CHAPTER IV.

AIR.

VENTILATION.

Air is a mixture, consisting chiefly of nitrogen, oxygen and carbonic acid gas, in the proportions by volume of about 7898 parts of nitrogen, 2099 of oxygen and 3 to 4 of carbonic acid in 10,000. The proportion of the latter varies but little in outdoor air. In that of occupied apartments, however, unless the air is frequently changed, the carbonic acid increases rapidly with accompanying ill effects.

This gas in moderate quantities is not harmful, but it is nearly always "found in bad company." It is mixed with the organic matter exhaled from the lungs and thrown off by the skin. In rooms having no special provision for ventilation the air must be breathed again and again, constantly becoming more foul. The porportion of carbonic acid in the air may be readily determined by several methods. It therefore forms the most convenient measure of the vitiation, since in occupied rooms the amount of harmful organic matter in the air is found to correspond with the proportion of carbonic acid.

When the number of parts of the latter exceeds 6 to 8 in 10,-000 of air, the room seems close to one entering from out of doors and a slight odor is perceptible. By the process of dilution the air may be kept, within limits, at any desired degree of wholesomeness. To maintain in a room continuously occupied for a number of hours an atmosphere in which the carbonic acid shall not exceed 6 parts in 10,000, an air supply of about 50 cubic feet per minute per occupant must be admitted. To accomplish this, much larger heating apparatus and flues than customary would be required. The public has not yet been educated to a full appreciation of what good ventilation really is. Therefore, for a time at least, we must be satisfied with the commonly accepted standard for schools—viz., 30 cubic feet of fresh air supplied per minute per occupant. This allowance will keep the carbonic acid down to about 7.4 parts in 10,000 of air.

Churches generally have 50 per cent. more space per occupant than schools, say, 300 cubic feet, and are occupied for much shorter periods. Therefore a smaller air supply is considered sufficient for such buildings.

An allowance of 20 cubic feet per minute is common, and some authorities recommend 1000 cubic feet per person per hour. In halls, which generally have a greater number of seats to a given space than the above classes of buildings, the air supply should be based on a 20 cubic feet per capita basis, provided this allowance will not change the air so frequently that uncomfortable drafts will be produced. In standard size school rooms the air is changed, on the 30 cubic feet per capita basis, once in 7 minutes.

This is about as rapid a change as can be recommended with inlets and outlets as commonly arranged.

In halls having perhaps only 100 cubic feet of space per occupant, unless the openings were very carefully arranged, an air supply of 20 cubic feet each would be likely to give trouble from drafts.

HUMIDITY.

The amount of moisture or water vapor contained in the atmosphere is expressed in terms of Actual Humidity, meaning the number of grains of water vapor per cubic foot of air, or Relative Humidity, meaning the ratio expressed in hundredths, between the weight of moisture in the air and that contained in an equal volume of saturated air at the same temperature. The Dew Point is the point at which the saturation is complete, when the vapor can no longer be held in suspension, but is deposited in the form of dew.

The effect of humidity on bodily comfort is marked, a person feeling far more comfortable on a hot, dry day, for example, than on a muggy day with a much lower temperature. It is a well-known fact that evaporation is accompanied by cooling, which accounts for the greater comfort experienced when the evaporation from the skin is rapid, as in a dry atmosphere.

Table X.

Box says that when the air contains about—

85 per cent. water vapor we consider it	damp.
65 per cent. water vapor we consider it	moderately dry.
50 per cent. water vapor we consider it	dry.
35 per cent. water vapor we consider it	very dry.
25 per cent. water vapor we consider it	extremely dry

Billings states that no discomfort is experienced in an atmosphere with a relative humidity of 30 to 40, and that at the Boston City Hospital no ill effects were observed with a relative humidity of 15 to 21.

The air supplied by furnaces is moistened to a very limited extent by means of the water evaporating pan. The capacity of air to absorb moisture increases rapidly with rise in temperature. For example, air at 72 degrees can absorb four times as much moisture as air at 32 degrees.

