capacity of power sufficient to do the work which it is intended to do. The air quantum needed depends upon the amount of atmospheric vitiation that may be expected to occur in the place to be ventilated. Thus, the changes that occur in a given volume of air during a single act of respiration may be seen in the following table:

TABLE V.

	CONTAINS IN VOLUME PER CENT.	
	Dry air.	Expired air.
Oxygen	20.96	16.03
Nitrogen	79.02	79.02
Carbon dioxide	.03	4.38

According to this table, the nitrogen of the air is the only one of its constituents that remains unchanged in quantity; oxygen is decreased about one-fifth and carbon dioxide has increased a hundredfold by the respiratory act. The following calculation will serve as an example of the method that is generally employed to determine the air quantum which the ventilating system must supply to a place in a given time, before our system can be pronounced satisfactory: Given an enclosure, hermetically sealed, of 40 cubic metres capacity, filled with fresh air, originally found to contain 0.5 part per 1,000 of carbon dioxide. Every cubic metre of this air contains, consequently, 0.5 litre of carbon dioxide. An average person confined in this space would produce 22.6 litres of carbon dioxide within one hour. This quantity, when added to that normally present in the above 40 cubic metres of air, would bring the total amount of CO_2 at the end of one hour up to 42.6 litres or 1.065 per thousand.

The maximum limit of CO_2 allowed by Pettenkofer for a good quality of air is 0.7 per 1,000, and this we see has been seriously surpassed. Roth and Lex have adopted 0.6 per 1,000 for their maximum limit, and Carnelly, Haldane, and Anderson want 1.0 per 1,000 adopted for dwellings. If we adopt for the sake of illustration the limit of Pettenkofer, and further assume that fresh outside air contains, on an average, never more than 0.5 per 1,000 or every litre 0.5 c.c. of CO_2, then every litre of air may take up 0.2 c.c. of CO_2 before the normal carbon dioxide maximum limit is exceeded. Consequently, we need 113 litres or 113×0.2 c.c. = 22.6 of CO_2; we need 113 cubic metres (3,991 cubic feet) of fresh air in one hour and for an average person, in order to keep the air of a place within respirable limits. Notter quotes Roth and Lex as estimating the amount of CO_2 produced by an average person per hour at 20 litres and the hourly quantity of air required at 100 cubic metres. If we state this quantity of air, with Notter, as 3,600 cubic feet per hour, it is just one cubic foot per second.

It will be seen that we can vary our calculations considerably either by extending our maximum limit of CO_2 or by starting with an air of a higher standard of purity to begin with. If, for instance, we would ventilate our test enclosure with an air that contained only 0.3 of CO_2 per 1,000, we would require only 56.5 cubic metres to take up the above 22.6 litres of CO_2 exhaled by an average person in one hour.

The needed air quantum is generally calculated according to the following simple rule-of-three: (1) $n : 1 = k : (p-q)$; (2) $n : \frac{k}{p-q}$; (3) $n = \frac{22.6}{0.7-0.5} = 113$ cubic metres; (4) $n = \frac{22.6}{1.0-0.5} = 45.2$ cubic metres (Märcke and Schultze, by Kirchner). Table VI. shows how the amounts vary within the limits of purity demanded.

Some of the medical officers of the French navy appear to be keenly aware of the needs of their service from a hygienic point of view. Thus, Rochard and Bodet, in their excellent work on "Naval Hygiene" (p. 143), make a strong and timely appeal for the introduction of more scientific methods in the investigation of naval sanitary

TABLE VI.

Maximum limit CO_2 allowed per 1,000.	AIR REQUIRED PER MAN AND PER HOUR.	
	In cubic metres.	In cubic feet.
0.6	226	7,981
.7	113	3,991
.8	75	2,649
.9	55	1,942
1.0	45	1,589

problems, an appeal which United States naval medical officers might take seriously to heart, very much to their advantage. They say: "Nous demandons instamment qu'on munisse les médecins-majors de tous les bâtiments de guerre d'un anémomètre de Cassella," etc., and they deplore the departmental penury in not providing naval surgeons with the instruments necessary for better research work.

For the determination of the air quantum they propose to employ what they have termed the "coefficient of ventilation." In this, the hour is taken as the unit of time. Any air space, no matter what its cubic capacity, in which the air is renewed once in an hour, has a coefficient of 1. Where the air is renewed twice in an hour, that enclosure has a ventilating coefficient of 2. Wherever it takes two hours, that place has a coefficient of $\frac{1}{2}$ etc. The coefficient is expressed by the fraction $\frac{R}{H}$ in which R represents the number of times the air is renewed and H is the time required to do it in. According to this plan, the facts in ventilation could be intelligently recorded. Thus, for instance, 5 cubic metres (176 cubic feet) is the average air space allotted to one man in the French navy. This space is so small that the air in it would have to be renewed 22.6 times, *i.e.*, it would have to receive a coefficient of $\frac{22.6}{1}$ in order to bring the air quantum up to that required by our average adult in the preceding example, which was 113 cubic metres.

But almost every work on ventilation tells us that the air in any enclosure cannot be renewed more than three and at most five times, lest there be danger from draught. If we allow the French sailor to breathe into his allotted air space of 5 cubic metres for one hour, assuming that the air originally contained 0.5 CO_2 per 1,000, then that air would contain 5 CO_2 per 1,000 at the end of the first hour. If we allow the air to be renewed three times, or employ a coefficient of $\frac{3}{1}$, it would contain 2 parts CO_2 per 1,000; with a coefficient of $\frac{5}{1}$, it would reach only 1.4 CO_2 per 1,000.

