PART I

HABITABILITY IN H.M. SHIPS

by

CAPTAIN (E) F. E. CLEMITSON, R.N.
Assistant Engineer-in-Chief

This article is the reproduction of a lecture given by Captain Clemitson to the Senior Officers' Technical Course at Portsmouth on 8th January, 1947. While giving a general review of the subject, its principal object is to summarise the effect of modern habitability requirements as regards the provision and maintenance of additional machinery.

Under the term *habitability* are included not only the major questions of ventilation and temperature of compartments, but also those of provision of what can be called, for convenience, *amenities*, i.e., laundries, domestic refrigerators, etc. Habitability is very much to the forefront in these days, both because of the need to maintain health and efficiency under the severe conditions of modern sea warfare, particularly in the tropics, and because of the call for improved living conditions onboard ships. The requirements which arise as a result are all very necessary, but, as in most other things, there is a price to be paid for them—that of further calls on weight and space, and maintenance of the additional machinery and other gear. This last requirement means additions to complement, i.e., further calls on already inadequate man-power, and more overcrowding in ships.

The brunt of habitability questions comes on the Director of Naval Construction, and it will be necessary to touch on his work from time to time. However, the Engineering Department, apart from being directly concerned in all machinery spaces, has to provide and maintain all the machinery required for habitability purposes, and it is this that is the principal subject of my talk.

It is proposed to commence with the questions of ventilation and temperature, that is to say, *habitability* in the more restricted meaning of the term, or more technically, *thermal conditions of compartments*, as these are certainly the most far-reaching and important.

Habitability of the ship generally

Much study has been, and is being, devoted to this. The work is in the hands of the Royal Naval Personnel Research Committee which was formed in November, 1942, and, in particular, is carried out by its Habitability Sub-Committee, on which E.-in-C. is represented. A.F.O. 6602/46 draws attention to B.R. 1472, a valuable and interesting document entitled *Environmental Warmth and its Measurement* which describes in simple terms the effect of temperature and humidity on human beings, with the limiting temperatures where physical efficiency falls off. This B.R. and the A.F.O. also deal with methods of measuring and reporting on thermal conditions.

Without going into any great detail it may be of interest to mention the final method of assessing the thermal condition of a compartment. The standard of measurement is called the *Effective Temperature*, or, if radiant heat is an appreciable factor, the *Corrected Effective Temperature*. This combines into one reading the aggregate effects of air temperature, relative humidity, air movement, and radiant heat when it is an appreciable factor. As a result of a considerable amount of experiment it is provisionally recommended that a corrected effective temperature of 80° F. represents the upper desirable limit for men to work and live in, and 86° F. is the limit above which full efficiency usually is impaired.

Principal factors influencing habitability

The three principal factors which influence habitability are :—

(i) The heat built up from machinery spaces,
(ii) The effect of heat transmission to, or from, the atmosphere, and
(iii) The ventilation provided.

The regulation of (i) and (ii) is largely a question of insulation, and in (i) the engineer is very much concerned. The heat leakage from machinery spaces has a considerable effect on the ship as a whole, and there is also the large question of making these spaces themselves habitable under extreme conditions. The problem is relatively greater in the larger ships, as in smaller ships where the main machinery spaces at least extend to the ship's side some of the heat given off is dispersed to the sea. It is a problem, too, of tropical conditions, as, indeed, the whole habitability problem is in the main. Under arctic conditions the object is to provide additional heat, and this is comparatively easy to achieve. Incidentally, good insulation has a beneficial effect both under arctic and tropical conditions. Lagging assists heating of living-spaces in the former ; it reduces the heating effect from severe solar radiation in the tropics.

When we consider the problem of checking the heat escape from machinery installations there is no doubt that modern machinery, with its superheated steam and turbo-auxiliaries, with joints and glands which are not easy to keep tight, has made conditions relatively more difficult than was the case with older machinery. The advancement in steam conditions for which we plan will increase the difficulties. When the marine gas turbine comes into being it will bring its own problems, too ; there will be no boilers to give out heat, but the turbines themselves will operate at very high temperatures, and the problem of lagging them efficiently is no easy one.

