Report on ventilation, 1865.

Contributors

Massachusetts. General Court. House of Representatives. Committee on ventilation of the Representatives' Hall.
Kimball, M. 1799-1868.
Massachusetts. General Court (1865) House of Representatives.
Shedd and Edson (Firm)
Francis A. Countway Library of Medicine

Publication/Creation

[Place of publication not identified] : [publisher not identified], [1865]

Persistent URL

https://wellcomecollection.org/works/k9j2jwnb

HOUSE....No. 5.

Commonwealth of Massachusetts.

Boston, January 16, 1865.

Hon. A. H. Bullock, Speaker of the House of Representatives:

Dear Sir,—I have the honor herewith to transmit the report of the Committee appointed at the session of the legislature of 1864, "to improve the ventilation of the Representatives' Hall."

Respectfully, &c.,

MOSES KIMBALL, *Chairman.*

Commonwealth of Massachusetts.

HOUSE OF REPRESENTATIVES, December 19, 1864.

The Committee appointed under authority of Chapter 85 of Resolves of 1864, "with full power during the recess of the legislature, to improve the ventilation of the hall of the House of Representatives, at an expense not exceeding fifteen hundred dollars," submit the following

REPORT:

The necessity for radical reform in the ventilation of the Representatives' Hall, and other apartments of the State House, has long been a subject of serious consideration to those conversant with, or compelled to occupy them. Repeated efforts have been made to improve their condition, and large sums have from time to time been expended in the attempts. But trifling results, however, have been accomplished in the right direction. No general plan has ever been adopted, and hence a failure to secure such a healthful atmosphere as should be desired. The extraordinary mortality amongst members of the legislature has long been a theme of comment by those who have given the subject attention. So patent is this fact, that many prudent persons are unwilling to subject themselves to the liability of injury to health, by accepting positions as legislators. During the present season a gentleman of eminent ability, whose services would have been of great value to the Commonwealth, declined a nomination for senator on that account. Members who have served in the House, and thus acquired practical experience, are unanimous in regard to the enervating and injurious effect produced upon them by a stay therein of only an hour or two. A former President of the Senate remarked to one of the Committee that the oppressive atmosphere of the House was always certain to give him a headache from remaining there only the time occupied by a convention of the two branches.

The sanitary history of the legislature of 1864 is a startling commentary upon the danger of allowing such a state of things to continue. To say nothing of the large numbers sick during the session, and those who are known to be suffering from impaired health, consequent upon inhaling the vitiated atmosphere of the House, the number of deaths actually brought to the notice of the House was very surprising. Within three months no less than five members deceased. What would be thought of the same rate of mortality, apart from the casualties of conflict, in a regiment of soldiers? Could men be readily found to enter upon employment so extra hazardous? The House consists of two hundred and forty members; a regiment of soldiers numbers one thousand. At the ratio of legislative deaths a regiment would lose two hundred and fifty men, or one quarter of its whole number, within the three years term of enlistment. A colonel who should establish, and continue his camp in a situation as unwholesome and dangerous as the Representatives' Hall, would be unworthy of his position, and deserve the execration of the civilized world. And yet the servants of the State have for years suffered as gross an indignity. It is not believed that, when the case is properly understood, such a state of affairs will be allowed to continue.

Partially aware of the necessity for action, the legislature passed the Resolve under which this Committee have acted. The consideration of the subject, an examination of the premises, and hearing of several experts, in relation to ventilation, has satisfied the Committee that the matter confided to their charge is of far greater magnitude and importance than was anticipated. To secure the desired results, the work must be done thoroughly and under some well-defined system. This can be accomplished only by adopting some mode of power ventilation. It is not safe to depend upon self-acting currents. They are sure to fail when most needed, and are at all times uncertain. For providing mechanical means it was found that the present method of warming the building afforded only limited conveniences, and that to remedy this would involve an expenditure far beyond the sum appropriated.

The Committee, therefore, ordered only such alterations as they believed could be practical within their means, and have attempted merely to afford partial relief to the members of the legislature of 1865. At the same time they endeavored that the work done should constitute something toward a perfect system hereafter. The improvements made consist mainly of conductors placed under the elevated seats, running to shafts, constructed at each of the front corners of the hall, through which, by a draught created by the heat of fires in open grates, it is believed the carbonic acid and other impure gases, as also the light dust and foul air near the floor, will be carried off, the current being always outward.

The flues under the Speaker's rostrum have also been changed. The heated air, which formerly came direct, will be carried to the extreme rear of the hall, and, through a chamber formed at the window, introduced at the top of the sash. Before being admitted this heated air passes over wet surfaces, and thus acquires a proper degree of moisture to render it a natural and wholesome atmosphere. This is thought to be a considerable improvement upon the furnace method. If nothing more has been gained than the certain benefit to the Speaker, and others in immediate proximity to the Chair, the Committee feel satisfied that the expenditure of a few hundred dollars, to accomplish this result, has not been misapplied, and that their efforts have not been in vain.

The improvements have been made under the direction of Messrs. Shedd & Edson, civil engineers, of this city, to whom the credit is due. These gentlemen have given special attention to the subject, and, at the request of the Committee, have furnished a statement of the requirements for complete ventilation, which is herewith submitted in an Appendix marked A.

The consideration of the subject has brought to the notice of the Committee certain matters which they deem it their duty to communicate for the information of the legislature. They are,—

First. The limited and inconvenient means for accommodation of most of the departments of State, and for committees of the legislature.

Second. The lack of ventilation in all the rooms.

Third. The imperfect and costly system of warming the building, and the danger from fire.

First—Insufficiency of room. This want has been felt and acknowledged for years. As long ago as 1854 the legislature endeavored to remedy it, by authorizing an enlargement of the State House, which was accomplished at a cost of some two hundred and fifty thousand dollars. Unfortunately, this large expenditure, in consequence of the mode of construction and other causes, failed to relieve the most pressing wants. Immediately upon completion, the greater part of the added premises were absorbed by the executive department, the library and offices for the secretary and treasurer. Thus, though built with a special view to provide for committees, they soon found that but few desirable or available rooms were left for them, and that they were about as badly off as before. The establishment of more departments, and additional room required for others, made necessary in consequence of the war,—the new boards and commissions that have been created, requiring accommodations, have so greatly increased, that already it has been found necessary to provide rooms, at large cost, elsewhere.

Second.—The ventilation. In most of the apartments the ventilation is about as bad as it can be, as the experience of all who occupy them gives practical testimony. Many thousands of dollars have been expended in efforts to improve their condition, but in vain. There seems to have been no method in what has been attempted, but rather a series of experiments at the expense of the State, by persons who had theories they wished to demonstrate practically; each subsequent one acting independently of the efforts of others, often succeeding only in destroying what was comparatively valuable by introducing what was completely worthless, if not absolutely injurious.

Third.—Heating apparatus. The method of warming the State House is at once novel in the mode of generating heat, and the variety of temperatures commonly found in different parts of the building. With thermometers in each apartment, almost every degree of temperature, from that of the torrid to that of the frigid zone, might be found indicated. The older and front part of the building has in the basement five coal furnaces, of different styles of construction and principles of operation. They might have been excellent in their day, but they are now far behind the improvements of the present time. They are large consumers, but return a poor equivalent in heat for the quantity of fuel that is furnished them. The main rooms of the enlargement are warmed by "hot water apparatus," which is universally admitted to be the most costly of all modes of heating. Scattered about the building are also thirty-five iron stoves, and thirteen grates and fire-places, which are almost constantly in operation during the sessions of the legislature. The great danger from so many fires, without any attendant to specially look after them, must be obvious to every one. The quantity of fuel annually consumed is between two and three hundred tons of coal, ten cords of wood, and a liberal supply of charcoal and other light material. The expense for care of so many fires is also large. Until 1854 the making and superintendence of fires devolved upon the watchmen employed, under the direction of the sergeant-at-arms; but on the introduction of "heating apparatus," and fires rendered necessary by the enlargement, a fireman was specially employed, for that and various other incidental services, the year round. The total cost of care of State House, including the salary of the sergeant-at-arms, and pay of watchmen and fireman, is now nearly seven thousand dollars per annum.

It was the intention of the Committee to have given a statement of the sums expended in previous years upon ventilation and heating apparatus, but they have found it impossible to do so, for the following reasons. Previous to the establishment of the auditor's department in 1849, the accounts of the Commonwealth were very imperfectly preserved, and in most cases the records are found so deficient, that it is now impossible to give a classification of many of the important expenditures authorized by the general court. During the eighteen years preceding 1849, there was paid, under authority of various laws and resolves, upwards of $113,000 for repairs on the State House. Extensive alterations and repairs were frequently made by direction of committees, or commissioners so authorized, and, under contracts entered into by them, large sums were paid from the treasury for which no vouchers, showing the details of such expenditures, were ever retained in possession of the State. The bills after payment, it is said, went into the hands of the committee, and the governor's warrant for the gross amount was the treasurer's voucher.

The following statement gives as accurately as can be ascertained, the result for the last twenty-four years. The amounts for the first nine years are necessarily in gross for reasons before mentioned.

1841–1849. (Nine years inclusive.)		
Furnaces, stoves, grates, fixtures and repairs, ...	$8,255 94	
Wood and coal, ...	12,209 85	
Watchmen, ...	15,100 00	
1849.		
Ventilation, (House and Senate,).	1,941 45	
		$37,507 24
1850.		
Furnace for Senate Chamber, .	$2,156 94	
Stoves, grates and furnace repairs,	777 43	
Wood and coal, ...	916 04	
Watchmen, ...	1,900 00	
		5,750 41
1851.		
Stoves, grates and furnace repairs,	$351 90	
Wood and coal, ...	761 55	
Watchmen, ...	1,900 00	
		3,013 45
1852.		
Furnace and stove repairs, . .	$98 34	
Wood and coal, ...	709 60	
Watchmen, ...	1,900 00	
		2,707 94
1853.		
Furnace repairs, ...	$67 20	
Wood and coal, ...	1,099 21	
Watchmen, ...	1,900 00	
		3,066 41
1854.		
Furnace repairs, stoves, ventilators and fixtures, ...	$2,444 87	
Wood and coal, ...	747 50	
Watchmen, ...	1,900 00	
Fireman, ...	600 00	
		5,692 37

1855.		
Steam heating apparatus for State House enlargement,	$6,781 38	
Furnace repairs,	218 00	
Wood and coal,	2,989 00	
Watchmen,	1,900 00	
Fireman,	600 00	
		$12,488 38
1856.		
Furnace repairs,	$141 02	
Wood and coal,	2,194 72	
Watchmen,	2,500 00	
Fireman,	600 00	
		5,435 74
1857.		
Furnace, stoves, repairs and fixtures,	$1,157 44	
Wood and coal,	1,682 59	
Watchmen,	2,500 00	
Firemen,	600 00	
		5,940 03
1858.		
Furnace and stove repairs,	$131 68	
Wood and coal,	1,364 68	
Watchmen,	2,700 00	
Fireman,	600 00	
		4,796 36
1859.		
Furnace repairs,	$74 81	
Wood and coal,	1,255 78	
Watchmen,	3,200 00	
Fireman,	600 00	
Ventilation of House,	840 42	
		5,971 01
1860.		
Furnace and stove repairs,.	$191 60	
Wood and coal,	1,404 57	
Watchmen,	3,200 00	
Fireman,	600 00	
		5,396 17
1861.		
Furnace repairs,	$95 95	
Wood and coal,	1,189 75	
Watchmen,	3,200 00	
Fireman,	600 00	
		5,085 70

1862.		
Furnace and stove repairs, ventilators, &c.,	$428 81	
Wood and coal,	1,545 83	
Watchmen,	3,200 00	
Fireman,	600 00	
Ventilation, (Governor's Room,)	200 00	
		$5,974 64
1863.		
Furnace repairs, ventilators, &c.,	252 71	
Wood and coal,	2,060 66	
Watchmen,	3,200 00	
Firemen,	600 00	
		6,113 37
1864.		
Furnace repairs, grates, stoves, &c.,	$76 20	
Wood and coal,	2,041 80	
Watchmen,	4,000 00	
Fireman,	600 00	
		6,718 00
Total,		$121,657 22

Recapitulation for 24 Years.

Furnaces, stoves, grates, repairs and fixtures,	$23,702 22	
Wood and coal,	34,173 13	
Watchmen,	54,200 00	
Fireman,	6,600 00	
Ventilation,	*2,981 87	
		$121,657 22

In conclusion, the Committee are of opinion that a proper regard for the health of members of the legislature and other occupants of the State House, requires that a complete system of ventilation should be adopted throughout the premises;

---

*The sum indicated as having been expended on account of ventilation is comparatively a small portion of the expense actually incurred for that purpose. It is known that previously to 1849 large sums were expended, particularly about the year 1846, when the matter was submitted to Professor Espy. The aggregate would be a large addition to the amount shown in the foregoing statement.

that, to secure ample and proper apartments for committees of the legislature, and for offices, the two wings of the building should be re-modeled, so that a vast quantity of waste room might be made available; and that to secure greater economy in warming, some other and more perfect method of heating than that now in use should be adopted.

MOSES KIMBALL,
JAMES M. STONE,
SOLOMON K. EATON,
Committee.

SUGGESTIONS

UPON THE

SUBJECT OF VENTILATION.

To Messrs. KIMBALL, STONE and EATON, *Committee of the Massachusetts House of Representatives:*

Gentlemen,—The following suggestions on ventilation are submitted, in compliance with your request, as a more extended presentation of the facts and theories on which have been based the recent improvements adopted by you in the ventilation of the Representatives' Hall, and as an aid in the consideration of the further improvements which seem necessary for an entirely satisfactory degree of ventilation.

We wish our remarks to be regarded simply as suggestions to this end, and not as an attempt at a complete treatise on the intricate subject of ventilation. If in some directions we have extended them farther than this immediate purpose would seem to warrant, it has been in accordance with your understood wish, to contribute something to the better popular understanding of this much neglected, but all-important subject.

Respectfully submitted,

SHEDD & EDSON, *Civil Engineers.*

BOSTON, January 1, 1865.

VENTILATION.

I.—Introductory.

The art of ventilation, in its common acceptation as *changing air*, is of recent origin in cold climates. In tropical countries it is a matter of necessity to keep the air in motion. In ancient Egypt, large openings in the roof, of peculiar construction, received the passing breeze and conducted it down through the building to be passed out through similar openings on the other side of the roof. The higher classes in India add to abundant openings and wetted screens, large fans kept in motion by their servants.

The cooler temperate climates naturally develop more care for keeping out the cold winds of winter than for drawing in the summer breezes. In the still cooler northern temperate regions, where within doors artificial heat is required more than half the year, with abundance of fuel, large open fires brought all the change of air that was required, until a growing need of economy in fuel, an increasing custom of large social and political assemblages, combined with increasing sensitiveness to discomfort, that keeps pace with refinement of habits and employments, began to call for special contrivances to preserve an agreeable and healthful atmosphere.

Most appropriately, the British House of Commons, for so long the largest and most important legislative body in the world, sitting in a climate that requires constant modification to make it salubrious, has done more experimentally to determine the requirements of a good ventilation than, we might almost say, all the rest of the world together.

From £200,000 to £300,000, Parliament is said to have expended in various attempts at ventilation ; and these attempts have done much by stimulating inquiry to develop the science.

Great success has been achieved in these parliamentary efforts. The operators have been able to change the air of the halls with any desired rapidity, preserving the temperature and moisture at any required point. Yet the sensitiveness and peculiar requirements of individuals have not failed to increase with increased facilities for satisfying them, and the continually increasing demands in Parliament, prove that the best that can be done now is but a stepping-stone to what will be required by succeeding generations. Civilization is advancing rapidly, and, with the cultivation of the higher faculties, the physical organization becomes more delicately sensitive ; more thorough control is demanded and obtained over material circumstances, as the mind labors to bring the body more and more into its own supremacy over the obstacles of time, space and matter. In what we do, therefore, that is to serve for the comfort of our successors, we cannot aim too high. We may be sure that their demands will be greater, and not less, than our own, in all that tends to refinement and to the delight and comfort of the higher faculties of mind and body. To the future we should look, rather than to the past. Tomlinson says :

> " We are told that the native porters of Canton are accustomed to balance the load which they carry on a pole upon their shoulders, by means of a large stone at the other extremity of the pole, and that they deemed the suggestion of an Englishman an impertinent interference, who wished them to balance one package by means of another. ' Our ancestors,' they said, ' were very wise men, and they never carried more than one package at a time, and this they balanced by means of a stone ; shall we be wiser than our ancestors ? ' So may a large proportion of our modern builders exclaim, ' Our ancestors were very wise men ; they never thought of providing special means for ventilation in rooms and public buildings ; shall we be wiser than our ancestors ? ' "

In considering the best and most suitable mode of ventilating the State House, it is necessary to review the whole matter of ventilation, its requirements and the means of answering them.

