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Methods of Testing the Efficiency of Ventilation

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METHODS OF TESTING THE EFFICIENCY OF VENTILATION

BY ELLEN H. RICHARDS, E. MARION WADE, ROYCE W. GILBERT, CARL E. HANSON, JAMES M. TALBOT

THE application of scientific knowledge to the daily living conditions of human beings is demanded today as never before. We are slowly learning that these applications may be made without, in all cases, using the time-consuming methods of exact science. It is a working basis for the betterment of conditions that is demanded, and a more general use of the facts as fast as learned.

Especially is this true of the examination of the air supply of rooms, shops, dining halls, and places of amusement and of study.

The general quality of the air is in question. Is it fit for human beings to breathe? The facts brought out in the course of the crusade against tuberculosis show that in a far too large number of circumstances the general conditions are dangerous, and that a concerted effort must be made to interest the people to better them.

To secure these general facts in a sufficient number of cases requires methods which shall be reliable and accurate within limits, and not so time-consuming as to be prohibitive.

A systematic effort has been made to meet this want by the classes studying Air Analysis at the Institute of Technology; namely, Course II, Mechanical Engineering, Option 4; Course V, Chemistry; Course VII, Biology; and Course IX, Sanitary Engineering. Some results of the past two years' experience are here given.

A general consensus of opinion among recent investigators points to recorded temperature as the most practicable means of controlling ventilation under modern conditions. The temperature of any given room may increase by any one or any combination of the following causes: (1) Heat given off by the bodies of the occupants and by their breath;

(2) Heat given off by the lights; (3) Rise of outside temperature; and (4) An excess of heat from the heating plant.

The last of these causes should be practically eliminated in a modern, well-constructed, and well-managed public structure. Of course the average private home has not yet reached this point of refinement in the perfection of its heating system, but it is not the small individual house or even the apartment house that is usually in need of ventilation. In a small room with few occupants, the doors, windows, and cracks usually provide sufficient change of air. It is in the large halls, office buildings, schools, etc., where many persons are congregated under one roof, that ventilation is most needed and inspection of ventilation is most important. In all such places the heating system is, or should be, designed to deliver a constant amount of heat for any given period of time.

Contrary to the old theory that a heating plant should "keep a room at a given temperature," and so automatically supply less and less heat as the heat derived from the occupants increases, the new idea is rather that the plant deliver a constant predetermined amount and that the ventilating plant keep the room at the desired temperature. This idea is really carried out in most of the buildings with which the ventilating engineer or inspector would have to deal. This being the case, any rise of temperature in a room would be caused by the animal heat of the occupants, effect of the lights, or by rise of the outside temperature. This last cause is slight in any instance and may usually be neglected.

Then, since in giving off heat the body and the lights (with the exception of electric incandescent) give off both CO_2 and moisture in proportion, we have in this increase in temperature an almost ideal index of the quality of the air. A recording thermometer with a large dial face, hung or placed so as to be as readily seen as a clock, is the best known gauge of an occupied room.

If the air current through an occupied space is sufficient to carry away the increased moisture and to keep the temperature even, it will lower the carbon dioxide in the same proportion. This may be accepted as true without chemical examination (there are occasionally other sources of CO_2). The humidity is therefore an excellent indicator of the degree of ventilation, and a recording hygrometer is most desirable to place alongside the recording thermometer. Frequent observation and record may replace these rather expensive instruments to a degree.

We feel safe in stating that probably the best engineering practice in ventilation today is in the use of these instruments, combined with training in the detection of odors. Only in cases of control or inspection will the determination of CO_2 be necessary when these instruments are at hand and when time for observing them is available. But there are frequent circumstances in which CO_2 is an equally good indicator and the tests for it more convenient of application, but they should partake of the rapidity and comparative accuracy of the instruments, and should not require the engineer to be burdened with cumbersome apparatus. For these purposes a sufficient degree of accuracy may be defined as within two-tenths to three-tenths of a part per 10,000, with a possible maximum error of five-tenths.