Prevention of heat dissipation

Heat can be given off machinery by conduction and by radiation, and also by steam leaks. It can be dissipated by :—

(i) leakage through the boundaries of the compartment, and
(ii) Increasing the heat content of the air flowing through the compartment.

The first brings discomfort throughout the ship and the second in the compartment itself. The first essential is to prevent the heat escaping from the machinery, and this we are doing by :

(i) The use of higher-grade insulating materials.
(ii) The application of the lagging in a more scientific and efficient manner, and the extension of its use to surfaces at lower temperatures than previously treated.
(iii) Reducing as far as possible radiant-heat emission. This is perhaps the worst offender in heat escape, and so all metal cleadings are being removed from machinery, except where they are absolutely necessary to protect the lagging. The blued steel casings which were a feature of the older engine-rooms are now a thing of the past.
(iv) Improved methods of making steam-pipe joints.
(v) Fitting of gland evacuation systems to reduce the wet heat released from turbine glands, This gland steam, in addition to raising the compartment

temperature, also raises the relative humidity, and makes conditions even more unpleasant.

The second essential from the point of view of the ship as a whole is to prevent the heat in the machinery compartment, *wild heat,* as it is rather fittingly called, from escaping into the ship. This is a matter of lagging decks and bulkheads, and the old type aluminium-foil insulating material has been replaced by asbestos in plastic form which is considerably more efficient. It is also necessary to consider the insulation of such fittings as steam-pipe supports where they are attached to the deck, and of steam-pipes where they pass through bulkheads. The present method of securing the pipes to the bulkhead allows a large radial heat flow to the bulkhead and adjacent decks and fittings. This area cannot be effectively insulated, and so investigations are being made to try to lessen the heat flow, by fitting a bellows bulkhead piece.

Another item, where there is considerable room for improvement, is in the lagging of boiler uptakes. These have a considerable heating effect on the ship, particularly the long uptakes in aircraft carriers, and means of improving the insulation are now being investigated.

Better habitability in machinery compartments

In order to improve the habitability of the machinery compartments and reduce the corrected effective temperature to proper limits, it is also necessary to consider the ventilation, which war experience showed to be inadequate. In past years, the amount of ventilation was based on so many changes of air in a given time, and the theory existed that conditions could not be improved by delivering more than a certain quantity of air, as the extra air swept across hot machinery, and collected more heat. Investigations showed that this was not correct, and data have been obtained where the quantity of air required for a machinery compartment can be related directly to the sum of the amount of air required for each machine on the basis of its horsepower. This quantity is considerably above that based on the old theory, and where the larger capacities have been introduced the results have been very satisfactory.

The benefit derived from the velocity of the air stream in hot compartments was not appreciated until tropical war conditions were experienced. The work of the R.N.P.R.C. showed that the corrected effective temperature was greatly reduced by increasing the velocity at which the air was delivered, and so velocities of 750 to 1,000 ft. per min. (with capacities of 2000 cu.ft./min./man) are now recognised as the acceptable standard for watchkeepers in hot compartments. This *spot-cooling* is much appreciated, although velocities of more than 1000 ft./min. can be a nuisance and cause eyesore and other inconveniences. All supplies to watchkeeping positions in machinery spaces are delivered at head-and-shoulder level where practicable.

Consideration has also been given to the temperature rise of the ventilating air whilst passing through trunking. This has been reduced by lagging the trunking, and reductions in temperature rise have been recorded from above 10° F. to less than 2° F. Inlet trunking inside the hot machinery compartments has likewise to be lagged.

The problem of hot air entrainment at the point of delivery in hot compartments is being investigated, but no means yet has been found of reducing this trouble.

The siting of supply and exhaust terminals at the deck positions has also been improved to prevent the close proximity of the two, thus correcting the fault whereby the hot exhaust delivered from the one was sucked into the inlet of the other.

