

Fig. 1 Car Temperature Variations for Open Road and City Traffic

the industry experience during the past several years. Some of these will be presented in the following paragraphs.

Capacity Requirements

Cooling capacity is often prescribed in terms of cool-down, steady driving, or both, i.e., sufficient capacity to cool down to 80 F in 10 min after being parked and closed in 110 F ambient. The ability of the unit to cool down the temperature in a car from its maximum temperatures when parked to reasonably comfortable conditions is of vital importance to the car owner because it occurs so frequently and the temperatures in a closed car are so very high. The need for frequent, rapid cool-down is one of the major differences between car air conditioning and residential air conditioning requirements. When parked in the sun on a 110 F day, the interior of an automobile will reach temperatures as high as 135 F. Even if the windows are opened to flush the car out with 110 F air, the air temperature is far from comfortable and the seats and other interior surfaces are still at 135 F or more. The unit must not only have adequate capacity to rapidly pull the air temperature down to a comfort level, but also reduce the temperature of the seats, door panels, ceiling, floors and instrument panel, all totaling a mass of at least 700 lb. To cool this quantity of material from 135 F to 75 F in 15 min would require a capacity of 28,000 Btu/h assuming an average specific heat of 0.2 Btu per (lb) (F deg). During this period the unit would also require sufficient additional capacity to balance the steady state cooling load.

At steady-state conditions, as well as during cool-down, the rate that outdoor air infiltrates into the car plus the amount of insulation in the panels, roof and floor are very significant factors affecting cooling capacity needs. Use of heat absorbing glass to reduce the direct solar radiation transmission from 67 percent for clear glass to 45 percent is also effective in reducing the cooling load. The steady-state cooling requirements can be evaluated at 25 mph, maintaining 75 F inside the car with an outside sunny ambient of 110 F, 25 percent relative humidity. The cooling load of a typical automobile would be broken down into various major sources as described in the table below:

Solar radiation (roof, walls, glass)	= 3000 Btu/h
Normal heat gain through glass	= 1200
Normal heat gain through walls, roof, floor	= 4250
Air leakage into car (estimated at 30 cfm at 25 mph)	= 950
Passengers (2), plus driver (sensible heat only)	= 800
Total	= 10,200 Btu/h

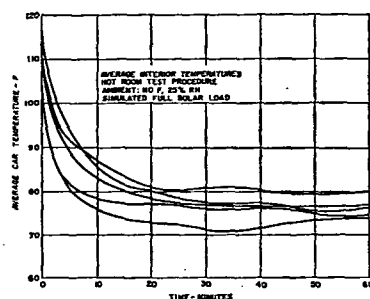


Fig. 2 Typical Pull-down Curves

By comparison, an American make compact car has a load of about 7800 Btu/h. Since this sensible capacity requirement is based on 110 F outdoor, and 75 F indoor temperatures, the sensible heat transfer factor of the typical car would be 300 Btu per (hour) (F deg). At a sensible ratio of 0.8 at total steady state load, including 20 percent latent heat, would be 12,750 Btu/h.

The result of several cool-down tests on some representative cars and units are plotted in Fig. 2. The cars were soaked in the hot room for 1 hr at 110 F with full solar load (125 watts per sq ft) with windows closed. The car was then started and run at an engine speed equivalent to 25 mph and with air approaching the car at the same speed. Temperatures were measured at ankle, lap and breast levels, and averaged to give the temperature plotted. Fig. 3, shows an actual test run made in Yuma, Arizona, compared to a simulated hot room test. Note that the correlation is within 2 percent over most of the cool-down curve. The steady state conditions at 25 mph after 60 min of operation are also shown and correlate quite well. Most auto air-conditioning systems available today have capacities in the range of 10,000 to 16,000 Btu/h when operating at the above steady-state conditions.

Speed Range

The air-conditioning system must function properly over car speeds from idle to 120 mph. This extremely wide speed range of 12 to 1 considerably complicates the design problems

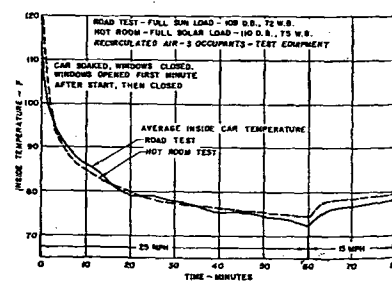


Fig. 3 Comparison of Road and Hot Room Tests

Surface Transportation Air Conditioning

in accomplishing adequate capacity at the low speed end, and reliability and endurance life at the high speeds.

Life

It is not unreasonable to expect the air-conditioning system to last the life of the car without major repairs. This is normally assumed to be 80,000 to 100,000 miles or 4 to 5 years. During this time some normal servicing and occasional addition of refrigerant is expected, but this should be confined primarily to good preventative maintenance practice.

