AIR CONDITIONING IN H.M. SHIPS

PART I

BY

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Introduction

The history of mechanical ventilation in H.M. ships is full of interest and a little of it should be included as the logical starting point for any paper on air conditioning.

Before the last war, mechanical ventilation was the established means of environmental improvement in H.M. ships and, even in the tropics, conditions were said to be tolerable if not entirely pleasant.

Systems were based on a set rate of air changes according to the type of compartment. The use of the compartment also dictated the choice of system, e.g., fan supply/natural exhaust, natural supply/fan exhaust, fan supply and exhaust.

In the late 1930's it was realized that this was an unsatisfactory basis of calculation, and ventilation systems were henceforth calculated on a basis of heat extraction, ensuring that the air did not rise in temperature more than 10 degrees F between the outside atmosphere and the compartment to which it was delivered. This remains the basis of calculation for compartments which have 'ordinary' ventilation and not air conditioning.

The 1939–45 war provided the real impetus for the introduction of air conditioning into the Fleet; particularly when the war moved to Far Eastern and tropical waters. Ship designers were more concerned with keeping water out of their ships than admitting air to it. Hence the degree of WT subdivision, the reduction in number of sidescuttles (hitherto provided with wind scoops for additional ventilation), the need to keep hatches closed, the introduction of additional scientific heat-producing equipment and the essential darken-ship arrangements at cruising stations all combined to make unsatisfactory the environmental conditions within the ship.

In the tropics they became intolerable and a large problem of immediate improvement was created. A habitability mission to the Far East was established in 1945, as a result of which a limited amount of air conditioning was introduced into important operational compartments containing heat producing electronic equipment.

The amount and application have been increasing ever since.

Definitions and Basis of Calculation

Air conditioning is defined as controlling artificially the following properties of the air which surrounds us:—

Temperature—by either heating or cooling

Humidity—by either humidifying or dehumidifying the air

Impurity content—by filtration (CO, CO_2, solid impurities, etc.).

In H.M. ships the term 'air conditioning' covers the process of heating, cooling, water extraction and filtration. Humidification is not normally provided for.

Air conditioning is concerned with the maintenance of certain conditions of comfort, i.e., it is not a relatively precise matter like determining the temperature of a substance: it is concerned with the subjective question of how comfortable (or uncomfortable) a man is in his surroundings. There are four factors which regulate one's reaction to one's atmospheric environment:

(*a*) Actual air temperature
(*b*) Humidity of the air
(*c*) Air movement
(*d*) Heat radiation.

Several attempts have been made to devise a single index to indicate how comfortable (or uncomfortable) one feels according to the variation of the above factors. The one of most interest to us is that of Effective Temperature, which is the one used by MOD(N) as the basis of calculations.

Effective Temperature (ET) may be defined as that temperature at which in still, completely saturated air, one would experience equal comfort as in the case under consideration. In H.M. ships we design to an ET of 78 degrees F in air conditioned compartments. The use of the sling and Assman psychrometers —variations of the 'wet and dry bulb' thermometer—to measure humidity is fairly well known, and the ET of 78 degrees is usually expressed as 85 degrees F Dry Bulb, 71 degrees F Wet Bulb. Other combinations will, *within limits*, give the same effective temperature. An upper limit of 70 per cent Relative Humidity is maintained.

For the purposes of design in H.M. ships, one of two ambient conditions is assumed, viz:

Tropical	88 degrees F DB 80 degrees WB RH = 70 per cent
Extreme Tropical	94 degrees F DB 86 degrees WB RH = 73 per cent

'Tropical' conditions approximate to conditions in Singapore and occur also in the eastern Mediterranean. 'Extreme tropical' are those experienced in the Persian Gulf in summer and, seasonally, elsewhere in the world.

For a new ship design the Staff Requirements state to which of these two standards the ship is to be air conditioned.

Ignoring the heating and filtration aspects for the moment, the most significant matter is to cool the air and reduce its moisture content.

The basis of calculation is to consider for each compartment involved, the total heat load output (both sensible and latent), from men and equipment within, boundary heat loads due to adjacent compartments or solar radiation, and by comparison with the conditions of the assumed external ambient, to calculate thereby the heat extraction required.