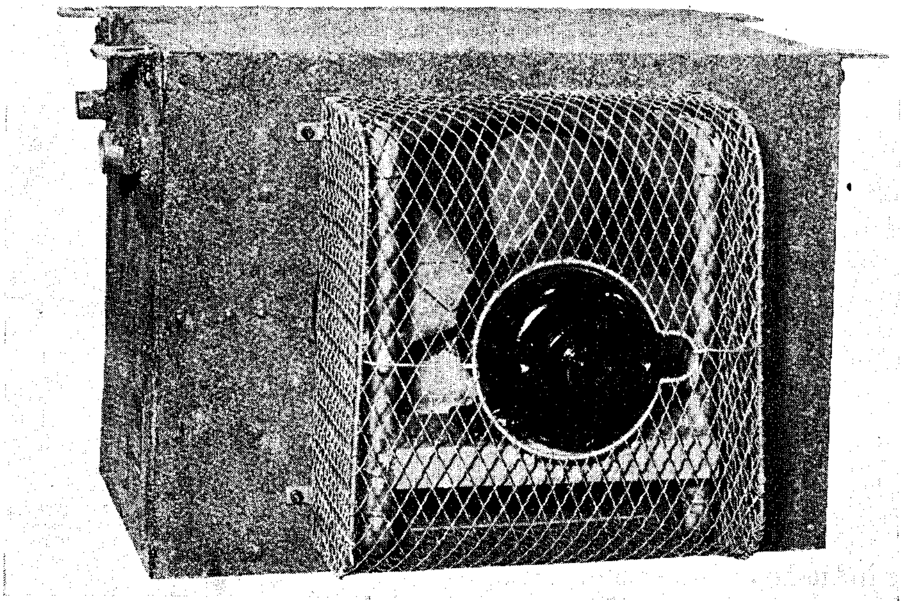

FIG. 2.—TYPE " A " AIR CONDITIONER—AIR COOLER (CORK DUSTED)

The foregoing review indicates briefly what is required, and what is being done to improve the habitability of machinery spaces, and, in addition, to make an important contribution to the habitability of the ship as a whole. It is one of the larger problems in this connection and, fortunately, the solving of it introduces no very great problems of weight and space, or additional maintenance. It is true that additional lagging and such items as gland evacuation systems entail some extra weight and maintenance, but they are not such as to worry us unduly.

Ventilation

The third principal factor in habitability which was mentioned—ventilation—is the constructor's headache, and will be referred to very briefly. As in the case of machinery compartments, in previous years quantities of air required were not assessed on a properly scientific basis, while the problems under recent war conditions were accentuated by the need to close down certain systems and to seal compartments generally, in order to obtain a high standard of watertight integrity. Considerations of watertight integrity have also entailed an appreciable reduction in the number of side scuttles provided. Yet another adverse factor has been the large quantity of additional electrical equipment which recent developments have necessitated being fitted. They all give off heat, and generators and alternators are specially prone to deliver heat to the surrounding atmosphere by way of their venting arrangements.

Ventilation requirements have now been based on scientific principles, and the fruits of a great deal of work will soon appear in a B.R. to be known as *Instructions for Design and Installation of Ventilation Arrangements in H.M. Ships*. This manual endeavours to lay down standards for ventilation based on scientific principles, incorporating the experiences of the commercial world in addition to that of naval construction. For example, the standards of air required for a living space are based on a formula taking into consideration :—

(i) Number of men in the space,
(ii) Heat dissipated by equipment, lighting, etc.,