By the term ventilation, as now generally applied, much more is meant than its original signification, which may be defined as *raising a breeze*. In its largest application, ventilation now involves not only changing the air of an apartment, but introducing and maintaining air of the greatest possible salubrity, in respect to composition, temperature, and statical condition. Ventilation is in fact the formation of an artificial climate, combining the qualities that most contribute to health, enjoyment and the exercise of our faculties. The necessity of this arises from the inequalities of our natural climate, and from its limited adaptation to the wants of our mode of life. Nothing can exceed the perfection of comfort and health found in the open air on certain rare days of the year. The warmth of nature is inimitable in softness and life-giving properties. In its middle measures are exquisite shades of variation, in which every want can be satisfied. In moisture, between parching dryness and soaking rain, any desirable degree may be found. In the variations from perfect stillness to the resistless hurricane, every wish will be gratified; while, for purity and freshness, a June or October morning on the hill-side, brings air so perfectly cleansed by the condensing dew, so delicately scented with the sweet apple blossom or spicy pine, that it cannot be surpassed in imagination.

To secure and to imitate these natural excellencies, and to combine them in most useful and acceptable proportion, is the art now included under the term, for want of a better, of ventilation. Their various elements of purity, moisture, temperature, and motion, have to be considered and regulated in due regard to each other; for, the removal of impure air from a room required to be heated above the out-door temperature, naturally involves a loss of heat which must be supplied. The simple heating of air renders it less sensibly moist than it was when cold, making it necessary to supply moisture with the added heat. Finally, the artificial supply of heat, and change of air for the sake of purity produce more or less motion of the air, which must needs be considered and regulated to prevent harmful or unpleasant results.

II.—Composition of the Atmosphere.

The composition of the atmosphere of a pleasant summer's day, with the temperature at 60°, containing 65 per cent. of the amount of watery vapor that would be held at saturation, may be stated as follows:—

	Weight per cubic foot, in grains.	Pressure in inches of Mercury.
Air (oxygen and nitrogen,)	531.60	29.676
Watery vapor,.	3.73	.309
Carbonic acid, ...	.54	.015
Ammonia, ...	Trace.	.000
Carburetted hydrogen, ...	Trace.	.000
	535.87	30.000

The first of these, pure air, a mixture of oxygen and nitrogen, was at one time supposed to be a compound, and it was thought, as stated by Dr. Kane, "that the relative salubrities of districts, and even of different localities in the same neighborhood, could be determined by the proportions of oxygen and nitrogen which the air of these places might contain; and that the admixture of pernicious substances, exhaling from a marsh, or generated within the ill-ventilated apartments of a hospital, or a jail, might be recognized, and the means discovered of removing them, or of destroying their activity, when their nature had become determined by the analysis of the air in which they had been contained." Further and more exact research has demonstrated that the amount of oxygen and of nitrogen in the air is always constant, and that it is far beyond the reach of chemical science to assign the quantity or even quality, except to a very limited extent, of the impurities of the atmosphere, though they be offensively apparent to the senses and deadly in their effects.

By weight, the constituents of pure air are, in 100 parts,—

Oxygen gas, ...	23.04
Nitrogen gas, ...	76.96

This constitution of atmospheric air is found to be permanent, and formerly led chemists to believe it to be a compound and not a mixture.

Dr. Kane says:

"The analysis not being then so accurately made, it was supposed to consist of one volume of oxygen, united to four volumes of nitrogen, a simplicity of proportion which characterizes chemical union among gases. It was also remarked that if the oxygen and nitrogen were merely mixed, their different densities should cause them to separate; the heavier, oxygen, accumulating near the earth, while the lighter, nitrogen, should occupy the higher regions of the air. The former ground has been completely disproved by later research, and the elements of air are separated from each other by such feeble means as would be unexampled in chemistry, among substances of a constitution such as it, if a true compound, should be supposed to have. Besides, its density, its refractive power, and its specific heat, are the mean qualities of the oxygen and nitrogen which form it; circumstances which necessarily occur if it be a mixture, but which do not take place in any case of chemical combination."

Oxygen is a colorless, transparent gas; its specific gravity is 1,102.6, and a cubic foot of it weighs 590.976 grains. Its most remarkable properties are, as is well known, its energy in supporting combustion, and its necessity for the support of human life.

Nitrogen, like oxygen, is colorless and transparent; its specific gravity is 976, and one cubic foot weighs 523.12 grains. The most important office of nitrogen is that of diluting oxygen, and thus rendering it suitable for the lungs. Though nitrogen never combines directly with oxygen, yet, by certain chemical manipulations, it can be combined.

One of the compounds which in some respects resembles air, is nitrous oxide, which is composed of

Nitrogen, ...	63.9
Oxygen, ...	36.1

This compound is in fact just what would be produced if we add to air, 23 per cent. of oxygen.

To oxygen and nitrogen, the next most important constituent of the atmosphere is watery vapor; we have taken 3.82 grains per cubic foot as being the healthy mean for a temperature of 60° Fahrenheit. At this temperature the air is capable of containing, in a perfectly invisible form, 5.87 grains, and when it does contain this amount, it is said to be saturated and to contain 100 per cent. of moisture. If the temperature of air in this condition is lowered, the moisture becomes visible in the form of fog or mist, but if, instead of lowering the temperature of the air, a foreign body of a lower temperature is introduced, the moisture will deposit itself upon it in minute globules of water, forming what we call dew, or, when frozen, frost.

It is usual to speak of the amount of moisture held or suspended in the air. This is not quite correct, for the moisture is not only not suspended by the air, but actually forces its own way into it. A certain amount of watery vapor permeates dry air as readily as it would a vacuum.

Water, even in the form of ice and snow, constantly gives off vapor. This action to a limited degree, is independent of all pressure of the atmosphere, and only influenced by the pressure of particles of the same kind. Vapor in the free atmosphere has a certain amount of expansion, called force of vapor and tension, which is constant for the same temperature. The same may be said of a vapor or gas in another gas, or in several different gases; for by the beautiful law discovered by Dalton, no pressure, however great, of one gas or vapor, can stop or even impede to any extent the permeation of another gas or vapor, in the same space. If this force of expansion of any vapor is resisted by a pressure superior to it, then the vapor at once becomes liquid; this is supposed to be true of gases, but cannot be demonstrated to be so.

The "force of vapor" of steam at 212° is equal to thirty inches of mercury, being the same as that of the air; hence at this temperature, vapor will form as long as there is water to form from; but the force of vapor for any temperature less than 212° is less than thirty inches, therefore no vapor could be formed in the atmosphere at a low temperature, if it were not for the power given to vapors and gases to enable them to diffuse or enter one into the other independent of the pressure of the gas or vapor penetrated. That there is such a power may be beautifully demonstrated by the following experiment. Take a small glass jar, having covered its mouth with a film of soap-water, and place it under a receiver in an atmosphere of ammonia; the ammonia will at once begin to go into the jar through the film of soap-water, which will be seen to rise up and, expanding, become so thin as to be hardly visible. It has been found by experiment that sulphuretted hydrogen will pass through a thin piece of rubber into the air, even against a pressure of fifty atmospheres, which shows conclusively that gases not only offer no opposition to mutual diffusion, but really have an attraction for each other.

This is modified slightly by the law that different gases diffuse into each other, not with equal rapidity, but with a rapidity inversely proportional to the square roots of their densities; thus if equal portions of hydrogen and carbonic acid gas were admitted into a room, the first would diffuse itself much faster than the latter; the hydrogen might be nearly all diffused while the carbonic acid would still remain almost intact near the floor of the room.

The law of the diffusion of gases may be exhibited thus:

	Specific Gravities.	Ratio of Diffusion.
Hydrogen, ...	0.0688	457.
Ammonia, ...	0.5898	130.
Watery vapor, temperature 65°, ...	0.6165	127.
Air, ...	1.0000	100.
Carbonic acid, ...	1.5239	81.

It will be seen from this table that hydrogen diffuses itself more than five times as fast as carbonic acid, and watery vapor once and a half as fast. The reasonable inference from these facts seems to be that, if from any source or sources air, carbonic acid, watery vapor, and hydrogen, are being introduced constantly into the room, they will diffuse themselves from the point at which they are introduced in the following order:—

1. Hydrogen in the ratio of	457
2. Watery vapor " "	127
3. Air, " "	100
4. Carbonic acid gas "	81

This ratio of the rapidity of diffusion is independent of the relative amounts, so that, expressed in time, the ratio of diffusion is this:

Air, . .	(relative time required for diffusion,)	100
Watery vapor,	“ “ “	78
Hydrogen,	“ “ “	22
Carbonic acid,	“ “ “	120

If the supply is at, or near, the bottom of the room, the hydrogen will be assisted in its diffusion by its lightness, and carbonic acid retarded by its heaviness, while both would be assisted by currents. It is evident, if the supply of these constituents is constantly maintained in a room in which there is but little motion of the air, and in which there is dead space not directly affected by the current from inlet to outlet, those gases which diffuse the most slowly will accumulate, and these relative proportions in the atmosphere of the room will gradually increase, so that finally the less diffusive gases will predominate.

If it were not for the law of diffusion, subtle as it seems, the atmosphere being destitute of vapor, would lose its power of retaining heat; the earth, scorched by day, would sink in temperature to many degrees below zero at night. But even this extreme of cold would be unheeded, for the earth would be perfectly uninhabitable by reason of the deadly sea of carbonic acid gas which would by its weight displace the lighter, healthful gases, and destroy all animal life, as on the floor of the Grotto del Cane, near Naples.

Carbonic acid gas is noted as one of the constituents of the atmosphere, never wanting, though the less there is of it, the purer is the atmosphere considered. In our ordinary out-of-door atmosphere its proportion is $\frac{1}{2500}$. When in excess, as we shall see, it is a foreign ingredient of baneful effects. The weight of carbonic acid gas is twenty-two times that of hydrogen, and one and a half times that of the atmospheric mixture of oxygen and nitrogen. This excess of weight does not prevent the diffusion of carbonic acid among other gases, but it somewhat retards it.

Of all the constituents of the atmosphere, the watery vapor is the most variable, and, in fact, may almost be said to be the only variable; yet its quantity can be easily measured and governed. The following table will give an idea of the amount and variations in a mild, healthy climate.

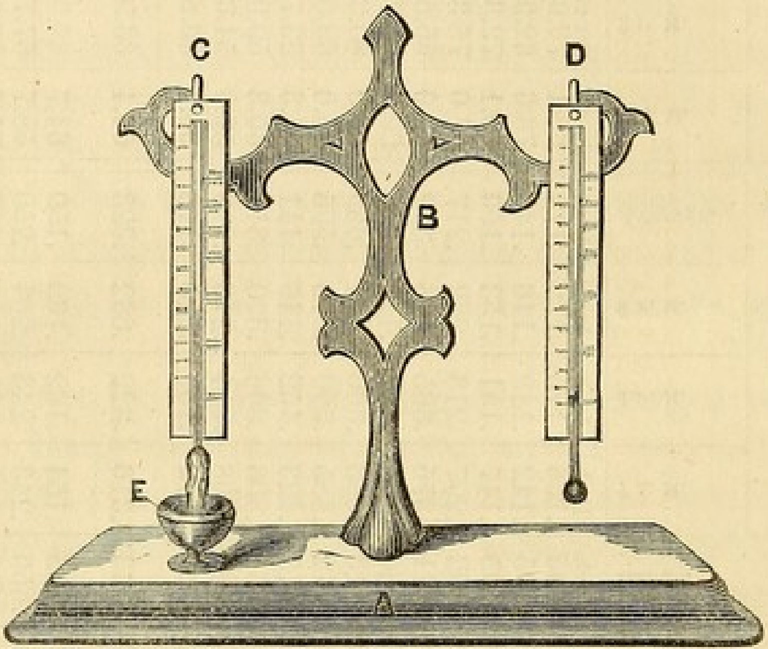
[From the Journal of the Franklin Institute.]

A General Abstract of the Meteorological Observations made at Philadelphia during the year 1863.

1863. MONTHS.	RELATIVE HUMIDITY.							FORCE OF VAPOR.							CLOUDS. SKY COVERED.				RAIN OR MELTED SNOW.	
				MEANS.							MEANS.									
	Maximum.	Minimum.	Range.	7 A. M.	2 P. M.	9 P. M.	Average.	Maximum.	Minimum.	Range.	7 A. M.	2 P. M.	9 P. M.	Average.	7 A. M.	2 P. M.	9 P. M.	Average.	Amount.	No. of days it fell.
	Pr. ct.	Pr. ct.		Pr. ct.	Pr. ct.	Pr. ct.	Pr. ct.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Per ct.	Per ct.	Per ct.	Per ct.	Inches.	Days.
January, . .	100	38	62	78.0	65.3	74.8	72.7	.462	.057	.405	.166	.175	.172	.171	68.1	70.0	60.6	66.2	4.698	14
February, . .	100	29	71	77.3	63.5	70.9	70.5	.322	.027	.295	.142	.149	.146	.146	73.6	62.9	63.9	66.8	3.824	13
March, . . .	94	26	68	75.4	56.4	70.2	67.4	.445	.050	.395	.147	.151	.153	.150	68.1	72.3	55.2	65.2	6.379	16
April, . . .	96	15	81	68.8	50.4	68.2	62.5	.404	.072	.332	.207	.213	.232	.217	57.0	75.3	58.0	63.4	7.294	16
May, . . .	91	28	63	72.3	48.3	69.8	63.5	.700	.189	.511	.375	.365	.406	.382	51.0	55.5	38.1	48.2	4.792	11
June, . . .	94	22	72	67.9	51.0	65.6	61.5	.687	.207	.480	.436	.433	.446	.438	69.7	66.7	46.3	60.9	4.053	11
July, . . .	92	43	49	77.7	64.6	75.2	72.5	.812	.399	.413	.663	.660	.684	.669	90.0	80.3	50.6	73.7	5.690	19
August, . .	88	41	47	76.8	60.0	75.0	70.6	.980	.268	.712	.585	.590	.610	.595	55.0	60.0	45.0	53.3	1.440	9
September, . .	90	38	52	72.6	57.6	69.8	66.6	.784	.166	.618	.423	.452	.449	.441	54.3	53.7	40.7	49.6	0.978	7
October, . .	95	28	67	78.9	51.5	71.7	67.4	.648	.094	.554	.303	.306	.320	.310	60.3	59.0	40.6	53.3	2.663	10
November, . .	97	25	72	73.7	52.2	66.0	64.0	.463	.074	.389	.208	.214	.216	.213	57.3	54.3	52.3	54.6	2.960	7
December, . .	96	35	61	74.1	59.8	68.5	67.5	.486	.051	.435	.142	.156	.145	.148	56.1	56.8	47.4	53.4	4.871	10
Annual means, .	100	15	85	74.5	56.7	70.5	67.2	.980	.027	.953	.316	.322	.332	.323	63.4	63.9	49.9	59.1	49.642	143
Winter, . .	100	29	71	77.9	63.4	73.5	71.6	.462	.027	.435	.154	.162	.160	.159	64.7	63.9	55.7	61.4	10.077	35
Spring, . .	96	15	81	72.3	51.7	69.4	64.5	.700	.050	.650	.243	.243	.264	.250	58.7	67.7	50.4	58.9	18.465	43
Summer, . .	94	22	72	74.1	58.5	71.9	68.2	.980	.207	.773	.561	.561	.580	.567	71.6	69.0	47.3	62.6	11.183	39
Autumn, . .	97	25	72	75.1	53.8	69.2	66.0	.784	.074	.710	.311	.324	.328	.321	57.3	55.6	44.5	52.5	6.601	24
Means for 12 years,	100	13	87	76.0	57.4	72.2	68.5	1.059	.013	1.046	.324	.339	.344	.336	59.8	60.3	45.2	55.1	45.328	128

Exactly how much vapor, or what per cent. of moisture is the most healthy, has not yet been determined. From much observation we have taken sixty-five per cent. of saturation, as the amount most likely to prove healthy.

The percentage or amount of moisture in the air is measured by means of various instruments called hygrometers. The following cut represents one of the most useful and practical of these : —



In which A and B are the base and standard, made of any suitable material. C and D, two thermometers attached to the standard B. The bulb of the thermometer D is exposed to the air ; that of C is enclosed in silk, which is connected with, and always kept moist by means of some strands of lamp-wick hanging into the water in the small vessel E.

