safely be taken as being in the range of 0.32 to 0.38 cu ft per (hr) (lb) of body weight. The heat emission by livestock also varies with the species, and with the size, activity, and sex. It is in the range of 2.4 to 8 Btuh for mammals and 5 to 14 Btuh for birds per pound of body weight.

The factors discussed here apply to an all-cargo airplane as well, but there, of course, primary consideration can be given to cargo requirements without concern for personnel comfort other than the crew. Cargo airplanes may also be equipped with refrigeration to transport such goods as fresh meat, fruit, or frozen foods. The entire cargo area may be refrigerated, or provisions may be made for transporting individually refrigerated containers.

SUPERSONIC TRANSPORTS

The problems of air conditioning airplanes at high subsonic speeds are compounded by the higher ram air and skin temperatures encountered at supersonic speeds. As the temperature of the ram air increases in the supersonic range, it is eventually lost as a heat sink and other suitable sinks must be found. Relatively small supersonic military craft have been successfully air conditioned, but the cooling load of a large passenger capacity transport will be much higher and the comfort requirements more exacting. An extension of the state of the art in many areas will be required.

The cooling load should first be reduced to a practicable minimum by the use of insulation and recirculation of all cabin air except that required to maintain pressurization. If the recirculated air is properly filtered, the makeup of cabin leakage should provide adequate fresh air. Heat intercept methods, where the cabin air is forced out of the cabin uniformly through a porous inner lining to absorb heat at the skin, may have some merit. Plating or coating of the airplane skin with a material to decrease the amount of heat absorbed should also be considered.

The fuel carried by the airplane is a possible heat sink with the heat rejected by the air-conditioning system being used to pre-heat the fuel before it is burned in the engines. This sink has undesirable limitations in that the quantity of fuel is variable, the temperature of the fuel must be limited to a safe value dependent on auto-ignition temperature and pumping considerations, and the fuel will absorb ram air heat which may necessitate pre-chilling before flight, insulation of the fuel tanks, or both. An alternate heat sink is the use of an evaporative fluid such as water or ammonia. This would probably be heavier, at least on take-off, than the fuel heat sink method.

The high ram pressure increase at supersonic speeds offers some advantage in that little or no additional pressure increase may be required to maintain an adequate cabin pressure, depending upon the operating speeds and altitudes.

The actual cooling equipment may be quite conventional, with vapor-cycle systems appearing to be the most promising at this time. The systems may be cascaded, and the use of an air-cycle system in series may offer some advantage in cooling the pressurization air. The greatest complication and refinement will probably have to be in the control systems. The rotating machinery will probably be required to operate in extremely high ambient temperatures, which will introduce special bearing and lubrication problems.

Vortex tubes and thermoelectric devices may be used for dissipating small localized heat loads where their unique characteristics may be used to advantage. Presently, endothermic reactions do not appear to offer anything, but they may be worthy of further consideration in the future.

CHAPTER 19

MARINE AIR CONDITIONING

General Design Requirements, Design Temperatures, Ventilation Requirements, Load Determination, Equipment Selection, Sheet Metal Ducts, Typical Systems, Air Distribution Methods, Controls, Regulatory Agencies

AIR conditioning of merchant vessels prior to World War II was limited to but a few of the better known passenger liners. Since the war, practically every new passenger vessel and converted passenger vessels, with few exceptions here and abroad, provide air conditioning for both passengers and crew in all living accommodations. The most significant recent trend has been the air conditioning of existing as well as new tankers and cargo vessels of all types.

The principal reasons for this increased interest in marine air conditioning are:

1. To safeguard against early obsolescence of the vessel.
2. To increase crew efficiency, particularly during operation in the tropics.
3. To attract and hold better qualified crews.
4. In new construction, to avoid long lay-up for adding air conditioning at a later date.

This chapter will cover the air conditioning applicable for all ocean going vessels whether they be the super luxury liners or the tramp steamer. The broad general principles of air conditioning which apply to land installations are applicable to marine, provided all of the factors affecting the construction and operation of a ship are afforded proper consideration.

