CHAPTER 11

SHIPS

THIS chapter covers air conditioning for oceangoing surface vessels, including luxury liners, tramp steamers, oil rigs, and naval vessels. Although the general principles of air conditioning for land installations also apply to marine applications, factors such as weight, size, and corrosion resistance take on greater importance, and new factors (e.g., tolerance for pitch and roll and shipboard vibration) come into play.

The importance of shipboard air conditioning depends on a ship's mission. On passenger vessels that focus completely on passenger comfort, such as cruise ships and casino vessels, air conditioning is vital. Aboard commercial vessels (tankers, bulkers, container ships, etc.) air conditioning provides an environment in which personnel can live and work without heat stress. Shipboard air conditioning also improves reliability of electronic and other critical equipment, as well as weapons systems aboard naval ships.

This chapter has two sections: Merchant Ships, which includes passenger and commercial vessels, and Naval Surface Ships. In general, the details of merchant ship air conditioning also apply to warships. However, all ships are governed by their specific ship specifications and warships are often governed by military specifications, which ensure air-conditioning system and equipment performance in the extreme environment of warship duty.

MERCHANT SHIPS

Load Calculations

The cooling load estimate considers the following factors discussed in Chapter 29 of the 2001 *ASHRAE Handbook—Fundamentals*:

- Solar radiation
- Heat transmission through hull, decks, and bulkheads
- Heat (latent and sensible) dissipation from occupants
- Heat gain from lights
- Heat (latent and sensible) gain from ventilation air
- Heat gain from motors or other electrical equipment
- Heat gain from piping, machinery, and equipment

The heating load estimate should include the following:

- Heat losses through decks and bulkheads
- Ventilation air
- Infiltration (when specified)

In addition, the construction and transient nature of ships present some complications, as addressed in the following:

SNAME. The Society of Naval Architects and Marine Engineers (SNAME) *Technical and Research Bulletin* 4-16, Calculations for Merchant Ship Heating, Ventilation and Air Conditioning Design, can be used as a guide for shipboard load calculations.

Outside Ambient Temperature and Humidity. The service and type of vessel determine the proper outside design temperature, which should be based on temperatures prevalent in a ship's area of operation. Chapter 27, Climatic Design Information, of the 2001 *ASHRAE Handbook—Fundamentals*, should be used to select ambient conditions, with special attention paid to high wet-bulb data; a ship's load is often driven by the latent load associated with the outside air. It is also common for different locations to be used for cooling and heating criteria. In general, for cooling, outside design conditions are 95°F db and 78°F wb; for semitropical runs, 95°F db and 80°F wb; and for tropical runs, 95°F db and 82°F wb. For heating, 0°F is usually the design temperature, unless the vessel will always operate in warmer climates. Design temperatures for seawater are 90°F in summer and 28°F in winter.

Solar Gain. Ships require special consideration for solar gain because (1) they do not constantly face in one direction and (2) the reflective properties of water increase solar load on outside boundaries not directly exposed to sunlight. For compartments with only one outside boundary, the temperature difference (outside dry-bulb temperature – inside dry-bulb temperature) across horizontal surfaces should be increased by 50°F and vertical surfaces by 30°F. For compartments with more than one outside boundary, the temperature difference should be increased by 35°F for horizontal surfaces and 20°F for vertical surfaces. For glass surfaces, the solar cooling load (SCL) is taken to be 160 $Btu/h \cdot ft^2$ for spaces with one outside boundary and 120 $Btu/h \cdot ft^2$ for spaces with more than one outside boundary.

Infiltration. Infiltration through weather doors is generally disregarded. However, specifications for merchant ships occasionally require an assumed infiltration load for heating steering gear rooms and the pilothouse.

Transmission Between Spaces. For heating loads, heat transmission through boundaries of machinery spaces in either direction is not considered. Allowances are not made for heat gain from warmer adjacent spaces. For cooling loads, the cooling effect of adjacent spaces is not considered unless temperatures are maintained with refrigeration or air-conditioning equipment.

Ventilation Requirements. Ventilation must meet the requirements of ASHRAE *Standard* 62, unless otherwise stated in the ship's specification.

Heat Transmission Coefficients. The overall heat transmission coefficients U for the composite structures common to shipboard construction do not lend themselves to theoretical derivation; they are usually obtained from full-scale panel tests. SNAME *Bulletin* 4-7 gives a method to determine these coefficients when tested data are unavailable.