The principle upon which this acts is this : that evaporation cools the body from which it evaporates, and, as has been found by experiment, this cooling is in proportion to the rapidity with which the evaporation proceeds, which again is in proportion to the dryness of the air in which the evaporation takes place. In other words, the lowering of the temperature of the covered bulb, is in proportion to the dryness of the air in which it is placed. In accordance with this fact, the following table has been made, which gives the percentage of moisture in the air, due to the lowering of the temperature, as indicated by the covered or wet bulb.

Table based on Regnault's Elements.

TEMPERATURE OF DRY BULB.	Grains per cubic foot of saturated air.	Amount of moisture, expressed in hundredths of the quantity that the air of this temperature is capable of holding.											
		DIFFERENCE BETWEEN WET AND DRY BULB.											
		2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
Degrees Fahr.													
32,	2.126	.78	–	–	–	–	–	–	–	–	–	–	
35,	2.379	.79	.69	.59	.50	–	–	–	–	–	–	–	–
40,	2.862	.82	.73	.64	.56	.47	.39	.31	.23	–	–	–	–
45,	3.426	.84	.76	.68	.61	.53	.46	.38	.31	.24	–	–	–
50,	4.089	.85	.78	.71	.65	.58	.51	.45	.38	.32	–	–	–
51,	4.234	.86	.79	.72	.65	.59	.52	.46	.40	.33	–	–	–
52,	4.383	.86	.79	.73	.66	.60	.53	.47	.41	.35	–	–	–
53,	4.537	.87	.80	.73	.67	.60	.54	.48	.42	.36	.30	.25	–
54,	4.696	.87	.80	.74	.67	.61	.55	.49	.43	.37	.32	.26	.20
55,	4.860	.87	.80	.74	.68	.62	.56	.50	.44	.39	.33	.27	.22
56,	5.028	.87	.81	.75	.68	.63	.57	.51	.45	.40	.34	.29	.23
57,	5.202	.87	.81	.76	.69	.63	.58	.52	.46	.41	.35	.30	.25
58,	5.381	.88	.82	.76	.70	.64	.58	.53	.47	.42	.37	.31	.26
59,	5.562	.88	.82	.76	.70	.64	.59	.54	.48	.43	.38	.33	.28
60,	5.756	.88	.82	.76	.71	.65	.60	.54	.49	.44	.39	.34	.29
61,	5.952	.88	.82	.77	.71	.66	.60	.55	.50	.45	.40	.35	.30
62,	6.154	.88	.83	.77	.72	.66	.61	.56	.51	.46	.41	.36	.31
63,	6.361	.89	.83	.78	.72	.67	.62	.57	.52	.47	.42	.37	.32
64,	6.575	.89	.83	.78	.73	.67	.62	.57	.53	.48	.43	.38	.34
65,	6.795	.89	.83	.78	.73	.68	.63	.58	.53	.49	.44	.39	.35
66,	7.021	.89	.84	.79	.73	.68	.63	.59	.54	.50	.45	.40	.36
67,	7.253	.89	.84	.79	.74	.69	.64	.59	.55	.51	.46	.41	.37
68,	7.493	.89	.84	.80	.74	.70	.65	.60	.55	.52	.46	.42	.38
69,	7.739	.90	.84	.80	.75	.70	.65	.61	.56	.52	.47	.43	.39
70,	7.992	.90	.85	.80	.75	.71	.66	.61	.57	.53	.48	.44	.40
71,	8.252	.90	.85	.80	.75	.71	.66	.62	.57	.54	.49	.45	.41
72,	8.521	.90	.85	.81	.76	.71	.67	.62	.58	.54	.50	.46	.41
73,	8.797	.90	.85	.81	.76	.71	.67	.63	.58	.54	.50	.46	.42
74,	8.081	.90	.85	.81	.76	.72	.67	.63	.59	.55	.51	.47	.43
75,	9.372	.90	.86	.81	.77	.72	.68	.64	.60	.56	.52	.48	.44
76,	9.670	.90	.86	.81	.77	.72	.68	.64	.60	.56	.52	.48	.45
77,	9.977	.91	.86	.82	.77	.73	.69	.65	.61	.57	.53	.49	.45
78,	10.292	.91	.86	.82	.78	.73	.69	.65	.61	.57	.53	.50	.46
79,	10.616	.91	.86	.82	.78	.74	.70	.66	.62	.58	.54	.50	.47
80,	10.949	.91	.87	.82	.78	.74	.70	.66	.62	.58	.55	.51	.47
81,	11.291	.91	.87	.82	.78	.74	.70	.66	.63	.59	.55	.52	.48
82,	11.643	.91	.87	.83	.79	.75	.71	.67	.63	.59	.56	.52	.49
83,	12.005	.91	.87	.83	.79	.75	.71	.67	.64	.60	.56	.53	.49
84,	12.376	.91	.87	.83	.79	.75	.71	.68	.64	.60	.57	.53	.50
85,	12.756	.91	.87	.83	.79	.75	.72	.68	.64	.61	.57	.54	.50

Having a hygrometer of this description, the process of finding the amount of moisture in a room is this: ascertain the temperature of the room by the dry bulb thermometer, note the difference between the wet and dry bulb thermometers, look in the table on line of differences for the observed difference, then follow the column down until, coming opposite the observed temperature, the percentage will be found. Thus, if the temperature of the room is sixty-eight degrees, and the difference between the wet and dry bulb thermometers is seven degrees, we find first, in the line of differences, the number seven; directly under this, and opposite sixty-eight, the observed temperature, is the number sixty-five, which is the percentage sought.

III.—Sanitary Properties of the Constituents of the Atmosphere.

Nitrogen, though making nearly four-fifths of the bulk of the air, seems to be of no importance for respiration, except as the vehicle and diluent of other gases, especially of its companion, oxygen, the great sustainer of life.

In the lungs, air is brought into contact with the blood. The windpipe, as it leaves the throat, divides into branches, which again are divided and sub-divided, like the branches of a tree, till at their extremities, where they are but from one-fiftieth to one-thirtieth of an inch in diameter, they end in little vesicles of scarcely greater diameter. These vesicles open from all the branches in every direction, like the leaves of a tree, and even from each other, so that the whole substance of the lungs is made up of vesicles, with only a very thin partition of tissue between them, and all opening eventually into the large air-branches and windpipe.

The vesicles again are lined with still smaller cells varying from $\frac{1}{100}$ to $\frac{1}{200}$ of an inch in diameter. The number of these cells is estimated at 600,000,000, in the lungs of a man.

Into their delicate walls is brought the black venous blood in most minute capillary vessels. Through the thin transparent covering of these vessels the oxygen of the air passes freely and is absorbed by the blood, restoring its bright red color, at the same time that the carbonic acid leaves the blood and passes out into the atmosphere. Carbonic acid being composed of carbon and oxygen, it has been a favorite theory with chemists that the carbonic acid which is exhaled from the lungs, is formed from the union of carbon, taken into the system as food, with the oxygen inhaled, and that, like the similar union of the carbon of coal with oxygen, this process of union or combustion, evolves a large quantity of heat and is the principal source of animal heat. Later researches go to show that the carbonic acid is mainly brought by the blood to the lungs as such, and not as carbon alone ; and that it is derived from the substance of the body in every part, rather than from the new food. Then it is assumed that it is formed from the union of oxygen from the atmosphere with the worn out particles of the body which are continually cast off, and this process it is thought may evolve the heat. It is tolerably certain that the carbonic acid comes from the decomposition of the used up and cast-off particles. But it is not so clear that the oxygen carried by the blood unites with the carbon directly for this purpose. It is rather supposed by late physiologists that the oxygen first becomes a part of the new substance of the body, and only passes off as carbonic acid when this substance is in turn decomposed. There is certainly no immediate correspondence between the amount of food eaten and the heat of the body ; animals kept without food, not losing their temperature in several days' time. And it is ascertained that the various tissues in their turn, like the lungs, absorb oxygen and give out carbonic acid. But wherever the exact point may be at which the carbonic acid is formed, it is agreed that in this, and perhaps other chemical processes, is evolved a large part of the animal heat. The whole quantity of blood in the body, estimated at, for a man, from twenty to thirty pounds, is reckoned to pass through the lungs as often as once in half a minute, for exposure to the air, and purification. The quantity of air inhaled at a breath, averages, as the mean of many experiments, twenty-five cubic inches. The quantity breathed by a man in a day, averages 350 cubic feet. The amount of oxygen absorbed by the blood is equal to one-ninth of its volume. The amount of carbonic acid given off is about one twenty-fifth part of the air exhaled. The carbon given off is supposed to be mainly the decomposed substance of the body, as it is renewed after the accomplishment of its work. According, therefore, to the vitality and labor of the system, is the amount of change and of carbon to be expelled, and the necessity for oxygen. According, also, to the supply of oxygen, in a measure, is the opportunity for the discharge of carbon and its actual expulsion. Thus, in some degree, according to the presence of oxygen is the vitality and power of the system ; the waste being supplied by a sufficiency of food.

Animals in a torpid state breathe little, as well as eat little, absorb little oxygen, give out little carbon, require little supply of fresh air, and evolve little heat. So, many animals winter in their holes, with little or no food, or change of air, and as little activity. Bees in cold weather are cold and quiet in their hives. But, if we disturb the hives, a tumult arises; they grow active, evolve heat, raising the temperature of the hive very rapidly, and consequently require more oxygen. What means they take to get a change of air will be shown hereafter.

The sluggishness of the degraded classes of men, is in keeping with their indifference to foul air, and, we may say, with their destitution of good food. It is a matter of history that, when certain factories in England were supplied with improved means of ventilation, the operatives demanded and received an increase of wages because of their increased need of food. No one can doubt that their increase in labor was in still greater proportion.

Carbonic acid gas, besides its deleterious effects in the air by diminishing by so much the supply of oxygen, is a fatal poison when present in any considerable quantity, partly by its own absorption, but still more by preventing the discharge of carbonic acid from the lungs, thereby causing an accumulation in the system. It is indeed never entirely absent, being found, as we have seen, in purest natural air in very small proportion. When this proportion is increased to five or six per cent. the air becomes dangerous to man; and even half this amount is soon fatal if it is formed at the expense of the oxygen of the air. The air that a man has once passed through his lungs would almost immediately suffocate him if he could get no other.

But, besides carbonic acid, the lungs expel much moisture laden with various impurities, some of which are more readily detected by their odor than by chemical tests, and others, the miasmas of contagious fevers, are known only by their sad results. Every person blessed, or afflicted, in whichever light it may be considered, with a sensitive organization, is painfully conscious of the common offensiveness of human breath. Decaying teeth, overloaded or disordered stomachs, unhealthy lungs, tobacco smoked or, worse, chewed, and other causes, some controllable and some not, contribute to the contamination of exhaled air.

Nor are the exhalations from the lungs the only cause of the personal contamination of the air. A no less constant cause in all cases and a much greater cause with those who do not pay particular attention to cleanliness, is the exhalations from the body. The lungs of a healthy man give forth, at ordinary temperature, from sixteen to twenty ounces of moisture in twenty-four hours; of this $\frac{3}{1000}$ are solid animal matter, in a state of decomposition. From the skin pores of a healthy man are given out fifty per cent. more vapor, with probably a greater proportion of animal matter. Carpenter estimates this at 100 grains in twenty-four hours. But, of offensive effluvia which cannot be measured or weighed, our sense of smell teaches us that the feet, the arm-pits and other portions of the body are much more prolific than the lungs. Oftentimes the air of an apartment becomes intolerable to sensitive organs, from the feet of a single person. There is a remarkable difference in individuals in this respect; the effluvia of some, with the utmost care, being a severe infliction on themselves and their neighbors. The effect is much increased with the excess of perspiration induced by heat or exercise, and in a crowded room, without rapid change of air, it becomes almost insupportable.

To these causes of contamination is added what is contained in the clothing. Woollen cloth is a great receptacle of impurities gathered from the various effluvia to which it is subjected. It is hardly possible to rid it of the smell of a barn or stable, or of any other foul atmosphere in which it may have been exposed, even for a short time. Shoe leather, too, is an unfortunate absorbent, not only of the effluvia of the feet, but of the rank oils often used in its manufacture, of the strong-smelling blacking with which it is dressed, and of the filth through which it has often to pass. These various impurities, added to the partial and offensive decomposition of the animal substance of leather, and woollen cloth, make them prolific means of the contamination of the air, especially in heat after exposure to wet.

All these impurities are matter in a state of decomposition. If collected on the surface of water, as they pass out of a room, they form a putrescent, bubbling scum, like that of a cesspool, with an intolerable stench. For they are mostly particles of animal substance thrown off in a state of partial decomposition;

and their decomposition is completed with great rapidity in their attenuated gaseous or vaporous condition. The odor of fruit — of apples or strawberries, for example — is agreeable when it first leaves the fruit; but if confined a single night in a box or cupboard, every one knows how rotten and offensive the smell becomes, even when the fruit itself remains quite sound. If this is the case with vegetable exhalations, what must it be with the exhalations of animal substance, the decay of which is so rapid and so pestiferous?

The poisonous effect of these various impurities is most strikingly seen in extreme cases, such as that of the notorious "Black Hole of Calcutta," where 123 out of 146 persons died immediately from one night's confinement, and more died from putrid fevers; and that of the Southampton vessel, with passengers from the Jersey Islands, whose hatches were closed as the wind arose, disclosing when opened again the dead bodies of the whole seventy passengers; and, later, the similar case of the British steam packet Londonderry, in which nearly half of 150 passengers died from the closing of the hatches in a storm. But a far more disastrous, because vastly more common, result follows from a less degree of exposure to these impurities. Carpenter, standard authority, says: "It cannot be too strongly impressed upon the medical practitioner, however, and through him upon the public in general, that the continued respiration of an atmosphere charged in a far inferior degree with the exhalations from the lungs and skin, is among the most potent of all the 'predisposing causes' of disease, and especially those *zymotic* diseases whose propagation seem to depend upon the presence of fermentable matter in the blood." This effect Carpenter attributes equally to the presence in the blood of the carbonic acid which is hindered from escaping by the presence of even a small amount of the same acid in the air, and to the deficiency of oxygen in the blood, from which cause the dead matter in the body is prevented from being changed to carbonic acid, and accumulates in the blood in a grosser, putrescent form. He cites many examples to show that, where cholera prevails, its extent is directly proportioned to the presence of foul air, whether this be owing to the immediate unremoved exhalations of men, or to decomposing masses of refuse. He says: "The only condition of atmosphere which can be compared to that arising from overcrowding, in its effect on the spread of cholera, is that produced by the diffusion of the effluvia of drains, sewers, slaughter-houses, manure manufactories, &c., which correspond closely in their nature and effects with the putrescent emanations from the human body." At Christ church workhouse, Spitalfields, out of four hundred children, sixty were seized in one morning with violent diarrhœa. The wind came from the direction of a manufactory of artificial manure close by. The manure business was stopped, the children were well again. A few months afterward the business was begun again. In one night again, with the wind from that quarter, forty-five boys, whose windows faced that way, were taken with severe diarrhœa. The business was then stopped permanently, and there was no more trouble. The common dwellings in Iceland have dried sheep-dung for floor, and dung or fish refuse is burned for fuel, with the least possible ventilation. In consequence, the population does not increase, and hardly holds its own. A large proportion of the children die when from five to twelve days old, and in some places nearly two out of three die before their twelfth day. In St. Kilda, one of the Western Hebrides, Scotland, in 1838, the inhabitants lived in a similar way, and four out of five of the children died between their eighth and twelfth day. In the Dublin Lying-in Hospital, previous to the year 1782, one in every six children died. Improved ventilation there reduced the proportion to one in nineteen and a half, and further improvements nearly put an end to deaths from the disease of which so many formerly died.

A century ago in the London workhouses, twenty-three out of twenty-four infants died within their first year. Improvements in ventilation reduced the number from 2,600 to 450 a year.

The impurities arising from the natural decomposition of animal and vegetable substances, are, perhaps, the most important ingredients in the atmosphere to be guarded against, because they are so universal and so inseparable from our existence, without special provision for the purpose. But some of the products of combustion are not less pernicious. Burning coal gives off carbonic oxide, as well as carbonic acid, in large quantity, which is even more deadly. This gas burns itself with a blue flame, and is often seen on fresh hard coal in a stove or grate. Still more quickly fatal is sulphuretted hydrogen, a gas that is readily perceived by its intolerable stench, as familiarly known in rotten eggs, and which often escapes from hard as well as soft coal, under slow combustion. It is also perceived in common burning gas, which is mainly carburetted hydrogen. Carburetted hydrogen is itself fatal in small proportion, but sulphuretted hydrogen in the proportion of $\frac{1}{1500}$ part of the air is soon fatal to a bird, and in $\frac{1}{800}$ part to a dog.

