tion of objectionable, combustible and toxic gases. Shipboard equipment must also be reliable inasmuch as specialized servicing facilities are not available at sea, and failure during an emergency may jeopardize the vessel's safety. Experience has demonstrated that *simple* and *foolproof* heating and ventilating arrangements are essential for satisfactory service. Ventilation systems on ships must be designed to operate in heavy weather with little or no attention, and to resist the efforts of unauthorized personnel to readjust the heat or air distribution. Also, they must be laid out in such a manner that the watertight and fireproof integrity of the vessel is not impaired.

Contrary to the impression among some engineers and designers, that there is a basic difference between marine and shore installations in the application of heating, ventilating and air conditioning arrangements, the same fundamentals apply to both shore and shipboard applications. The air capacity handled by a system ashore will equal the capacity that an identical system will deliver afloat. The same laws of heat transfer apply, and the same heat balance must be maintained in the human body. The only variation between ship and shore applications is that emphasis is placed on different practical aspects of the design.

## SHIP CONSTRUCTION FEATURES

The seaworthiness of the vessel is increased by subdividing the main watertight hull space into a number of watertight compartments. This is usually done by providing transverse watertight structures (bulkheads) so located along the ship's length that the vessel will not sink even when the shell is pierced in one or more watertight compartments, by collision, torpedoing, or other causes. It is obvious that the watertightness of these bulkheads is very important, particularly under war conditions. Every effort is made to lead ventilation ducts so that they do not pass through such structures. Where openings must be cut for ventilation or other purposes, special watertight closures are fitted to protect the watertightness of the bulkheads.

In addition to the obstructions caused by the main transverse bulkheads, the ship's interior is fitted with decks and flats (partial decks) that are spaced to suit the use to which the space is put. The deck height (floor height) in cargo spaces generally varies from 9 to 30 ft. This height in living quarters varies from 7½ to 9 ft. Usually in main machinery spaces, the entire depth is subdivided only by a few flats, with gratings provided where necessary to service the equipment.

Bulkheads, shell, and decks are designed to suit structural as well as watertight requirements of the vessel, and consequently, the designer must always contend with beams, stiffeners, stanchions and brackets.

Fig. 1 indicates the arrangement of a typical cargo vessel, and shows the main transverse watertight bulkheads, decks, structural members, and many other pertinent characteristics. Living quarters are usually located on and above the weather deck, this custom being based on the assumption that better natural air and light are available in this location. It is obvious that the upper 'tween deck and other spaces can be conveniently used for additional living and working spaces, but that natural ventilation is far less effective in this case.

The foregoing description mentions some of the limits and natural boundaries which affect the design and layout of ship ventilation and heating systems. It should be added that there are also equipment, wireways, and miscellaneous piping which must be considered. Since



there is very little unassigned space, fan rooms are usually quite congested and many studies must be made to ascertain the arrangement of equipment which will best suit the conditions. Cuts in structural members must be limited in number and size. Lack of headroom often causes poor aspect ratios, inaccessibility, and other undesirable conditions. It therefore follows that the design of a ship's heating and ventilating system is far more than a theoretical calculation. A good designer must be familiar with all phases of ship construction and operation in order to provide sufficient and efficient ventilation and heating, and to locate the equipment where it will interfere least with basic arrangements, major equipment, stability, and other important factors.

## FACTORS AFFECTING DESIGN

A ship may be favorably compared to a *floating hotel*. Its make-up includes living accommodations, dining rooms, shops, power plants, commissary spaces, etc., all of which must be so arranged and maintained as to make it self-sustaining for long periods of time. In contrast to a hotel, however, a ship may, on a single cruise, move from arctic to tropical climates. On the other hand, it may be built to operate only in one single locality. It is therefore necessary to assume maximum and minimum design air temperature conditions based on the intended use of the vessel so that adequate cooling and heating may be provided. For vessels designed to operate generally in all parts of the world, a maximum summer temperature may be taken as 88 F and a minimum winter temperature as 10 F. For other ships, those which spend long periods in port or in inland waters, the maximum and minimum temperatures may be taken as 90 and 0 F respectively.

Preliminary design of heating and ventilating installations aboard ship is simplified by the uniformity of the conditions which apply to all ships. Among such conditions are (1) the necessity for the vessel to supply its own power, (2) the availability of an unlimited supply of sea water, (3) the drastic restriction of shipbuilding materials because of strength requirements, corrosion resistance and fire hazard, and (4) the limitation of available space and permissible weight. On the other hand, shipboard space, weight, and power limitations require precise layouts with minimum design safety factors, and this necessitates unusual attention to design details. Particular attention should be given also to the adjustment of a system after installation, because designed air quantities are usually close to the minimum acceptable and therefore, improper balance will result in unsatisfactory conditions in some spaces.

Each space aboard ship must be treated in accordance with the particular requirements of its use. The ventilation of most spaces is determined by empirical calculations. The quantity of air supplied must be not less than that which satisfies (1) maximum allowable temperature rise, (2) minimum allowable fresh air per person, and (3) permissible air change, named in order of importance.

The present practice of various ship designers may be to supply the quantity of air which satisfies only one of these requirements, but the most satisfactory ship ventilation will result from the use of that quantity which is large enough to satisfy all three.

When heating and cooling loads are estimated, the cooling effect of the water through which the vessel is sailing must be considered if the space is at or below the waterline. Maximum and minimum water temperatures of 85 and 35 F are usually used for such calculations. This factor is