Chemical Notes on Ventilation.

By Percy Norton Evans.

What is the direct cause of the enervating and injurious effect of poor ventilation on the human system is still uncertain. The old theory that it is due to increased carbon dioxide and decreased oxygen in respired air seems quite inadequate in view of the smallness of the actual difference between ordinary poor air and fresh air; to be sure the carbon dioxide may be increased many times, but it is not poisonous, and experiments have shown that equal quantities added to air by purely chemical means have no such marked physiological effects; and the concentration of oxygen is altered to a scarcely appreciable extent in any case of ordinary poor ventilation.

It is held by some that definite toxic substances are exhaled in respiration, and that these, rather than the alteration in the proportions of inorganic constituents of the air, are responsible for the undesirable effects. Exhalations from the skin have also been considered of importance, and this hypothesis receives some measure of confirmation from the very noticeable difference in the intensity of the effect of a well-washed and a not-well-washed crowd in a poorly ventilated assembly room, the respiration products being the same in both cases presumably. Again, some claim that the excessive moisture is an important factor, but this seems an insufficient explanation, for the air of badly ventilated buildings in cold weather contains nothing like the amount of moisture present in fresh air in warm, damp weather.

Whatever the cause or causes—and they may be many—of the evil effects of poor ventilation, it is surely true that anything that tends to carry away the air that has been exhaled or in contact with the person and replace it by fresh air, must be beneficial.

Elaborate provision is often made to insure by mechanical means this movement of air. As will be shown, something can also be done by automatic physical means to bring about the same result, and where mechanical means are employed they should for economy and efficiency operate in such a direction as to assist rather than oppose the natural automatic movement.

It was formerly thought that foul air, that is air that has been breathed, was more dense than fresh air, because part of the oxygen of the latter is replaced by carbon dioxide in the lungs, and carbon dioxide is denser than oxygen, and consequently that expired air tended to fall and foul air to accumulate at the floor of a room, so that for the best results the removal of air should be from near the floor. This reasoning overlooked the fact that oxygen is also replaced by water vapor in the lungs, and water vapor is lighter than oxygen; also that the expired air is at a higher temperature than the air of the room and on this account less dense. This error is no longer generally made in the discussion of the principles although often in practice. As will be shown, expired air is actually lighter than fresh air under ordinary ventilation conditions, and therefore tends to rise and accumulate near the ceiling. This is assisted by the natural upward movement of air in a building warmer than its surroundings, as in a flue, and further by upward currents in the neighborhood of any body warmer than its immediate surroundings, such as a stove, a burning lamp or gas jet or electric light, or even the body of a person. That foul air tends to accumulate near the ceiling is very evident to those occupying the gallery of a crowded auditorium.

An experiment to test this upward movement of respired air was made by the writer in a class room about 27 by 30 feet and 16 feet high. The room temperature was 24° C. (75° F.), and the outdoor temperature 10° C. (50° F.); the moisture in the air of the room as shown by a Mitthof hygrometer was between 50 and 60 per cent. of saturation. The windows and door and a ventilator were closed during the period of experiment and the only source of artificial heat in the room was a vertical steam pipe, the radiator being shut off by the automatic thermostat.

The room was occupied by 26 adults for 50 minutes and was then unoccupied for 10 minutes immediately before the period of experiment, which also lasted 50 minutes, 36 adults being present, seated.

Carbon dioxide was determined in the air with a Lunge air tester, samples being taken alternately from within 6 inches of the ceiling and the floor, through tubes, and analyzed on a table, near the center of the room. The analytical method consisted in forcing the air through a standard solution of sodium carbonate colored pink with phenolphthalein, by squeezing a rubber bulb until the pink color disappeared, the number of squeezes being counted, and ranging in this experiment from 8 to 5, fresh outdoor air requiring 48 squeezes with the apparatus used.

The results for the successive samples from near the ceiling were 14.5, 16.0, 18.0, and 21.0 parts of carbon dioxide in 10,000 parts of air by volume; near the floor the figure obtained was 14.5 in 3 successive samples. Moisture readings with the hygrometer showed an increase from 52 to 58 per cent. of saturation during the experiment near the ceiling, and from 55 to 58 below the table—a greater increase near the ceiling. These results show that the respiration products, carbon dioxide and moisture, move upwards under these conditions.

The influence of the temperature and moistness of the air of the room on the upward movement of expired air will be shown in what follows.

The temperature of the exhaled air is necessarily body temperature, 37° C. (98.6° F.) ; that of the surrounding air of the room can be controlled in an artificially heated building, and since cold air is denser than warm air the lower the room temperature the greater will be the difference in density between it and the exhaled air, and the greater the tendency of the latter to rise and be automatically removed from the respiration level. Failure to take advantage of this principle probably accounts in part at least for the enervating and depressing effects of overheated rooms in our homes, schools, offices, public buildings, and, worst of all, our hotels. The usual temperature aimed at in this part of the country is well up in the seventies—a very mistaken form of luxury; it should be at least ten degrees lower, and sensible habits in clothing, especially on the part of fashionable women, would soon remove the apparent hardship. The accepted temperature for school rooms in England is said to be 58° F., and the standard temperature of the room generally accepted in European scientific work is 15° or 15.5° C. (59° or 60° F.).

The moisture factor is similar to the temperature factor in its effect and to a less degree in its control. The exhaled air is always saturated with moisture, the air of the room if at a higher temperature than out of doors is not saturated unless moisture is added to it after entering the building, and in frosty weather is commonly not over one-fifth saturated. Since, as already stated, water vapor is lighter than air, and since it displaces an equal volume of air, the less moisture there is in the air of the room the greater will be the tendency of the expired air to rise. There may be other reasons against having very dry air in buildings, such as irritation of the nose and throat, though this objection is at present debatable and not in agreement with the generally recognized benefits of breathing fresh air even at low temperatures; also there may be injury to furniture and wood-work, but from our present standpoint the drier the room air the better. In harmony with this is the very noticeably depressing effect of a very moist atmosphere.