It does not seem to be possible in the present state of our knowledge to devise chemical tests for carbon dioxide which may be put with safety into the hands of unskilled persons, as may thermometers, but chemists and trained inspectors may use one of the following methods with confidence in their accuracy after a considerable practice, always using *outside air as a standardizing* medium. This will show at once any errors due to changing strength of the testing solution or fault in the manipulation.

The testing solution is not only carefully prepared, but protected against change while using by clamping the rubber stopper with a screw, or, in the case of additional bottles to be transported, by covering the stoppers with paraffin. The mounted automatic pipette ("Air, Water, and Food," page 42) is most convenient, but the inspector may mount an ordinary burette to answer the same purpose of delivering a measured 10 c.c. of solution.

The apparatus most used for this purpose in recent years is the Fitz or the Wolpert "shaker" ("Air, Water, and Food," page 43), a graduated glass tube in which successive small quantities of air are brought into contact for a definite time (thirty seconds) with a known volume of standard lime water, using the same solution for each partial sample of air, until the color of the indicator disappears. The relation between the quantity of CO_2 present and the total amount of air required to decolorize 6.3 c.c. of a standard saturated solution is shown in Table A.

TABLE A — FITZ SHAKER, PISTON, OR CYLINDER. 6.3 C.C. SATURATED LIME WATER PER LITER

Cubic centimeters of air.	Parts CO_2 in 10,000.
50	15.6
70	12.4
90	10.2
110	8.7
130	7.5
150	6.6
170	5.8
190	5.2
210	4.8
230	4.5
250	4.3
270	4.1
290	3.95
310	3.8
330	3.7
350	3.6

The taking of successive portions at even this short interval involves errors in sampling which in unskilled hands are liable to be serious. There is also an irregularity of action due to the fact that, as the solubility of a gas from a gaseous mixture is proportional to its partial pressure, the first portion of air gives up a larger part of its CO_2 than the later portions, in the same time; and therefore a much longer time should be allowed for absorption, which is not very practicable.

This property of gases is utilized, however, in another manner by the method of Cohen and Appleyard, in which the lapse of time is used to indicate the amount of CO_2 present in the mixture. This method, based as it is on a well-known scientific principle, has not received the attention it deserves; although it has been experimented with until it is, we think, on a workable basis.

The following methods of collecting the sample may be used according to circumstances and may be described as (*a*) the water siphon; (*b*) the piston apparatus; (*c*) the steam-caused vacuum.

The alkaline solution is the same whatever method of collection is used and is made from a saturated solution of "lime water" of whatever strength is desired. 2.5, 5, and 10 c.c. to the liter are most available, according to the character of the air to be tested, the medium strength being of most general usefulness. Sodium or potassium carbonate, which readily takes on another molecule of carbon dioxide, may be substituted, whenever weighing out the pure solid is preferable to preparing the lime water. There may be also a slight increase in rapidity of action. These acid carbonate solutions keep better than caustic standards.

(*a*) *The Water Siphon Method.*—Two bottles (diameter one-third the height) of nearly equal capacity are fitted with rubber stoppers carrying small glass tubing, connected by several feet of rubber connector, with clamps (Fig. 1). One bottle is completely filled with water, nearly free from carbon dioxide.

The pair of bottles is taken to the place from which the air is to be collected. The inlet tube may be long to reach to near the ceiling, or short; if long, the first siphoning should be rejected, to secure filling the inlet tube with the air desired, the stoppers exchanged, and the sample taken. The air-filled bottle is stoppered and taken to the laboratory; or the test solution is at once added, the bottle stoppered and shaken, noting minutes and seconds. One bottle of water with a small reserve will serve for a number of takings before absorbing a deleterious amount of CO_2.

(*b*) *The Piston Method.*—In the piston method a glass cylinder containing approximately 600 c.c. is used. The two ends of the cylinder (Fig. 2) are of brass, one being pierced by a stopcock to admit the air to the tube, and the other by the connecting rod of the piston, which is made to fit the walls of the cylinder as closely as possible. The piston must be tight against the bottom of the cylinder. Then, with the apparatus at arm's length, the stopcock in the bottom is opened, and with a steady pull on the connecting rod the cylinder is filled with the desired air, care being taken to pull the piston tight against the upper end of the cylinder. After closing the stopcock the cylinder is ready to be taken to the laboratory for testing.