Table XI.—The Weight of Water Vapor per Cubic Foot of Saturated Space at Different Temperatures.

Temperature.	Weight of vapor in grains per cubic foot.	Temperature.	Weight of vapor in grains per cubic foot.
0	0.54	50	4.09 = 4 approx.
10	0.84	60	5.76
15	0.99 = 1 approx.	70	7.99 = 8 approx.
20	1.30	80	10.95
30	1.97 = 2 approx.	90	14.81
40	2.88	100	19.79 = 20 approx.

1 pound avoirdupois = 7,000 grains.

Approximately 1,000 heat units are required to evaporate a pound of water.

Since the capacity of air to absorb moisture rapidly, increases with a rise in temperature, as shown in Table XI, to maintain even a moderate relative humidity a great quantity of water and a corresponding amount of fuel will be required.

Take, for example, an eight or nine room house having an air supply of about 800 cubic feet per minute = 48,000 cubic feet per hour. Outside temperature, 30 degrees.

Suppose the air entering the furnace has a relative humidity of 65. Now 1 cubic foot of saturated air at 30 degrees temperature will contain approximately 2 grains of water vapor, hence with relative humidity of 65 per cent., 1 cubic foot will contain $\frac{65}{100} \times 2 = 1.30$ grains. Each cubic foot of air entering at 30 degrees temperature will, on being heated to 70 degrees, expand to 1.08 cubic feet. A cubic foot of saturated air at the latter temperature will contain approximately 8 grains of moisture, or with relative humidity 50, for example, will contain 4 grains.

Since the 48,000 cubic feet of air entering the furnace at 30 degrees becomes expanded to 48,000 × 1.08 = 51,840, at 70 degrees temperature, we have as the amount of water which must be evaporated per hour to maintain a relative humidity of 50 in the air at 70 degrees

51,840 cubic feet × 4 — 48,000 × 1.3 = 154,960 grains = 22.14 pounds.

As about 1000 heat units are required to evaporate 1 pound of water, 22,140 heat units will be required per hour, and assuming that 8000 heat units are utilized per pound of coal burned, we have $\frac{22,140}{8000} = 2.77$ pounds coal per hour = 66½ pounds coal per day.

EXPANSION OF AIR AND ABSOLUTE TEMPERATURE.

Air expands and contracts with changes in temperature according to a known law—viz., for each degree rise or fall in temperature from 32 degrees F. air expands or contracts $^1/_{491}$ of its volume at that temperature. If a cubic foot of air be heated through 491 degrees from 32 degrees, or to 523 degrees, it will double in volume. On the other hand, if a cubic foot of air be cooled through 491 degrees from 32 degrees, or to 459 degrees below zero, it will theoretically contract $\frac{491}{491}$ of its original bulk, or will entirely disappear. This point, 459 degrees below zero, or more accurately 459.4 degrees, is known as absolute zero, and is the point from which the expansion of air is reckoned in determining its relative volume at different temperatures, the volume being proportional to the absolute temperature. For convenience in making ordinary calculations 460 degrees F. below zero may, with sufficient accuracy, be considered absolute zero. Hence the absolute temperature of a body is equivalent to 460 degrees plus its Fahrenheit temperature. Suppose, for example, we wish to determine how much space 1 cubic foot of air entering a furnace at 0 degree F. will occupy when heated to 140 degrees

F. Since the volume varies in proportion to the absolute temperature, we have:

Absolute temperature of air at 0° F = 0° + 460° = 460 Absolute temperature of air at 140° F = 140° + 460° = 600	Volume at 0° is to volume at 140° as 460 is to 600.

Hence, volume at 140 degrees $= \frac{600}{460} \times$ volume at 0 degree; volume at 140 degrees = 1.3 cubic feet.

Table XII.—The Approximate Volume to Which 1 Cubic Foot of Air at 0° Will Expand When Heated to the Temperatures Stated in the Table. Volume of Air at 0° = 1 Cubic Foot.

