conditioning one method of control includes a thermostat located in the passenger section to start and stop the refrigeration compressor. If the compressor is driven by the bus engine a clutch is provided which can be energized or de-energized by operation of the thermostat. On systems employing a compressor, driven by a separate engine, automatic means of starting and stopping the engine are controlled by the thermostat. Modulating control of engine driven compressors may be accomplished by automatic control of the engine throttle by a thermostat in the passenger section. Some systems provide for continuous operation of the compressor when cooling is required, the compressor being manually started by the operator. Temperature in the interior of the bus is maintained by reheating the air from the cooling coil. Automatic control of temperature is provided by a thermostat in the passenger space or the return air to the blower which operates a modulating valve on the engine coolant supply to the reheat coil.

AUTOMOBILE SUMMER AIR CONDITIONING

The basic components used for automobile air conditioning are fundamentally the same as in any stationary air conditioning system using the vapor compression cycle. For automobile application the source of power is always a major obstacle to overcome. The best solution to date for automobile applications is to operate the condensing unit by belt drive from the car motor and then control the variable refrigerating capacity caused by the variable car motor speed by suitable means.

One to seven or more horsepower are required. Compressors must be capable of operating at speeds of 4000 to 5000 rpm to last in this service. Refrigeration capacity required is about 1¼ to 1½ tons. Radiant heat, as well as high conduction heat gain due to single-glazed large glass areas, and lack of adequate insulation in car bodies require this much capacity. Proper air distribution to avoid undesirable drafts on passengers also requires careful design. Air distribution fans and electrical controls secure power from the car's electrical system which in some cases may require heavier generators and batteries to handle the load. Most systems weigh about 200 lb or less.

Early designs, and many current ones, have the cooling units installed in the rear of the car with the cooled air introduced through the package shelf at the rear of the passenger compartment. Cooled air is then distributed with or without ducts. Warm air is returned through a grille in the package shelf, or below the rear seat, thence through a filter into the cooling units. Refrigerant lines from condensing unit to cooling unit are carried from the engine compartment to the luggage compartment along the car frame under the body.

Performance at open-road speeds has been very satisfactory (even with early systems—when they were operating properly). Twenty percent or more outdoor air should be supplied, especially if passengers smoke. This air may be picked up by scoops on the side of the car or cowl, carried into the cooling unit, and mixed with returned warm air from the car.

Car temperature control, compressor capacity control to compensate for the variable compressor speed, and prevention of ice formation on the evaporators (a common fault of early systems) are accomplished by bypassing compressor discharge gas into the low-pressure side of the system, or cycling the compressor with a magnetic clutch. The solenoid bypass valve or a magnetic clutch is electrically operated by a thermostat, usually controlled by the return air to the cooling unit. The bypass is opened or the compressor stopped when the air gets too cold.

A recent development is a complete factory-assembled system, charged with refrigerant and ready to run, which is dropped into position ahead of the *fire wall* of the car and bolted into place. Flexible suction, liquid, and discharge lines are used to connect the refrigeration components together. This facilitates initial installation. It also simplifies removal for service and maintenance and eliminates the necessity to open the refrigeration components to the atmosphere with resultant loss of refrigerant or infiltration of moisture into the system.

This system combines winter heating with summer cooling. It also permits use of all or limited quantities of outdoor air, with or without heating or cooling. Outdoor air is taken in through cowl openings. This air is then pulled through a combined heating and cooling coil assembly by a fan inside the car on the fire wall. Cooled air is discharged from adjustable nozzles on the dash inside the car. Hot air for heating is discharged onto the floor as with conventional car heaters. Dampers change the air distribution from heating to cooling, and dash controls activate or shut off either heating or cooling.

Temperature control, prevention of evaporator icing and compensation for variable compressor speed are controlled by a thermostat with bulb in the air leaving the evaporator. This cycles the compressor on a magnetic clutch.

Public acceptance of current offerings has been excellent. Performance has been very satisfactory. What service difficulties have been encountered have been readily cared for by car dealers who have trained personnel to render this type of service, or by competent refrigeration service organizations. Future demand is estimated as high as 10 percent of total car production by one major manufacturer, while another estimates a million or more of its cars will be equipped in the not too distant future.

AIRCRAFT AIR CONDITIONING

In recent years, heating, cooling and ventilating of airplanes has progressed from comparatively simple systems to highly complex multi-purpose designs. The attendant control problem has become correspondingly complex. 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. On both types, the cabin temperature was adjusted by positioning the face and bypass dampers. While these were sometimes moved by an automatic modulating control, in the majority of cases they were positioned by one of the ship's crew. As these planes cruised at less than 200 mph and normally operated at low altitudes, changes in outdoor air temperatures were generally gradual enough so that manual readjustment of controls could maintain reasonably comfortable cabin conditions. Nearly all of these heating systems were marginal in respect to heat available, and the main problem was lack of heat, rather than inadequate control.

Non-Pressurized Cabins

With the advent of the combustion type heater, and use of larger and faster planes, use of manual controls became impracticable. The combustion type heaters reach full rating in less than a minute after being turned on, and as they are rated at 100,000 Btu per hr and up, and since several heaters are generally used, it would take full time of one crew member to keep cabin temperature regulated. As ships of this type are not pressurized, the heating system is still comparatively simple.