10 c.c. of lime water solution, colored by phenolphthalein, is run into the cylinder and the stopcock immediately closed. The tip of the burette, containing the 10 c.c. of lime water, is held at the lip of the stopcock

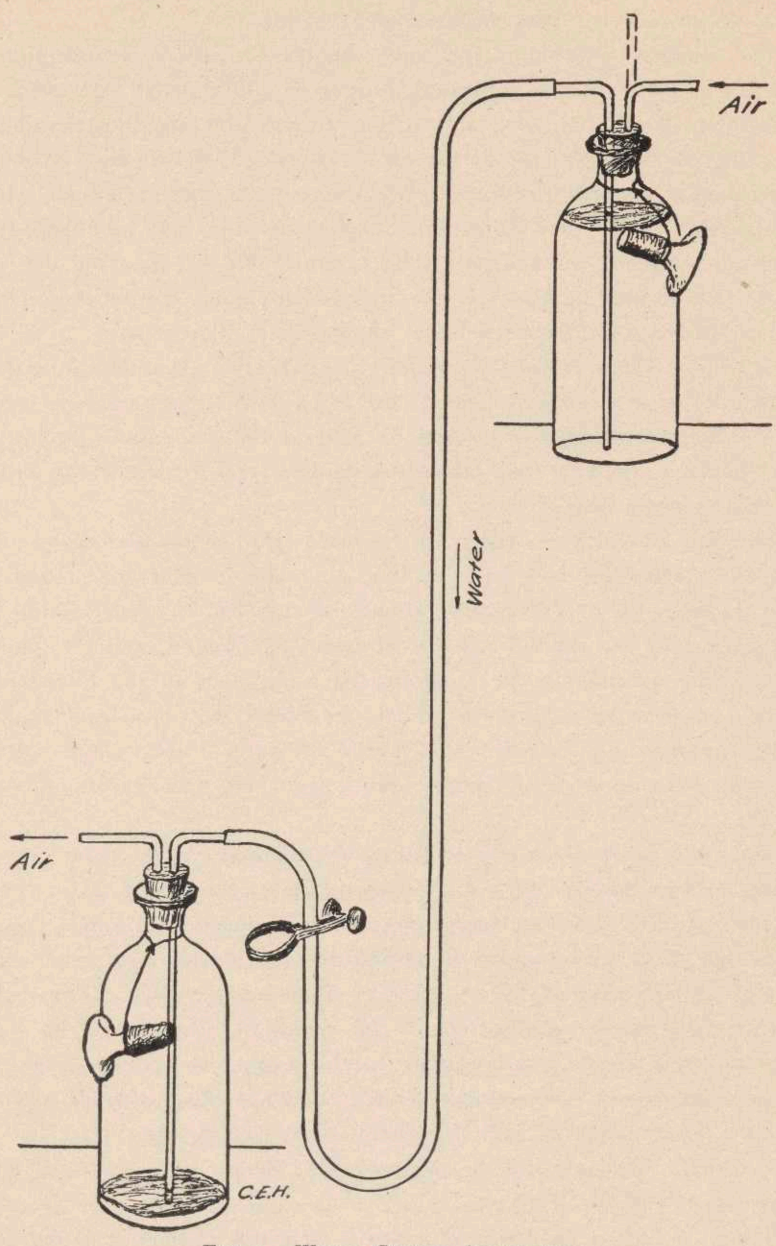

FIG. 1.— WATER-SIPHON APPARATUS

(made with a lip for the purpose), and the solution runs down the interior sides of the stopcock as the displaced air comes out of the centre. The number of seconds of gentle shaking before the color of the indicator disappears over white paper is recorded. This method may be used for samples taken by the siphon or vacuum methods, as well as the piston. From the known strength of the solution and the time, the number of parts of CO_2 per 10,000 may be read from the table.