The escape of these gases from burning coal, lamps, candles, gas-burners, and leaking gas-pipes, is a most fruitful source of foulness and noxiousness in the atmosphere of our buildings. Smoky chimneys are too well known as a baneful nuisance, to need mention. More to be reprehended, because unnecessary and often scarcely known, is the bad construction or bad management of coal stoves and furnaces, whereby their fatal gases are permitted to escape into air that is to be breathed. The greatest care is necessary in all modern stoves and furnaces, which check their draft by openings admitting air into the smoke flue, or the flue will be open when fresh coal is on, and these noxious gases, which are then formed most copiously, will escape. Gas-pipes, too, require greatest care to prevent leakage, and in large buildings it is sometimes found necessary to shut the gas off from the whole building during the daytime. And in large evening assemblies, where much gas is burned, it is indispensable that there should be means of taking off directly the products of combustion, before they can be mixed with the general air and inhaled.

Dr. Wyman says:—"For every cubic foot of gas burned, an equal quantity of carbonic acid is produced, and renders, according to Leblanc, one hundred cubic feet of air unfit for respiration." A common Argand burner consumes about four feet of gas an hour, and will, therefore, in that time render four hundred cubic feet of air unfit for respiration. In other words, two burners will in an hour's time render every foot of air unfit for respiration in a room ten feet square and eight feet high. It is hardly necessary to add that no peculiar arrangement of a burner can in the least diminish the amount of carbonic acid produced from a given quantity of gas. These facts need to be often dwelt upon, because the product of gas-burning being invisible, it frequently happens that persons are suffering from the effects without once thinking of the true cause. At the present moment we hear of a case where some thirty persons are employed, and a gas-burning flat-iron heater is used, with four irons. This arrangement had been in operation a few days. The overseer complained to us of feeling much oppressed with headache, &c., without knowing any reason for it. On entering the room we at once discovered the cause in the very sensible carbonic acid gas. We mention this case because of the efforts now made to introduce the use of gas for many heating purposes. Our attention was called quite recently to a new contrivance just patented for the purpose of warming rooms with gas or kerosene. It consists simply of a sheet-iron cylinder, closed at the top, and hung over the burner to receive the radiated heat, and to communicate it to the air of the room. The first thing to be said of any such arrangement as this, is that it can by no possibility increase the amount of heat which the burner itself would communicate to the room; it can only check the radiation and convection of the heat, which would otherwise go to the walls or be diffused in the room, and thus make it more apparent near the source. The second is, the fact as stated above, that four hundred cubic feet an hour of air is vitiated by every burner used. That this is the case with the new contrivance, which is only one of several similar inventions, was very evident to us in the exceedingly vitiated air of the room where we found it in operation.

Bunsen's burner, by mixing atmospheric air with the gas before burning, greatly increases the production of heat, while it lessens the amount of light. Gas stoves which adopt this principle are very efficient heaters, but, whatever assertions those interested may make to the contrary, they all evolve and diffuse in the air the same amount of deadly carbonaceous compounds for the quantity of gas consumed, and vitiate the air in the same proportion. These remarks apply only to arrangements which let the products of combustion into the room. All such arrangements, no matter what the fuel burned, that consume it in the room to be warmed, without special provision for taking the products of the combustion out of the room, are of precisely the same death-dealing nature as the charcoal pans with which the Parisian unfortunates close their existence. That the effects are not always immediately perceived by those who are exposed to them, is a remarkable instance of the manner in which the system is made to adapt itself to the circumstances in which it is placed. An animal inclosed in a vessel into which carbonic acid is gradually introduced, will come slowly into something like a torpid condition in which he can endure the excess of acid, when a fresh animal introduced will drop dead. But though the effect is thus more violent on the animal entering fresh, as it is on persons just entering an oppressive room, the injurious consequences to health and vitality are not less sure, in their degree, to those who have been longer and more gradually exposed.*

Oxygen is the only element of the air that we have mentioned as of life and health-giving value. The only other element that we have to consider in this relation is that of moisture; and the value of this to the human body, in ordinary cases, is rather for preventing inordinate evaporation from the body than for any more positive service. In this capacity, however it is indispensable.

The amount of moisture in the air is something that few persons observe, except when it is excessively large or small. A very moist day is noticed by the water that is deposited on everything that happens to be cooler than the air. A very dry day is noticed in the dryness and parched feeling of the skin. And the much greater dryness of air heated by a red-hot furnace, without evaporation of water, is remarked by almost every one in the shrinking of their furniture, if not in the dryness of their skin. But the more moderate degrees both of moisture and dryness are seldom observed except by men of science or of peculiar sensitiveness, and by those engaged in mechanical occupations with materials that are affected by every change. The farmer has little care for the moisture of the air except when he is making hay; then he finds that a good drying day, as his wife would call it if it happen to be

---

* While these pages are going through the press, we notice in the papers a practical illustration of the danger of allowing the products of combustion to escape into the room.

"We are informed that the death of Mr. and Mrs. Defrees, at Ballardvale, was occasioned by the escape of coal gas from a stove in their sleeping-room, the damper in the funnel having been closed too tightly."—*Boston Journal, January* 20.

washing day, will make his hay twice as fast as a moister day, though both be fair. And no farmer is ignorant of the increase of weight in a load of hay on a damp day, whether he buys or sells. A cabinet-maker has far more interest in the dryness of the atmosphere, which he is obliged to secure by artificial heat. And on the other hand, an iron-worker of uncommon success has been known to wait weeks for air moist enough to suit him for tempering knife-blades.

If the degree of moisture in the air so sensibly affects these grosser materials, it is not surprising to learn that it has very serious effects on the delicate tissues of the human system. Dr. Wyman says:—

"The influence of this agent upon the human system is exceedingly important. The lungs are continually exhaling moisture,—its quantity depending upon the hygrometric state of the atmosphere. Whatever be the condition, as to moisture of the inspired air, it is uniformly expired very nearly saturated with aqueous vapor; and as its avidity for moisture is inversely as the quantity it contains, it is obvious that the amount removed from the lungs must also vary in the same proportion. The skin also loses moisture by the two processes of insensible perspiration and transudation, or sweating. The former of these, by which much more (nearly six times as much, under ordinary circumstances,) is lost than by the latter, is greatly influenced by the hygrometric state, the motion and rarefaction of the atmosphere. If the air be too dry, the lining membrane of the lungs, throat and mouth may be deprived of its necessary moisture so rapidly that an uncomfortable degree of dryness, or even inflammation may be induced.

"During cold weather, when a room is heated by means of a stove or a hot-air furnace, many persons experience a painful sensation in the chest, produced by the excessive dryness of the air, consequent upon raising that possessing only the amount of moisture due to thirty-two degrees to the temperature of seventy degrees. This unpleasant feeling, which is often confounded with too great heat, is frequently relieved by placing a vessel of water upon the stove or in the furnace; but it is rare that the quantity thus evaporated is sufficient to give the necessary amount of moisture.

"Some animals may be destroyed by exposure of the skin and lungs to dry air. In some diseases these organs are dry, and it becomes necessary to prevent all evaporation, or even to add moisture to them. This can be done by generating a large quantity of steam, and diffusing

> it thoroughly in the air to be breathed. Late observations have led some physicians to believe that breathing an atmosphere saturated with moisture affords the greatest relief, and does more towards the cure of that terrible disease of children, *membranous croup*, than any other known means."

According to Dr. Carpenter, there is good reason to suppose that, in certain cases at least, the skin and the lungs absorb moisture to a considerable extent. Instances are recorded of jockeys whose weight had been reduced with great care, but which increased two and even six pounds within an hour of their starting, although they had taken nothing but a glass of wine or a cup of tea. In these cases there was plainly an extraordinary thirst of the body that absorbed water in any way it could get it. And the same is doubtless true of cases of excessive fluid secretion and discharge, in which the weight of the discharge far exceeded all known supply. It does not appear that in ordinary cases there is any absorption of moisture through the skin or lungs into the body. But the outward flow through the skin and lungs, amounting, as was said above, to forty-five ounces a day, is very dependent on the degree of dryness in the air. Neither form of excess would be salutary. Dr. Wyman says,—

> "Undoubtedly the best constitution of air is that which nature affords. During the summer months the air has gradually increased in temperature, and appropriated from rivers and other sources that amount of vapor which is required. In our houses we should imitate the same course, and, in heating air from below thirty-two degrees to seventy degrees, provide a sufficient supply of water, if not for health, at least for the preservation of our wood-work and furniture."

Scientific and medical authorities generally concur in the opinion that in-door air, after heating, should contain nearly the same proportion of moisture as the average of out-door air of the same temperature; but when air is brought in from out of doors at the temperature of zero, and raised by heaters to sixty-eight degrees, it would require, as seen in the table given below, the addition of $4\frac{348}{1000}$ grains of water, per cubic foot of air to bring it up to the required degree of moisture. For the proper moistening then of fresh warmed air introduced at the rate of twenty cubic feet a minute for each one of 300 persons two hours, the air taken at zero and at the average degree of moisture, no less than fifty-nine gallons of water would require to be added.

Out-of-Door Air containing 70 per cent., or an average winter degree, of watery vapor,		The same Air raised to 68°, retaining its absolute quantity of watery vapor, has the following percentage of moisture.	Must be added of watery vapor to give 65 per cent. of moisture at 68°—per cubic foot.
At a Temperature of	Has of watery vapor per cubic foot.		
Degrees.	Grains.	Per cent.	Grains.
0,	.546	.07	4.348
1,	.567	.07	4.327
2,	.588	.07	4.306
3,	.609	.08	4.285
4,	.630	.08	4.264
5,	.651	.08	4.243
6,	.679	.09	4.215
7,	.700	.09	4.194
8,	.728	.09	4.166
9,	.749	.10	4.145
10,	.777	.10	4.117
11,	.805	.10	4.089
12,	.833	.11	4.061
13,	.868	.11	4.026
14,	.896	.11	3.998
15,	.927	.12	3.967
16,	.959	.12	3.935
17,	.987	.13	3.907
18,	1.029	.13	3.865
19,	1.064	.14	3.830
20,	1.106	.14	3.788
21,	1.141	.15	3.753
22,	1.183	.15	3.711
23,	1.225	.16	3.669
24,	1.267	.17	3.627
25,	1.309	.17	3.585
26,	1.351	.18	3.543
27,	1.400	.18	3.494
28,	1.449	.19	3.445
29,	1.498	.19	3.396
30,	1.547	.20	3.347
31,	1.603	.21	3.291
32,	1.659	.22	3.235
33,	1.715	.22	3.179
34,	1.771	.23	3.123
35,	1.834	.24	3.060
36,	1.897	.25	2.997
37,	1.960	.26	2.934
38,	2.023	.26	2.871
39,	2.093	.27	2.801
40,	2.163	.28	2.731
41,	2.233	.29	2.663
42,	2.310	.30	2.584
43,	2.387	.31	2.507
44,	2.464	.32	2.430
45,	2.548	.33	2.346
46,	2.632	.34	2.262
47,	2.716	.35	2.178
48,	2.807	.37	2.087
49,	2.898	.38	1.996
50,	2.996	.39	1.898
51,	3.094	.41	1.800
52,	3.192	.43	1.702
53,	3.297	.44	1.597
54,	3.402	.45	1.492
55,	3.514	.46	1.380
56,	3.626	.47	1.268
57,	3.738	.49	1.156
58,	3.857	.51	1.037
59,	3.983	.52	.911
60,	4.109	.54	.785
61,	4.242	.55	.652
62,	4.375	.57	.519
63,	4.515	.59	.379
64,	4.655	.61	.239
65,	4.809	.63	.085
66,	4.956	.65	–
67,	5.110	.67	–
68,	5.271	.70	–

The rate at which evaporation will take place, in air under certain conditions, may be seen by the table given below, showing the full evaporating force for each degree of temperature, expressed in grains of water that would be raised per minute from a vessel of one foot area, supposing there were no vapor already in the atmosphere :—

Table of Evaporation on Dalton's Basis.

TEMPERATURE.	Tension in Mercury.	Weight in Grains per foot.	EVAPORATION IN GRAINS PER MINUTE FOR ONE FOOT OF SURFACE.		
			Still Air.	Gentle Breeze.	Brisk Breeze.
Degrees, Fahr.					
0,	.064	.33	.502	.377	1.122
1,	.066	.37	.604	.529	1.275
2,	.068	.41	.786	.681	1.428
3,	.071	.45	.888	.833	1.581
4,	.074	.49	.990	.985	1.734
5,	.076	.54	1.092	1.137	1.887
6,	.079	.58	1.194	1.289	2.040
7,	.082	.63	1.296	1.441	2.193
8,	.085	.67	1.398	1.593	2.346
9,	.087	.72	1.500	1.745	2.499
10,	.090	.77	1.602	1.897	2.652
11,	.093	.82	1.704	2.049	2.805
12,	.096	.87	1.836	2.201	2.958
13,	.100	.92	1.938	2.353	3.111
14,	.104	.97	2.040	2.505	3.264
15,	.108	1.03	2.142	2.657	3.417
16,	.112	1.08	2.244	2.809	3.570
17,	.116	1.13	2.346	2.961	3.723
18,	.120	1.19	2.448	3.113	3.876
19,	.124	1.25	2.550	3.265	4.029
20,	.129	1.31	2.650	3.417	4.182
21,	.134	1.37	2.754	3.559	4.335
22,	.139	1.43	2.856	3.621	4.488
23,	.144	1.49	2.958	3.723	4.641
24,	.150	1.55	3.060	3.927	4.794
25,	.156	1.62	3.162	4.029	4.947
26,	.162	1.68	3.315	4.182	5.202
27,	.168	1.75	3.417	4.386	5.355
28,	.174	1.82	3.570	4.590	5.610
29,	.180	1.89	3.672	4.743	5.763
30,	.186	1.97	3.774	4.845	5.967
31,	.193	2.05	3.927	5.049	6.171
32,	.200	2.13	4.080	5.253	6.426
33,	.207	2.21	4.233	5.457	6.630
34,	.214	2.29	4.386	5.661	6.885
35,	.221	2.37	4.540	5.814	7.089
36,	.229	2.47	4.692	6.018	7.395
37,	.237	2.56	4.845	6.222	7.599

Table of Evaporation on Dalton's Basis—Continued.

TEMPERATURE.	Tension in Mercury.	Weight in Grains per foot.	EVAPORATION IN GRAINS PER MINUTE FOR ONE FOOT OF SURFACE.		
			Still Air.	Gentle Breeze.	Brisk Breeze.
Degrees, Fahr.					
38,	.245	2·66	4.998	6.426	7.854
39,	.254	2.76	5.202	6.681	8.160
40,	.263	2.86	5.355	6.885	8.415
41,	.273	2.97	5.559	7.140	8.721
42,	.283	3.08	5.763	7.395	9.078
43,	.294	3.19	6.018	7.701	9.435
44,	.305	3.31	6.222	8.007	9.792
45,	.316	3.43	6.426	8.262	10.149
46,	.328	3.55	6.681	8.568	10.506
47,	.339	3.68	6.936	8.925	10.863
48,	.351	3.81	7.140	9.180	11.220
49,	.363	3.95	7.395	9.486	11.628
50,	.375	4.09	7.650	9.792	12.036
51,	.388	4.23	7.905	10.149	12.444
52,	.401	4.38	8.160	10.506	12.801
53,	.415	4.54	8.466	10.863	13.311
54,	.429	4.70	8.721	11.220	13.719
55,	.443	4.86	9.027	11.628	14.178
56,	.458	5.03	9.333	11.985	14.688
57,	.474	5.20	9.690	12.393	15.198
58,	.490	5.38	9.996	12.852	15.708
59,	.507	5.56	10.353	13.311	16.269
60,	.524	5.76	10.710	13.770	16.830
61,	.542	5.95	11.067	14.229	17.391
62,	.560	6.15	11.424	14.688	17.952
63,	.578	6.36	11.781	15.147	18.513
64,	.597	6.58	12.189	15.657	19.176
65,	.616	6.80	12.546	16.116	19.737
66,	.635	7.02	12.954	16.677	20.349
67,	.655	7.25	13.362	17.187	21.012
68,	.676	7.49	13.770	17.697	21.624
69,	.698	7.74	14.229	18.309	22.338
70,	.721	7.99	14.688	18.870	23.103
71,	.745	8.25	15.198	19.533	23.868
72,	.770	8.52	15.708	20.196	24.684
73,	.796	8.80	16.218	20.859	25.500
74,	.823	9.08	16.779	21.573	26.367
75,	.851	9.37	17.340	22.287	27.234
76,	.880	9.67	17.952	23.052	28.203
77,	.910	9.98	19.115	23.868	29.172
78,	.940	10.29	19.176	24.633	30.141
79,	.971	10.62	19.788	25.449	31.110
80,	1.000	10.95	20.400	26.214	32.079
81,	1.040	11.29	21.216	27.285	33.354
82,	1.070	11.64	21.828	28.050	34.323
83,	1.100	12.00	22.440	28.866	35.241
84,	1.140	12.38	23.256	29.886	36.567
85,	1.170	12.76	23.868	30.957	38.046

Table of Evaporation on Dalton's Basis—Concluded.