Air Distribution

The method for distributing the cool air into the conditioned space is one of the most important and probably one of the most controversial factors in automobile air-conditioning system design. The fact that the cooling load in relation to the volume of the conditioned space is so great places auto air-conditioning distribution systems in a group of their own. The body volume of a middle class 4-door sedan is about 140 cu ft. The volume of a residential or office space that can be air conditioned with approximately the same capacity would be in the neighborhood of 3000 cu ft. The usual four occupants in the car occupy about 12 cu ft or 10.5 percent of the total space, and they extend from the floor to within 4 or 5 in. of the ceiling. Ten occupants in the above room would take up 1 percent of the space, and their heads would be 2 to 4 ft from the ceiling. The free space in a car available for circulating the cool air within the passenger compartment without direct impingement on the passengers is very limited.

Another air distribution problem arises from the fact that direct sunlight through some portion of the glass that surrounds the top half of the car shines directly on two of the four passengers. The front floor temperatures are usually higher than the other panels. The cooling must be more concentrated in these hotter areas.

The type of distribution desired during the cool-down period is much different than at normal relatively steady state conditions after the car has reached the comfort temperature. During cool-down the air-off temperature is quite high and with the inside of the car being very warm, spot cooling or direct impingement on the occupants is desirable. When the car and air-off temperatures level out, direct impingement of the cold air is very undesirable. An ideal distribution system would:

1. Supply adequate air (approximately 250 cfm) to the car interior without excessive drafts or direct cold air blasts on the passengers.
2. Permit controlled amounts of cooling to the various areas of the car such as the sides, front floor area, rear seat area, and breast level.
3. Accomplish good distribution without objectionable noise from grilles, blowers, etc., with a minimum power requirement.
4. Provide for all recirculated air during the cool-down period.

The tolerable air motion is considerably higher in an automobile due to more direct radiation through the windows from the direct sun and from hot surrounding areas. It must be controllable, however, in the event that cooling is required when the radiation effects are low. The air velocity normally can be in the order of 200 to 300 fpm without discomfort.

When the air-conditioning air system is common with the heating system, provisions must be made for satisfactory heating as well as cooling. A combination air distribution system that has been used effectively has provisions for directing air up and down for cooling, and down for heating.

Temperature and Humidity Control

Along with air distribution, suitable comfort air conditioning also requires temperature control and, to some extent,

humidity control. The controls must maintain a minimum temperature variation in all parts of the conditioned space with controls that are as simple and low cost as possible. A description of some of the various control methods used today are discussed in the control section under Design Requirements of Specific Components. Again the number of variables in load distribution and rate of load changes while driving complicate the problem of maintaining close temperature control. The rate of temperature change at the thermostat sensing element is much faster than the rate in most residential or commercial air conditioned areas. The wide variations in unit capacity make it necessary to provide methods of coil freeze-up protection.

Ventilation

The air infiltration into the car when it is in motion provides a varying amount of outdoor air depending upon the car speed and leakage. This air is unconditioned as it enters the car and mixes with the air in the conditioned space. Additional quantities of outdoor air are often desirable to control odors. The factory installed systems have provisions for introducing precooled ventilating air into the car after the car has pulled down to a comfortable temperature. The field installed systems depend upon normal infiltration and at times a slightly open window to ventilate the car.

Filters

Filters are generally not used on auto air conditioners today, although earlier factory installed systems did include them. The limited space for adequate filter area and inaccessible locations have made filters quite impractical for auto air conditioners. Elimination of filters from these systems is not too serious since most of the dirt is made up of dust and small greaseless particles which wash off the evaporator coil with the condensate. Lint and long fiber materials or grease vapors that would cling and clog the coil are not prevalent in automotive applications.

Space Limitations

Currently air conditioning is installed on only 5-10 percent of the automobiles as they leave the factory. For this reason the air conditioner holds a fairly low priority on available space. At the present time the evaporator, compressor and condenser are each in separate locations, and even with them split up in this manner each section has only a very limited space. The condenser must be set between the radiator and grille, a space normally used for the horns. The compressor is belt driven from the engine and therefore is in the same proximity with the generator, water pump, power steering, air ride compressor, and engine fan. All these are working in the usual narrow space between the engine and radiator. The space for a front-end evaporator section is limited by the air cleaners, power brake mechanism, wiper motors, glove compartment, transmission housing, etc. Evaporators located under the rear deck in the trunk are limited the least for space but the long refrigerant lines become objectionable.

Effect of Air Conditioning on Engine Performance and Operation

The engine cooling system must be of vital concern when designing and applying air conditioning to an automobile. The radiators, fans and pumps are carefully developed to cover the extreme range of engine cooling requirements. For economic reasons they must be designed closely with little reserve capacity. In every air conditioning system today the condenser is