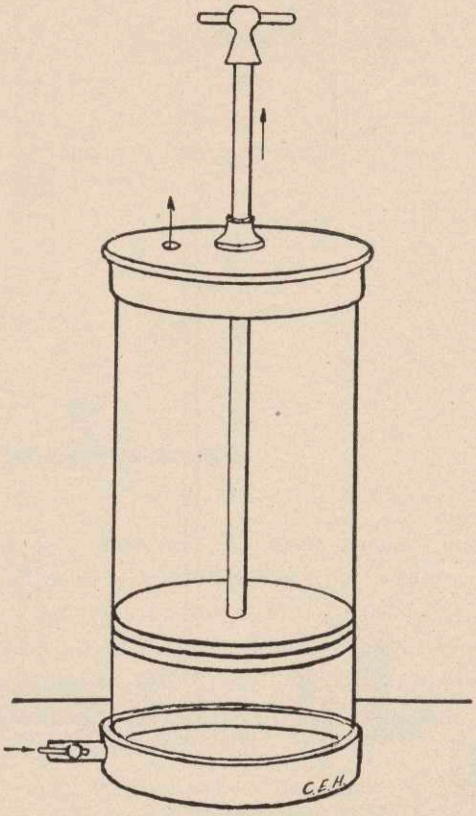

FIG. 2.—CYLINDER WITH PISTON

TABLE B — TIME METHOD. SAME SOLUTION AS IN TABLE A

Time.		Parts CO_2 in 10,000.
Minutes.	Seconds.	
0	30	15.6
0	45	12.1
1	0	9.9
1	15	8.4
1	30	7.2
1	45	6.3
2	0	5.5
2	15	4.9
2	30	4.4
2	45	4.0
3	0	3.8
3	15	3.7
3	30	3.6

(*c*) *The Steam Vacuum Method.*—The steam is supplied by a 500 c.c. flask serving as a boiler, with a Tirrill burner to supply the heat. The flask (Fig. 3) is fitted with a rubber stopper carrying a No. 6 glass tube, bent so that one end extends within ½ inch of the bottom of the bottle when placed in position on the stand. The bottles used are of about 500 c.c. capacity, made for a ground-glass stopper but fitted with a rubber stopper.

To prepare the jet, the water in the flask is allowed to boil for five minutes in order to expel completely the air in the water and the flask. The pressure should be sufficient to throw the vaporized steam at least 1 foot above the exposed end of the tube.

The empty bottle is placed on the stand in an inverted position and allowed to remain for three minutes. In the meantime a thin coating of vaseline is applied half way up the sides of the stopper. The vaseline acts as an unguent, reducing the coefficient of friction to such an extent that the principal resistance is due to the reaction of the stopper against compression. This enables one to force the stopper in far enough to bring the glass and rubber into intimate contact, which is essential. The vaseline also fills the interstices between the rubber and the glass, which makes leakage impossible.