A sailor on active duty generally turns into his hammock at 9 P.M. and is called at 5 A.M., when not called out for a watch before. He would sleep for eight continuous hours in a space the air of which, at the end of that time, would scarcely keep a candle burning, even under a coefficient of $\frac{3}{1}$. It is difficult to imagine that he would wake up again, as we all know he does, unless actually supplied with more air than our calculation allows him. Can any one doubt that, in practice, he somehow gets much more air, draught or no draught, than our theory allows him to get? There are ships in the United States navy, and training ships at that, in which the average air space per man is only two-thirds that allowed in the French navy, which apparently shows much more strongly than does the above instance, that more air *must* get into living spaces than even a coefficient of $\frac{5}{1}$ could put there.

The more the question is studied and the better we are becoming acquainted with the facts, the more it is found that the rules that have been worked out to govern the ventilation of houses and buildings on land do not and cannot be made to apply to ships without considerable modification. We shall have to break with fixed standards as regards the number of times we are allowed to renew the air in enclosures and part company with dangers from draughts, when going to sea in ships.

The coefficient of Rochard and Bodet may be said to

EXPLANATION OF
PLATE XLVI.

EXPLANATION OF PLATE XLVI.

Plans of the United States Steamships *Kearsarge* and *Kentucky*, illustrating the plenum system of ventilation, installed by Naval Constructor J. J. Woodward, U. S. N.

FIG. 1.—Plan of Upper Deck, Showing Trunks and Cowls for Passage of Air.

FIG. 2.—Represents a Vertical Longitudinal Section, Showing Trunks and Cowls for the Supply of Air.

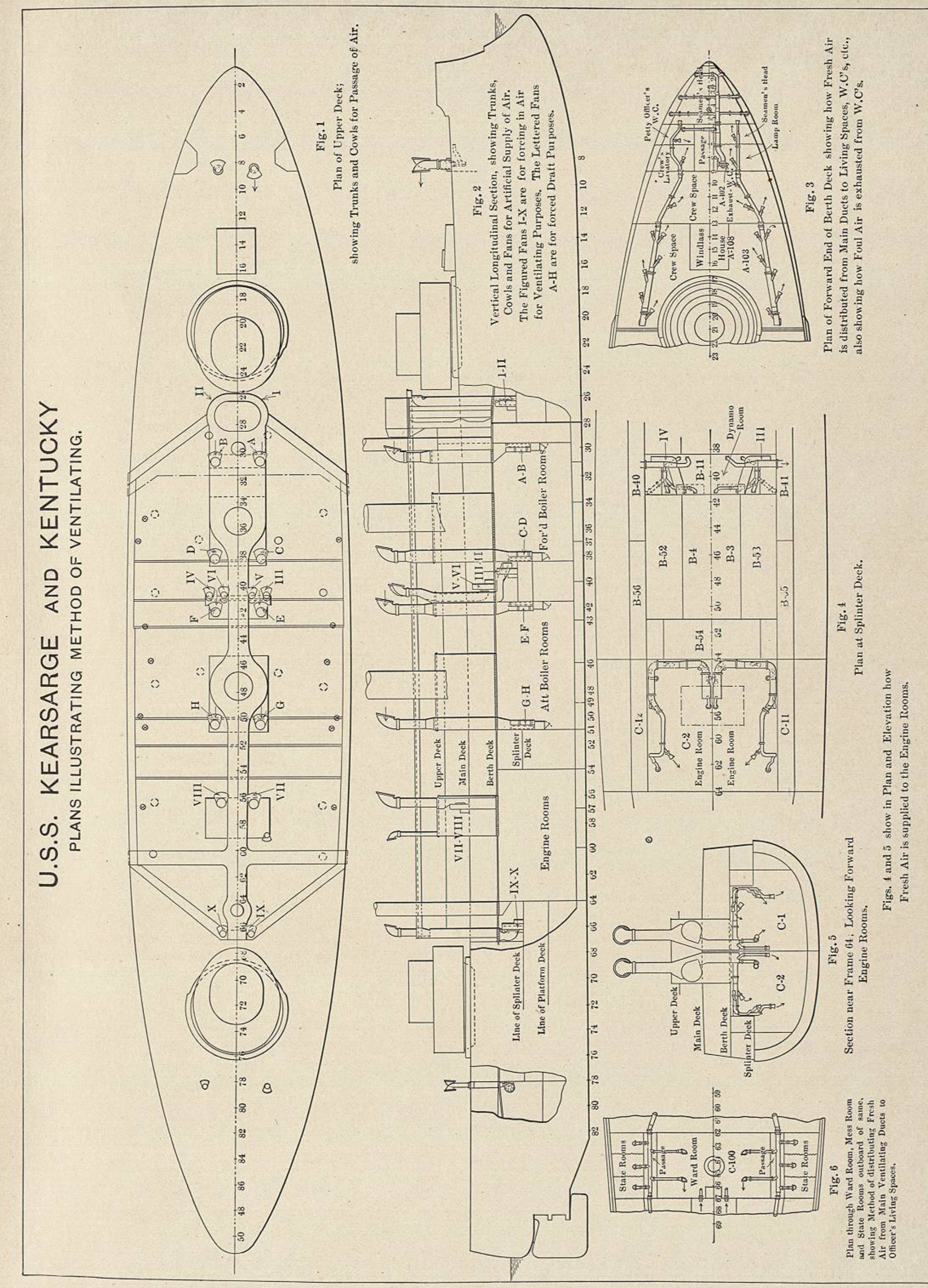
FIG. 3.—Represents Forward End of Berth Deck, Showing How Fresh Air is Distributed from Main Deck to Living Spaces, Water-Closets, etc.

FIG. 4.—Plan at Splinter Deck.

FIG. 5.—Looking Forward from Engine Room. Figs. 4 and 5 show, in plan and elevation, how fresh air is supplied to the engine-rooms.