Volume when heated to— Degrees.	Cubic feet.	Volume when heated to— Degrees.	Cubic feet.
10	= 1.02	110	= 1.24
20	= 1.04	120	= 1.26
30	= 1.06	130	= 1.28
40	= 1.09	140	= 1.30
50	= 1.10	150	= 1.33
60	= 1.13	200	= 1.44
70	= 1.15	300	= 1.65
80	= 1.17	400	= 1.87
90	= 1.20	500	= 2.09
100	= 1.22		

Table XIII.—The Weight of Dry Air per Cubic Foot at Different Temperatures.

Temperature. Degrees F.	Weight of a cubic foot in pounds.	Temperature. Degrees F.	Weight of a cubic foot in pounds.
0	0.0864	112	0.0694
12	0.0842	122	0.0682
22	0.0824	132	0.0671
32	0.0807	142	0.0660
42	0.0791	152	0.0649
52	0.0776	162	0.0638
62	0.0761	172	0.0628
72	0.0747	182	0.0618
82	0.0733	192	0.0609
92	0.0720	202	0.0600
102	0.0707	212	0.0591

THE FLOW OF AIR IN PIPES.

The resistance to the flow of air through pipes may be approximately stated as follows:

The resistance is proportional to the surface over which the air passes and to the square of its velocity. In other words, the resistance varies directly with the length of the pipe and the square of the velocity and inversely as the diameter. With pipes of the same length and air traveling at the same velocity the resistance will be inversely proportional to the diameter.

VELOCITY OF AIR IN FLUES.

The velocity of air in a flue is governed by its hight and the difference between the inside and outside temperature. Suppose we have a flue 1 square foot in area and of hight h, represented in Fig. 27.

The air in the flue is balanced by a column of colder outside air of hight H, leaving an unbalanced force represented by the hight

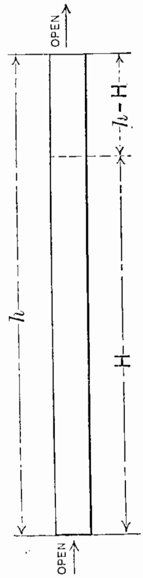

Fig. 27. Flue Diagram.

$(h - H)$, tending to produce a velocity at the base of the flue equivalent to that developed by a body falling freely through a distance represented by the hight $(h - H)$.

The velocity acquired by such a body, neglecting friction, is expressed by the equation

$$v = \sqrt{2gh} \quad \ldots\ldots (a)$$

Here v = velocity in feet per second, g = the acceleration in feet per second due to gravity, = 32.2 feet, h = the hight through which the body falls—in this case represented by $(h - H)$.

Now let

w_O = the weight per cubic foot of outside air.
w_F = the weight per cubic foot of air in the flue.
t_O = the absolute temperature of the outside air = Fahrenheit temperature + 459.4°.
t_F = the absolute temperature of the air in the flue = Fahrenheit temperature + 459.4°.

We have seen that the velocity at which the air enters the base of the flue is expressed by

$$v = \sqrt{2g(h - H)} \quad \ldots\ldots (b)$$

Now since the columns of air represented by h and H balance each other we have weight of column h = weight of column H; *or,*

$$h\,w_F = H\,w_O \ldots\ldots (c) \quad \text{hence} \quad H = \frac{h\,w_F}{w_O} \ldots\ldots (d)$$

The density of the air, or its weight per cubic foot, varies inversely as the absolute temperature; hence we may substitute for $\frac{w_F}{w_O}$, $\frac{T_O}{T_F}$ equation (d) becoming $H = h\frac{T_O}{T_F} \ldots\ldots (e)$

Substituting this value of H in (b) we have

$$v = \sqrt{2g\left(h - h\frac{T_O}{T_F}\right)} = \sqrt{2gh\left(\frac{T_F - T_O}{T_F}\right)} \ldots\ldots (f)$$