Trunk sizing calculations, which follow, are based on a pressure-drop method with a maximum air velocity of 3000 ft/min.

Most of the air handled is recirculated. There is a fresh air make up of not less than 10 cu ft/man/min admitted to the ship (compared with about 30 for an 'ordinary' ventilation system) and an equal quantity must therefore be lost from the compartment. This is done by 'bleeding off' into passageways, WCs, bathrooms or other non-air-conditioned compartments as a welcome source of 'second-hand' conditioned air, from which compartments the air is discharged overboard by the ventilation exhaust.

In performing the heat load calculations, certain advantageous assumptions are made, viz:—

(*a*) The heat transfer coefficient (k) of boundary insulation is doubled to allow for bad workmanship in fitting.

(*b*) Multiple occupation of compartments is assumed, e.g., the latent and sensible heat of men are used at least 3 times: at the man's place of work, in his mess space, in the dining hall.

(*c*) The sun is assumed to shine on both sides of the ship at the same time (but not on both sides of any individual compartment).

As a result of the above, in a properly designed and installed system the ET actually achieved will be below 78 degrees, say about 76 degrees.

Under heating conditions, dry bulb temperature gives much of the information regarding physical comfort, and the concept of effective temperatures does not apply. Under these conditions, therefore, we normally design to achieve a compartment temperature of 65 degrees F in an ambient of 14 degrees F. The air system is already designed for cooling conditions. This fact, and varying compartment heat loads, may produce unequal compartment temperatures when heating. Hence we design to a lower figure and employ branch heaters.

In particular cases, e.g., icebreakers, we design to an assumed ambient of —20 degrees F and in such cases the need for humidification must be given consideration.

Extent of Air Conditioning

The present trend is to air condition all operational spaces, electronic compartments, living and recreational spaces, offices, workshops and similar spaces. Excessively hot compartments, e.g., machinery spaces, galleys, etc., are not at present air conditioned although galley preparation spaces should be given a cooled air supply (not recirculated). Store rooms, etc., according to purpose are not usually air conditioned but may be ventilated from a suitable a/c system if an advantageous simplification of trunking results.

Types of System

As far as air distribution is concerned, there are two types of system in use in H.M.ships viz (i) the group or centralized system and (ii) the unit cooler system (see FIG. 1).

In the first, a percentage of fresh air is mixed with recirculated air (as previously mentioned) and the whole passed through an Air Treatment Unit (ATU) where it is heated and/or cooled and then distributed to compartments by means of trunking.

In the second, a more limited amount of fresh air is admitted to the ship, treated as above in a much smaller ATU and then distributed to compartments by trunking. Within these compartments are situated recirculatory unit coolers, consisting of a filter, a fan and a cooling coil (and sometimes a heater).

Selection

FIG. 2 compares the advantages of the two systems. The Working Party on Ventilation and Air Conditioning in H.M. ships, which produced its report in April, 1968, agreed unanimously to recommend the use of centralized systems as the standard means of air conditioning H.M. ships.