Let us now consider the numerical values concerned in these densities under ordinary conditions.

Accepting Halliburton's values for the composition of fresh air and expired air both in the dry condition,

Fresh air—

Oygen .... 20.96 per cent. by volume
Nitrogen .... 79.00 per cent. by volume
Carbon dioxide .... 0.04 per cent. by volume

Expired air—

Oxygen .... 16.12 per cent. by volume
Nitrogen .... 79.45 per cent. by volume
Carbon dioxide .... 4.43 per cent. by volume

the densities, compared with hydrogen at the same temperature and pressure, are

Fresh air: $$\left(\frac{20.96}{100}\times\frac{16}{1}\right)+\left(\frac{79.00}{100}\times\frac{14}{1}\right)+\left(\frac{0.04}{100}\times\frac{22}{1}\right)=14.42$$

Expired air: $$\left(\frac{16.12}{100}\times\frac{16}{1}\right)+\left(\frac{79.45}{100}\times\frac{14}{1}\right)+\left(\frac{4.43}{100}\times\frac{22}{1}\right)=14.68$$

Considering now the effect of moisture on the density of expired air, the tension of aqueous vapor, or vapor pressure of water, is 47 millimeters of mercury at 37° C. (98.6° F.), therefore any gas saturated with water vapor at this temperature consists of $\frac{47}{760}\times\frac{100}{1}$ or 6.2 per cent. water vapor and 100 - 6.2 or 93.8 per cent. by volume of all other constituents together. The composition of expired air saturated with moisture at body temperature is therefore

Oxygen .... 16.12×.938, or 15.12 per cent. by volume
Nitrogen .... 79.45×.938, or 74.52 per cent. by volume
Carbon dioxide .... 4.43×.938, or 4.16 per cent. by volume
Water vapor .... 6.20 per cent. by volume

The density of this mixture compared with hydrogen at the same temperature and pressure, calculated as before, the density of water vapor being 9, is 14.33.

Comparing then the densities of dry fresh air and expired air saturated with moisture, both at 37° C. (98.6° F.), we find them to be 14.42 and 14.33 respectively, the addition of the moisture having a greater effect in decreasing the density than the replacement of part of the oxygen by carbon dioxide in increasing it, if the inspired air is dry.

Taking into account such differences in temperature as are likely to occur between the inspired and the expired air, we find that since the density of any gas or mixture of gases is proportional to the absolute temperature, a density of 14.42 for dry fresh air at 37° C., or 310° absolute, becomes at 20° C., or 293° absolute, $\left(\frac{14.42}{1}\times\frac{310}{293}\right)$ or 15.26, so that the relative densities of dry fresh air at 20° C. (68° F.), and ordinary exhaled air (at 37° C.), are 15.26 and 14.42. The difference between these figures, which is favorable to the automatic removal of respiration products from the level of respiration, decreases with any increase in temperature of the fresh air. A density of 14.42 at 37° C. becomes 14.33 at 39° C., for $\left(\frac{14.42}{14.33}\times\frac{310}{1}\right)$ or 312° absolute is 39° C.; therefore dry fresh air would have at 39° C. (102° F.), the same density as ordinary expired air (saturated with moisture and at 37° C.), and at 39° C. the automatic upward removal of respiration products due to difference in density ceases.

Having considered the case of perfectly dry fresh air, let us take the other extreme of fresh air saturated with moisture at certain temperatures. The tension of aqueous vapor at 30° and 35° C. is respectively 32 and 42 millimeters of mercury, so, by reasoning similar to that on page 58, the composition of fresh air saturated with moisture at these temperatures is

At 30° C.—

Oxygen	20.96 × .958, or 20.08	per cent. by volume
Nitrogen	79.00 × .958, or 75.68	per cent. by volume
Carbon dioxide	0.04 × .958, or 0.04	per cent. by volume
Water vapor	4.20	per cent. by volume

At 35° C.—

Oxygen	20.96 × .945, or 19.81	per cent. by volume
Nitrogen	79.00 × .945, or 74.65	per cent. by volume
Carbon dioxide	0.04 × .945, or 0.04	per cent. by volume
Water vapor	5.50	per cent. by volume

The densities of these mixtures compared with hydrogen at the same temperature, say 37° C., are respectively 14.20 and 14.11, calculated as before, while ordinary exhaled air has the density 14.33 compared with the same standard (hydrogen at 37° C.). Imagining these mixtures cooled down to 30° and 35° C., respectively, their densities become 14.53 and 14.20, calculated as before from the absolute temperatures. By interpolation we find that if densities 14.53 and 14.20 correspond to temperatures 30° and 35° C., 14.33 corresponds to approximately 33° C.; therefore if fresh air is saturated with moisture it has at about 33° C. the same density as ordinary exhaled air (saturated with moisture and at 37° C.), therefore at 33° C. (91° F.) the useful upward movement of expired air ceases if the surrounding air is saturated with moisture.

A certain temperature between 33° and 39° C. corresponds to each degree of saturation with moisture.

It has been shown that under all ordinary conditions of ventilation the products of respiration move upwards; that this upward movement, by which the harmful products are removed from the level of respiration, is assisted by a low room temperature, and by dryness of the air of the room; also, that the fresh air has the same density as expired air (saturated with moisture and at body temperature) at 33° C. or 91° F. if the fresh air is saturated with moisture, at 39° C. or 102° F. if perfectly dry, and at temperatures intermediate between these with different degrees of moistness.

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LaFayette, Indiana,
November, 1911.