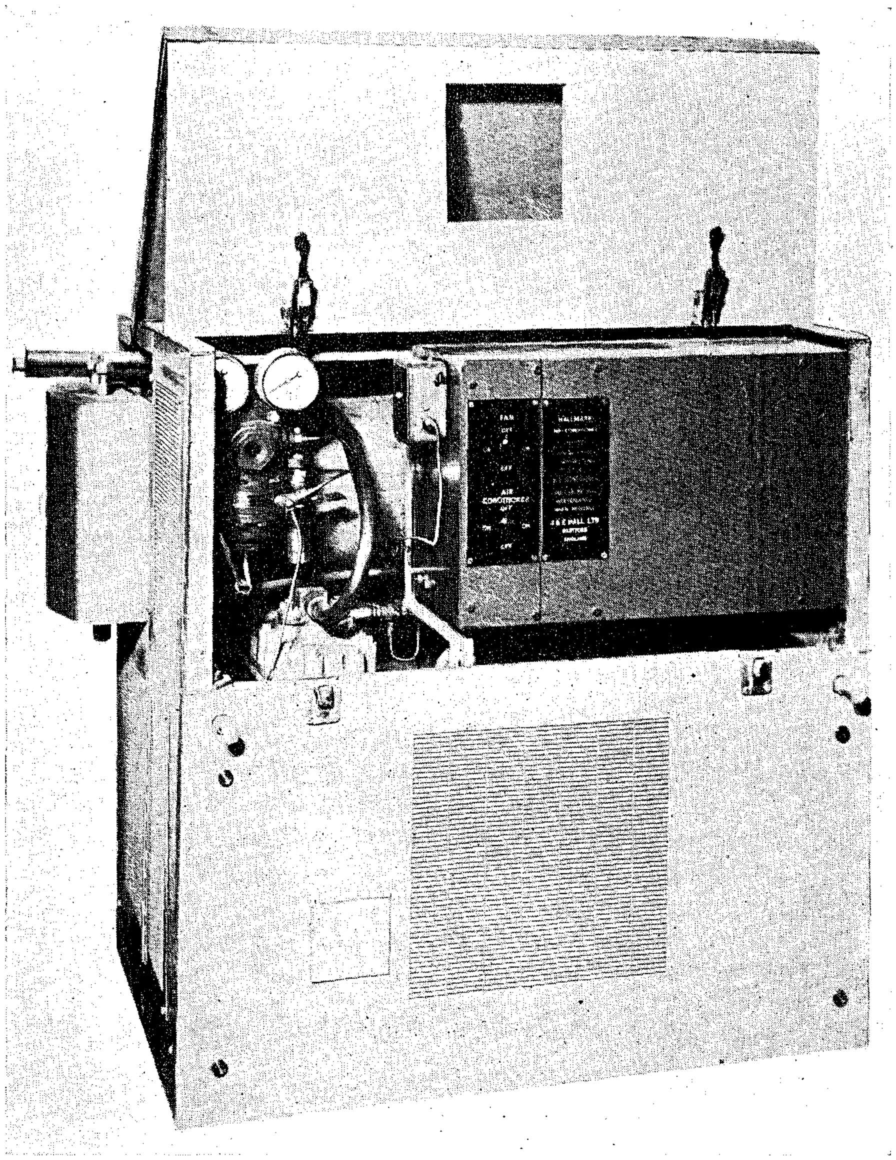

FIG. 3.—TYPE " A " AIR CONDITIONER—CONDENSING UNIT

(iii) Heat input to the compartment through its boundaries, i.e., from hot adjacent compartments and solar radiation,

whereas previously, the air introduced was merely based on an air change per minute principle, laid down for various types of compartments irrespective of their contents.

The nett result is more and larger fans, including forced exhaust arrangements, quantities of table and overhead fans, with more ventilation trunking in some cases. This must mean an increase in weight and a considerable increase in electrical maintenance, possibly to the extent of additions to complement. There are other points, too, where increase in weight and maintenance comes in, i.e.,