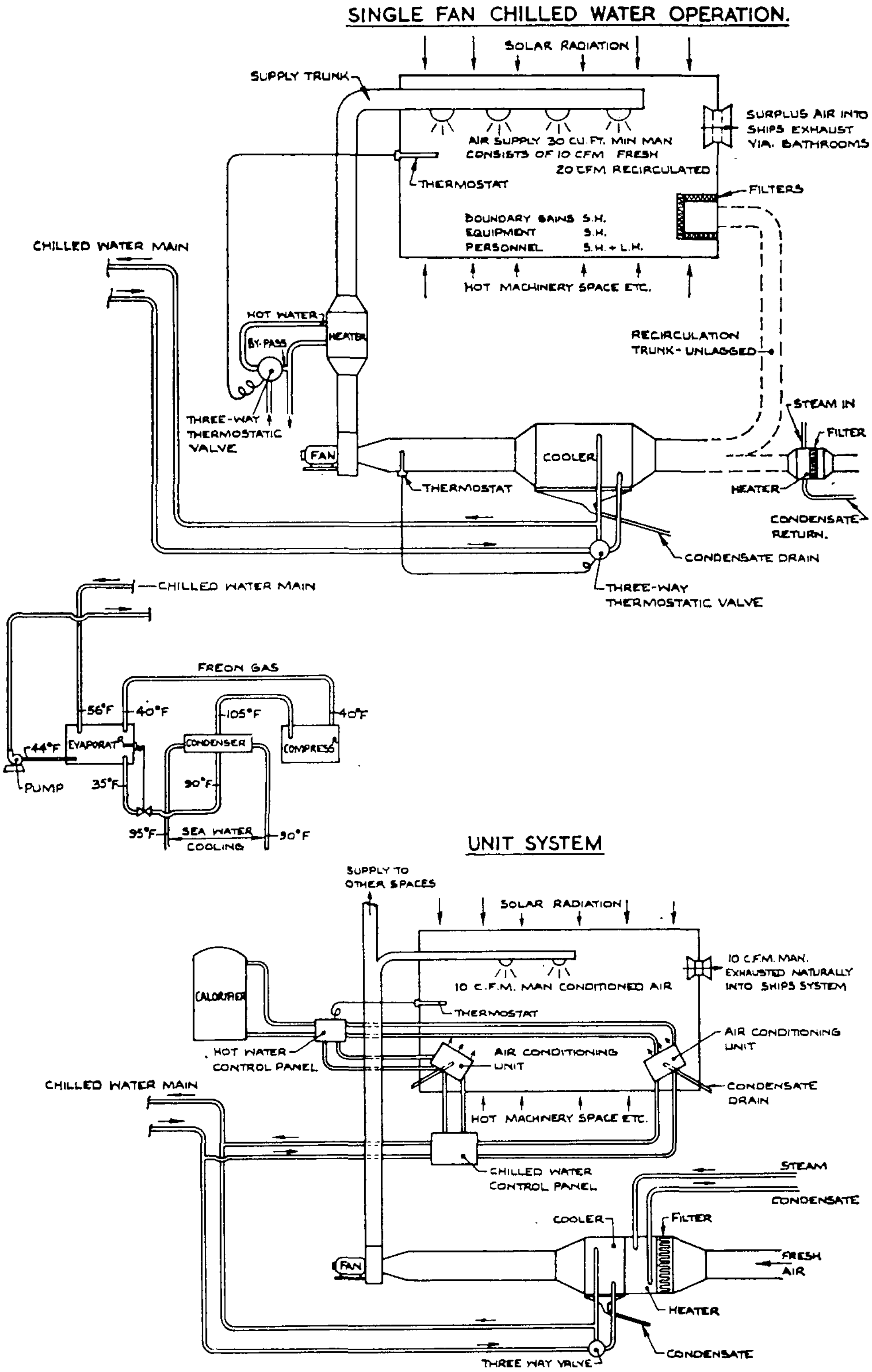


FIG. 1—AIR-CONDITIONING SYSTEMS

While it must be agreed that there are circumstances in which a unit cooler is a satisfactory answer, D.G. Ships has, with time, become increasingly convinced of the correctness of the Working Party's recommendation. In mess spaces, for example, provided with unit coolers, while a reasonable temperature distribution may be obtained, the average layout makes the achievement of a good air velocity distribution almost impossible. This is the reason for the frequent complaints of stuffiness and stagnant pockets.

Centralized System	Unit Cooler System
1. Better air distribution within the compartments served.	1. Less trunking, smaller air treatment unit compartments. (Only fresh air handled by ATU.)
2. Better disposal of smells and odours.	2. Balancing of system is simplified.
3. Less incidence of stuffiness and headaches.	3. Breakdown of a unit has less effect than the breakdown of the fan in a centralized system.
4. Better compartment layouts are possible than with unit cooler system.	4. Conditions in any compartment are less influenced by those in others.
5. Simplification of: (*a*) Electrical supply arrangements (*b*) Chilled-water supply piping (*c*) Condensate drains (*d*) Control arrangements.	5. Closing down systems if a fire occurs disrupt a smaller area.
6. Reduced maintenance load compared with unit system.	6. Suitable for making simple additions if the chilled water capacity is available.
7. Better distribution of filtered air from AFUs when ship is closed down.	

FIG. 2—AIR DISTRIBUTION SYSTEMS—RELATIVE ADVANTAGES

The Heating and Ventilating Research Association (HVRA) at Bracknell in in Berkshire has recently performed for MOD(N) some experiments on air distribution in simulated mess spaces. The results fully bear out the above.