Inside Air Temperature and Humidity. Thermal environmental conditions for human occupancy are given in ASHRAE *Standard* 55.

People. Ships normally carry a fixed number of people. The engineer must select the location where the ship's fixed compliment of people creates the greatest heat load, and then not apply the people load elsewhere. Note that occupants are only counted once when

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determining the chiller or condensing-unit load; however, air coils in each zone must be capable of removing the heat load associated with the maximum number of people in the zone.

Ventilation in the zone can also be reduced when occupants are not present. For the ventilation load, occupants are counted once, in the location where they create the greatest ventilation requirement. The practical way to apply this concept is by measuring CO_2 levels in a space and adjusting outside air accordingly. Although using this principle can reduce required chiller or condensing-unit capacity on all ships, it is most significant aboard passenger ships.

Equipment

In general, equipment used for ships is much more rugged than that for land use. Sections 6 through 10 of ASHRAE *Standard* 26 list HVAC equipment requirements for marine applications. When selecting marine duty air-conditioning equipment, the following should be considered:

- It should function properly under dynamic roll and pitch and static trim and heel conditions. This is especially important for compressor oil sumps, oil separators, refrigerant drainage from a condenser and receiver, accumulators, and condensate drainage from drain pans.
- Construction materials should withstand the corrosive effects of salt air and seawater. Materials such as stainless steel, nickel-copper, copper-nickel, bronze alloys, and hot-dipped galvanized steel are used extensively.
- It should be designed for uninterrupted operation during the voyage and continuous year-round operation. Because ships en route cannot be easily serviced, some standby capacity, spare parts for all essential items, and extra refrigerant charge should be carried.
- It should have no objectionable noise or vibration, and must meet noise criteria required by the ship's specification.
- It should occupy minimum space, commensurate with its cost and reliability. Weight should also be minimized.
- A ship may pass through one or more complete cycles of seasons on a single voyage and may experience a change from winter to summer operation in a matter of hours. Systems should be flexible enough to compensate for climatic changes with minimal attention from the ship's crew.

The following general items should be considered when selecting specific air conditioning components:

Fans. Fans must be selected for stable performance over their full range of operation and should have adequate isolation to prevent transmitting vibration to the deck. Because fan rooms are often adjacent to or near living quarters, effective sound treatment is essential.

Cooling Coils. If more than 30% outside air is brought across a cooling coil, the use of copper tube, copper fin, or epoxy-coated coils must be considered. To account for the ship's movement, drain pans should have two drain connections. Because of size constraints, care must be taken to prevent moisture carryover. Face velocity limits (in fpm) for different coil materials and different fin spacing are as follows:

Face Velocity Limits, fpm

Fins per Inch (fpi	Aluminum Fins	Copper or Coated Fins
8	550	500
11	550	425
14	550	375

Off-coil temperatures are another concern. Ships typically have low ceiling heights and can not tolerate low air-introduction temperatures. Typically 55°F db and 54°F wb are used as limiting off-coil temperatures.

Electric Heaters. Sheathed heaters are typically required. The only exception is when the electric heaters, approved by a regulatory body such as UL, are incorporated in a packaged unit.

Air Diffusers. Care must be taken with the selection of air diffusers because of the low ceilings typical of shipboard applications.

Air-Conditioning Compressors. Compressors of all types are used for marine applications. Care must be taken when using a non-positive-displacement compressor (such as centrifugal) because low-load, high-condensing temperature is a common off-load condition.

When high discharge temperatures are a concern, seawater-cooled heads are not normally an option; other methods such as fan cooling or liquid injection must be considered for maintaining acceptable discharge temperatures.

Whenever possible, compressors should be the same types used for ship's service and cargo refrigeration, except for the number of cylinders or the speed (see Chapter 30, Marine Refrigeration, in the 2002 *ASHRAE Handbook—Refrigeration*).

Typical Systems

All types of systems may be considered for each marine application. The systems are the same as in land applications; the difference is the relative weighting of their advantages and disadvantages for marine use. This section does not review all the systems used aboard ships, but rather some of the more common ones.