FIG. 6.—Represents Plan through Ward-room, Mess-room, and Staterooms Outboard of Same, Showing Method of Distributing Fresh Air from Main Ventilating Ducts to Officers' Living Spaces.

PLATE XLVI



Naval Hygiene.

be a simple, convenient, and accurate means of recording the ventilation of an air space. It might with great advantage be used in company with the "air cube." The air cube is expressed by the fraction $\frac{I}{M}$. I stands for cubic space, M for the number of men in it. Thus a space of 100 cubic metres capacity with four men in it, has an air cube of 25 cubic metres.

Testing the Sufficiency of a Ventilating System.—This is done (1) by determining the cubic capacity of the living spaces with the air quantum supplied to each in a given time, and (2) by examining the air both chemically and bacteriologically. For the measurement of the cubic capacity of ships' spaces, the three simple rules given by MacDonald are still sufficiently accurate and answer all the purposes of the sanitarian: (1) Take the largest measurements of length, breadth, and height that the space will admit of, for the determination of the main cubic capacity. (2) Take the cubic capacity of all irregular spaces and recesses in communication with the principal space, and add their sum to the latter. (3) Take the measurements of all obstructive bodies and projections and of everything that impinges upon the available air space and subtract the sum from the gross capacity already obtained. Since it will greatly facilitate calculation to take down the measurement in feet and tenths of feet rather than in feet and inches, the following table may prove useful:

TABLE VII.

Inches.	1	2	3	4	5	6	7	8	9	10	11	12
Decimals of a foot........	0.08	0.17	0.25	0.33	0.44	0.5	0.58	0.67	0.75	0.83	0.92	1

A few simple rules will satisfy the requirements of the sanitarian. For example, the area of the segment of a circle equals two-thirds of the product of the chord and height, plus the square of the height divided by twice the chord $(Ch \times H \times \frac{2}{3}) + \left(\frac{H^2}{2Ch}\right)$.

The area of the triangle equals the base multiplied by one-half the height. The circumference of a circle equals $D \times 3.1416$. To ascertain the area of an ellipse, multiply the product of the two diameters by 0.7854. The cubic capacity of a cylinder equals area of base multiplied by height.

The total number of cubic feet, with additions and deductions made, must now be divided by the number of berths or hammock swings in the different crew spaces and the result is the cubic space per head or air cube.

The total air quantum that passes through a space can be determined only by means of an anemometer and the area of the ventilating trunks. The velocity of an air current in metres per second is ascertained in accordance with the formula $v = a + b\frac{n}{2}$ where a and b are constant; a refers to internal friction and b to vane inclination; n is the number of turns and z the duration of the observation in seconds. The air volume is then calculated by the formula: $L = f. v. 3{,}600$, where f is the area of the intake in square metres. For example: The hands of the anemometer stand at the beginning of the observation at 3,420, and after operating $z = 120$ seconds, the reading of the hands indicates 3,900. The instrument had made $n = 480$ turns. The constants are $a = 0.18$ and $b = 0.14$, and thus we get $v = 0.18 + \underbrace{0.14\frac{480}{120}}_{0.56} = 0.74$.

The measurements of the inlet area gave 0.26×0.38 m. or $f = 0.0988$, consequently the pipes propelled $L = 0.0988$, 0.74, $3{,}600 = 263.2$ cubic metres of air per hour.

Pressure differences existing between different compartments of a ship are ascertained by differential manometers; these serve chiefly to indicate inequalities of ventilating power in different compartments with relation to each other and to determine the direction of the air currents existing between adjoining compartments from one with more into the one with less pressure.

An ingenious method for determining the amounts of air discharge which occurs in an enclosure—a method which can be applied to ships—was devised by Pettenkofer. After closing all openings into a room, he generates CO_2 by burning stearin candles. The candles furnish a definite amount of CO_2 per hour and the CO_2 of the air is also known. When the power of the ventilating system is to be ascertained, the blowers are started and the air from the centre of the enclosure is examined at intervals for CO_2. The rate at which the CO_2 disappears gives testimony of the efficiency of the ventilating capacity of the system under investigation.

Carbonic-acid examinations by any one of the above-described methods will complete the test of the ventilating sufficiency. Bacteriological examinations of the air of ships have not yet been made to my knowledge. The difficulties of preserving or making culture fluids are alone to blame for this serious omission. Special research work has, however, shown that the number of germs in a cubic metre of air decreases at sea in direct proportion to the distance from land, until, in midocean, the air is found absolutely sterile but a few feet above the upper deck of a ship. Fischer (*Zeitschrift f. Hygiene*, Bd. 1, 1886, p. 421), in examining sea air, found one germ in 44 litres of air; at a distance of one hundred and twenty miles from the coast, it was found to be sterile.

Ventilation of Different Types of Vessels.

1. *Battleships "Kearsarge" and "Kentucky"* (see Plate XLVI. and description of figures).—Most excellent examples of ventilation on the plenum principle are furnished by these two battleships of recent construction. They are practically sister ships and the ventilating system is the same in both. The *Kearsarge* and *Kentucky* are the best ventilated ships in the United States navy (see Plate XLVI.).

The United States Steamship *Kearsarge* is a twin-screw armored sea-going battleship with a displacement of 11,526 tons; she was built at Newport News, Va., and was first commissioned on February 20th, 1900. She has an upper deck, main deck, berth deck, splinter deck, protective deck, holds, and double bottoms. There are in all ten fifty-inch electrically driven fans, of twelve horse power each, and giving each a speed of 500 revolutions per minute with an output of 160 volts. Every fan forms an independent supply system for a certain part of the vessel and is located as near as practicable to that part of the vessel which it is intended to supply with air. All the air is drawn from above the spar deck and propelled down below the main deck; from thence it is driven through a system of branches into the various compartments into which these are made to open through numerous small outlets, provided with adjustable cowls or terminal trumpets that can be turned in any desired direction or closed at will by shutters.