Cooling Systems

There is a choice of two systems for cooling the air:

(*a*) *The Direct Expansion System* in which the coil over which the air passes is part of the actual refrigeration circuit, and the fluid passing through it is a refrigerant, such as Freon.

(*b*) *The Chilled-Water System* in which the fluid in the cooling coils is chilled water which has been conveyed from the refrigerating plant by a chilled-water main.

The small self-contained air-conditioning unit—widely used for providing some air conditioning as an afterthought—is an example of a small direct-expansion plant. But our concern is mainly for group systems and in this the chilled-water system has the following significant advantages for naval use:—

(*a*) A limiting distance between the cooling coil and the compressor in a direct-expansion system imposes restrictions on the siting of ATUs and plant.

(*b*) A chilled-water system lends itself to a main running the length of the ship with as many plants feeding it as necessary, and branches to ATUs or equipment requiring cooling as necessary.

(*c*) Cross-connection of plants and the provision of stand-by plants is easier in a chilled-water system.

(*d*) Chilled-water leaks are less troublesome than refrigerant leaks

(*e*) A warship with a large electronic cooling load requires a chilled-water system for this purpose in any case, so there is little, if any, simplification in the use of direct-expansion plant for air conditioning.

(*f*) Shore connections to enable chilled water to be supplied from shore plant when the ship is in refit are easily provided. This is difficult with direct-expansion systems.

FIG 3. shows a simplified diagrammatic arrangement of the type of chilled-water system which it is attempted to fit in new ship designs.

Equipment

The most significant components of a system are plant, fans, coolers, heaters, filters and distribution equipment. A few remarks follow concerning these items, with the exception of the plant which is dealt with in more detail by D. G. Greaves in Part II of this article.

Fans

Apart from a limited number of fans for special purposes, two ranges of fans have been established as SYMES items. They are:—

(*i*) *The AX/ACT range of axial fans.* Some 34 fans covering outputs from 500 to 25 000 cfm at water gauges ranging from 1 in. to 6 in.

(*ii*) *The CN/CW range of centrifugal fans.* 24 fans covering a more limited range of outputs than the axials but at rather higher pressures.

These fans are direct driven, which in general has several advantages for naval use. In some special cases, belt driven fans may appear to have other more significant advantages and in a few isolated cases these are used.

Coolers

A range of 10 chilled-water coolers for compartment cooling, with an associated range for the cooling of electronic equipment, has been designed and will be established in the SYMES index. Until quite recently the process of obtaining a chilled-water cooler was to invite tenders stating the thermal performance and acceptable physical dimensions, accepting thereafter more or less what the manufacturer offered. The establishment of a standard range is an obvious improvement and long overdue.

Unit Coolers

These comprise a chilled-water heat exchanger and an associated fan. The specification for these has resulted in two separate ranges according to manufacturers, viz:

(*i*) 'Thermo-Units' (Thermotank)—5 units: 4000–15 000 Btu/hr.

(*ii*) 'Tornel' or 'Tanflo': Keith-Blackman or Norris Warming—5 units: 3380–13 500 Btu/hr.

Heaters

The standard coolers mentioned above can be used as hot water heaters, although none has been so used up to the present. In addition, there has been established for some time the standard 'Admiralty Range' of steam heaters—which do not require any particular comment.

A more significant matter is that D.G. Ships is now considering the establishment of a full range of electric fresh air heaters. This decision is the result of the use of gas turbine propulsion and the consequent reduction in the availability of steam for heating. It is thought that in new designs electricity will be a strong contender as a heating medium and must not be excluded through lack of suitable equipment.

Filters and Filtration

In view of the difficulty in cleaning the inside of an air-conditioning system—trunking, fans, cooling and heating coils, etc.—and to minimize the amount of impurities in the air breathed, filtration is important to limit the ingress of dirt at source.

Fresh air filters are provided against atmospheric and industrial dirt—of particular value when in harbour—and recirculation filters prevent internally produced impurities such as blanket fluff from being taken in to the system.

