Table 3 .... Relative Cost Comparison for Railroad Air-Conditioning Systems

Type System	First Cost[a]	Operating Cost[b]	Maintenance Cost[c]
Steam Ejector	Highest	Low	High
Ice Activated	Lowest	Highest	Low
DX Component (DC Power)	High	Medium	Medium
DX Component (AC Power)	Medium	Low	Low
DX Package Unit (DC Power)	High	Medium	Medium
DX Package Unit (AC Power)	Low	Lowest	Lowest

[a] First cost is based on relative cost of air conditioning equipment and installed costs and does not include power equipment.
[b] Operating cost is based on power consumed only.
[c] Maintenance cost does not include maintenance cost of power equipment.

proximately 500 lb less than a comparable d.c. unit. The motor starters and controls are also much smaller and lighter. The light weight and smaller size permits installation of 8 ton units in the ceiling on double deck or gallery type commuter cars. The self-contained unit greatly reduces the amount of work that the carbuilder previously had to do when a component system was used. In theory, the package unit lends itself to a complete change out of a unit for major repairs, however, the weight of 1100–1500 lb is usually too heavy for yard handling. It is therefore necessary to provide complete access to all parts for servicing or replacement.

COST CONSIDERATIONS

From a standpoint of *initial cost* of the air-conditioning equipment to the railroad or carbuilder, the component system is usually cheaper than the unitary system. However, the installed cost of the component system is much higher, since the cost of piping, wiring, charging, and testing must be added to the initial cost of the equipment. By its very nature, direct-current equipment will cost approximately 20 percent more than the alternating-current unit.

Operating cost for the alternating-current self-contained unit is generally lower as far as the air-conditioning unit itself is concerned. The higher efficiency of the hermetic compressor and other motors results in less power. If the cost of producing the power such as individual diesel or propane generators is taken into account, the savings is more equalized. A single head end power plant would be more efficient than several individual power units. The cost of power such as on direct current axle driven generators is difficult to determine accurately because the power comes from the diesel locomotive.

A comparison of the *service and maintenance cost* between the different systems would show the a.c. self-contained unit the lowest. With the self-contained units above the floor the cost of cleaning condenser coils is reduced. Likewise, the problem of damage from flying ballast, corrosion from snow and ice is practically eliminated. All the equipment is located in one place on the car which cuts down on the time of checking or servicing the equipment. At this point it should be mentioned that because of the compact design of the unitary system, it is not always as easy to replace defective items as it would be where more working room is available such as on the component systems.

Table 3 shows a comparison of the first cost, operating cost and maintenance cost of 6 different systems presently in service. The axle driven compressor has been purposely omitted because very few, if any, are being applied.

PART III: BUS AIR CONDITIONING

This section will discuss the design considerations, capacity requirements, air distribution systems, drives, and controls for air-conditioning of passenger buses.

DESIGN CONSIDERATIONS

The requirements for bus air-conditioning equipment involve considerations which in other air-conditioning applications are of less importance.

One of the first of these special considerations is space limitations imposed by the overall bus design. Normally, it is very difficult to find a large enough volume of the correct shape to accommodate a self-contained air-conditioning unit. For this reason, most systems are installed with components located to make optimum use of available space.

Tied in with equipment location is the matter of weight. Of course, it is desirable for all components to be as light in weight as economically practical. However, special consideration must be given to some components, depending upon their location, in relation to wheel loading. As a result, present day bus air-conditioning systems use compressors with aluminum crankcases, and some use all aluminum evaporators and condensers. Also, to save weight and fit limited space, high speed compressors, sometimes using Refrigerant 22, are becoming more prevalent. Applications using high speed compressors are usually those where the compressor is driven directly from the main bus engine without the use of an automatic speed changing device between the engine and the compressor.

The power requirements for this application are somewhat dictated by the space and weight limitations. In many cases, for example, the optimum fan selection for a bus air-conditioning system would be considered as requiring excessive power compared to a conventional stationary system. Likewise, the power requirement for the compressor drive is usually greater than normal because provision must be made for extreme operating conditions.

Special consideration must be given to design for reliable operation even under the most severe conditions. The equipment is installed in revenue producing vehicles, and unscheduled stops for repairs due to a design deficiency cannot be tolerated. Factors such as road shock, dust, rain, snow, hail, sleet, and unusually high temperatures all must be considered. Even such items as location of condenser air openings can prove to be troublesome if not adequately considered. For example, a high velocity discharge from the condenser can cause annoying dust at stops if not properly directed.

Tied in with reliability is design for ease of maintenance. All points requiring regular servicing or adjustments must be readily accessible for maintenance to be accomplished in a minimum time. Wearing part components must be so located and attached as to be readily replaceable with minimum disassembly of other parts. To provide for these factors, some systems have swing-out condensers for ready access to the rest of the system. Electrical controls on some installations are located in separate compartments, accessible from the outside of the bus.

However, probably the most important feature to keep in mind is design simplicity to allow trouble shooting and maintenance time to be kept to a minimum. Temptation to design in features or gadgets for improved efficiency at the expense of added complication must be avoided.