(i) *Store Rooms.* Owing to the needs of watertight integrity, little

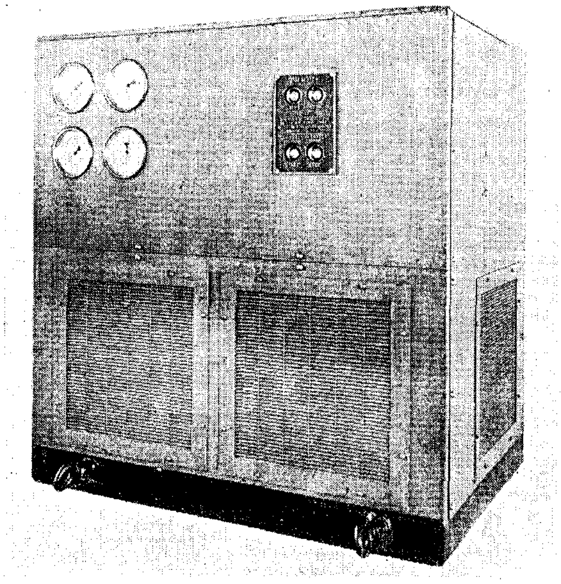

FIG. 4.—TYPE "B" AIR CONDITIONER CONDENSING UNIT

ventilation can now be provided for store rooms, and there is an increased tendency for condensation which may cause serious deterioration of the stores. Chemical drying plants have, therefore, to be fitted in certain cases.

(ii) *Galleys.* The very bad conditions in many of the older ships can be largely attributed to radiant heat from the ranges. In new construction, electric ranges have been introduced and conditions have been considerably improved, but this means a large increase in electrical load, and, may mean more dynamos, weight, space, maintenance and an increase in the number of watchkeepers.

Air Conditioning

By the very nature of warships there is a limit to what can be done by the various means that have been already outlined to make habitability conditions satisfactory, particularly in certain compartments where personnel in action, or awaiting action, must be at the highest peak of efficiency.

Thus the use of air conditioning has to be considered, and its use is now being considerably extended. This introduces at once appreciable problems in weight, space, and maintenance, the greatest of which perhaps is the finding of space. It is unlikely that we shall be able to do without air conditioning to some extent at least in the future, and so the problems have to be faced.

Air conditioning plants at present in use, or envisaged, are of four types :—

(i) Small portable plants which can deal with selected action positions only. These have been fitted to meet immediate war requirements, and will continue to be used until existing stocks are exhausted. Examples of compartments in which they are used are :—
   Telephone Exchanges,
   Sick Bays, and
   Radio Maintenance Rooms.

(ii) Larger units up to about 90,000 B.Th.U./hr. capacity for servicing single compartments. These are, in effect, small refrigerating machines, where the cooling effect of the refrigerant is transferred to the air circulating in the compartment. They are fitted for compartments such as :—
   Air Crew Ready Rooms,
   Communication Offices, and
   H.A.C.P.'s.

(iii) Cooling units of over 90,000 B.Th.U./hr. capacity for multiple services. These operate on the same principle as the plants mentioned above, but the cooling effect is transferred to a brine system which circulates round the various air treatment units. These are fitted for similar compartments as the units mentioned in (ii) above.