The present approved material for recirculation filters is de-membraned polyurethane foam sheet; an effective, cheap and durable material which may be washed easily and re-used over and over again. It is also being introduced for fresh air filters as an alternative to the longer established wire mesh oil-wetted filter.

In spaces in which considerable numbers may congregate there is a need to remove odours and tobacco smoke. Special bulkhead or deck-head mounted units are provided for this purpose, consisting of a fan and filter element. Tobacco smoke filtration cannot conveniently be carried out in conjunction with the air conditioning system air supply, as the degree of filtration required is much higher and the air velocity over the filter element must be much lower. The units therefore operate as a quite separate recirculation device within the air-conditioned space.

The unit at present in use is not deemed to be entirely satisfactory and enquiries are being made to industry and the Chemical Defence Establishment, Porton Down, regarding the design of a better unit which will also have some odour extraction capability.

In addition, special filters are used where special requirements exist, e.g., galley grease filters, lint filters in laundries.

Distribution Equipment

The punkah louvre is a well established and widely known item for this purpose. Modern punkah louvres may be adjusted to give either an air jet or a diffused supply and many are still in use in situations in which it is desirable to have a positive stream of cool air directed on to the occupants of a compartment, e.g., galleys, machinery space watchkeeping positions, etc.

In general, the punkah louvre is not entirely satisfactory in air-conditioned spaces and diffusers are to be preferred. The previously mentioned trials at HVRA include comparative trials of different diffusers.

PARTICULAR FEATURES OF WARSHIPS

Special considerations must be taken into account when designing air-conditioning systems for warships. These would not be applicable in the case of passenger liners or shore installations, where more sophisticated systems with a greater degree of control are often fitted. The particular considerations are:—

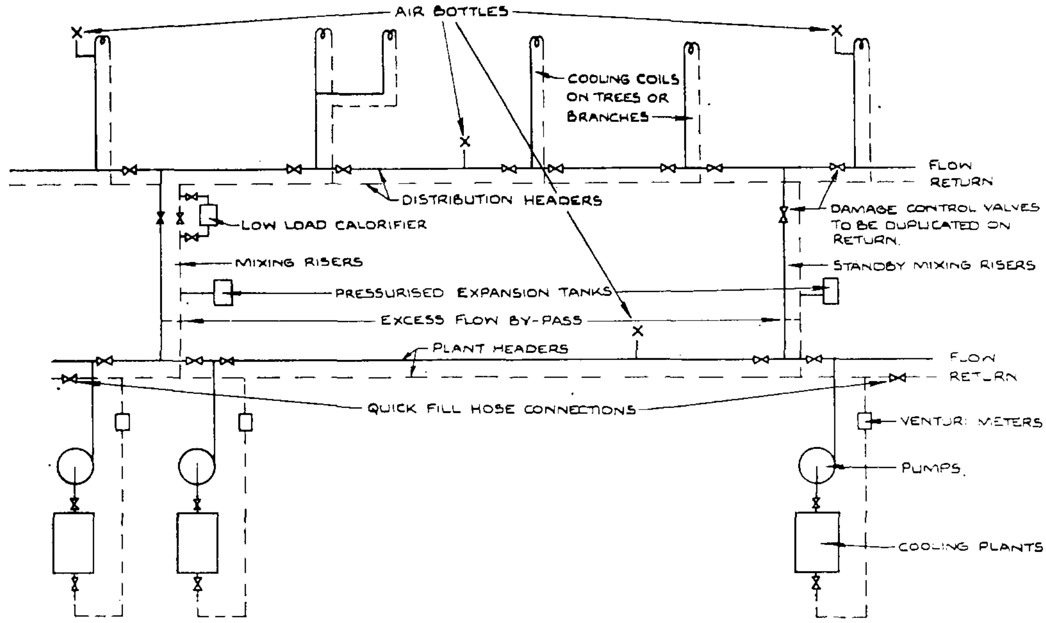
(*a*) Space is at a premium: trunking needs to be small and robust. Inefficient leads of trunking must sometimes be accepted.

(*b*) The above results in systems of moderately high velocity. (2000 ft/min is preferred, but velocities of up to 3000 ft/min have to be accepted.)

(*c*) Shock and vibration are allowed for by paying suitable attention to robustness, method of mounting etc.

(*d*) Penetration of bulkheads and decks must be limited in the interests of watertight integrity.