TEMPERATURE.	Tension in Mercury.	Weight in Grains per foot.	EVAPORATION IN GRAINS PER MINUTE FOR ONE FOOT OF SURFACE.		
			Still Air.	Gentle Breeze.	Brisk Breeze.
Degrees, Fahr.					
86,	1.210	13.15	24.480	–	–
87,	1.240	13.55	25.296	–	–
88,	1.280	13.96	25.908	–	–
89,	1.320	14.38	26.520	–	–
90,	1.360	14.81	27.336	–	–
91,	1.400	15.25	27.948	–	–
92,	1.440	15,70	28.560	–	–
93,	1.480	16.17	29.376	–	–
94,	1.530	16.65	30.192	–	–
95,	1.580	17.14	31.008	–	–
96,	1.63	17.65	31.824	–	–
97,	1.68	18.16	32.436	–	–
98,	1.74	18.69	33.048	–	–
99,	1.80	19.23	33.864	–	–
100,	1.86	19.79	34.680	–	–
105,	2.18	22.77	38.600	–	–
110,	2.53	–	42.760	–	–
115,	2.92	–	46.846	–	–
120,	3.33	–	51.000	–	–
125,	3.79	–	59.976	–	–
130,	4.34	–	69.109	–	–
135,	5.00	–	80.032	–	–
140,	5.74	–	92.530	–	–
145,	6.53	–	107.350	–	–
150,	7.42	–	123.610	–	–
155,	8.40	–	140.970	–	–
160,	9.46	–	159.050	–	–
165,	10.68	–	178.930	–	–
170,	12.13	–	201.960	–	–
175,	13.62	–	228.980	–	–
180,	15.15	–	260.250	–	–
185,	17.00	–	295.330	–	–
190,	19.00	–	332.420	–	–
195,	21.22	–	371.520	–	–
200,	23.64	–	412.640	–	–
205,	26.13	–	455.770	–	–
210,	28.84	–	500.920	–	–

Having given the temperature at which the aqueous atmosphere begins to be condensed into water, and the temperature of the air, to find the quantity of water that would be evaporated in a minute from a vessel of one foot area:—

Solution.—Subtract the grains opposite to the lower temperature from those opposite to the higher one, in the first, second or third column of grains, according to the strength of the wind, and the remainder will be the quantity evaporated in a minute, under those circumstances, nearly.

Example.—Let the point of condensation be 52°, the temperature of the air 65°, with a moderate breeze.

The number opposite 52° in the second column of grains is 10.506, and that opposite 65° is 16.116, the difference, 5.61 grains, is the evaporation per minute.

In the following table may be seen other

Properties of the Air and Gases.

BAROMETER, 30; THERMOMETER, 60°.

SPECIFIC GRAVITY WILL BE,		Weight of 100 cubic inches in grains will be for		Specific heat for equal weights.
Air being 1000.	Water being 1000.			
1000.0	1.231	Air,	31.01	.2379
1102.0	1.357	Oxygen,	34.20	.2182
976.0	1.202	Nitrogen,	30.256	.2440
68.8	0.084	Hydrogen,	21.328	3.4046
1177.0	1.449	Sulphuretted hydrogen,	36.487	–
1523.9	1.876	Carbonic acid,	47.240	.2164
14.06	0.017	Watery vapor,	.4358	.4750

IV. TEMPERATURE.

In importance hardly second to that of the very existence of the atmosphere, is its temperature, or rather the temperature that may be brought to bear upon us in it. The human body itself is wonderfully uniform in its inward temperature; it rarely varies two degrees either way from ninety-eight degrees. Five or six degrees variation is said to be fatal. We do not know the secret power of the vitality that maintains this temperature, but we know some of the means that it uses for the purpose. We know that the chemical changes which are constantly going on in the body are of a nature to evolve heat; and the evaporation of the perspiration is evidently the chief means by which the temperature is kept down, under exposure to excessive heat. By this means men have endured an atmosphere of five hundred or six hundred degrees without suffering; the perspiration being very great and its evaporation absorbing the excess of heat.

As an external temperature of seventy degrees is as high as is generally agreeable, the body seems to require for its comfort about thirty degrees of difference between its own temperature and that around it. In other words it needs opportunity for giving off heat all the time as fast as can be received by the atmosphere at thirty degrees less temperature. This should be understood as a somewhat still atmosphere. If it is in quick motion it will take off heat much more rapidly, and must be of a higher temperature to be felt as equally warm. But the temperature of the atmosphere is not alone to be considered ; a small portion only of the heat that passes off from the body is received immediately by the air about it ; probably a much larger portion, according to circumstances, passes through the air, by radiation, till it meets other substances.

Pure air itself takes none of this heat that passes through it, having the power to receive heat only from contact with hot bodies. But the watery vapor in the atmosphere receives a great deal of the heat that is radiated through it. If, however, nothing but pure air surrounded us, our heat would go off so rapidly into space that we should freeze to death at once. Standing in the cave of an iceberg would be nothing to it. We say that the ice would strike its cold into us ; this is the appearance, but the truth is that our heat would strike into the ice, and would have but little effect in warming its very cold substance, so that it would be continually demanding more, faster than we could supply it. In fact, though, the ice would receive the heat and send back a portion to us, so that the demand upon us would be considerably less than if there were no ice and we were in open space.

The earth receives heat during the day from the sun ; at night it radiates much of this heat back into space. In fact it radiates in the day as well, but the loss is then more than supplied by the sun, and is perceived as loss only in the night. That the loss is not far greater than it is, is owing to the watery vapor in the atmosphere, which, as we have seen, is the great agent for retaining and diffusing heat. This is known to gardeners, who take extra care to protect their plants from frost on a cloudless night.

The degree of the retention of our heat, then, depends mainly on what is returned to us by the substances with which we are surrounded. The atmosphere does much, but not near all we require. If, for instance, we were to enter a room with very cold stone walls, though an atmosphere were introduced with us at a temperature of seventy degrees, we should be soon chilled through ; and so, whenever the walls or furniture about us are at a temperature much more than thirty degrees below that of the body, they take off our heat so fast as to make something more than an otherwise comfortable atmosphere necessary to keep us from being chilled. The air must be raised to a higher temperature, or a fire or some hot body must be near enough to give us as much heat as we require to balance our loss to the cold bodies. As the heat of the substances about us, or of any considerable portion of them, is raised, the temperature of the air may be diminished ; and for immediate comfort we may say that as the temperature of the air is raised, that of surrounding bodies may be less. But it is doubtful whether this latter may be said in point of health and safety.

The body accommodates itself to the heat about it ; in a high temperature it opens its pores for the free passage of its perspiration, by the evaporation of which it is kept cool. The temperature of the air immediately in contact with the skin is probably what chiefly determines its state. If, then, the pores be open for this reason, and the heat radiated goes off too fast by its absorption in cold substances, there is danger of chills and sudden stoppage of the pores, causing colds and fevers. Thus we find in spring time, when the balmy air entices us to free exposure, that we are in great danger of taking cold from the coldness of the ground. And the same is true of warm, early summer evenings ; but in late summer or early autumn, when, though the air begins to be cool, the earth is warm, there is much less danger, the system being braced, as we call it, by the cooler air, to more cold than we get from the earth. Thus, of the two, it is safer and more comfortable to have the solid surfaces of the room at a higher degree of temperature than the air, than the reverse.

The mode in which our heat is maintained in a mild summer day, is, beyond comparison, the most charming we ever experience or can imagine ; we are surrounded with a gently changing atmosphere at a temperature of from sixty to seventy degrees, warmed by the sun and by contact with the ground. The ground itself well warmed by the sun supports us with its mild temperature; and the sun's own rays beam upon us with life-giving, glowing warmth, just so far as we choose to receive them.

Without theory, we may assume as facts within the knowledge of all: 1st, that a moderately heated air is desirable. 2d, that the hotter the air, above a moderate degree, the more headaches there will be. 3d, that the liability to headache from fires or heated substances, not directly exposed to the head, is very much less for the same comfortable temperature, than from hot air. 4th, that a room, heated in part by fires or hot surfaces in the room, is more favorable for a number of occupants of various temperaments, than one heated wholly by hot air, with which all are encompassed equally.

The best possible imitation of nature's conditions of heat, is a blazing fire on the hearth, or in the grate; with the walls, floors, &c., warmed to a temperate degree; and air warmed similarly. In a small room such a fire will do much itself to warm the room and the air. Nothing more is required than to provide for the warming of the new air that comes into the room, before it strikes upon the occupants. In a large hall this arrangement is impracticable, because of the impossibility of warming the walls and floor by the direct heat of the fire, and of giving all the occupants a fair chance at the blaze. In such places it is necessary to depend more largely on the introduction of warmed air, which is the more suitable because of the necessity for much fresh air for the many occupants. At the same time the more heating surface, in the form of steam-pipes or otherwise, that can be introduced into the hall unobjectionably, the better, because of the less need for a high temperature of the air.

V.—Air Movement.

Of the circumstances of artificial climate, we have remaining to be considered, the motion or statical condition of the air. As the air is almost always at a lower temperature than the body, any motion of the air tends to cool the body, by bringing fresh particles to receive its heat. Even air at seventy degrees will be felt as cold when in rapid motion. Strong currents in a room not overheated are, therefore, unpleasant, and to be avoided; indeed, they are more frequently the cause of complaint than want of ventilation.

The worst currents, however, are those which enter from out of doors, through cracks and crevices; the old proverb quoted by Dr. Arnott,—

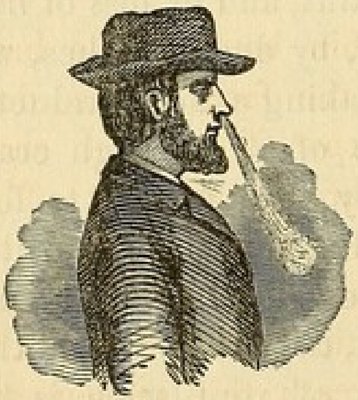
> "If the cold wind reach you through a hole,
> Go make your will, and mind your soul,"

has a great deal of truth in it. When the system has adapted itself to a warm room, relaxing and opening its pores, a cold draft, affecting only a part of the body, finds it all unprepared to resist, takes it at disadvantage, and is likely to cause serious results.

An additional cause of cold currents is the large cooling surface of windows, from which, in cold weather, there descends a constant current of air, made cold and heavy by contact with the glass, which is often mistaken for air entering from out of doors. This cause of complaint, and of loss of heat, may be easily remedied, in great part, by double-sashes, with some inches of air between; this air making a non-conducting packing. For preventing the entrance of air through cracks and other accidental openings, the only sure way is to force such a supply of fresh warm air into the room, that it will be always pushing out, instead of cold air coming in. As regards the general movement of the air in a hall, the rule is simply that, other things being equal, that system of ventilation is best which produces least commotion and force of current about the audience.

The essential point of ventilation, indeed, is constant change of air,—the removal of the air that becomes laden with the secretions of the body, and its replacement by fresh air. In nature this change is generally effected by currents of wind that rapidly sweep away and renew the air. In addition, according as the air is cooler than the body, the portion coming in contact with the person is warmed, and, becoming lighter than the rest, has a tendency to rise and give place to new air. This tendency is shown by a sensitive wind-wheel, in low temperatures, at the distance of a few inches from the body.

The heat of the breath also has been assumed to be the special provision for its removal and replacement with fresh air. This has been a favorite theory even among scientific men. Mr. Gurney was one of the first to stoutly deny the fact; in his testimony before committees of Parliament in 1854, he asserted that the downward propulsion which the breath received by the position and direction of the nostrils, did not cease, so far as the impurities with which it is laden are concerned, till it deposited them on the ground. We have not been able to verify Mr. Gurney's assertion, that on a frosty day the vapor from a person's mouth may be seen to describe a parabolic curve to the ground; but any one may see the vapor of the breath driven from the nostrils taking at first a downward course. A breath of fair strength, with the thermometer near the freezing point, may be seen, by its condensed vapor, driven downward and slightly outwards, for a foot or more. The subjoined sketch is an accurate representation of the visible breath seen in air of twenty-six degrees Fahrenheit, the rate of breathing being twenty-one to twenty-two times a minute.



In this observation, the wind-wheel moved rapidly, near the body, and steadily at a distance of six inches in front, and also at two feet above the head. Notwithstanding this upward current, the breath was strongly marked, by the condensed moisture, fourteen inches below the nostrils, and would doubtless have been seen farther down but for the dissipation of the moisture. In a room with the air at sixty-five degrees, the same wind-wheel was in motion close to the vital parts of the body, but stopped entirely at two or three inches distance from the body, or above the head. This was to be anticipated, because the force that carries the wheel is the rising of the air in consequence of its greater heat and lightness than that of the surrounding air, and is proportioned to the difference of temperature.

In order to determine the amount of heat operating to cause the air to rise, a thermometer was placed within the clothing near the vital parts of the body, where it was found to stand at eighty-two degrees, while the person remained in air at sixty-five; on going into air at twenty degrees, with additional clothing, the thermometer stood at seventy-six degrees. The air around the body in a warm room, therefore, would rise with a force not far from seventeen degrees, while in outer air at twenty degrees, it would rise with a force not far from fifty-six degrees. In point of fact we suppose the air would rise with a velocity somewhat less than these figures, but, relatively, we think they are nearly correct. A more sensitive instrument would have been affected at a greater distance, but the same wheel showed a distinct downward motion of the breath fifteen inches below the nostrils, in opposition to all the rising tendency, by reason of the warmth of the breath, and of the air about the body; and this motion also would have been shown to a greater distance by a more sensitive wheel.

Let us now suppose, to be well within bounds, the breath to be moved twelve inches below the face. The downward motion having ceased, the upward motion should then begin which is to carry the breath up out of the way. This old breath has about one second in which to rise, from rest or reverse motion, more than twelve inches, in order to be out of the way at the next inhalation. The difference of temperature necessary to give the breath this movement of twelve inches in the first second, if the breath rises by heat alone, will surprise any one not familiar with such calculations. It is not less than one hundred and eighty degrees; that is to say, the breath, in order to start from rest and rise twelve inches in one second through air at sixty-five degrees, would have to be at a temperature of two hundred and forty-five degrees.

The absurdity to which this calculation and experiment reduce the idea that our breath is carried away from the face by its upward tendency from heat, is increased by the observation, which every one may make, that a thermometer at sixty-five degrees cannot be raised more than one degree by breathing upon it at nine inches distance, and that at ten inches no effect can be perceived. But the upward tendency of the breath is doubtless much increased from the diffusion and lightness of its aqueous vapor, and possibly from other causes, though, under the most favorable circumstances, all causes combined are not sufficient to carry the expired breath up out of the way before another inhalation, as may be seen on a frosty day; and it is evident to all that the air contaminated by the body, if carried upward, must in some measure be inhaled.

The fact, then, in regard to the removal of the expired air from the face is rather the reverse of the theory that it is carried upward out of the way. It is carried downward at ordinary temperatures with force, as of a steam-jet, that, for aught we know, deposits it with its impurities, as Mr. Gurney says, at the floor. Though we have not traced its descent more than a third of the distance, a calculation of its downward impulse shows it to be sufficient to overcome all the upward tendency of its own heat, and that of the air about the body to a considerably greater distance than that of the floor. The supply of fresh air for inhalation comes in from above and about the face, to supply the partial vacuum created by the downward jet; and in this jet, as Mr. Gurney has pointed out, not in the upward tendency of the warm breath, is the admirable provision of nature for carrying away the expelled air, before more is to be inhaled.

We are not, however, to conclude that the rising force imparted to the air about a person, by heat of skin and lungs, is absolutely nothing, although in warm rooms it is practically of small account. More heat is given off from the body by radiation than by contact of air. Enclose a person in a non-conducting cylinder not much above his size, and the accumulation of heat about him would give some force to the air. And so, in an assembly, the heat accumulated around and among the persons gives the air a certain amount of rising force. Taking for a basis Péclet's estimate of the amount of heat given off by an individual in moderate temperature, the upward force given to air by three hundred persons in an hour would be equal to the power of five pounds of coal. This is an extreme, outside calculation of the force of the heat imparted by the body. If the usual deductions should be made for the wasteful manner of this application of heat to raise the air, less than half this amount of coal would be seen to balance the elevating effect on the air of three hundred persons.