The ten supply systems are distributed about as follows: (1) Two systems, supplying all the forward compartments of the vessel, have the blowers located symmetrically on each side of the centre line of the vessel in the blower room, on the splinter deck, and underneath the conning tower. (2) Two systems, supplying the dynamo-rooms and ammunition passages on splinter deck, with blowers symmetrically located on each side of centre line of vessel, on berth deck over dynamo-room; they receive their fresh air through two ventilators, situated between the smokestacks and outboard of the two ventilators supplying the berth deck. (3) Two systems supplying compartments in midship portion of splinter deck, including passages, also upper and lower dynamo-rooms; blowers symmetrically located on each side of centre line of vessel, in upper dynamo-room; they take the air through two ventilators situated between the smokestacks and inboard of the ventilators that supply the dynamo-room. (4) Two systems supplying the engine-rooms; blowers located in the engine-room hatch on main deck and taking their fresh-air supply through two ventilators abaft the after-smokestack, and in the engine-room hatch. (5) Two systems, supplying all the after-compartments of the vessel; blowers symmetrically located on each side of the centre line and in blower-rooms on spar deck abaft the main mast.

The fresh air supplied in this manner, after doing its ventilating work, finds its way out of the ship through the various hatches and the exhaust-leads of the smokestack. There are besides some special exhaust blowers of three horse power each for the steering engine-room, officers' water-closets and lavatories, crew's and petty officers' lavatories and closets. The large vertical exhaust-trunks from the fire- and engine-rooms are made to extend high above the upper deck in order to increase their draught and so as to prevent the escape of hot and foul air from these compartments into the living spaces.

The eight firerooms are supplied with air for forced-draught purposes. There are eight steam-fans located underneath the firerooms' ventilating trunks, each fan supplied with air by means of a separate smaller trunk, coming from above the upper deck, and fitted with a portable cowl. When forced draught is being used in any fireroom, that fireroom is kept closed and all the air that is forced in finds its way out through the furnaces and thus goes up the smokestack. Incidentally, of course, this forced draught furnishes fresh air to the firemen, stokers, engineers and others who may happen to be in the fireroom. When the forced draught fans are not running, the same ducts furnish fresh air, by natural means, such as temperature differences, to the men in the fireroom.

No fans or other artificial means are provided for forcing air into the coal bunkers. The free admission of air into these is effected by separate inlets; while the outlets are connected with the exhaust leads of the smokestack system. With regard to the working efficiency of this system on the U. S. S. *Kearsarge*, Medical Inspector J. C. Boyd, in his annual report to the Surgeon-General, 1901, says: "The total volume of air that is brought into the ship per minute has never been accurately determined, but estimating the probable capacity of the blowers, based upon the cubic feet of air per minute that can be delivered for each horse-power, it will be readily seen that the air throughout the ship can be changed within a few minutes. The cubic capacity of the ward-room is 5,376 feet, and it has been found that the air is changed 15.6 times per hour, or every 3.8 minutes."

2. *Battleship "Illinois."*—The ventilation of the *Illinois*, like that of the *Kearsarge* and *Kentucky*, has the power also those of the compartments above this deck which are located forward of the diagonal armor. The four after-ventilating shafts supply the staterooms above the protective deck and the storerooms and magazines which are below this deck. They also supply those compartments of the ship above the protective deck which are included between the diagonal armor and the sides of the after-part of the ship. All the fans are driven by steam except the two that supply the dynamo-rooms; these are driven by electricity.

The discharge of foul air is effected: (1) through two large shafts, leading from the engine-rooms high above the spar deck; (2) through gratings in both the protective and the splinter decks, and (3) through the military mast which has the outlet immediately beneath the first gun platform. The exhaust side of the system has no fans and does not seem to need any.

The mid-ship section of the *Illinois*, which includes the engine- and firerooms, is supplied with four large supply shafts on each side of the centre line. The air is taken from above the spar deck and driven by strong steam fans through the fire- and engine-room spaces. Foul air escapes through hatches and gratings as well as through the fires and smokestack.

The steam steering-room is ventilated on the combined plan, having driving fans on both the supply and exhaust sides of the system, while the W.C.'s have the power on the exhaust side only. To judge by the smell that hovered about these, they did not seem to be sufficiently ventilated. Besides the above, there are two separate shafts, also provided with steam fans, which supply all the quarters located above the protective deck and between the diagonal armor and the sides of the ship.

The maximum temperature observed in the fireroom during the entire trip was 110° F. The adjoining table shows temperature in the engine-room:

TABLE VIII.—TEMPERATURES, DEGREES FAHRENHEIT.

.	Engine-room, port.			Upper grating, starboard.		
Forward	121	122	122	114	116	116
Outboard	116	120	118	118	119	120
Inboard	116	116	115	109	110	111
Aft	114	118	119	106	106	108
Average	114	119	119	112	113	114

All temperatures were taken at 11, 12, and 1.

3. *The French Battleship "Hoche."*—This ship deserves special mention in connection with the subject of ventilation, because it presents a novelty in not showing a single windsail above the upper deck. All the air is taken into the ship through eight hatchways, extending from the upper deck down to the protective deck. The system has the great advantage of allowing the air to pass between decks before reaching the lowest compartments, much to the advantage of these compartments between decks during the night. The eight large hatchways of the *Hoche* on the upper deck have an areating surface of 42 square metres (see Fig. 3505); to this must be added the openings of the smoke boxes, and those of the ammunition hoists of the four turrets, which may in reality be regarded as hatchways. The access of air down to the protective deck is assured in sufficient quantity by three large hatchways, arranged like air pits between the upper and the protective decks.