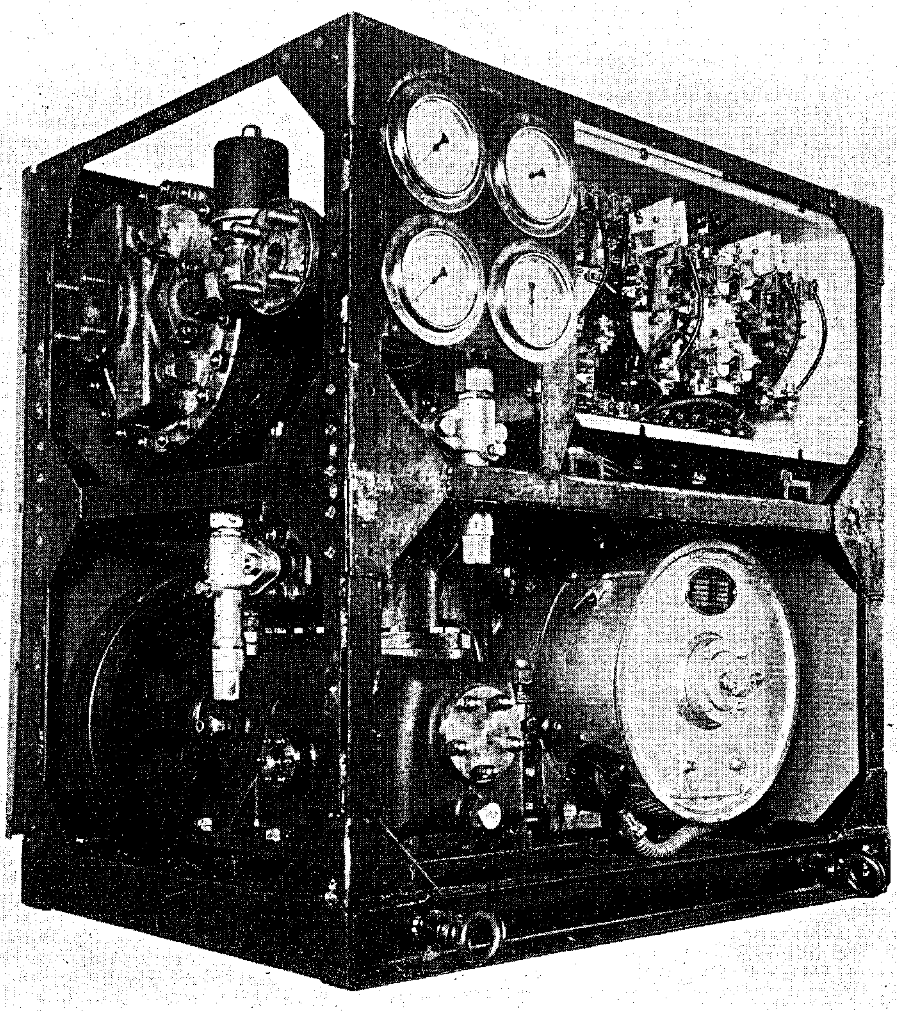

FIG. 5.—TYPE " B " AIR CONDITIONER CONDENSING UNIT WITH COVERS REMOVED

(iv) Steam jet refrigeration plants of large capacity—180,000 to 500,000 or 1,000,000 B.Th.U./hr. which can again be used for multiple services, including living spaces. A plant of this type is already fitted in H.M.S. *Vanguard* and will be fitted in *Ark Royal* and *Hermes* Classes for vital compartments. It is also under consideration to air condition the lower mess decks in later fleet carriers, by this means.

Above capacities of 500,000 B.Th.U./hr. such plants are rather more economical in weight and space requirements than the other types, although they are at a disadvantage as regards fuel consumption. Even so, it is a vast proposition. It is estimated that to effect the minimum desirable improvement on a mess deck 1,800 B.Th.U. per man per hour is required, or, say, 180,000 B.Th.U./hr. for a mess deck accommodating 100 men. In a large ship, where the load must of necessity be split between more than one large plant, and where there are many other vital spaces to be considered as well, it can be seen that weight and space problems will inevitably arise.

A 90,000 B.Th.U./hr. direct expansion unit requires about 100 sq. ft. of deck space, and weighs approximately 2–3 tons. A 500,000 B.Th.U./hr.

steam jet plant occupies about 160 sq. ft. of deck space and weighs about 6–7 tons. Perhaps something like seven or eight of one, and six of the other would be required in a fleet carrier if mess decks are to be included; no small increase in weight and space requirements. Then there is maintenance. The compressor plants in particular require skilled maintenance, and good day to day attention, and the writer considers that an increase in complement would be inevitable for it—not great, perhaps, but every little tells these days.

The main object of air conditioning is, of course, to maintain the efficiency of personnel under tropical conditions, but arctic conditions have also to be considered. All the plants are, therefore, designed to give heating, if required, by adjusting a damper on the air treatment unit so that the fresh air and re-circulated air can pass over a heating coil.

