

on some, the air going to the cabin from the jet engine compressor can change the temperature at the rate of 150 deg per second. This, coupled with the fact that on smaller size pursuit ships air is changed in the cabin as much as four times per minute, makes the instantaneous sensing of change and an extremely rapid control movement essential. Also, in airplanes operating at Mach numbers in excess of 0.7, the control must react to the large adiabatic temperature rises encountered.

SHIP AIR CONDITIONING

In air conditioning a ship, the designer is faced with all problems that would normally arise on shore installation plus additional factors. Mechanical ventilation is an absolute necessity for the comfort of passengers and ships' personnel, and for utility and preservation of cargo and stores. Ships are constructed with water-tight bulkheads dividing the vessel into several compartments. This complicates the running of ductwork and results in a multiplicity of both supply and exhaust fans. Temperature and humidity requirements of various spaces aboard ship vary widely. Passenger staterooms and public spaces must have year-round air conditioning, which is also being applied more and more to the quarters of the officers and crew. Boiler rooms, galleys, laundries, etc., must have ventilation, and some must have tempered air. Cargo spaces are quite likely to need dehumidification in addition to ventilation.

Inasmuch as ventilation is such a necessary factor aboard ship, the majority of recently built vessels have been utilizing the air distribution system for heating purposes.

A ship is a self-contained structure quite likely to be away from repair ports for long periods. Adequate spare parts, therefore, form an integral part of equipment furnished. The same type of equipment should be used in as many places as possible throughout the ship, in order to reduce the number of spare parts to be carried.

Preliminary system design is simplified by uniformity of conditions which apply to most ships. Among such conditions are: (1) the necessity for the vessel to supply its own power, (2) the availability of an unlimited supply of low cost steam at suitable pressure, (3) limitations of available space and permissible weight.

The problem of heat transfer and insulation must be given careful consideration. The thermal conductivity of ship building material, such as steel, copper and brass, is many times the value of building material used ashore. The length of ducts between heat sources and fans necessitates extra duct insulation. Hull insulation must be of high quality, with attention given to fireproofness, low density, low thermal conductivity, ruggedness, vermin resistance, and ease of application. Board types are most common.

Duct insulation must have the same characteristics as hull insulation. Semi-rigid and rigid board are most common. Corrugated asbestos is not used because in the presence of moisture, it tends to disintegrate. There is a growing use of natural cork on chilled air ducts because of great difficulty in applying an adequate vapor seal due to space limitations.

SHIP HEATING AND VENTILATING

It is usually most economical in weight and space to use steam duct heaters for heating spaces served by

mechanical supply systems. Spaces which do not have mechanical supply, or do not require ventilation in cold weather, are heated by steam convectors or, where the load is large, by unit heaters. Ventilation air, except that supplied to auxiliary and main machinery spaces, is usually preheated to temperatures of 50 to 70 F. No recirculation is used in ventilation and heating systems, but a manual reduction (25 to 50 percent) of air quantity is made during the heating cycle. All heaters are automatically controlled, and preheaters are designed and installed to minimize possibility of freezing of condensate. Preheaters are frequently located close to the outdoor air intake in order to conserve insulation and, for the same reason, zone reheaters are located as close as possible to each zone. Where a reheater serves only one space, it is commonly located in the space.

Table 1.... Design Conditions for Ships

Area	Outdoor Design Temperatures			Indoor Conditions	
	Heating	Ventilating	Cooling	DB & R.H.	Effective Temp.
Living Quarters	F	F	F	F %	F
	0	95	95 (DB) 80 (WB)	80 50	73-74
Public Spaces...	0	95	95 (DB) 80 (WB)	80 55	73 1/2-74 1/2
Naval Vessels...	+10	88 (DB) 80 (WB)	88 (DB) 80 (WB)	85 50	75-78

Combinations or variations of duct type and convection or radiant heaters are used, depending upon basic design requirements, such as weight and space limitations, and the economic justification of the cost of the type selected.

Some design temperatures and humidities for various spaces aboard ship, are given in Table 1. The resulting quantities of air should be checked against typical heating and ventilation practices for ships.*

Living Spaces

The minimum quantity of ventilation air provided for any sleeping or office space, including hospital space, should be based on a temperature rise over the outdoor air of not more than 10 deg (a rise of 7 deg is more satisfactory), with not less than 30 cfm per person.

In spaces fitted for eating, recreation, or manual work, the rise may be taken at 10 deg with not less than 20 cfm per person. The same requirement applies to mechanical exhaust, although natural exhaust may be used where only a short run of duct exists.

Heat should be furnished to maintain the following temperatures:

Staterooms, Berthing, Messing and Office Spaces	70 F
Working Spaces and Shops	60 F
Hospital Spaces	75 to 78 F

Machinery Spaces

The prime purpose of machinery space ventilation is to maintain a habitable temperature for the operating

* See Ventilation and Heating of Maritime Commission Ships, by J. W. Markert (Heating and Ventilating, Feb. 1943, p. 833).

personnel. It is more practicable to use spot cooling of personnel at working areas than to attempt to obtain uniform ambient temperature. The permissible temperature rise (above outdoors) at working stations is usually 15 deg, while the overall temperature rise is usually between 30 and 50 deg.