DIAGRAMMATIC SKETCH OF STANDARD CHILLED WATER SYSTEM.



NOTE:- (1) ANY ONE COOLING PLANT MAY BE STANDBY PLANT.
(2) FOR THE PURPOSE OF PIPE SIZING, ASSUME ALL PLANTS RUNNING.

FIG. 3

(*e*) The wide range of types of compartments served, some with high sensible heat ratios (unmanned electronic compartments) and some with low (offices, living spaces, etc.). The two types of compartments should ideally not be combined in a common system, but requirements of compartment siting sometimes make separation difficult.

(*f*) Wide range of climatic conditions in which H.M. ships serve.

(*g*) Chilled-water systems have to be modified from the 'ideal' shown in FIG. 3, to allow for the possibility of action damage, e.g.,

(*i*) Duplication and separation of risers.

(*ii*) Separation of delivery mains into 'essential services' main and non-essential main.

Provision of stand-by plant is essential since the modern warship contains a large amount of electronic equipment, without which the ship becomes non-operational and, in addition, environmental conditions become intolerable when it breaks down.

Provision of 'truflo' switches and solenoid-operated valves to isolate sections if damaged to minimize loss of chilled water.

(*h*) Both chilled-water and air systems must be made as simple as possible in order to limit maintenance.

(*i*) The small trunks and comparatively high air speeds and sometimes unavoidably tortuous runs of trunking sometimes produce noisy systems. As well as being unpleasant to live with, noise is an obvious operational disadvantage and means need to be taken to reduce it.

The standard fan ranges were designed with noise reduction in mind. Other features are resilient mounting, flexible connections between fans and trunking (for shock and vibration reasons also), avoidance of features likely to cause air turbulence, etc.

(*j*) A naval messdeck consists essentially of a compartment divided into a sitting-out area and an area containing rows of 3-tier bunks—fundamentally an arrangement in which it is difficult to achieve satisfactory air distribution.

(*k*) There is an operational requirement to close down warships. Hence arrangements are made to close all fresh air intakes and to work on recirculation alone, apart from a greatly reduced quantity of filtered fresh air admitted through Air Filtration Units (AFUs).
Conditions within the ship may be as good when closed down as at any other time, if not better. This is hardly surprising since if one refrains from admitting hot air to the ship, the temperature within might well be expected to be lower.

(*l*) The number of external openings must be limited to simplify the closing down problem. This, of course, tends to increase the size of trunking, contrary to the need of (*a*) above.

(*m*) Systems must be grouped for NBC reasons:
Q Keep running
R Close down temporarily
S Close down essential.

TROUBLES IN SERVICE

Complaints concerning installed systems fall into a number of well-defined groups and the most significant are discussed below.

Lack of Cooling

This may be due to inadequate provision of cooling plant, resulting perhaps from the total heat load finally proving to be greatly in excess of that allowed for in the design stage. A 25 per cent capacity margin in plant provision is made to allow for such situations.

On the other hand, improper chilled-water system and plant operation may be the reason. D.G. Ships is attempting to improve the standard of operators' handbooks supplied to ships which it is hoped will improve the position.

Air locks in inadequately vented chilled-water systems reduce the cooling effect.

Lack of Air—Stuffiness

These are two separate complaints in fact, but are often made in association with each other.

Where the amount of air handled in a compartment is up to the design quantity, and the coolers are working properly, stuffiness is the result of bad distribution.

True lack of air can result from a number of causes:—

(*a*) *Design and installation.* Basic design work and fan selection is done at an early stage in a ship design. During the ship-fitting stage additional resistance may be built into a system by revision of trunking layouts, the introduction of additional or sharp bends or unsatisfactory trunking leads adjacent to the fan (bearing in mind that this last factor also reduces the fan output below that assumed).
Serious faults of this nature should come to light during the balancing of the system on completion. Where, however, the design requirements appear to be only just met, natural deterioration of performance during service will bring the deficiency to light unless a margin is provided.