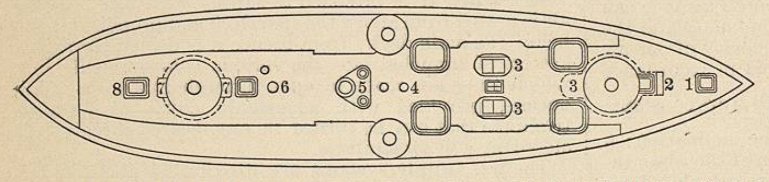


FIG. 3505.—Shows the Plan of the Upper Deck of the *Hoche* with its Eight Hatches, Marked by Treble Lines. Four small ones are in the centre line of the deck, and the four large ones (engine-room hatches) are arranged symmetrically by twos on each side of the centre line of the deck. (From Rochard et Bodet.)

on the supply side of the system, and is, therefore, effected on the plenum principle. The following description is from a few notes taken during her speed trial and will only give the leading points: There are, on the *Illinois*, eight large square air shafts, serving as inlets and taking the fresh air from above the upper deck. Four of these inlets are distributed about the forward side of the forward turret of the ship and four of them are distributed similarly about the after-turret of the ship. Of the four forward ventilating shafts, two supply the dynamo-rooms and two supply the quarters, storerooms, and magazines below the protective deck, as

There are in all twelve large inlets (see Fig. 3506), each section of the ship having its own; the last three sections alone are ventilated by a common hatchway. This last one is very large, because the spaces which it is intended to ventilate are the steering engine-room, that of the pumping engine, etc. The various firerooms

have their own inlets, each opening being 7 metres square.

The fortunate position of the exits (see Fig. 3507) for vitiated air permits the inlets in the protective deck to have their full effect. The fourteen sections into which the vessel is divided are not, however, equally well cared for in this respect. The three forward sections being for the most part storerooms, are merely aerated by one circular opening, which serves both as a supply and an exhaust at the same time. The last two sections, which include the steering engine-room, have likewise but one hatchway. Everywhere else, a large number of conduits is arranged so as to take the hot air out from the compartments below the protective deck and conduct it above the spar deck. These are (1) the military mast system, which exhausts the forward turret, the section for the wounded, and the forward pumping engine-room; (2) the chimney mantle system, which exhausts the four firerooms; (3) the protective casing of the conning tower, through which escapes a portion of the air from a space between the engine-room and the fireroom; (4) the great central shaft, divided into several smaller trunks, lets out (*a*) the hot air from the engines, the exhaustion of which is effected by a fan through a perforated deck ceiling; (*b*) the air of the midship pumping engine-room, steam pipes, store- and ammunition-rooms; (5) an isolated conduit for the after ammunition-room; and (6) the after military mast, through which escapes the air from the after pumping engine-room and ammunition storeroom. It is interesting to note that the exhaust pipes are placed inboard of the supply shafts.

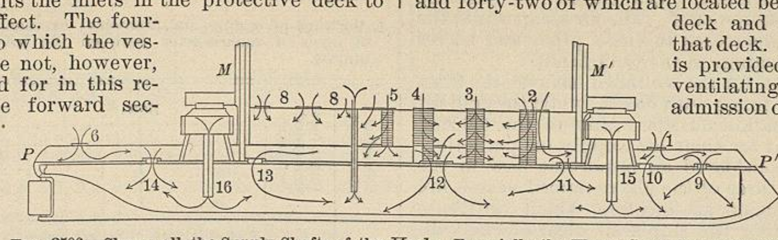


FIG. 3506.—Shows all the Supply Shafts of the *Hoche*, Especially the Three Great Superimposed Hatchways Extending from the Upper Clear Down through the Main Deck to the Protective Deck. (From Rochard et Bodet.)

3a. *H. M. SS. "Glatten" and "Devastation."*—According to MacDonald the plenum system of ventilation has been adopted without exception in Great Britain ever since the earlier seventies. Examples are H. M. SS. *Glatten* and *Devastation*. The *Glatten* has a rectangular supply shaft, five feet six inches by six feet four inches, beginning twelve feet above the upper deck and reaching down to the level of the main deck, just abaft the smokestack. At the bottom of this shaft there are four fans connected with two transverse trunks, the upper of which is sixteen by twelve, and the lower sixteen inches square. The fans, driven by steam, take the fresh air from the shaft and send it into the trunks, through which it is propelled by means of smaller pipes into every cabin and compartment of the ship, fore as well as aft, by goosenecked funicular ends that open a few inches from the floor of the deck. There are in the *Glatten* one hundred and thirty-three of these outlets. All the fans are provided with distinct sets of engines which work independently, but in the *Devastation* the arrangement is such that, in case one or two shafts get accidentally blocked or otherwise rendered useless, the third can be made to supply all the compartments whose ventilation would be thus interfered with.

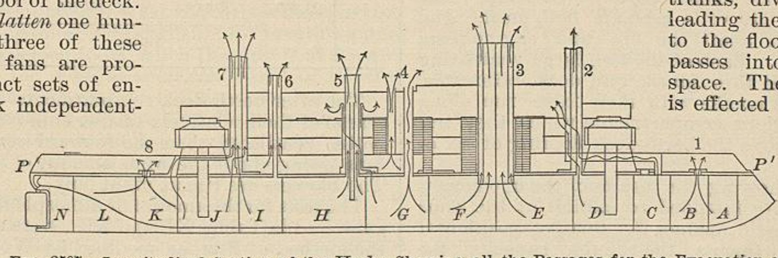


FIG. 3507.—Longitudinal Section of the *Hoche*, Showing all the Passages for the Evacuation of Foul Air, also the Independence of the Different Compartments from one another. (From Rochard et Bodet.)