Now the weight of air leaving the flue must be equal to the weight of air entering—that is,

Velocity of air leaving flue × w_F = velocity of air entering flue × w_O .... (g)

Velocity of air leaving flue =

$$\frac{\text{velocity of air entering flue} \times w_O}{w_F} \ldots\ldots (h)$$

Or, since the weight varies inversely as the absolute temperature,

Velocity of air leaving flue =

$$\frac{\text{velocity of air entering flue} \times T_F}{T_O} \ldots\ldots (i)$$

Equation (f) gives the velocity of the air entering the flue, hence Velocity of air leaving or passing through the flue =

$$\frac{T_F}{T_O}\sqrt{2gh\left(\frac{T_F - T_O}{T_F}\right)}$$

Allowing 50 per cent. for friction, and substituting the value of $g = 32.2$, the velocity in feet per minute in the flue is

$$V = 240 \frac{T_F}{T_O} \sqrt{h \left(\frac{T_F - T_O}{T_F} \right)}$$

from which the following table is calculated:

Table XIV.—The Approximate Velocity of Air in Flues of Various Hights

Outside temperature 32 degrees. Allowance for friction 50 per cent. in flue one square foot in area.

Hight of flue. Feet.	Excess of temperature of air in the flue over that out doors. 10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	120°	140°
	Velocity of air in feet per minute.											
5	77	111	136	159	179	199	216	234	250	266	296	325
10	109	156	192	226	254	281	306	330	354	376	418	460
15	133	192	236	275	312	344	376	405	432	461	513	565
20	154	221	273	319	359	398	434	467	500	532	592	650
25	173	248	305	357	402	445	485	522	560	595	660	728
30	189	271	334	390	440	487	530	572	612	652	725	798
35	204	293	360	423	475	527	574	620	662	705	783	862
40	218	311	386	452	508	562	612	662	707	753	836	920
45	231	332	408	478	538	597	650	700	750	800	887	977
50	244	350	432	503	568	630	685	740	790	843	935	1030
60	267	383	473	552	622	690	750	810	865	923	1023	1125
70	289	413	510	596	671	746	810	875	935	995	1105	1215
80	308	443	545	638	717	795	867	935	1000	1065	1182	1300
90	327	470	578	678	762	845	920	990	1060	1130	1252	1380
100	345	495	610	713	802	890	970	1045	1118	1190	1323	1455

The volume of air in cubic feet per minute discharged by a flue equals the velocity in feet per minute multiplied by the area in square feet. Knowing any two of these terms, the third may be readily found.

$$\text{Velocity} = \frac{\text{volume}}{\text{area.}} \qquad \text{Area} = \frac{\text{volume}}{\text{velocity.}}$$

Example.—Find the area of a flue 20 feet high that will discharge 3000 cubic feet per minute, when the excess of temperature in the flue over that out doors is 40 degrees.

Opposite 20 in left hand column and under 40 on upper line is the number 319, representing the velocity in feet per minute. The volume $3000 \div 319 = 9.4$ square feet, the required area. In estimating the effective hight of a warm air flue from a furnace, consider the flue to begin 2 feet above the grate.

Table XV.—Wind Velocity

Weisbach defines winds as follows:

Scarcely appreciable wind	90 feet per minute equals 1.02 miles per hour.
Very feeble wind	180 feet per minute equals 2.04 miles per hour.
Feeble wind	360 feet per minute equals 4.1 miles per hour.
Brisk wind	1080 feet per minute equals 12.3 miles per hour.
Very brisk wind	1800 feet per minute equals 20.4 miles per hour.
High wind	2700 feet per minute equals 30.7 miles per hour.
Very high wind	3600 feet per minute equals 40.1 miles per hour.
Violent wind	4200–5400 feet per minute equals 47.8–61.4 miles per hour.
Hurricane	6000 feet per minute equals 68.1 miles per hour.

The United States Weather Bureau defines a gale as a wind blowing 40 miles per hour.