Yet on the assumption of an effective lifting power in the heat given off from the body, has been based the prevailing system of ventilation,—that is, of taking the fresh air in at the bottom of the room and the foul air out at the top. This is claimed to be the natural system,and therefore the cheapest and best. The claim is admissible in cases where no power exists to change the air except this slight difference of temperature; but what becomes of it in cases where tons of coal are burnt a day for the sole purpose of producing a power to move the air, and where, as is common, all the air taken out at the top is brought down again in pipes to the ground before being sent off through a chimney shaft? Is it not more natural, cheaper, and better to go on as nature begins, and take the foul air of breath and body directly down through the floor to its exhausting chimney?

These two theories of ventilation have been often argued and both practised with varying success. We will consider the circumstances of a large hall of assembly, and show the operation of the two systems.

We must suppose a floor well packed with people, at the bottom of a cubical or hemispherical hall; suppose them to have entered at once, the hall being previously filled with pure air; directly the whole lower stratum of air, in which the audience are, is contaminated by their exhalations and emanations. Now the problem is to get that stratum of air out of the hall before any of it can come to use again, and to replace it with fresh air of the right temperature. It is obvious that it cannot be taken out sideways, because then many would have to breathe over again the breath of others. It can be taken only either up or down. If it is taken up, the fresh air that is to supply its place must enter at the floor from which the foul air rises; for no air will leave a spot till other air is ready to fill its place. In order, then, to lift the whole of the foul air bodily from the floor, it is necessary that the whole floor should be open for the admission of fresh air. Wherever there is a piece of solid floor through which the air cannot pass, there will be a dead space of foul air above it, which will not rise with the rest, but will remain to be gradually mixed with the fresh air entering around it. If the dead space is considerable, the whole amount of air required must enter in the limited space of the openings, and the velocity must be proportionately increased. According as this space is reduced and the velocity increased, the air entering has a force that carries it up beyond the place where it is to be used, and mixes it with the foul air passing off; a part of which mixture will return in counter-currents and gradually replace the air in the dead spaces. The operation may be seen by a simple experiment.

Take a bucket full of turbid water and lower it into a tub of clear water of equal temperature and density. If the bottom of the bucket could be removed without disturbance, the sides might be lowered gently and the clear water would replace the turbid water in the bucket completely, without much mixing. So, too, if the bottom of the bucket is entirely perforated, leaving very slender partitions between the perforations, the clear water may replace the turbid with little disturbance and mixing. But if the perforations are limited to holes of, say, half the space in the bottom, on pushing down the bucket, the clear water will rush up into the midst of the turbid water, and the turbid water on the solid spaces of the bottom will remain, till, mixed by friction and counter-currents with the pure water, it is gradually carried up. The fewer and smaller the holes, the longer the turbid water will remain in the dead spaces; and, if its turbidness is from a constant source, it will be likely to increase rather than diminish.

Dr. Reid, the most scientific and experienced, perhaps, of the advocates of the upward system, seeing this necessity for introducing his fresh air through the whole extent of the floor, when, after experience in the temporary Houses of Parliament, he was called upon to arrange the ventilation of the new House of Commons in Westminster Palace, had the entire floor made of perforated iron. This was afterwards covered with haircloth carpeting, and through nearly its whole extent the fresh air was admitted. No expense was spared, and the system was tried for some years under most favorable circumstances. The result was, that, on account of the raising of dust by the entering air, and still more on account of the uncomfortable draughts brought up against the honorable members' legs, nine-tenths of the floor came to be covered with sheet lead under the carpet. And when the entrance for fresh air was thus limited, it being through the carpet but a fraction of the nominal extent, complaints became so loud both of strong currents and of foulness of air, that the whole matter of ventilation was turned over to Mr. Goldsworthy Gurney, who undertook it on the opposite system of introducing the fresh air above and taking out the foul air at the floor.

In the French Senate Chamber, formerly supplied with fresh air through the rising steps behind the members' seats, these openings were closed because of the draughts about the senators' legs, and, according to Morin, in 1862 they had no ventilation at all.

Such are some of the difficulties of changing the air of a crowded hall by introducing it at the bottom and taking it out at the top. To avoid them, Sir Charles Barry, the architect of the new Houses of Parliament, introduced his main supply of fresh air in the House of Lords through the middle compartment of the ceiling, expecting it to descend to the floor, then to rise at the sides and to be taken out in the side compartments of the ceiling. This was expecting too much of atmospheric nature, and after a few years' trial, this hall too was given over to Mr. Gurney, who proposed to take the air out at the floor. We shall not dwell on the system of taking both the fresh air in and the foul air out at the top, or on that of taking the fresh air in and the foul air out at the bottom, because these systems, to be equally effectual, must double the amount of current that would be caused by taking the air in one way and out the other, and are for that reason not to be recommended for large halls, where the great difficulty is to change the air fast enough without making unpleasant currents.

Introducing the air at the upper part of a hall and taking it out at the bottom, known as downward ventilation, has certain obvious advantages. 1. It takes the emanations of the skin and lungs out of the room immediately after they are given off, before they have a chance to be inhaled. 2. Consequently, the fresh air coming unimpaired directly to the heads of the audience, a much less supply is required to secure the freshness of what is inhaled than is necessary when the new air is brought first to the feet, or becomes mixed with foul currents. 3. The warm air introduced has the opportunity of spending something of its heat on the ceiling and walls before it comes to be breathed, instead of being breathed at its highest temperature. 4. The fresh air is diffused over the whole area of the hall, even if introduced through few apertures, before reaching the audience; by which means the air is brought upon them more gently than if it came directly upon them through limited apertures. The greater the number and area of apertures for the exit of the foul air at the floor, the better, and the less will the current be felt. But this current being downwards will always be felt in a much less degree than a similar current upwards about the legs, for obvious reasons; and the dust and odors of the floor will be carried down instead of up into the air to be breathed.

For illustration of downward ventilation, take, as before, a bucket of water, turbid near the bottom, and sink it in a tub of clear water. Suppose the bottom to be well perforated, or even but partially so, clear water coming in at the top as the bucket is raised, will force out the turbid water very effectually at the bottom, whatever may be the position of the openings at the top. In other words, air passing through a room will drive out more thoroughly and uniformly the air at the side at which it goes out than that at the side it enters.

The gain effected by bringing the fresh air to the face, to be breathed before it sweeps the body, is quite important. It may be estimated by considering how much less supply of fresh air would be sufficient for a man enclosed in a cylinder just large enough to hold him, in case the air came down to his head first, than in case it came to his feet first, and up by his body to the face. A crowded assembly may be considered as a set of such cylinders, closely packed together, with their occupants like bees in their cells. The great advantage, in point of economy of freshness, of sending the air downwards instead of upwards is here very apparent; and it is obvious that in the one case may be obtained perfect purity of the air, while in the other it can never be more than an approximation.

The heating of the walls, ceiling, floor and furniture of a hall is of great importance. Otherwise, very hot air will not suffice to keep the occupants comfortable. If, as in most cases, this heating is to be done by the warm air alone, the more there is accomplished before the air is breathed, the less will be the comparative heat of the air entering the lungs.

This we consider, in itself, a decided advantage, and it is obtained in greater degree when the warm air is introduced above than when it enters at many points through the floor.

When air is introduced at the top of a hall and drawn out at the bottom, it is rapidly diffused through the whole upper space, and then begins to descend slowly and very uniformly to the floor. This is the case even at present in our Representatives' Hall, where the warm air enters at a single opening above the Speaker's chair. This air rises at once into the dome of the hall, as seen by experimental balloons, where it is quickly diffused, and then descends almost vertically in all parts of the hall to the floor. This arrangement, though designed only as a temporary and experimental step to the still better plan of introducing the air directly into the dome, proves, in a degree, that much greater gentleness and uniformity of motion, with freedom from needless currents, may be obtained with downward ventilation than it is possible to have with upward ventilation. For, in the latter, the rising air can occupy but very much less space, must have, at the level of the audience, proportionally greater velocity, and must alternate with additional counter-currents.

The objections to the downward system are: 1. Its supposed antagonism to the natural laws of upward movement of heated air. 2. The supposed greater heat of the upper air in the hall under that system.

The first objection we have already sufficiently considered. Practically, even those who favor upward ventilation, admit that there is no difficulty in taking the foul air out at the bottom by the application of a moderate force; and nothing in the art of ventilation is more universally admitted than the necessity, under any form of ventilation, in all public buildings, for the employment of some special power.

Nor is the objection strengthened materially by the common impression of greater foulness at the top than at the bottom of a crowded room. There is some truth in this impression, in regard to rooms which have no ventilation, though most careful experiments by eminent chemists fail to show any considerable or uniform increase in carbonic acid in the upper part of crowded halls; perhaps, as many experiments have shown the greater amount at the bottom as have shown it at the top. What slight increase there may sometimes be at the hottest state, is probably more than lost as the heated carbonic acid cools, and, to some extent, sinks from its weight. Sensitive observers, too, have found that though the upper portion of a heated, ill-ventilated hall smells most offensively, and, from its heat, is oppressive, the lower portion most seriously affects their state of health. In our Representatives' Hall, there has been the most serious complaint of oppression on the lowest portion of the floor, around the Speaker's desk. In point of fact, we believe, the idea of the greater foulness of air at the top arises mainly from crowded evening assemblies, where the heated products of combustion from gas-lights contaminate the upper air to a great extent.

It is of the utmost consequence that these products should have some direct means of removal. This is provided for in the best ventilated halls by so disposing the gas-burners that they may have direct and independent outlets for their smoke and gas. Another obvious explanation of the frequent greater impurity of the upper air in crowded, ill-ventilated halls, is that, without special force of supply, there is always a rush of fresh air into the hall through the doors as they are frequently opened; this air being cooler, of course, forces the warm foul air upwards. After all, the greater heat at the top of a room is probably the chief cause of the impression of greater foulness, though with the heat may be associated some light odorous gases. But all this is of no importance against systematic downward ventilation. When the foul air is taken off at the bottom, it is no longer found in excess at the top.

Morin's very accurate experiments in the smaller hall of the Conservatory of Arts and Trades, ventilated from above downward, show, on the average, a scarcely perceptible difference between the temperature of the air above and that below. In our own Representatives' Hall, where now the warm air is introduced thirteen feet above the Speaker's platform, and the foul air taken out at the floor, though the arrangements for supply and exhaust are, at present, quite limited and much less than we should desire, we have found as the average of over five hundred observations in eighty-six different positions, with the exhaust ducts open, the temperature opposite the gas-burners above the gallery, only about two and one-half degrees above the average throughout the hall; while that of the lower seats was not two and one-half degrees below the average. When, however, in the midst of these observations, the exhaust ducts were temporarily closed, the difference soon doubled, though the whole average temperature was slightly lowered.

To give these results more in detail:—

OBSERVATIONS IN LEVEL PLANES.	VENTILATING DUCTS.	
	Open.	Closed.
Average in dome of hall, ...	78.5°	85°
Average opposite gas lights above gallery, . . .	71.46°	73.54°
Average opposite gas lights below gallery, . . .	68.57°	66.50°
Average in the seats, ...	66.63°	63.72°
Average throughout the hall, ...	68.86°	68.17°

It is essential to the system of downward ventilation, as well as to all other systems, that a constant current should be maintained by keeping the inlet and outlet always open. When less heat is desired, the change must be effected, not by stopping the warm air inlet, but by letting into it cooler air. And when the heat of the room goes off too fast, especially when it is empty, the heat may be economized by letting the air at the floor back into the heating chamber instead of out of doors.

In support of the downward system, we will only refer to Mr. Goldsworthy Gurney's testimony before the committees of both Houses of Parliament, who has for the last ten years had charge of the ventilation of the Houses of Parliament, and who has introduced the downward system with great success, in court houses and other public buildings, in England; to the book of Mr. Ruttan, of Canada, who has introduced the system most successfully in railway cars, on some of our roads, as well as in buildings; and to the conclusions of General Morin, well known for his valuable scientific works on different departments of engineering, and the author of the latest and most elaborate work on ventilation (Etudes sur la Ventilation, Paris, 1863, 2 vols, 8 vo. pp. 1017.)

General Morin says, in treating of the ventilation of large halls :—

"The numerous observations which I have gathered, and which any one may repeat, have shown me, as I have already said, that there are very sensible inconveniences in making the new air, warm or cold, enter near the occupants of a hall.

"This air is always necessarily at a temperature different from that of the hall; warmer, if it is desired to raise, or even sometimes to maintain, the inside temperature, as is the case in winter, to compensate the cooling effect of the walls, and when there are few present; and, on the other hand, cooler, if the outer temperature is somewhat high, and if there are many occupants.

"In the one case, as in the other, the neighborhood of the apertures, for the entrance of air, is disagreeable, and, whatever care is taken to limit the velocity by giving the apertures the greatest possible extent, it is seldom that the velocity can be less than 1.3 to 1.7 feet per second, from which there is sometimes an uncomfortable sensation."

After referring to the experience in the English House of Commons, and to that in the French Senate Chamber, in both of which the apertures for the admission of air had been gradually closed, because of the objectionable currents, till ventilation had almost ceased, General Morin continues :—

"It does not seem to me, then, suitable for amphitheatres, or for any other place of a similar kind, to admit the new air through the floor, by the steps or the step-risers. On the contrary, here as elsewhere, the air should be made to enter as far as possible from the audience; and as it may be often necessary the same day, and from time to time, to vary the temperature of the air admitted, within certain limits, arrangements must be adopted which will render the mixing of warm and cold air as complete and as easy to modify as possible, before it comes in contact with the audience. This, it must be said, is the most delicate condition to well fulfil, and amphitheatres are, perhaps, the case in which the difficulty is presented in the highest degree.

"After having reflected much and observed well the various effects of the introduction and evacuation of the air, this is the solution which has seemed to me the surest, and which I have settled upon for the amphitheatres of the Conservatory of Arts and Trades. It has already been applied to one of them as completely as the local conditions would permit in a building of old construction. The vitiated air being that which it is necessary to draw out, it is desirable to hinder it from diffusing in the hall, and consequently to extract it at the spot where it is vitiated, that is to say, as near as possible to the individual occupants, through perforations, in the risers, or backs of the steps, in order to make it pass out under the amphitheatre.

"The introduction of fresh air presents two principal phases, quite distinct.

"In the first, which precedes the arrival of the people, the amphitheatre should be brought up to a moderate temperature, which may, however, be raised to 64.4°. At this moment it is evident that the movement of air from inside to outside of the hall should be, in general, completely interrupted; and in order that there may be established throughout the hall a suitable temperature, it seems natural to allow the warm air to be introduced then by passages communicating with the heaters and opening through the floor at the lowest points.

"In the second period, on the contrary, soon after the entrance of the audience, and according to their number, more or less, we must extract a portion of the air now vitiated, and more or less heated, and replace it with pure air. But this fresh air would be, as is daily observed, very uncomfortable if its temperature were much lower than that of the air of the hall, and especially if it flowed in too near the audience.

"From this results: 1. The necessity of introducing the fresh air first into a receiver, which we call the mixing chamber, where, by the simultaneous entrance of hot air and cool air, in proportions which can be easily regulated, the means are kept of admitting into the hall only air of the desired temperature. 2. The obligation, not less imperative, to place the openings for the admission of this fresh air as far as possible from the audience, that is to say, about the ceiling of the amphitheatre, if the circumstances of the place permit, or at least at a considerable height. In general, whenever the construction will permit, it is preferable to bring the fresh air through the ceiling or the cornice, by openings so proportioned that the mean velocity of the air will not exceed 1.3 to 1.7 feet per second."

The general rules adopted by Morin are as follows:—

1. Place the exhaust orifices as near the points where the air is vitiated as possible.

2. Have as many orifices of exhaustion as the construction of the building will admit of.

3. Orifices of exhaustion should be so proportioned that the velocity of the air passing through them may be from 2.6 to 3.3 feet per second.

4. Unite the different groups only by entering them into the common conduit, or into the chimney of exhaust, and as far

as possible from their openings into the rooms. Arrange in such a manner that they can be easily examined and repaired. Protect from cold.

5. Give to the general chimney of exhaust all the height admissible, and so arrange the heating apparatus that the air in the chimney may acquire a temperature of from sixty-eight degrees to seventy-seven degrees in excess of the external air. This will be effectual in all simple systems.