GENERAL DESIGN REQUIREMENTS

Factors to be considered in the design of an air-conditioning system for shipboard are as follows:

1. The system should be designed to function properly under conditions of roll and pitch to which a ship is normally subjected.
2. The materials of construction should be suitable to withstand the corrosive effects of sea air and water.
3. The system should be designed for uninterrupted operation during the voyage and continuously all year round. Since ships en route cannot be easily serviced, some standby capacity, spare parts of all essential items, and extra refrigerant charges should be carried.

The system should be designed so that there will be no objectionable noise or vibration. Although the ship's engines and auxiliaries may mask the noise and vibration of the air conditioning systems while in voyage, it must be realized that the main engines and many auxiliaries are shut down while the ship is in port and that the noise level under port conditions must be within the acceptable limits established for land practice.

5. In view of the high premium for space on shipboard, the equipment should be designed to occupy a minimum of space commensurate with cost and reliability. Weight should be held to a minimum.
6. Since a ship may pass through one or more complete cycles of seasons on a single voyage, and experience a change from winter operation to summer operation in a period of days or even hours, the system should be designed to provide the necessary flexibility to compensate for these climatic changes with a minimum of necessary attention by the ship's operating personnel.

Ambient and Indoor Temperature

In determining the proper outdoor design temperatures, consideration should be given to the intended service and type of the vessel. In addition to their regular itinerary, many liners frequently make off-season cruises during which more severe heating and cooling loads may be encountered. The selection of the ambient design should be based upon the temperatures prevalent during the voyage. In general, for the cooling cycle, outdoor design conditions for North Atlantic runs are 95 F dry-bulb and 78 F wet-bulb; for semi-tropical runs 95 F dry-bulb and 80 F wet-bulb, and for tropical runs 95 F dry-bulb and 82 F wet-bulb. For the heating cycle, 0 F is usually used as the design conditions unless it is definitely known that the vessel will always operate in higher temperature climates.

Effective temperatures from 71 to 74 ET generally are selected as inside design conditions for the cooling cycle for passenger and cargo ships. Tankers and non-passenger ships have been designed for 76 ET to 78 ET for crews' quarters, although the trend now is toward greater comfort with lower effective temperatures.

Public spaces and passenger staterooms are designed for 76–80 F dry bulb and from 45–50 percent relative humidity for summer and 70–75 dry bulb for winter. Crews' quarters aboard tankers and cargo vessels can be designed for 80–85 F with 40–50 percent relative humidity. Consideration in the design of the air-conditioning system should be given to maintaining more comfortable room conditions during intermediate outside ambient conditions. Quality systems are designed to provide optimum comfort when outdoor ambient conditions of 65–75 F dry bulb and 90–100 percent relative humidity exist, and to insure that proper humidity and temperature levels are maintained during periods when sensible loads are light. The latter is very important because of large variations in sensible loads (solar, lights and people) in spaces throughout a vessel.

Ventilation Requirements

In staterooms and cabins a minimum of 12½ to 15 cfm outdoor air per person for recirculation systems is supplied and where all primary air is employed, higher air quantities (25 cfm per person or more) are recommended for adequate purging. Specifications often require a minimum of 40 cfm total air to be supplied regardless of the size of the space. In no event should the outside air be less than a 30-min air change. In public spaces, mess rooms, lounges and other spaces of relatively high occupancy the outdoor air requirements should provide a minimum of 10 cfm per person. Toilet spaces within air-conditioned areas are provided with an exhaust which will change the air at least 10 times per hour or a minimum of 35 cfm, whichever is the greater. Fifteen air changes are used where it can be achieved without penalizing the refrigeration load. Some shipowners prefer higher quantities of outside air which of course result in higher air-conditioning loads. Automatic damper controls frequently are provided to increase the amount of outdoor air when outside conditions are such that it can be done without overloading the plant. Of course, under favorable conditions the cooling