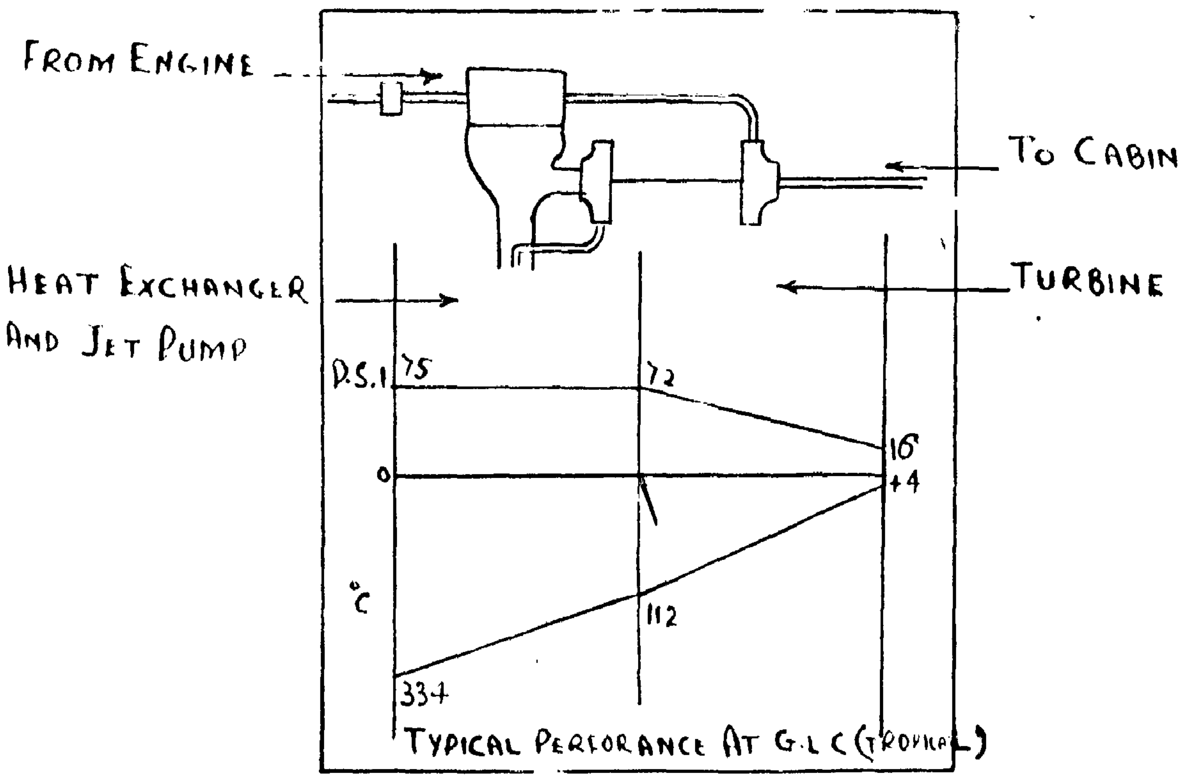


FIG 35 DIAGRAM OF JET PUMP COLD AIR UNITED & ITS PERFORMANCE

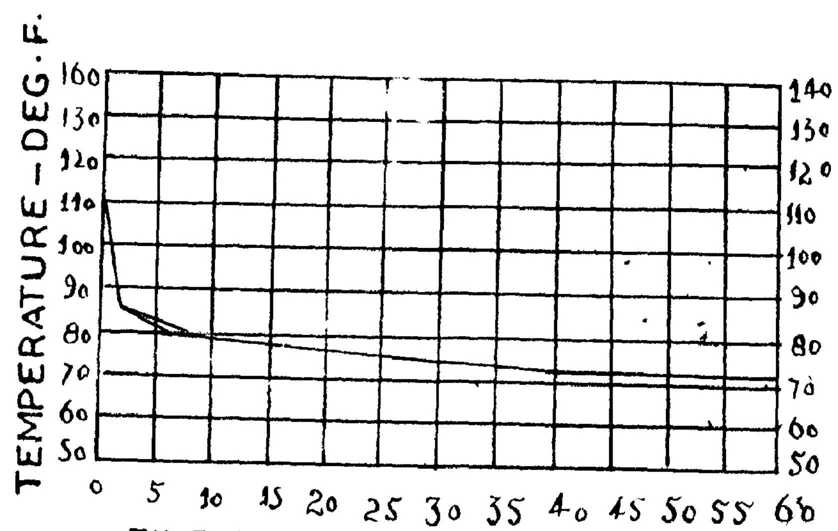


FIG 32 TIME FROM START OF CAR & COMPRESSOR MIN.