6. So arrange the chimneys and general arrangements for heating that on extraordinary occasion the amount of air exhausted may be increased to suit the requirements.

> "Do not place the orifices, for the entrance of fresh air, near the floor; it is proved in the French Senate that where the orifices were near the floor, currents of *warm* air, having a velocity of from one and three-tenths to one and seven-tenths feet per second, were disagreeable; currents of cold air should be avoided for much stronger reasons.
>
> "The above is agreeable to the conclusions of both French and English engineers."

The whole discussion of the matter of ventilation before committees of Parliament for twenty years, ending some ten years ago, is full of interest and instruction; through it all Mr. Gurney appears in behalf of downward ventilation, in opposition to Dr. Reid, who, for that time, was attempting to ventilate the Houses of Parliament satisfactorily on the upward system. When, in 1854–5, the committees of both houses determined to give their ventilation into the hands of Mr. Gurney, they seem to have adopted the conclusion of Mr. Robert Stephenson, who, himself a member, was examined by a committee of the House of Commons in 1852, and testified that, for a crowded hall, he preferred downward ventilation, unless the gas-lights should interfere; and that it was as easy to draw the air out downward as upward.

Walter Bernan, though repeating the absurd assertions about the breath rising with the force of a temperature of ninety-eight degrees, says that the downward system "in practice preserves an agreeable and salubrious atmosphere, and the heat is even more equally diffused than with an upward current." He adds that, "on the small scale in which only we have seen it, it appeared, notwithstanding the cogent reasons against its principle, to be in many cases the preferable mode, particularly where dust was reckoned an annoyance." (History of the Art of Warming and Ventilating Buildings.)

Dr. Arnott, who gives the preference to upward ventilation on the old theory of the rising of the breath, when examined by a committee of the House of Commons, admits the difficulty of dust and currents on this system, and the superiority of downward ventilation in preventing local currents. He concludes that the latter system will do well when the air is renewed fast enough. (Parliamentary Reports, 1852.)

Even Dr. Reid, the great experimenter in upward ventilation, admits, with candor and discrimination, the practicability of downward ventilation. In his elegant "Illustrations of Ventilation," he says: —

> "In cases of forced ventilation, where the ingress and egress of air is subject to the action of a power that may be regulated at pleasure, it may be expedient, under peculiar circumstances, and where special difficulties present themselves, to resort to a descending movement, leading the air from the ceiling to the floor, instead of from the floor to the ceiling. Such movements are necessarily more expensive than the ordinary ascending movement; they are applicable only where the products of combustion from lamps, candles, or gas, are removed by exclusive processes from the descending atmosphere; they should be resorted to only where peculiar difficulties occur, which cannot be overcome by other means At one period, when it was affirmed that peculiar difficulties presented themselves in regulating the atmosphere of the House of Commons, I made several trials with the descending atmosphere, considering it, under these circumstances, the most desirable for that building; but subsequent investigations led me to ascertain that the objections made at that period were not tenable, when the arrangements were maintained in proper operation, and no descending atmosphere accordingly has ever been introduced during the debates. It may be stated, however, that, as the first movement of the air from the nostrils proceeds in a downward direction, it would not be impossible to prevent the expired air from returning again upon the system by a downward movement, where very large quantities of air are freely introduced."

It should be noted that this was published in 1844, ten years before Dr. Reid's system in the House of Commons was abandoned.

Dr. Morrill Wyman, whose little treatise on ventilation contains more scientific and sensible information on the subject than almost any other book in the English language, though he gives assent to the prevailing theory of upward ventilation, says:—

> "There is no impossibility, however, of producing a constant and equable downward movement, which shall also effectually prevent all respired air from being again presented to the organs of respiration. The first movement of expired air is from the mouth, horizontally, and from the nostrils, downward, before it begins to rise; consequently, a downward current may, without much difficulty, be brought to bear upon and remove it."

As regards the manner of applying power to effect the change of air, it is sometimes applied to the exhaustion of the foul air, and sometimes to the supply of fresh air. Either way is effectual in a degree, but neither alone accomplishes quite all that is to be desired. Forcing the fresh air in abundantly will drive out the air already in the hall at every outlet, and it is essential for security against the intrusion of cold currents through cracks and doorways. But it will drive the air out mainly at the easiest outlets, and some of the most important may be neglected, because of being out of the easiest way for the air to pass. The only sure way to get the air out just where you want it to go out, is to apply an exhausting force at the outlets, to guide and assist the expelling force. The filling method is called the plenum method, and the exhausting, the vacuum method. Much has been said about the superiority, for working vigor, of air in a plenum, or over-pressure condition. There is no doubt of the fact that under a high atmospheric pressure a man has greater power than under a low pressure. But the amount of superior pressure that can be obtained in a common hall is very slight, and can hardly have a perceptible effect. A nearly even balance of the filling and exhausting forces, making the in-door barometer about the same as the out-door, but with the filling force enough in excess to keep out all air seeking to enter without leave, is the most economical and satisfactory condition to obtain.

VI.—PRODUCTION AND DISTRIBUTION OF HEAT.

The ever present phenomena of heat are so varied and manifold, that even to give a list of their different aspects would far exceed the limits of this report, and we can only refer to their general characteristics in relation to the sensations due to changes of temperature, or, in other words, the sensations resulting from being more or less acted upon by substances giving off or receiving heat.

The natural sources of heat are the sun and the earth ; the artificial sources are friction, concussion, electricity and chemical action or combustion ; upon the last of these we depend for artificial warmth.

Combustion only takes place by the combination of oxygen with some other substance. This phenomenon is usually accompanied by heat and light, but not always.

Oxygen has the remarkable property of uniting with all simple bodies and with a great number of compound bodies ; all these bodies are classed under the general name of combustibles.

Combustion may take place in air, in pure oxygen, or in a compound of oxygen and any other gas, or even with solid bodies or liquids, and is in all cases simply a combination of oxygen with a combustible body. When combustion takes place in air, the oxygen is supplied from the air ; when the air becomes exhausted the combustion ceases. When a metal is dissolved by an acid, the metal is truly burned, and the oxygen is supplied from the acid or the water. And, finally, when gunpowder explodes, the sulphur and carbon of which it is made form the combustible, and the saltpetre supplies the oxygen.

We have already said that heat and light usually accompany combustion. It appears that, in general, light commences to manifest itself when the temperature of the combustible reaches 752°. At this temperature the light is of a dull red, and scarcely visible ; but, as the temperature is augmented, the light is more brilliant, and becomes cherry red ; finally, at a very elevated temperature, the light becomes perfectly white.

When a combustible is solid and remains so during the time of combustion, this phenomenon takes place only at its surface, which alone is luminous. The surrounding air, though submitted to a very elevated temperature, is not luminous, because gases are not susceptible of becoming luminous by communcated heat, however great the heat may be.

If a combustible body is susceptible of being reduced to a vapor at a lower temperature than is necessary for the combustion of the body, the combustion will take place in the vapor itself. The location of the flame will be above that of the combustible, for all vapors at the temperature at which they burn are lighter than the air. The form and direction of the flame depend on the movement of the air. If the combustible body, instead of reducing itself to vapor, decomposes into combustible gases, as, for example, wood, pit coal, and oils, their gases in burning exhibit the same phenomena.

Flame is luminous only at its surface, for it is there only that it is in contact with the air and can burn.

During the combustion of any body, solid, liquid, or gaseous, the quantity of heat disengaged is always equal for the same quantity of the same combustible, whatever may be the circumstances of the combustion, whether in air under a pressure greater or less than that of the atmosphere, and whether in oxygen pure or mixed. Light, on the contrary, for the same combustible, and the same consumption in the same time, varies with circumstances, above all with the velocity of the current of air.

It is usual to designate as a unit of heat the quantity required to raise the temperature through 1° Fahrenheit, of 1 pound of water ; and to designate as the heating power of a combustible, the number of units of heat that the complete combustion of a pound of the body will produce.

Below will be found the heating power of one pound each of several of the more common combustibles.

	Units of Heat.	Pounds of Water Evaporated.
Hydrogen,	62,032.	63.81
Carbon changing to an oxide,	4,451.4	4.58
Carbon changing to an acid,	14,544.	14.96
Carbonic oxide,	4,325.4	4.44
Carburetted hydrogen,	23,513.4	24.19
Alcohol,	12,929.4	13.30
Sulphur,	4,032.	4.14
Olive oil,	18,783.	19.32
American anthracite coal,	9,321.5	9.59
American bituminous coal,	9,652.	9.93

The amount of heat emitted by the human body per hour, according to Péclet, is 318 units; of this amount 150 units are consumed in the formation of vapor, leaving 168 to be expended as apparent heat.

The most important practical fact shown by the above table is, that in the combustion of carbon, the important ingredient of all fuel, two compounds may be formed; the formation of one of which, carbonic oxide, evolves but $\frac{4451}{14544}$, or less than one-third, of the heat that would have been evolved had the other compound, carbonic acid been formed. From this fact it can be seen why one heating apparatus may be so vastly superior to another. The one so arranged that a part of the carbon escapes in the form of carbonic oxide, cannot give anything like the amount of heat that would be given off if nothing but carbonic acid was produced. The cause of the formation of the oxide instead of the acid is either the insufficient supply of oxygen in air, or the too low temperature at its point of union with the carbon. The presence of carbonic oxide may be readily detected in any combustion chamber by watching the burning. If the flame has a bright cherry red color and has no dull fumes hanging over it, carbonic acid is being formed; but if it burns dull, with a blue flitting flame, carbonic oxide is being formed and the fuel is being wasted.

When a fire is found to burn blue and dull, the case is apt to be that there is too much new coal on, or that there is not sufficient inlet for air through the fire. But sometimes there is too much air let in, especially over the fire, reducing the temperature too low. Careful experiment only can determine for different fires, with different draughts, such a balance of the supply of air and of coal as will secure the best combustion ; the convenient and true test of good and economical combustion being always a bright-burning fire.

The law of the distribution of heat from, through and into different substances, depends upon certain relations that different substances have to heat. Every substance with which we are acquainted has some or all of the following properties, which affect the reception and transmission of heat.

1. Specific heat.
2. Diathermancy.
3. Conduction.
4. Convection.
5. Radiation.
6. Absorption.
7. Reflection.

1. *Specific Heat.*—It is found by experiment that the same weight of different substances requires a different amount of heat to raise them through one degree. As we have stated above, the unit of heat is that amount required to raise one pound of water through one degree of Fahrenheit. Hence we say that the specific heat of water is 1. By comparing with the amount of heat required to raise water one degree, the amount required to raise equal weights of other substances one degree, we determine their specific heat. Thus, comparing water with air, it requires only about one-fourth of the amount of heat to raise the same weight of air one degree, that it does for water. Hence we say that the specific heat of air is about 0.25. The practical application of this law to the heating of air by water, is as follows. A pound of water in losing 1° of temperature would warm about four pounds of air 1°. But water is 812 times heavier than air; hence, comparing equal volumes, a cubic foot of water in losing 1° of temperature would raise four times 812, that is, 3,248 cubic feet of air. The same process of calculation may be applied to steam with equally practical results.

The following table gives the specific heat for equal weight, of several of the most important solid and fluid substances:—

Water,	1.00000	Plumbago,	0.20187
Iron,	0.11379	Pine wood,	0.65000
Cast iron,	0.12983	Oak wood,	0.57000
Zinc,	0.09555	Flint glass,	0.19000
Copper,	0.09515	Air,	0.23790
Lead,	0.03140	Oxygen,	0.21820
English tin,	0.05695	Watery vapor,	0.47500
Marble,	0.20989	Carbonic oxide,	0.24790
Charcoal,	0.24150	Carbonic acid,	0.21640
Anthracite coal,	0.20100		

2. *Diathermancy* is the power of instantaneously transmitting heat, as a transparent body transmits light. This property is possessed by every transparent body, but not in equal degree. A substance may be almost perfectly transparent to light, and nearly opaque to heat, or the reverse. With one exception, the transparency of bodies for radiant heat, varies with the quality of the heat; rock salt is the only known body equally transparent to all kinds of heat. Glass is remarkable for its varying transparency to rays of heat of different qualities or intensities, as will be seen below. If one hundred rays of heat of the different intensities that come from heated bodies at the different temperatures, of the sun, of 1,500°, 1,100°, 752°, and 212°, fall upon a plate of rock salt, there will go directly through, about 100 rays of those from the sun, and 92 of those from each of the other temperatures. But there will go through glass, from heated bodies of these temperatures, rays in the following proportions, about 100, 39, 24, 6, 0.

Thus it appears that glass is almost opaque to the transmission of heat from bodies at a low temperature. The very valuable effect of this property of glass, is that glazed windows admit into our houses nearly all the heat from the sun that strikes upon them. But, when this heat has reached the substances of the rooms, and is reflected or radiated back from them, with the low intensity of their moderate temperature, none of it is permitted by the glass to pass through; nor is any of the artificial heat that is radiated upon it.

Snow and ice are similar to glass in this respect, though in less degree. A familiar illustration is found in the melting of snow or ice near a leaf, stick, log or stone, under the rays of the sun. The snow and ice let nearly all the rays pass through till they strike some more impervious substance. This substance, if it does not conduct away the heat too rapidly, reflects and radiates it back at a low degree of intensity; in which state the ice or snow will not let it pass, but stops it, is warmed by it, and melt.

We copy from Tyndall the following table of diathermanic powers of different substances as determined by Melloni:

Names of substances reduced to a common thickness of 1-10 of an inch.	Transmission: Percentage of the Total Radiation.			
	Locatelli Lamp.	Incandescent Platinum.	Copper at 752°.	Copper at 212°.
Rock salt,	92.3	92.3	92.3	92.3
Glass,	39.0	24.0	6.0	–
Alum,	9.0	2.0	–	–
Ice,	6.0	.5	–	–

3. *Conduction* is the term applied to the property which bodies have of passing the heat they receive, from one particle to another, through their substance. This property varies in different bodies, some having very much more than others. The difference in conducting power is of great importance in the economy of heat. Thus substances of exactly the same temperature may produce very different sensations to the hand. If we grasp in one hand a piece of wood and in the other a piece of metal, both of the same temperature, 20° for instance, the sensation produced by the metal will be nearly unbearable, while that from the wood will hardly affect the hand. If the temperature had been 180° instead of 20°, the result would be the same, except that the marked sensation would be that of heat, from the iron, while in the first case it was that of intense cold. In one case the wood and the iron conducted heat from, and in the other to, the hand; but the conduction by the wood was so slow and gentle, as to be hardly perceptible, while that of the iron was so rapid as to cause pain.

From this fact we may understand why it is so much more difficult to start a fire in a cold iron fire-pot, than in one of brick, or in one already warm; for the heat applied to ignite the fuel in the cold iron pot is conducted away so rapidly that the fuel is cooled and the fire may be extinguished. If the walls of the furnace were poor conductors, or already warmed, the heat, instead of being conducted away, would raise the temperature of the fuel and thus cause combustion. When we are seeking to retain heat, we use those substances suited to our purpose, that are poor conductors; and when we desire to secure the transmission of heat, we use the best conductors.

The following table gives the relative conducting power of some of the most common and important substances:—

Silver,	100	Iron,	12
Copper,	74	Lead,	9
Gold,	53	Platinum,	8
Brass,	24	German silver,	6
Tin,	15	Bismuth,	2

The following results of experiments by Count Rumford show the relative rapidity of the conduction of heat through some common substances, valuable for their non-conducting properties:—

Twisted silk,	917	Beavers' fur,	1,296
Fine lint,	1,032	Eider down,	1,305
Cotton wool,	1,046	Hares' fur,	1,312
Sheep's wool,	1,118	Wood ashes,	927
Taffety,	1,169	Charcoal,	937
Raw silk,	1,264	Lamp black,	1,117

4. *Convection*, a property confined to fluids, is the distribution of heat by the transfer of masses of the fluid from place to place. Within the fluid body this property is called diffusion, in contradistinction to conduction, which is the process for the distribution of heat in solid bodies.