(*b*) *Lack of Maintenance.* Dirty systems result in increased frictional resistance of trunking and components, with correspondingly reduced air flow. Cases are recorded of incredible collections of rubbish, dockyard material, etc., being discovered within ventilation trunking.
It must be admitted that the fault for neglected cleaning does not invariably lie with the Fleet; some systems are so constructed that proper cleaning is virtually impossible. The necessity for ease of access to the internals of the system must be borne in mind during the design and installation stage, particularly where masking of ventilation by pipe systems can occur, or where trunking is run behind linings.

(*c*) *Interference with Systems.* This is usually the result of someone thinking he can improve his own conditions by some slight modification, and ignoring the effect of his action on the remainder of the system. It covers such diverse activities as limiting an uncomfortable draught from a punkah louvre by the insertion of a foreign body into the trunking ('old socks' are traditionally quoted as the medium used), through irresponsible adjustment of 'set' baffles to actual modifications to the air distribution system, using the ship's more than adequate workshop facilities. These actions are dangerous because they tend to mask fundamental faults which may be present in the system.

(*d*) Fans are sometimes wired electrically incorrectly so as to cause reverse running and lowered output.

Condensation

Where air-conditioning trunking or chilled-water piping passes through non-air-conditioned spaces, efficient lagging is essential to prevent the air in contact with the outside of the trunk or pipe being cooled to below the dew point and so causing condensation. In this connection, of more importance than the insulation itself is the provision of an efficient vapour seal. This is particularly important in the region of trunk or pipe hangers, flanges, valves, etc.—which are easy to overlook. The adoption of a suitable material to form a satisfactory vapour seal for ventilation trunking is a difficulty of long standing. New methods are however, being introduced experimentally into the Fleet, which are of some promise.

In passing it may be noted that satisfactory arrangements are not always made for drainage from the driptray of cooling coils. Insufficient slope will prevent the proper disposal of condensate from the coils: an obvious point but sometimes overlooked.

FUTURE DEVELOPMENTS

Much attention is focused today on habitability—in particular the furnishing and decor aspects of the sailor's living surroundings. Improvements in this field will inevitably cause changes in the air-conditioning system. In the sitting-out areas of messdecks there will be an increasing tendency for trunking to be run behind lining for the sake of appearance; the more familiar types of distributor will probably be replaced by something with more aesthetic appeal. When the QE2 was visited at Southampton some months ago, it was found difficult to discover the points of entry of conditioned air in one of the public rooms, so well were they incorporated into the decor.

As far as technical changes are concerned D.G. Ships may be called upon to introduce the following features:—

Lower Design Criteria

The present design figure is 78 degrees F effective temperature, which was thought in 1945 to be the highest acceptable for human efficiency, i.e., rather than comfort. Already the USN designs to 74 degrees ET (the disparity is actually lessened by differences in calculation methods) and in shore installations in such places as Singapore designs to 70–72 degrees ET are not uncommon. So there may be requests to design within the accepted comfort zones, e.g., 80 degrees F DB: 50 per cent RH (i.e., an ET of 74 degrees) for cooling, and 70 degrees F instead of 65 degrees when heating.

Control

At present control is not provided when cooling, but if lower design criteria are adopted control will become essential for comfort and to provide compatability of total cooling requirements without over-provision of cooling plant.

Such control arrangements would probably allow also for the selection of intermediate conditions between heating and full cooling. If electric heaters are introduced, they will be controllable to fairly close limits.

It may be observed that if such finer control is introduced D.G. Ships will have to look critically at the present design margins.

Changes in Equipment

Possible directions of change have already been mentioned. One other strong possibility worth mentioning is the adoption of the 'packaged unit' type of ATU composed of our present standard items mounted on a common bedplate. Some exploratory work on this proposal is already in hand.

Design Methods

In the future greater use will be made of computers for performing design calculations. A number of programs exist: some are currently in the process of being proved and 'de-bugged' where necessary; and a critical look is being given to the form and value of all existing programs.

As regards manual calculation, some of the existing methods can and will be simplified. It should also be observed at this point that even with the time-saving use of the computer, much manual work remains to be done.

CONCLUSION

Ventilation has always been a plentiful source of complaints from the Fleet and will no doubt continue to be so. Fundamentally this is not a bad thing as it provides a constant impetus for advancement and for further improvement. To go any further into the subject would be to enter the realm of conjecture; the foregoing is intentionally a broad appreciation of a most important feature of the modern fighting ship.