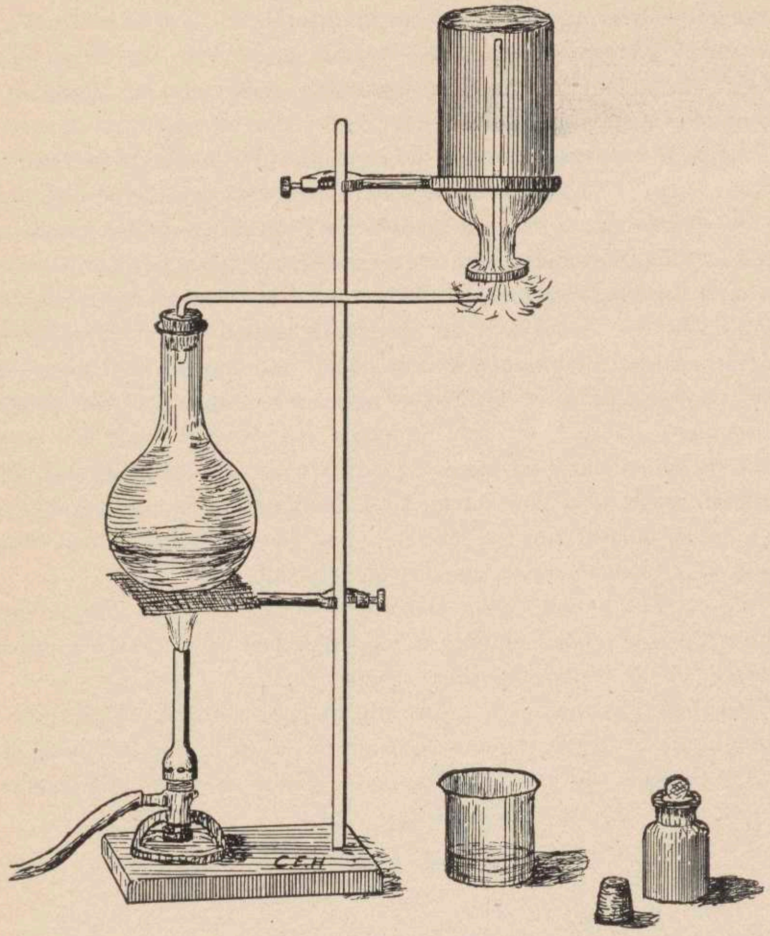

Fig. 3.— Steam-Vacuum Apparatus
From the thesis of Carl E. Hanson, 1908

Protecting the hand with a cloth, the bottle is raised from the stand, and the instant it clears the end of the tube the stopper is inserted while the bottle is still inverted. The stopper may be pushed in more securely by pushing it against the table with a few pounds' pressure while the bottle is still in the inverted position. The stopper is kept in under this pressure for a few minutes until the vacuum begins to form, after which the atmospheric pressure will keep it in place.

All the bottles required are treated in the same way. The rubber stoppers should be at least one size larger than would ordinarily be used for the bottles, and should project three-eighths of an inch or more to be easily removed when the sample is to be taken.

Sample bottles may be tested for completeness of vacuum by holding them in an inverted position under water at 70° F., free from carbon dioxide, and removing the stopper. After the water has replaced the vacuum, the stopper is inserted and the bottle removed.

Testing the Apparatus.—For the testing of the methods we have used the "live box," or air-tight room, devised in 1897 by Herbert E. Smith for his thesis on schoolhouse ventilation. Small weighed candles are placed in a flat-bottomed glass dish, lighted, the box closed and screwed tight, and the candles allowed to burn out. The electric fan is kept running to mix the air. After an hour samples may be drawn from the space at any of the three different levels desired, through glass tubes which the box carries. The following are examples of tests made in this manner.

Two candles three-eighths of an inch long and weighing six-tenths of a gram each were burned in a box containing 12 cubic feet of air. The candles burned for five minutes, and the resulting carbon dioxide content was from twenty to twenty-eight parts.

Two candles 2 inches long and together weighing 6.8 grams, burned in the large box (cubic contents 86.625 cubic feet) for forty-five minutes, produced an air containing thirty parts CO_2.

That the air in the box is uniformly charged with CO_2 (when the fan is running) and that it remains constant is shown by the following times of neutralization by the time method. These samples were taken at different times during the same day:

Trial.	Whole Solution.	Half Solution.
	Time.	Time.
	Seconds	Seconds
1	15	25
2	15	25
3	15	23
4	15	23
5	15	25

The outdoor air has too low a carbon dioxide content to serve for the test of an apparatus designed to detect larger quantities, and the air of well-ventilated rooms, as most of the schoolrooms are, is not only too good, but subject to too many variations to serve as reservoirs of constant air. The "box" has served us well in these respects, and with weighed candles repetition of the tests is easy. The air may remain constant for two weeks if only the small quantities are removed.

Interpretation of Results.—If in a crowded hall the temperature is less than 70° F., if the wet and dry bulb thermometers are 7° apart (less than 70 per cent. humidity), with no appreciable odor, and if the carbon dioxide is less than seven parts per 10,000, the air may be said to be satisfactory; but if the temperature is 80°, the wet and dry bulb only 4° apart (humidity 83 per cent.), and the carbon dioxide eight parts, with a close odor, then measures should be taken at once to remedy the condition.

The ideal condition for constant occupancy is: thermometer 68°, humidity 68 per cent., or wet and dry bulb 6° to 7° apart, with carbon dioxide less than six parts per 10,000 of air.

If these general results may be obtained, the smaller differences in readings may be discarded until the public is educated to this extent.