It is hoped that what has been said gives some idea of the problems of air conditioning. While it would be premature at this stage to do more than briefly refer to it, it is apparent that the coming of atomic weapons may force us, whether we like it or not, to a great extension of air conditioning. Contaminated water spray released as a result of an atomic explosion may make the existing system of fan ventilation unsuitable, as any of the affected water drawn into the vent trunking would prove a great menace to personnel, and even have fatal results in a number of cases. Air conditioning may be the only answer to this problem, particularly in the case of machinery compartments where large quantities of air are necessary for habitability. While air conditioning units capable of dealing with the heat load in a main engine or boiler room can be produced, their size might make it impracticable to fit them in conjunction with other air conditioning requirements. In an engine room the problem might be met by placing the watchkeepers in an air conditioned control room with all necessary controls fitted in it. The engine room itself could then be ventilated in the normal way, and only occasionally visited by the watchkeepers. In boiler rooms the air for combustion would have to be trunked directly to the boilers—in fact we shall probably come to this in any case, for other reasons. A control room for the watchkeepers could then be fitted, as in the engine rooms.

Amenities to improve habitability

Having dealt with the major problems of habitability, I can now pass on to those items which can be classed broadly as amenities.

Fresh water

Firstly, fresh water, although this really is a necessity rather than an amenity. The recent war showed us that our provision for distilling capacity in many cases was definitely inadequate under war conditions, particularly when ships had to be self-supporting for long periods. Many years ago the allowance of fresh water per man for all purposes was 7–8 gallons a day. Just before the war this allowance was 17–18 gallons per man per day, but for various reasons—increases in complement, lack of opportunities for maintenance, increased consumption of feed water—this was not achieved under war conditions.

In new construction, as far as space allows in existing ships, the aim is to provide 20 gallons per man per day, taking all the factors into consideration.

Continual efforts are being made to reduce the maintenance required, and to develop more efficient types of evaporator, but this increase of fresh water supply must mean more evaporators, further space and weight required, increased maintenance and more watchkeepers.

Laundries

The desirability of having laundries in ships has been recognised for a number years ; it is considered that adequate provision and operation of laundries are most important items, both from the point of view of health and general amenities. Again, however, consideration must be given to the effect which the space requirements have on other features. An adequate laundry for 700 men requires rather more than 600 sq. ft. of deck space, properly trained operators to run it, and someone to maintain the machinery.

At present, laundries capable of washing and finishing 5½ to 8 lb. of washing per week for each man in the complement are being fitted in all the larger cruisers and above. In the *Dido* Class cruisers, where the space is severely limited, the laundries will be capable of washing only—not finishing— 3 to 4½ lb. per man per week.

The question of providing some laundry facilities in small ships generally is also being actively pursued, and constant endeavour is being made to improve the design of laundry machinery with the object of increasing output, and reducing space requirements.

Requirements for refrigerated space

The provision of adequate refrigerated space is, also, one of the constructors' problems, and it is a question of arranging additional space now that ships have to spend such long periods at sea under war conditions. Apart from taking up more space, these requirements also mean additional refrigerating machinery, and, therefore, more maintenance, if not more watchkeepers.

The latest approved capacities for refrigerated stowage, per 1,000 men, are :—

Cold storage—Meat	45 days	2850 cu. ft.
,, ,, Butter, Eggs and Cheese	45 ,,	750 ,, ,,
Cool storage—Fruit and Vegetables	45 ,,	2850 ,, ,,

Health considerations demand a good supply of fresh fruit and vegetables and the cool storage represents, in effect, an addition to previous stowage allowed, and this also means the provision of two extra refrigerating machines.

Supply of cool drinking water

The provision of cool drinking water is another amenity which is of high importance in the tropics, and for the previous lack of which our ships have been unfavourably compared with the American ships. However, water coolers have now been supplied to our ships for some little time, and A.F.O. 5256/45 lays down a scale of fitting, *e.g.* :—

Vanguard	8
Ark Royal Cl. ...	12
Larger Cruisers ...	3
Destroyers ...	2, etc.

The aim was to provide up to three pints of cooled water per man per day in addition to normal fresh water consumption, but it has recently been proposed to double this scale, with the ultimate aim of producing a gallon per man per day.

The coolers do not take up much additional space, although in some cases top weight compensation is required for them, but they do present an appreciable maintenance problem, and it is advisable to have properly trained men to deal with them.