CURVE SHOWING TIME FROM START OF COMPRESSOR UNTIL CAR INTERIOR REACHED COMFERTABLE TEMPERATURE. CAR WAS STARTED AFTER STANDING IN SUN WHEN AMBIENT WAS 105 F

BREATH LEVEL TEXAS SUN TRIP

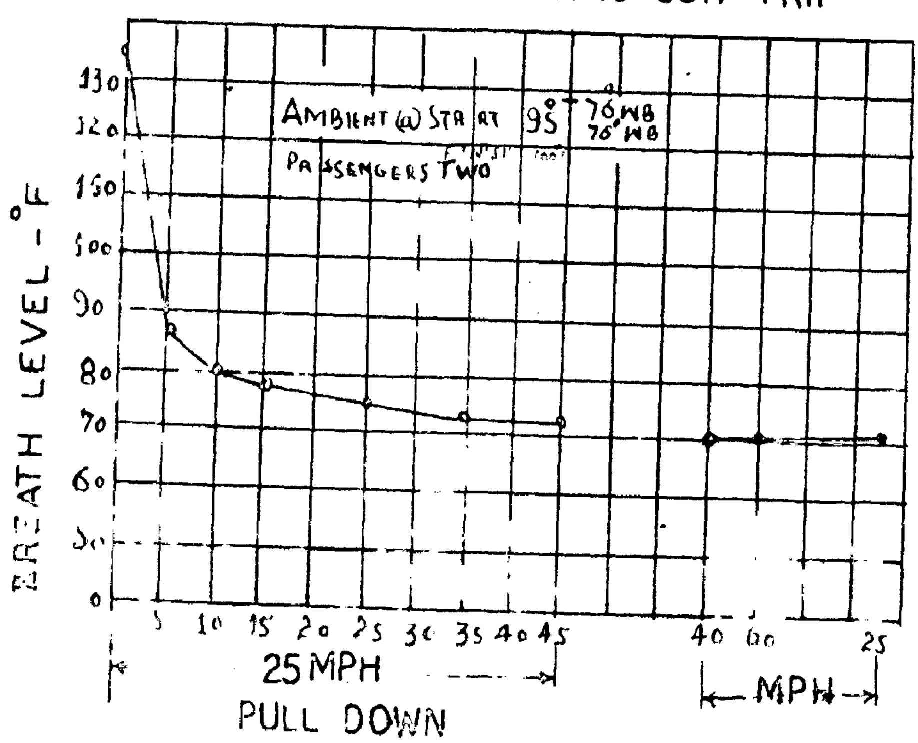


FIG 33 PERFORMANCE OF AUTOMOBILE AIR CONDITIONING SYSTEM

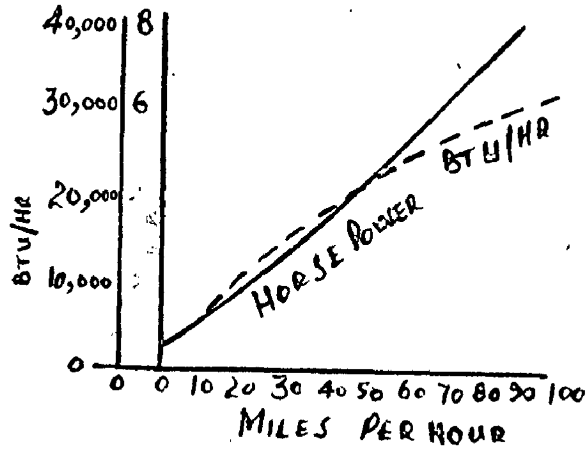


FIG 30 A CURVE SHOWING THE RELATIONSHIP BETWEE
CAR SPEED HEAT LOAD & HORSE POWER
REQUIRED TO DRIVE THE AUTOMOBILE COOLING
MECHANISM