In one type, two 100,000 Btu heaters are placed in parallel positions and the ram air from an external scoop is passed through the heaters and discharged through a series of distributing outlets located in the cabin ceiling. The cabin air is discharged through grilles located in the bottom walls of the cabin. An auxiliary nose heater is used by the crew to obtain additional heat for the cockpit or for windshield defrosting.

The cabin is maintained at the desired temperature by means of an automatic control which operates both heaters simultaneously. This control consists of two duct thermostats, one being mounted in the air inlet duct between the air scoop and the heaters so that it is affected by outdoor ambient temperatures, and the other being mounted in the heater outlet duct so that it is affected by the discharge air temperatures. A thermostat in the cabin is so located that a continuous stream of cabin air passes through it. This type of control has been found to respond to a 1 deg temperature change in less than a second.

As the outdoor temperature starts to drop, the outdoor air duct thermostat decreases in resistance, unbalancing an electronic bridge. This unbalance is amplified by vacuum tubes and causes a power tube to close a relay, turning on the combustion heaters. The resulting increase in temperature is sensed by the warm air duct thermostat which increases in resistance, thus rebalancing the bridge and causing the relay to open. If there were no loss by radiation or convection from the aircraft cabin, these two duct thermostats would be sufficient for adequate control. However, the cabin thermostat is given approximately 30 times more influence than the duct thermostats and so acts as the master controller, and the duct thermostats prevent overheating or underheating and keep the discharge air from alternating between extreme cold and extreme heat.

In a slightly more elaborate system, two combustion heaters supply a plenum chamber which is maintained at a constant temperature. Air from the plenum chamber is then mixed with outdoor air to maintain desired cabin temperature. All of the warm air is discharged into the cabin through the walls. The discharge grilles are located on the floor under seats, and a modulating-type controller varies proportions of heated and outdoor air necessary to maintain desired cabin temperature. The same type of control system as previously described is used, except that an amplifier operates a two-phase motor capable of positioning control dampers instead of operating a relay which would merely open and close the fuel valve. An auxiliary duct, running from the plenum chamber, is used by the pilot as a source of windshield defrosting air.

Pressurized Cabins

With the advent of the new high-speed pressurized transport planes, and the addition of cabin cooling in addition to heating, the control problem becomes more complex. On all of these airplanes, the heat of compression from cabin supercharger must be controlled, the air cycle or expansion turbines must be turned on and also, the heat exchanger or combustion heaters, which are used in the system when cooling is required for additional heat, must be automatically controlled.

Assuming that one of these airplanes is operating in an extremely cold climate, the sequence of operation would be as follows:

The automatic controller for the supercharged-air intercooler would be in full closed position, so that none of the heat of compression would be removed, and the air would bypass the expansion turbine and its compressor and the secondary after-cooler. An additional automatic controller would be operating the combustion heater and supplying the additional heat necessary to maintain the desired cabin temperature. If a heat exchanger were used as a supplemental source of heat, a modulating control operating a damper on this exchanger would run towards full heat position.

As the airplane enters a warm climate and heat requirements drop, the combustion heater would cease operation or the heat exchanger would go to full cold position, and the modulating control on the supercharger compressor would move towards the cold position. When the outdoor ambient temperature rises so high that cooling is desired, the cabin supercharger intercooler would be opened wide. If further cooling were required, the air would go into an air cycle turbine, which is modulated to deliver the required amount of cold air to maintain a comfortable cabin temperature.

Pressure in the cabin is maintained by providing a controlled, constant rate of air flow into the cabin sufficient to maintain ventilation, and adjusting the cabin-pressure relief valve setting, by means of a cabin pressure selector, to maintain the desired cabin pressure. Limits on maximum inside to outside pressure may be of the order of 4 or 5 psi, and safety controls should be provided to prevent exceeding this limit. There is a maximum rate at which the cabin can change to a newly selected value, this rate being in some cases also adjustable.

The requirements for controls of this nature are extremely rigid. It is commonplace for ships of this type to experience changes in outdoor ambient temperatures of as much as 100 deg in a space of 5 min. For this reason, speed of sensing a change and rapidity of response in the control system is essential if satisfactory control is to be accomplished. The older type thermostats cannot be used in airplanes, due to mass of the thermostat and to vibration experienced on all airplanes. All modern controls use some type of bridge system with temperature-sensitive resistors as sensing elements. In some types of controls, the bridge system feeds a sensitive balanced relay, which in turn runs a modulating motor or controls an on-off power relay. A recent sensitive and quickly responding type uses an electronic amplifier, which in turn controls a two-phase motor, or, through relays, controls a d-c motor, or merely closes and opens a power relay for on-off applications.

In addition to extreme speed and accuracy which are required of all aircraft temperature controls, they must be able to operate under great extremes of temperature, pressure and humidity, and also withstand continuous extreme vibration. Heaters should have, in addition to control from thermostats, suitable limit controls to prevent overheating due to failure of air supply, or any other cause. Also, there should be safety devices to shut off fuel in case of flame failure.

On the latest *high speed jet airplanes*, the temperature control problem is still more severe than on the latest transports; as in addition to the accuracy required, control response must be phenomenally fast. For example,