Domestic refrigerators

War experience and demands for better care of food require a considerable extension in provision of domestic refrigerators. Where, in past years, the supply was probably confined to the Admiral and the Wardroom, there are now large numbers fitted. There is no scale of supply laid down at present, but it is roughly a domestic refrigerator for each officers' mess, for each enclosed mess, and for each galley and preparing room ; *Vanguard*, for instance, carries twenty-two.

These machines do not make any great demands on weight and space, but they do on maintenance—certainly, at present.

There has, in the past, been a continual stream of complaints from the Fleet about the behaviour of D.A.R's, some of them justifiable, and others due to bad handling and bad siting. Some Engineer Officers have gone so far as to say that their D.A.R's give more trouble than the main engines. However, that may be, it does remain a fact that these machines do require to be properly looked after by men who know something about them, and, if there are a number of them, it will mean additions to complement for the purpose.

With the object of reducing the amount of maintenance required and improving the performance of the machines we are paying more attention to siting them in suitable positions onboard, and are also issuing a pamphlet containing hints for operation and maintenance. At the same time we are trying to get better designs. If alternating current was to be adopted for ships we would be helped in this respect, as we could then fit the sealed unit type which is in common use ashore, and which has advantages over the types with open machinery we now use. Unfortunately, the sealed unit type cannot work on D.C. We are also going to try out machines of the Electrolux type which have no moving parts, but there is some suspicion that the vibration which must be experienced in ships will have a bad effect on the refrigerating mixture. Furthermore, they do not function satisfactorily in the high ambient temperatures sometimes met with onboard.

Ice cream machines

Ice cream is an amenity which it is understood was rated very high in the British Pacific Fleet, perhaps on account of the contacts with the Americans. It has now been decided to supply ice cream machines to all ships having N.A.A.F.I. canteens. N.A.A.F.I. operate them and service them in harbours where there is an agent of the makers available, but, generally speaking, they will be yet one more machine for the Engineering Department to look after.

From these remarks on the amenities desirable to improve habitability you will have seen, I think, that, although some of them are small things in themselves, they do add up to a respectable total from the point of view of space, weight and maintenance. If, further, air conditioning on any scale is included, the total is quite formidable.

Let us consider the hypothetical case of a fleet carrier with reasonably extensive air conditioning, including living-spaces, and all the amenities, and see what is entailed compared with older ships.

Air conditioning

Say, six 500,000 B.Th.U. steam jet plants. A rough total of 950 sq. ft. of deck space and 40 tons of additional weight.

Say, seven 90,000 B.Th.U. smaller cooling units. A rough total of 600 sq. ft. of deck space and 15 tons of additional weight.

Perhaps a number of the small portable units as well.

Fresh water

More and larger evaporators than at present.

Laundry

Say, 1,400 sq. ft. of floor space and 30 tons additional weight.

Extra refrigerated space

Say, 5,000 cu. ft. and two additional refrigerating machines.

Water coolers

Twenty-four.

Domestic refrigerators

Say, about twenty.

Ice cream machines

One or two.

In addition to the weight and space it takes up, which will mean so much less for other things, all this gear has to be maintained—by the Engineering Department at present—and it seems quite clear that extra ratings will be required for this work. They, again, may have to be accommodated at the expense of somebody else.

Conclusion

To conclude, we have, for the sake of health and efficiency, and also for the improvement which the present age demands in general living conditions, to improve the habitability of warships as far as we can. In fact, atomic warfare may well force us to it in certain directions. At the same time, these things must not be allowed to reduce the fighting efficiency of the ship—its primary purpose. The writer hopes he has shown there is an appreciable price to be paid for habitability, and in the warship to pay Peter we have to rob Paul.

The need is to strike the correct balance between material efficiency and amenity, since in the strictly limited space afforded by a warship any undue emphasis laid upon one of these factors will undoubtedly react on total fighting efficiency. This, however, is no new problem—it appears periodically in varied forms.