Direct refrigerant cooling systems are often used for small, single-zone applications. Aboard ships, places like control rooms and pilot houses lend themselves to a direct refrigerant system. For larger spaces, air distribution is of more concern; direct refrigerant cooling is thus less likely to be the optimum solution.

Two-pipe and **four-pipe fan coil systems** are often used for large systems. The water piping used in these systems takes up only a fraction of the space used by an all-air ducted system. The disadvantage is fan noise in the space being cooled.

Many types of **all-air systems** are used aboard ships. Space, cost, noise, and complexity are among the leading parameters when comparing different all-air systems. Using high-velocity air distribution for an all-air system offers many advantages; unitary (factory-assembled) central air-handling equipment and prefabricated piping, clamps, and fittings facilitates installation for both new construction and conversions. Substantial space-saving is possible compared to conventional low-velocity sheet metal ducts. Maintenance is also reduced. Noise is the one major drawback of a high-velocity system, which many times leads to selection of a low-velocity system.

Terminal reheat air conditioning (described in Chapter 2 of the 2000 *ASHRAE Handbook—HVAC Systems and Equipment*) is commonly used because of its simplicity and good zone control characteristics. However, as systems become larger the energy inefficiency of this system becomes a significant drawback.

Dual-duct systems (also described in Chapter 2 of the 2000 *ASHRAE Handbook—HVAC Systems and Equipment*) have the following advantages:

- All conditioning equipment is centrally located, simplifying maintenance and operation
- Can heat and cool adjacent spaces simultaneously without cycle changeover and with minimum automatic controls
- Because only air is distributed from fan rooms, no water or steam piping, electrical equipment, or wiring are in conditioned spaces

The major drawback is the inability to finely control temperature and humidity. This disadvantage is enough to preclude using these systems in many passenger vessel applications.

Aboard ships, **constant-volume systems** are most common. Their advantages include simplicity (for maintenance, operation, and repair) and low cost. However, for large passenger vessels, the energy efficiency and the tight control of zone temperature make **variable-volume/temperature systems** very attractive.

Table 1 Minimum Thickness of Steel Ducts

All vertical exposed ducts	16 USSG	0.0598 in.
Horizontal or concealed vertical ducts		
less than 6 in.	24 USSG	0.0239 in.
6.5 to 12 in.	22 USSG	0.0299 in.
12.5 to 18 in.	20 USSG	0.0359 in.
18.5 to 30 in.	18 USSG	0.0476 in.
over 30 in.	16 USSG	0.0598 in.

Air Distribution Methods

Good air distribution in staterooms and public spaces is difficult to achieve because of low ceiling heights and compact space arrangements. Design should consider room dimensions, ceiling height, volume of air handled, air temperature difference between supply and room air, location of berths, and allowable noise. For major installations, mock-up tests are often used to establish exacting performance criteria.

Air usually returns from individual small spaces either by a sight-tight louver mounted in the door or by an undercut in the door leading to the passageway. An undercut door can only be used with air quantities of 75 cfm or less. Louvers are usually sized for face velocity of 400 fpm based on free area.

Ductwork on merchant ships is constructed of steel. Ducts, other than those requiring heavier construction because of susceptibility to damage or corrosion, are usually made with riveted seams sealed with hot solder or fire-resistant duct sealer, welded seams, or hooked seams and laps. They are made of hot-dipped, galvanized, copper-bearing sheet steel, suitably stiffened externally. The minimum thickness of material is determined by the diameter of round ducts or by the largest dimension of rectangular ducts, as listed in Table 1.

The increased use of high-velocity, high-pressure systems has resulted in greater use of prefabricated round pipe and fittings, including spiral-formed sheet metal ducts. It is important that field-fabricated ducts and fittings be airtight. Using factory-fabricated fittings, clamps, and joints effectively minimizes air leakage for these high-pressure ducts.

In addition to the space advantage, small ductwork saves weight, another important consideration for this application.

Control

The conditioning load, even on a single voyage, varies over a wide range in a short period. Not only must the refrigeration plant meet these load variations, but the controls must readily adjust the system to sudden climatic changes. Accordingly, it is general practice to equip the plant with automatic controls.

Regulatory Agencies

Merchant vessels that operate under the U.S. flag come under the jurisdiction of the U.S. Coast Guard. Accordingly, the installation and components must conform to the Marine Engineering Rules and Marine Standards of the Coast Guard.