The following table, IX., shows the relative number of supply and exhaust fans in some of H. M. ships; it clearly shows how even the combined system is gradually giving way to the plenum system of ventilation in the royal navy.

4. *The Austrian Coast Defence Vessels "Monarch," "Wien," and "Budapest."*—All these ships have a very large number of water-tight compartments, one hundred and forty-two of which are located beneath the protective deck and thirteen are above that deck. Each compartment is provided with its own two ventilating pipes, one for the admission of fresh air, the other for the discharge of foul air. The two pipes reach above the main deck and are themselves water-tight.

As a general rule, all efforts at ventilating water-tight compartments do in a measure endanger the purpose which these compartments are designed to serve. In all English vessels of this type the protective deck is left intact, while in French and in Austrian ships the bulk-heads are almost never perforated.

TABLE IX.—(FROM NOTTER.)

Name of ship.	Exhaust Fans.		Supply Fans.	
	Number.	Diameter.	Number.	Diameter.
Devastation	4	4 ft. 6 in.	4	5 ft. 6 in.
Thunderer	4	4 ft. 6 in.	4	5 ft. 6 in.
Trafalgar	3	Two 6 ft. — one 4 in.	4	4 ft.
Nile	3	4 ft. 6 in.	4	4 ft. 6 in.
Impérieuse	2	3 ft. 6 in.	4	4 ft. 6 in.
Edinburgh	2	3 ft.	6	4 ft. 1 in.
Colossus	2	3 ft.	6	4 ft. 6 in.
Inflexible	1	3 ft. 3 in.	8	4 ft.
Vulcan	2	4 ft.	2	4 ft.
Polyphemus	1	3 ft. 6 in.	2	One 4 ft. — one 3 ft.
Howe	1	3 ft.	5	4 ft.
Anson	1	3 ft.	4	4 ft.
Camperdown	1	3 ft.	4	4 ft.
Royal Sovereign	..	....	12	Six 6 ft. — six 5 ft. 6 in.
Royal Arthur	..	....	5	Four 5 ft. — one 3 ft.
Dreadnaught	..	....	6	4 ft.
Neptune	..	....	4	4 ft.
Collingwood	..	....	4	4 ft.
Severn	..	....	2	4 ft.
Galatea	..	....	2	3 ft.
Barossa	..	....	2	3 ft.
Barham	..	....	2	3 ft.
Bellona	..	....	2	3 ft.
Calliope	..	....	1	3 ft.

The engine-rooms on all these ships are ventilated on the plenum principle. The air is taken from above decks and pressed into horizontally arranged ventilating trunks, divided into branches leading the air down the sides to the floor deck, whence it passes into the engine-room space. The escape of foul air is effected through one large shaft, located amidships over the engine-room and provided with an electric exhaust fan with cowl on top.

The boiler-rooms are supplied with air through eight air shafts, four of which have fans, while the foul air escapes through the chimney, the hatch openings, and several special exhaust pipes. All the other compartments are ventilated through a large number of electrically driven fans which act on the plenum principle. The coal bunkers are merely connected with the system of exhaust pipes which lead into the chimney casing and the military masts. The various cells for the confinement of prisoners are traversed by the ventilating pipes intended as supplies for the ammunition storerooms. The air escapes into the cells through small apertures in these pipes and leaves the cells through openings in the bulk-heads.

The forward station for the wounded has one, the after station two fresh-air inlets with cowls, while the foul air escapes through separate outlets. Most of the officers' cabins are dependent for their air supply on perflation, and this must be considered an important flaw in the whole system. All three of the above-named vessels are also provided with steam ash ejectors, which contribute largely toward keeping the ship's air clear of finely divided particles of inorganic matter.

5. *U. S. Training Ship "Prairie."*—We will conclude the chapter on ventilation with a description of the *Prairie's* system of ventilation, giving at the same time the results of some investigations into the working efficiency of the latter. The present training-ship *Prairie* is the converted steamer *El Sol* of the Morgan Line Steamship Company. She has a length of 404 feet over all and a beam of 44 feet; she has a gross tonnage of 6,782 tons, and is provided with a single screw, driven by a vertical, inverted three-cylinder triple-expansion engine of the ordinary marine pattern for commercial use, built at the Cramps' shipyard in 1890, and last commissioned at the Boston navy yard on November 9th, 1901; she has a spar deck, a gun deck, and a berth deck with the usual holds and storerooms below.

Since the berth-deck compartments are the only ones which have artificial ventilation, all her other compartments depending upon ventilation by perflation, the former will be the only ones included in the following description. The berth deck of the *Prairie* is divided by the large engine- and fireroom hatch into a forward and an after section of nearly equal dimensions, and between them there is no communication, the two iron bulkheads of the hatch reaching clear across from one side of the ship to the other.

The forward section of the berth deck is again divided by two cross bulkheads into three compartments with two communicating doors, symmetrically placed on each side of the two dividing bulkheads. The most forward of the three compartments is used for sick-quarters, the one next to this comprises the petty officers' quarters, and the third gives berthing space to a large number of men.

The after-section of the berth deck is likewise divided into three compartments, the most forward of which accommodates the dynamos, the next gives berthing space to the marine guard, and the last is for the chief petty officers.

There are three large square and three small oblong and rather narrow hatches in her decks, all superimposed and therefore well intended to send both light and air directly down into the deeper parts of the ship. The two electric fans of 110 volts each are both on the gun deck, just fore and abaft the fire- and engine-room hatches respectively. Each of the two large ventilating trunks, after passing through the gun deck, bifurcates, and the two branch trunks with their inlets run along the sides of the various compartments which they traverse, at a height above the berth-deck flooring of six or seven feet.