CAPACITY REQUIREMENTS

For the urban bus, the cooling requirements are quite severe. The cooling load is made up of three parts: (1) the

Table 4 .... Test Data for Door Operation of a City Bus (Taken during the rush period on a 35 passenger bus in San Antonio, Texas)

	Front Entrance Door	Center Exit Door
Door Open		
Times per mile	7¼	5¼
Times per hour	70	44
% of operating time	35	15
Longest time open	55 sec	34 sec
Shortest time open	3 sec	3 sec
Average time open	13.5 sec	12.5 sec

passenger load, (2) the load due to ventilation air and infiltration, and (3) the load due to heat transmission.

The passenger load is extremely severe because a city bus may seat up to 50 people and carry an equal number as standees. The fresh air and infiltration load is also severe because of the great number of door openings. Table 4 shows a record of door openings from actual test. It should be realized that a city bus may stop once in each city block and may open both front and rear doors to take on and discharge passengers.

The amount of transmission load depends on whether the bus is fitted with single or double glass and the amount of insulation. However, the transmission load is usually a relatively small part of the total.

The maximum cooling capacity required for the average urban bus is in the order of 7–10 tons of refrigeration. However, the equipment must be flexible enough to range from zero to maximum promptly as required. This is necessary because the passenger load on a city bus can vary greatly, depending on location and time of day.

The heating of a present day bus equipped with air conditioning is usually accomplished by means of a heating coil located in series with the evaporatory. Traction engine coolant is piped to this heating coil, and in some cases individual supplementary heaters are provided for windshield defrosting. It is usual that the cooling capacity need for the main engine is sufficient to heat the bus even under the most severe weather conditions.

With this type system, ventilation air is usually taken in through fixed openings in the side of the bus. These openings and duct-work to the return air passage should be so sized to admit outside air in a ratio of approximately 20 percent outdoor air to 80 percent recirculated air.

The inter-urban bus has a somewhat different problem in cooling and heating than the urban bus. The cooling load is less because the maximum passenger load is less and there are fewer door openings. However, the quality of cooling must be better because the passengers remain on board for longer periods. For this reason, placement of the main heater coil in series with the evaporator to provide reheat is probably much more important in this service.

Ventilation requirements for the inter-city bus are also more important. Normally, openings are provided in the side of the bus to bring outside air into the return air duct. Also, in addition, some systems provide manually operated dampers for introduction of outside air directly into the conditioned space. Since smoking may be allowed on an inter-urban bus, it is desirable to admit about 15 cfm per person.

The heating system normally used on an inter-urban bus is essentially the same as that described above for a city bus.

AIR DISTRIBUTION SYSTEMS

Where the conditioned air is distributed overhead, various systems of outlets have been used. Some buses have been fitted with a perforated ceiling air distributor system. This system gives good air distribution, but uses up valuable head room which in many cases is not available. Some systems employ individual air outlets located in the center of the ceiling. This system alleviates the headroom problem and furnishes reasonably even distribution throughout the bus. However, serious draft problems are usually encountered which are specially disturbing to standees.

Use of overhead distribution also precludes the possibility of using this system for heating. It is important to provide heat at the floor level.

Side wall outlets above the windows have been used with favorable results. However, on modern buses it is very difficult to provide duct work of sufficient size to serve these outlets.

Most popular are side wall outlets located just below the windows. The duct system for such outlets is more practical, headroom is not affected, and cooling air is delivered close to the heat gain from the side walls and windows. The main disadvantage of this system is the possibility of drafts affecting the passenger in the window seat. This is usually overcome by making outlets as long as possible to minimize velocity.

Floor outlets are not desirable for cooling and therefore are normally used only for heating. This is because it is most desirable to keep the passengers' feet warm. The simplest way to heat the bus is by means of small fan coil units located at intervals and provided with hot water from the main engine cooling system. These recirculate the air locally and involve the least amount of duct work.

In any air conditioning system, the air return must be given careful consideration. The most satisfactory arrangement of air supply and return is for the air to be delivered near the ceiling and removed near the floor. It may also be delivered near the ceiling and removed at a different part of the ceiling, depending upon the location of the cooling coils.

EQUIPMENT LOCATION

The cooling equipment which consists of the high side compressor and condenser assembly and the low side evaporating coil and air circulating fans may be located all under the floor, all in the roof, or in split arrangements where the high side is under the floor and the low side is mounted in the ceiling or on the roof on the bus. In certain city buses, part of the high side is on the roof, and part of it is under the floor.

The under-floor system offers many advantages for the high speed inter-urban bus. Among other things, it keeps the center of gravity low. It also reduces the amount of duct work necessary. It is actually quieter than the overhead system. It does have the problem of using up valuable luggage space, particularly on a long distance bus.

The split level offers a number of advantages because it uses up less luggage space by putting the evaporator unit upstairs. The roof mounting of the condenser of a split system is of interest. This has been done on many urban bus installations. This makes available to the condenser, air which is much cooler than that which can be drawn off the road. It also eliminates a great deal of dirt which otherwise would tend to clog the condenser surface. If the appearance of a bump on the roof can be accepted, it apparently does not exceed the clearance of obstruction such as bridges, and therefore, occupies space which otherwise would not be used. In these installations, the compressor itself is usually mounted under the floor.

DRIVE

One of the earliest and most commonly used drives for the air conditioning system is by means of a separate engine. This