Comfort air-conditioning installations do not primarily come under the American Bureau of Shipping. However, certified pressure vessels and electric components approved by independent agencies (e.g., ASME, UL) must be used. Wherever possible, equipment should be manufactured to comply with the American Bureau of Shipping Rules and Regulations. This is important when vessels are equipped for carrying cargo refrigeration, because air-conditioning compressors may serve as standby units in the event of a cargo compressor failure. This compliance eliminates the need for a separate, spare cargo compressor. Safety of Life at Sea (SOLAS) is an agency that governs the use of fire dampers and duct wall thickness when passageways or fire boundaries are crossed.

NAVAL SURFACE SHIPS

Design Criteria

Outside Ambient Temperature. Design conditions for naval vessels have been established as a compromise, considering the large cooling plants required for internal heat loads generated by machinery, weapons, electronics, and personnel. Temperatures of 90°F db and 81°F wb are used for worldwide applications, with 85°F seawater temperatures. Heating-season temperatures are 10°F for outside air and 28°F for seawater.

Inside Temperature. Naval ships are generally designed for space temperatures of 80°F db with a maximum of 55% rh for most areas requiring air conditioning. The *Air Conditioning, Ventilation and Heating Design Criteria Manual for Surface Ships of the United States Navy* (USN 1969) gives design conditions established for specific areas. *Standard Specification for Cargo Ship Construction* (USMA 1965) gives temperatures for ventilated spaces.

Ventilation Requirements. Ventilation must meet the requirements of ASHRAE *Standard* 62, except when ship's specification requires otherwise.

Air-Conditioned Spaces. Naval ship design requires that air-conditioning systems serving living and berthing areas on surface ships replenish air in accordance with damage control classifications, as specified in USN (1969):

- Class Z systems: 5 cfm per person
- Class W systems for troop berthing areas: 5 cfm per person
- All other Class W systems: 10 cfm per person. The flow rate is increased only to meet either a 75 cfm minimum branch requirement or to balance exhaust requirements. Outside air should be kept at a minimum to minimize the size of the air-conditioning plant.

Load Determination

The cooling load estimate consists of coefficients from *Design Data Sheet* DDS511-2 of USN *General Specifications for Building Naval Ships* or USN (1969) and has allowances for the following:

- Solar radiation
- Heat transmission through hull, decks, and bulkheads
- Heat (latent and sensible) dissipation of occupants
- Heat gain from lights
- Heat (latent and sensible) gain from ventilation air
- Heat gain from motors or other electrical equipment
- Heat gain from piping, machinery, and equipment

Loads should be derived from requirements indicated in USN (1969). The heating load estimate should include the following:

- Heat losses through hull, decks, and bulkheads
- Ventilation air
- Infiltration (when specified)

Some electronic spaces listed in USN (1969) require adding 15% to the calculated cooling load for future growth and using one-third of the cooling-season equipment heat dissipation (less the 15% added for growth) as heat gain in the heating season.

Heat Transmission Coefficients. The overall heat transmission coefficient U between the conditioned space and the adjacent boundary should be estimated from *Design Data Sheet* DDS511-2. Where new materials or constructions are used, new coefficients may be used from SNAME or calculated using methods found in DDS511-2 and SNAME.

Heat Dissipation from People. USN (1969) gives heat dissipation values for people in various activities and room conditions.

Heat Gain from Sources Within the Space. USN (1969) gives heat gain from lights and motors driving ventilation equipment. Heat gain and use factors for other motors and electrical and electronic equipment may be obtained from the manufacturer or from Chapter 29 of the 2001 *ASHRAE Handbook—Fundamentals*.

Equipment Selection

The equipment described for merchant ships also applies to U.S. naval vessels, except as follows:

Fans. A family of standard fans is used by the navy, including vaneaxial, tubeaxial, and centrifugal fans. Selection curves used for system design are found on NAVSEA *Standard Drawings* 810-921984, 810-925368, and 803-5001058. Manufacturers are required to furnish fans dimensionally identical to the standard plan and within 5% of the delivery. No belt-driven fans are included.

Cooling Coils. The U.S. Navy uses eight standard sizes of direct-expansion and chilled-water cooling coils. All coils have eight rows in the direction of airflow, with a range in face area of 0.6 to 10.0 ft^2.