The two tables, showing the results of the anemometrical observations, are intended to exhibit at the same time in a diagrammatic manner the relative position of the different compartments, their cubic capacity, the number of inlets, and also the relative distance of the inlets from the fans or blowers. As may be seen in the columns of "cubic feet exhausted per hour," the amounts of air taken up by the different inlets decrease very rapidly and directly with their distance from the blowers. Inasmuch as the observations on the inlets and outlets rarely agree exactly, the largest figure is always taken as indicating the true value of the amount of work done by the fans.

TABLE X.—ANEMOMETRICAL OBSERVATIONS ON THE VENTILATION OF THE BERTH-DECK COMPARTMENT, MADE ON U. S. S. *Prairie*, AT SEA, ON JANUARY 5TH BETWEEN THE HOURS OF 1 AND 3 A.M. NUMBER OF INLETS TWENTY-SIX, WITH AN AVERAGE SQUARE AREA OF 0.4 FEET.

I. Forward of engine- and firerooms; average difference in number of turns of anemometer between the inlets is eighty-five per minute.

Number inlets, port.	Cubic feet exhausted per hour.	Bow.	Cubic feet exhausted per hour.	Number inlets, starboard.	Sum.
13	15,900	Sick-quarters, cubic air space, 4,700 feet, exhausted 22 times per hour; available air per head and per hour, 5,370 cubic feet.	15,900	13	
12	17,880		17,880	12	
11	19,920		19,920	11	107,400
10	21,960	Forward berth deck, cubic air space, 10,209 feet, exhausted 23 times per hour; available air per head and per hour, 2,674 cubic feet.	21,960	10	
9	24,060		24,060	9	
8	26,100		26,100	8	
7	28,140		28,140	7	200,520
6	30,120	Main berth deck, cubic space, 25,604 cubic feet, exhausted 16.5 times per hour; available air per head and per hour, 1,726 cubic feet.	30,120	6	
5	32,160		32,160	5	
4	34,260		34,260	4	
3	36,300		36,300	3	
2	38,280		38,280	2	
1	40,320		40,320	1	422,880
		Blower.	Grand	total,	730,800

II. Berth-deck compartments abaft the engine- and firerooms; average difference in number of turns of anemometer between the inlets is thirty-eight per minute; decreasing in a direction from the blower.

Number inlets, port.	Cubic feet exhausted per hour.	Blower. ↑		Cubic feet exhausted per hour.	Number inlets, starboard.	Sum.
1	33,780	Dynamo.		33,780	1	
2	32,880			32,880	2	133,320
3	31,980	Marines' quarters, cubic air space, 9,827 feet, exhausted 30 times per hour; available air for breathing purposes per hour and per head, 4,875 cubic feet.		31,980	3	
4	31,080			31,080	4	
5	30,120			30,120	5	
6	29,220			29,220	6	
7	28,320			28,320	7	301,440
8	27,420	Chief petty officers' quarters, cubic air space, 10,209 feet, exhausted 25 times per hour; available air per head and per hour, 3,430 cubic feet.		27,420	8	
9	26,520			26,520	9	
10	25,800			25,800	10	
11	24,900			24,900	11	
12	24,000			24,000	12	257,280
13	23,100	Closets.	Pantry.	23,100	13	46,200
14	22,200	Stores.	Stores.	22,200	14	44,400
		Stern.		Grand	total,	782,640

The after berth-deck compartments of the *Prairie*, by reason of their relatively smaller cubic capacity, are much better ventilated than the forward compartments, both fans doing about the same amount of ventilating work. The blowers are run at night only.

The tests for the amount of atmospheric carbon dioxide, exhibited in Tables XI. and XII., were made according to the method of Fitz, as modified by Woodman and Richards and described in the preceding pages. In making these examinations, it was the intention to get, as nearly as that was possible under the circumstances, a true and absolutely fair estimate of the amount of carbon dioxide present in the atmosphere of the different parts of the ship. None of the dark places in which the air naturally stagnates, such as storerooms and holds, and where the carbon dioxide was found up to 22 to 40 parts in 10,000, were included in these observations. The tests shown in

TABLE XI.—CARBON-DIOXIDE* OBSERVATIONS, SERIES I., U. S. S. *Prairie*, HAMPTON ROADS, VA., DECEMBER 27TH TO 28TH. SHIP HEADING N.E. BY E. AND W.S.W. RESPECTIVELY. WIND N.E., STRENGTH 2. ATMOSPHERIC TEMPERATURE DURING PERIOD OF OBSERVATIONS VARIED FROM 39° TO 45° F. WEATHER PARTLY MISTY AND PARTLY CLOUDY.

Time of day.	Sick-quarters.	Forward B. D.	Main B. D.	After B. D.	Warrant Off.	Forward G. D.	Remarks.
9 P.M.	10.0	8.5	10.0	12.0	14.0	10.0	Hatches partly covered.
11:30 P.M.	10.0	6.5	9.0	9.0	9.0	7.5	Blowers started at 12 midnight.
1 A.M.	8.4	4.3	5.5	6.2	6.0	5.0	Blowers stopped at 5:30 A.M.
6 A.M.	9.0	6.0	7.2	8.2	5.5	7.2	Gun-deck ports closed.
10:30 A.M.	8.6	6.2	4.1	6.0	5.5	3.1	Gun-deck ports open.
11:30 A.M.	7.5	3.5	3.0	4.0	4.0	3.0	Gun-deck ports open.
1 P.M.	5.0	3.2	4.5	4.0	3.4	3.0	
7 P.M.	7.5	4.0	10.0	4.2	4.6	14.0	Raining; hatch covers on; hammocks.
Averages.							
General	8.3	5.5	6.1	6.4	6.0	5.9	
Night	9.5	6.7	8.3	8.0	7.8	8.7	
Day	7.0	4.3	3.9	4.7	4.3	3.0	
Difference	2.5	2.4	4.4	3.3	3.5	5.7	Difference between night and day, averages.