These spaces must be exhausted adequately, preferably by mechanical means. Every attempt should be made to remove air at or close to the heat sources. The capacity of the mechanical exhaust systems should be greater than the supply, taking into consideration the expansion of the supply air, to insure an indraft through access openings to the space.

Heat is not required for machinery spaces, except for those fitted with electrically operated equipment, which may remain inactive during periods while in port when heating to about 50 F will be required.

Storerooms and Cargo Spaces

The ventilation provided for these spaces depends on the type of vessel, location of space, and nature of cargo.

Ventilation is required for all closed spaces. Even if ventilation is not necessary to preserve the stores or cargo, it is required to prevent the accumulation of toxic or combustible gases and odors. One air change in 15 to 30 min is common practice, except where inflammable liquids or proximity to hot spaces requires additional ventilation. Mechanical supply and natural exhaust are usually used. However, where inflammable gases may exist, natural supply and mechanical exhaust are provided.

Many ships are fitted with dehumidification facilities for eliminating damage to the dry cargo by preventing condensation and dampness. The dehumidification load consists of moisture removed from the ventilation air passed through the dehumidifier, plus the moisture on, or given off by, the cargo, packaging, dunnage, battens, and other materials in the ship's holds. The most severe outdoor condition requires a moisture removal of 90 grains (140-50) per pound of dry air, with 88 F cooling water. The largest cargo ships are provided with equipment for removing about 250 lb of water per hour.

The dehumidifying systems generally utilize silica gel or lithium chloride with inhibitor. (See Chapter 42.) In most cases central drying equipment is provided. On large passenger ships consideration is given to the use of two dehumidifying units, because the cargo-carrying spaces are usually concentrated at the extreme ends of the vessel. A simple duct system distributes the dry air to the hold supply ventilation system. These ventilation systems use outdoor air when weather conditions are favorable. Recirculation and dehumidification are used only when necessary, i.e., when the weather dew point approaches or exceeds the temperature in the hold. Two control stations are generally provided, one in machinery space and one in chart or wheelhouse. These stations are arranged so that either may change the cargo conditioning system controls from use of outside air to use of conditioned air.

AIR-CONDITIONED SPACE TREATMENT FOR SHIPS

The application of air conditioning to new American passenger ships is well established. All passenger staterooms, except steerage and third class, are usually air conditioned. This includes staterooms for ship's personnel

and offices within conditioned passenger areas. Third class staterooms are air conditioned on some ships, depending on the particular trade. Theaters, lounges, smoking rooms, beauty shops, barber shops and similar closed public spaces are usually air conditioned.

All messrooms, recreation rooms, officers' offices, crew's inboard rooms, and those having fixed portlights are usually air conditioned on passenger vessels. The treatment depends on the requirements of the operator and the proposed itinerary of the vessel.

SHIP SYSTEMS AND CONTROLS

The types of comfort conditioning systems used to date generally have followed conventional lines, except for those serving staterooms, offices, and similar small spaces. Large public spaces are fitted with individual systems which supply dehumidified and cooled air during the cooling cycle, and warm air during the heating cycle. In many cases these rooms are fitted with large glass windows and doors, and require direct radiation to offset the downdraft which would occur in cold weather. Finned-tube radiation running the full length of the glass area is commonly used for this purpose. Introduction of warm air at the sill, in lieu of direct radiation, is also used.

Systems serving most public spaces are designed to provide all outdoor air as long as the refrigeration load is less than the capacity of the cooling equipment. Many central systems are simplified by using 100 percent outdoor air all-year-round. The important problem in ship air conditioning concerns the treatment of the small spaces such as passenger staterooms, offices, and crew quarters. Low headroom, congested quarters, double berths, and unsymmetrical arrangements make each space a problem in air distribution and treatment.

The simplest system used for small spaces consists of a central filter bank, supply fan, preheater, and cooling and dehumidifying coil. The preheater steam valve and cooling coil water valve are controlled in sequence by a duct thermostat, in the fan discharge, set to maintain a constant outlet air temperature. Zone reheaters are provided to take care of variations in heating loads. The reheater steam valve is controlled by a submaster thermostat at the reheater outlet. Control of room temperature is obtained by operating manual dampers in the air supply to the space. A recirculation exhaust fan is frequently provided, and operates in conjunction with automatic dampers to utilize the maximum quantity of outdoor air consistent with capacity of the cooling coils.

One system utilizes the same central supply equipment and recirculation exhaust system as the one just described, except that zone reheaters are replaced by individual space hot water reheaters. Each reheater is provided with a control valve, controlled by room thermostat. Generally, a forced-circulation single-pipe hot water system is used. This system is generally used for staterooms and small spaces devoted to first and second class passengers. The average total air per person is about 60 cfm, and average outdoor air per person is about 18 cfm.

A third system, used to a limited extent, is similar to the system just described, except that each room is provided with an induction unit (floor type where possible) which reheats the primary air supply. Control of heating coil in the induction unit is the same as noted for the system described in the previous paragraph. The average primary air supply is about 40 cfm per person. Recircula-