Coils are selected for a face velocity of 500 fpm maximum; however, sizes 54 DW to 58 DW may have ace velocity up to 620 fpm if the bottom of the duct on the discharge is sloped up at 15° for a distance equal to the height of the coil. Construction and materials are specified in MIL-C-2939.

Chilled-water coils are most common and are selected based on 45°F inlet water with approximately a 6.7°F rise in water temperature through the coil. This is equivalent to 3.6 gpm per ton of cooling.

Heating Coils. The standard naval steam and electric duct heaters have specifications as follows:

Steam Duct Heaters

- Maximum face velocity is 1800 fpm
- Preheater leaving air temperature is 42 to 50°F
- Steam heaters are served from a 50 psig steam system

Electric Duct Heaters

- Maximum face velocity is 1400 fpm
- Temperature rise through the heater is per MIL-H-22594A, but is in no case more than 48°F.
- Power supply for the smallest heaters is 120 V, three-phase, 60 Hz. All remaining power supplies are 440 V, three-phase, 60 Hz.
- Pressure drop through the heater must not exceed 0.35 in. of water at 1000 fpm. Use manufacturers' tested data in system design.

Filters. Characteristics of the seven standard filter sizes the U.S. Navy uses are as follows:

- Filters are available in steel or aluminum
- Filter face velocity is between 375 and 900 fpm
- A filter-cleaning station on board ship includes facilities to wash, oil, and drain filters

Air Diffusers. Although it also uses standard diffusers for air conditioning, the U.S. Navy generally uses a commercial type similar to those used for merchant ships.

Air-Conditioning Compressors. In the past, the U.S. Navy primarily used reciprocating compressors up to approximately 150 tons; for larger capacities, open, direct-drive centrifugal compressors are used. On new designs, the U.S. Navy primarily uses rotary compressors (e.g., screw and centrifugal). R-134a is the U.S. Navy's primary refrigerant. Seawater is used for condenser cooling at 5 gpm per ton for reciprocal compressors and 4 gpm per ton for centrifugal compressors.

Typical Air Systems

On naval ships, zone reheat is used for most applications. Some ships with sufficient electric power use low-velocity terminal reheat systems with electric heaters in the space. Some newer ships use a fan-coil unit with fan, chilled-water cooling coil, and electric heating coil in spaces with low-to-medium sensible heat per unit area of space requirements. The unit is supplemented by conventional systems serving spaces with high sensible or latent loads.

Table 2 Minimum Thickness of Materials for Ducts

Sheet for Fabricated Ductwork				
	Nonwatertight		Watertight	
Diameter or Longer Side	Galvanized Steel	Aluminum	Galvanized Steel	Aluminum
Up to 6	0.018	0.025	0.075	0.106
6.5 to 12	0.030	0.040	0.100	0.140
12.5 to 18	0.036	0.050	0.118	0.160
18.5 to 30	0.048	0.060	0.118	0.160
Above 30	0.060	0.088	0.118	0.160

Welded or Seamless Tubing		
Tubing Size	Nonwatertight Aluminum	Watertight Aluminum
2 to 6	0.035	0.106
6.5 to 12	0.050	0.140

Spirally Wound Duct (Nonwatertight)		
Diameter	Steel	Aluminum
Up to 200	0.46	0.64
Over 200	0.76	0.81

Note: All dimensions in inches.

Air Distribution Methods

Methods used on naval ships are similar to those discussed in the section on Merchant Ships. The minimum thickness of materials for ducts is listed in Table 2.

Control

The navy's principal air-conditioning control uses a two-position dual thermostat that controls a cooling coil and an electric or steam reheater. This thermostat can be set for summer operation and does not require resetting for winter operation.

Steam preheaters use a regulating valve with (1) a weather bulb controlling approximately 25% of the valve's capacity to prevent freeze-up, and (2) a line bulb in the duct downstream of the heater to control the temperature between 42 and 50°F.

Other controls are used to suit special needs. Pneumatic/electric controls can be used when close tolerances in temperature and humidity control are required, as in operating rooms. Thyristor controls are sometimes used on electric reheaters in ventilation systems.

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Note: MIL specifications are available from Commanding Officer, Naval Publications and Forms Center, ATTN: NPFC 105, 5801 Tabor Ave., Philadelphia, PA 19120.