* Numbers in columns indicate amount of CO_2 contained in 10,000 parts of air.

TABLE XII.—CARBON-DIOXIDE OBSERVATIONS, SERIES II., U. S. S. *Prairie*, JANUARY 4TH TO 5TH. AT SEA BETWEEN LATITUDES 16° 13′ 30″ AND 15° 08′ N. AND LONGITUDES 64° 25′ AND 63° 40′ W. COURSE E. BY S. STRENGTH OF WIND 4. ATMOSPHERIC TEMPERATURE VARIED FROM 78° TO 81° F. SKY PARTLY BLUE, PARTLY CLOUDY.

Time of day.	Sick-quarters.	B. D. main.	B. D. aft C. P. O.	Warrant Off.	G. D. aft.	G. D. forward.	Remarks.
9 P.M.	8.8	8.8	8.8	5.6	5.6	5.6	Wind forward, weather clear.
11 P.M.	4.1	4.1	5.0	3.7	3.7	3.6	Wind athwartship; ports open.
1:30–2:30 A.M.	5.8	6.2	6.3	4.3	4.0	3.9	Blowers running half speed.
11 A.M.	4.3	7.0	8.2	5.0	3.7	3.6	No one occupying sick-quarters.
1:30–2:30 P.M.	4.8	4.8	5.5	4.4	3.6	3.6	All gun-deck ports open.
5 P.M.	5.0	5.2	5.8	4.2	4.0	4.6	All gun-deck ports open.
Averages.							
General	5.5	6.0	6.6	4.8	4.2	4.2	Influence of open gun-deck ports shown; tends to lessen the difference between the night and day averages.
Night	6.2	6.5	6.5	4.4	4.4	4.4	
Day	3.7	5.6	6.5	4.4	3.7	3.9	
Difference	2.5	.9	.0	0.0	.7	.5	

the tables represent the compartments that are included in the general circulation of the area ventilated by the blowers. The results show what the carbon-dioxide content of the ship's atmosphere available for breathing purposes may be expected to be, when the ship is at sea and is sailing under the *most favorable* conditions of weather and climate. The influence of hatches, whether open or closed, of gunports, of the direction of the winds and of the blowers upon the carbonic-acid content, may be seen in the tables and studied in connection with the column of remarks.

As the blowers operate on the vacuum principle, it must, of course, be expected that the air, when it reaches the breather, is at its worst. The differences between the night and day averages in series I. were rather large, as compared with those shown in series II. The colder climate at Hampton Roads made it necessary for the comfort of the men sleeping below to keep the hatches covered and the ports closed. Under such conditions the vacuum system of ventilation shows its weak points. The fans arranged in accordance with the plenum principle would easily remedy these defects and convert a very faulty system of ventilation into an efficient one.

In concluding the chapter on ventilation we would emphasize two leading and important factors influencing a ship's ventilation, namely: (1) The plenum system of ventilation for ship's purposes is unqualifiedly recommended. (2) That the high atmospheric temperatures and humidities prevailing in warm climates, together with the prominent part played by physical heat regulation on the part of the men, make it possible that the air in ships may be renewed from fifteen to twenty times per hour, without danger from draughts.

II. WATER.

Every living organism, every single microscopic cell of this organism, has its normal amount of water under which alone it can perform its proper function, and the slightest departure from this normal percentage amount of water peculiar to its composition begins to initiate the series of changes that can have but one ending, namely, the death of the organism. The human body has in its composition sixty-five per cent. of water, of which it loses 2,500 gm. daily. As it receives from 500 to 800 gm. in the food, the remaining loss must be made good by drink. In experimental animals death inevitably ensues whenever the loss of water amounts to from twenty to twenty-five per cent. Those of us who live in temperate climates, in which water is found everywhere in sufficient quantity to supply our daily needs, hardly ever think of the possibility of dying of thirst; but those who live in the tropics know well how pressing and dangerous thirst can become as compared to hunger. As a means of personal cleanliness, it has become well recognized that it is economy to be lavish with the water supply, especially among soldiers and sailors, who must be so trained that cleanliness of person becomes to them a necessity and a habit.

With regard to the water-supply of ships, the last fifty years have brought about great changes. The general introduction of steam has made not only the voyages shorter, but it has been the means of making ships almost entirely independent of the shore as regards their water-supply. In times of wooden ships and long passages across the seas under sail alone, the water question was one of most serious concern to all seafaring men. Besides this, the generally prevalent lack of knowledge at that time of the importance of cleanliness in collecting, storing, and distributing the water on board ship was the cause of untold misery and long suffering, due to poor water and to the separation from a base of supply. The water was carelessly collected and then stored in tanks or barrels down in the dark holds of the ship. Often neither the water nor the barrels were examined, and consequently they left much to be desired as regards cleanliness. After a time the water began to emit a disagreeable odor, the essence of which was sulphureted hydrogen. This gas was produced by the decomposition of the sulphates in the water. In the course of time this gas was reoxidized and the disagreeable odor disappeared. This periodical reduction of the sulphates and oxidation of sulphureted hydrogen recurred several times during a voyage, and it was a common saying among sailors that the water had to putrefy three times before it became potable.

It certainly was true that the water did cease fermenting after a time, and consequently it was often better at the end of a voyage than at the beginning. We now are perfectly well acquainted with the causes of this fermentation and make use of this very property of water to purify it before filtration. It is the septic-tank method which has been found so effective in removing a large percentage amount of germs and fermentable organic matter, and which makes subsequent sand filtration so much more effective in producing a pure and potable water than it would be without it.

Although most of the naval vessels are supplied with distillers for the production of drinking-water from seawater, it cannot be said that all ships of the navy are absolutely independent of water supplies from natural