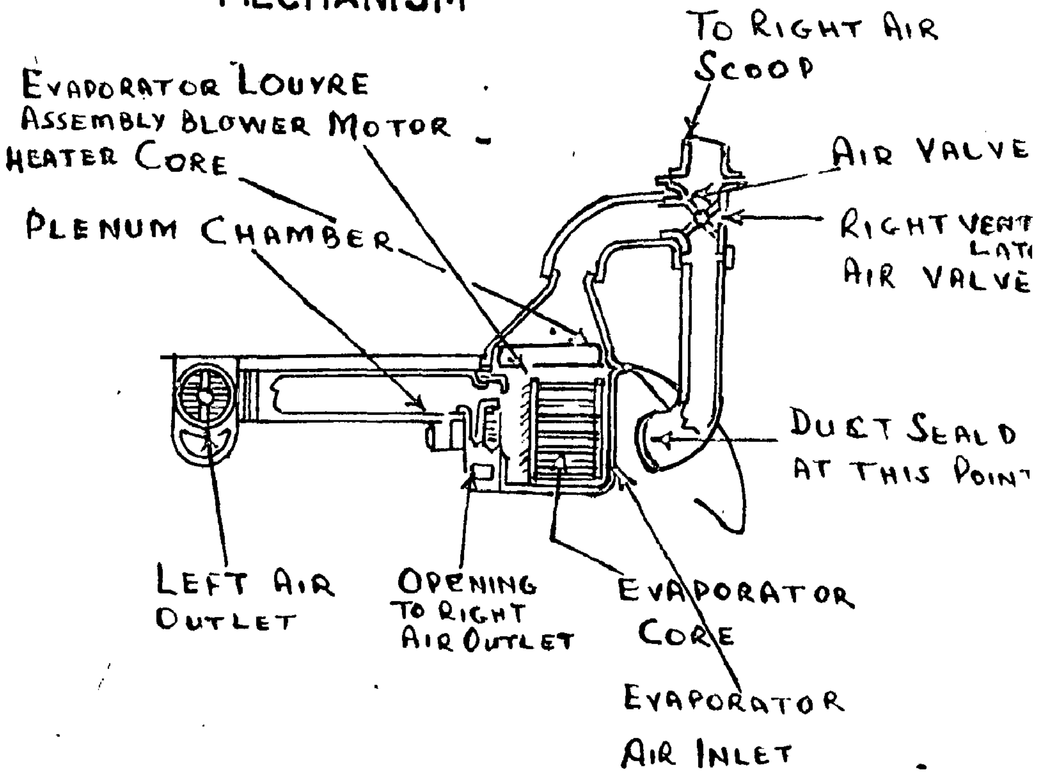


FIG 31 FRONTE END SYSTEM HEATING & COOLING COMBINE
OUTSIDE AIR INTRODUCED FROM FRONT END OF CA

Air-conditioning of transportation is no longer a luxury but has become almost a necessity, because there are people who are forced to spend lot of their time in transportation. It is rather important to ensure the satisfactory efficient and economic working of air conditioning systems installed on the mobile units.

The performance of one air-conditioning system on an automobile under summer operating conditions is shown in figure 30. The capacity is 3 tons at a vehicle speed of 50 mph. It can be seen from figure that 8 H.P. is required for 3 tons refrigeration which is 2½ times than that required for stationary systems. Some work has to be done to reduce the power requirement. This result can be achieved by using means to drive the compressor at constant speed and to locate the condenser and evaporator more suitably.

Figures 31,32 & 33 show performance of another air-conditioning system. It has been found that for 90^{o}F ambient the temperature of the interior goes upto 140^{o}F in hot sun, and the time to bring it to the comfortable range is about 45 minutes, with vehicle speed 25 mph. However it is possible to bring the interior temperature to the degree of comfort in 10 to 15 minutes if driving conditions are suitable i.e. 40-60 M.P.H.

Although there being many problems in air conditioning of Railroad cars, the existence of more than

16000 cars in U.S. and Canada show that the problems can be surmounted. Mechanical compression system has prevailed on other cooling systems due to its more efficient performance.

The performance of air cycles are shown in figures 34,35 & 36. The performance of particular condenser and evaporator used in vapor cycle is also shown in figures 37 & 38.

Mr.B.L.Missinger in S.A.E. journal March,1946 published that air cycle is better than vapor compression system.

Due to this controversy it is suggested that in weight aspect, attention should be focussed to the use of engine air bleed and the use of high voltage 400 cycle A.C.Power for driving anxiliaries.

Pressurization methods should be reviewed for minimum power loss under take-off conditions and for adequate ventilation in passanger aircraft.

For high altitude passanger aircraft the provision of oxygen is disputable.

In the light of many factors involved in the commercial aircraft air-conditioning the requirement may be red-rafted at least in so far as they can serve as a guide to design control.

There is no doubt about the use of vapor cycle compression for the control of ground humidity and for cooling passanger air-craft.

The field of refrigeration and air-conditioning is fast developing in this country. Some refrigerated cars have been put into service for goods but the comfort air-conditioning however is in its developing stage . In India at present the number of air-conditioned automobile vehicles, railroad cars and airplanes is rather small and a lot is yet to be done in this field to catch up with the other advanced countries of the world.

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