Though fluids are very poor conductors, large quantities may be warmed very rapidly by taking advantage of the principles which govern their internal motion. When any portion of a liquid is heated, it generally expands, and, becoming lighter, rises to the surface, and is replaced by heavier and colder portions, which in their turn become heated and ascend, generating a current that will soon cause the whole mass to be equally warmed. Water has, in common with some other fluids, a temperature at which its density is greatest, and if, from that point, the temperature is raised or lowered, the water becomes lighter; this temperature is 39½°. Hence, if we wish to warm water that has a temperature below 39½°, heat should be applied to the top. This fact has no value in ordinary practice, but in the economy of nature it is of the utmost importance. Water in rivers, lakes, seas and oceans, is constantly, in the colder portion of the year, taking heat from the earth and radiating it into space, until its surface attains that temperature at which the amount of heat it loses by radiation is only (or nearly) equivalent to that which it receives, when it ceases to lose heat, and consequently keeps a uniform temperature. This equilibrium would never take place until all the water had become solid ice and ceased to convey heat, except by ordinary slow conduction, if it were not that when the cooling process has gone so far as to reduce the water to a temperature of 39½°, it is at its greatest density, and the direction of the conveyance of heat is reversed. From this point the lower stratum can become no cooler, but on the contrary, is protected, by the further cooling of the surface, from any loss by convection. When the gentle warmth of spring plays upon the frozen surface, the ice is first melted, leaving the water at a temperature of 32°; then the heat imparted to the water is carried downward until the whole mass is raised to a temperature of 39½°, when this process is reversed, and the earth vies with the sun in warming external nature.

On these laws depends the preservation from total and eternal congelation of all bodies of water, large and small.

5. Radiation is a common property of all bodies to send out heat in straight lines in all directions. This mode of imparting heat, the grand one of nature, is independent of distance, and apparently requires no communicating medium. Any interposing substance impedes it to a greater or less extent, though certain diathermanous bodies, as we have stated, allow rays of particular intensities to pass directly through. From experiment it is evident that radiation is independent of the color of a body,

that it does not take place from the extreme surface, but from within the thin layer which gives character to the surface, and that upon this external film depends the radiating power of a body, supposing the supply constantly maintained; thus, in the case of a polished metal, the external film is much compressed, and the radiating power correspondingly impaired. If the thin, polished, and consequently hardened, film is removed, leaving the surface in a softer, less compressed state, the radiating power is increased; or if, instead of removing this film, a new one of different character, paint for instance, is overlaid, then this new substance becomes the medium of radiation, and, being a much better radiator than the compressed metal, gives off a greater amount of heat. Rays of heat generally follow the same laws, in regard to refraction and reflection, as those of light, though this is not true in every respect. Radiation in free air is affected in a remarkable manner by the presence of odors. Tyndall says,—

"Scents and effluvia generally have long occupied the attention of observant men, and they have formed favorite illustrations of the 'divisibility of matter.'"

No chemist ever weighed the perfume of a rose; but in radiant heat we have a test more refined than the chemist's balance.

"The number of atoms of air must be regarded as almost infinite in comparison with those of the odors; still the latter, thinly scattered as they are, do, in the case of patchouli, 30 times the execution of the air [in absorbing radiated heat;] otto of roses does upwards of 36 times the execution of the air; thyme, 74 times; spikenard, 355 times, and aniseseed, 372 times the execution of the air. It would be idle to speculate on the quantities of matter implicated in these results. Probably they would have to be multiplied by millions to bring them up to the tension of ordinary air. Thus,—

'The sweet south
That breathes upon a bank of violets,
Stealing and giving odor,'

owes its sweetness to an agent, which, though almost infinitely attenuated, may be more potent, as an intercepter of terrestrial radiation, than the entire atmosphere from 'bank' to sky."

For a table of the radiating powers of different substances see page 73.

6. ABSORPTION is, in many respects, the converse of radiation, and is that property of bodies which enables them to receive heat by radiation; generally a good absorber is a good radiator, and the converse. Under the head of Diathermancy, we have seen that rays of certain intensity pass through transcalescent substances freely; but the same rays reflected, and becoming of different intensity, cannot repass. A modification of this law is also true for absorption and radiation. Thus, if we take any body, a piece of iron, for instance, and place it near a hot stove, the radiated heat, of an intensity proportioned to the temperature of the source, is absorbed by the iron. Now, if this iron did not act upon these rays and reduce their intensity, radiation would take place with a rapidity equal to that of the absorption, and the body become no warmer. But these rays are acted upon, and their character so changed within the receiving body, that absorption takes place much more rapidly than radiation, until the body has been warmed to a temperature nearly equal to that of the source of heat, and the rays radiated from the body have an intensity equal to those from the original source; when the iron can become no warmer. The rapidity with which one body accumulates heat from another body, is dependent upon its own nature, upon its surface, and upon the difference of temperature between it and the source from which it derives its heat.

Though two bodies of the same weight and of the same temperature, say 32°, may receive the same absolute amount of heat, yet their apparent increase of temperature will be very different. Thus, if we take a pound of water, a pound of iron, a pound of lead, and a pound of marble, all at a temperature of 32°, and impart to them an equal amount of heat, 1 unit, for instance, we shall find that the temperature of the water will be 33°, iron, 40.75°, lead, 65°, and marble, 37°.

From this we see that the rapidity with which the apparent temperature increases, does not indicate the relative absorptive powers of the bodies. Water, in common with other liquids, absorbs heat until it arrives at a certain temperature, that is, to the boiling point. After that, heat continues to be absorbed, but the apparent temperature remains the same. The heat absorbed changes into power, and is commonly called latent heat.

If a metal is allowed to absorb heat, its apparent temperature will steadily rise until it arrives at the melting point, then the apparent temperature becomes constant, though it is still absorbing heat. If the process of absorption goes on, the temperature will eventually again commence to rise until the metal commences the process of sublimation, when the further heat applied is converted into power, and the apparent temperature of the body again remains the same.

Color influences the absorbing power of the body in a remarkable degree. If two pieces of cloth, one white, the other black, be laid upon snow and exposed to the sun, that which is black will, by absorbing more heat, melt the snow under it, and sink deeper. It is, therefore, with reason that darkest colored cloths are preferred for winter use, and light colors for summer.

The great difference in the absorbing power of a blackened and of a metallic surface, may easily be shown by coating the bulb of one thermometer with silver leaf, and that of another with black paint, and exposing them both to the sun. It will be seen that the temperature of the blackened one is much above that of the silvered one.

A French physicist recently constructed a small instrument to boil water by the direct rays of the sun. This instrument consisted of a globular vessel of blackened metal, enclosed by a sphere of glass. If the inner vessel is filled with water and the apparatus exposed to the sun, nearly all the rays will strike at once through the glass, and, being absorbed by the blackened vessel, will raise the temperature of the water within, which in its turn will begin to radiate heat. But this radiated heat, coming from water below 212°, is of so low an intensity as to be utterly incapable of passing through the glass of the outer sphere; thus all the heat coming to the apparatus is confined within it, and the water, of necessity, boils.

The relative absorptive powers of bodies (independent of color,) being similar to their radiating powers, it is not necessary to give a table; that given for radiation on page 73, will suffice.

7. Reflection of heat obeys the same laws as that of light. The rays may be collected by means of a concave mirror so as to produce the most intense heat.

The reflecting power of different bodies is generally estimated to be inversely as the radiating power. Upon this assumption the following table of relative reflecting power is based:—

Brass,	100
Silver,	90
Tinfoil,	85
Block tin,	80
Steel,	70
Lead,	60
Tinfoil softened by mercury,	10
Glass,	10
Glass coated with wax,	5

The reflecting power of bodies under the following circumstances has been exactly determined by Buff. Of 100 rays incident at an angle of 60° from the perpendicular, there are reflected by

Polished gold,	76
" silver,	62
" brass,	62
Dull brass,	52
Polished brass varnished,	41
Glass plate silvered on the back,	20
Glass plate blackened on the back,	12
Metal plate blackened.	6

The mode of determining the amount of heat emitted by a heated body is as follows. We will suppose a metallic vessel full of water at a given temperature. Now as metals are good conductors, the temperature of the outer surface of the vessel will be about equal to that of the water which it contains; and if we multiply the weight of the water and the vessel, in pounds, by the specific heat of the water, which as we have seen above is 1, we shall have, very nearly, the number of units of heat contained in the vessel and water.

Suppose this vessel to be a cylinder one foot in diameter and one foot high, which has a superficial area of 4.71 square feet;

filled with water, it weighs say fifty pounds, which multiplied by the specific heat of water, 1, gives us 50 as the number of units of heat which it would lose while cooling down one sensible degree; cooling through 2° the amount of heat given out will equal $2 \times 50 = 100$ units. Now if this amount of heat is all expended in raising the temperature of the surrounding air, it is easy to determine the quantity of air that can be raised by it 1° in temperature. We have seen above that one unit of heat will raise through 1° about four pounds of air, or more exactly, 4.203 pounds. It is also true that if, instead of raising the whole amount of air 1°, we wish to raise a portion of it through several degrees, the amount raised will be exactly in the inverse ratio to the number of degrees through which it is raised. Thus if 4.203 pounds be warmed 1°, one-half the amount would be warmed 2°, or one-tenth the amount 10°.

For a practical illustration, let us assume our vessel of water to be at a temperature of 200°, and that of the surrounding air 32°; we wish to know how much air can be raised to a temperature of 68°, or through 36°, by the amount of heat given off from the vessel while cooling through 1°. This amount of heat would raise $50 \times 4.203 =$ about 210 pounds of air through 1°, and consequently, $\frac{210}{36} = 5.83$ pounds through 36°. This reduced to volume will give $75\frac{1}{2}$ cubic feet as the amount of air raised from 32° to 68° by the heat given off from the vessel while cooling through 1° of temperature.

In practice our source of heat is kept at a uniform temperature, or nearly so; and the problem to be solved is how much heat is given off per minute, and per foot, for some given temperature. As there are many practical difficulties in ascertaining directly the amount given off while heat is constantly supplied, owing to the difficulty of insuring uniformity in the supply, as well as of exactly measuring the amount emitted, we find it more easily and surely by measuring the amount lost in a given time by a body cooling from half a degree above to half a degree below the given temperature; as it is evident that this amount must equal that which would have been given off if the mean temperature had been maintained.

Newton supposed that the rate of cooling of a body in the air is proportional to the excess of the temperature of the body cooling, over that of the surrounding air. He gives this formula, $v = qt$; v being the rate of cooling, t the difference of temperature, and q a co-efficient, variable with the nature of the body; but this law has been found by experiment to be inexact, as the ratio of cooling increases with the temperature.

MM. Dulong and Petit, by an extensive series of experiments upon the cooling of a thermometer bulb placed in a reservoir filled with different gases, under different pressures, and maintained at a constant temperature by being immersed in a water bath, have established the following facts:—

1st. The cooling of a body results from radiation and from contact with the surrounding fluids.

2d. The velocity of cooling from radiation is the same for all bodies, but its absolute value varies with the nature of their surfaces. This velocity is represented by the formula,

$$\mathrm{v} = \mathrm{m}\,\mathrm{a}^{\frac{\mathrm{T}-32}{1.8}}\left(\mathrm{a}^{\frac{\mathrm{t}}{1.8}}-1\right)$$

in which m represents a number which depends upon the nature of the surface of the body, a the number 1.0077, T the temperature of the surrounding fluid, and t the excess of the temperature of the body over that of the surrounding fluid.

3d. The rate of cooling from contact of the surrounding fluid is, also, the same for all bodies; but its absolute value is independent of the nature of the surface; it depends only on the form of the body, and the excess of its temperature over that of the surrounding air. This rate for air, under the pressure of thirty inches, is represented by the formula

$$\mathrm{v} = \mathrm{n}\left(\frac{\mathrm{t}}{1.8}\right)^{1.233}$$

in which n is a number, variable with the form and extent of the surface of the body, and t the excess of the temperature of the body, over that of the surrounding fluid.

Let us represent the whole amount of heat given off by a given area and in a given time by M. This total consists of the amount given off by radiation, which we will designate by R, and that by convection, which we will call C; then we have

$$M = R + C.$$

The value of R, the quantity of heat emitted by radiation per unit of surface and unit of time, is independent of the form and size of the body, provided that the surface has no re-entering parts and depends only on the nature of the surface and on the excess of its temperature over that of the encircling medium, and on the actual temperature of this medium.

The quantity of heat given off by radiation from a vessel or pipe, per square foot, per hour, is given by the formula

$$R = V \times 46. \times a^{\left(\frac{T-32}{1.8}\right)} \times \left(a^{\frac{t}{1.8}} - 1\right)$$

in which a is a constant equal to 1.0077, T represents the temperature of the surrounding air, and t the excess of the temperature of the radiating surface over that of the surrounding air.

The value of V, a variable coefficient, has been found by experiment to vary with the nature and surface of the material of which the radiating body is made, and is, in fact, proportional to the radiating power of the body. These values for several of the more common materials are given below:—

Polished silver,	0.13	Fine sand,	3.62
Silvered paper,	0.42	Oil paint,	3.71
Polished brass,	0.258	Paper,	3.77
Copper,	0.16	Lampblack,	4.01
Zinc,	0.24	Stone,	3.60
Tin,	0.215	Plaster,	3.60
Sheet iron, polished,	0.45	Wood,	3.60
Sheet iron rubbed with black lead,	0.65	Sawdust,	3.53
Sheet iron, common,	2.77	Powdered charcoal,	3.42
Sheet iron, rusted,	3.36	Woollen,	3.68
Cast iron,	3.17	Cotton,	3.65
Cast iron, rusted,	3.36	Silk,	3.71
Glass,	2.91	Water,	5.31
Powdered chalk,	3.32	Oil,	7.24

For paper and cloths the color is without influence. We see from the table that powdered materials have all nearly the same power. M. Masson has made known the fact that very fine powders, obtained by precipitation, have all the same emissive power.

THE VALUE OF C, the loss of heat by convection in the air, is independent of the nature of the surface of the body and of the temperature of the air; it depends only upon the excess of the temperature of the body over that of the surrounding air, and on the form and dimensions of the body. This loss of heat per square foot, per hour, is given in the formula

$$C=V'\times 0.2024\times \left(\frac{t}{1.8}\right)^{1.233}$$

in which t represents the constant excess of the temperature of the body over that of the surrounding air, and V′ the number which varies with the form and dimensions of the body.

THE VALUE OF V′ FOR A SPHERE.

If the heating body is spherical in form, we have

$$V'=1.778+\frac{0.43}{r},$$

r representing the radius of the sphere in feet.

THE VALUE OF V′ FOR CYLINDRICAL PIPES.

If the heat is imparted from horizontal cylindrical pipes we have the formula

$$V'=2.058+\frac{0.1253}{r}$$

r representing the radius of the pipe in feet.

THE VALUE OF V′ FOR A VERTICAL CYLINDER.

For vertical cylinders the value of V′ depends upon their height and diameter, and we have the formula

$$V'=\left(0.726+\frac{0.0345}{\sqrt{\frac{r}{3.2809}}}\right)\times\left(2.43+\frac{0.8758}{\sqrt{\frac{h}{3.2809}}}\right)$$

In this formula r is the radius and h the height, both in feet.

THE VALUE OF V′ FOR VERTICAL PLANES.

For vertical planes the value of V′ is given by the formula

$$V' = 1.764 + \frac{0.636}{\sqrt{\frac{h}{3.2809}}}$$

h being the vertical height, in feet.*

If, in the general formula, $M = R + C$, we substitute for R and C the values found above, we shall have

$$M = V \times 46 \times a^{\left(\frac{T-32}{1.8}\right)} \times \left(a^{\frac{t}{1.8}} - 1\right) + V' \times 0.2024 \times \left(\frac{t}{1.8}\right)^{1.233}$$

which expresses the whole amount of heat given off by the cooling body.

In case we have a certain amount of air to be warmed through a certain number of degrees of temperature by means of coils or banks of radiators, the amount of radiating surface is easily ascertained, for the radiator chamber can be so protected by non-conductive walls that very little heat will be lost. But if the problem takes the common form, that is, having a room to be warmed by means of radiators kept at a given temperature, to determine the amount of radiating surface, it will be found much more difficult to solve; the given elements of the problem must be—

1st. Amount of air to be supplied.

2d. Temperature of the external air.

3d. Required temperature of the room.

4th. Nature and construction of the enclosing walls, ceiling, and floor.

5th. Area of windows.

The solution involves—

1st. The amount of radiating surface required to warm a given quantity of air, from its original to its required temperature.

2d. The radiating surface necessary to furnish the amount of heat lost by absorption, conduction, radiation, &c., by the windows and walls.

---

* We are indebted to Péclet—Traité de la Chaleur—for much of the foregoing information in regard to the distribution of heat.

The determination of the amount of surface required to warm a given amount of air is very simple, as we have already shown. The amount of heat lost by the windows will be found by the general formula given above, substituting for V, 2.91, the co-efficient for glass, found in the table on page 73, and for V′ its value as determined for vertical planes; T represents the temperature which it is desirable to maintain in the room, and t the difference between the temperature of the room and that of the lowest external temperature to be expected.

The heat lost by being absorbed, and given off externally by the walls, &c., can only be determined approximately. For this purpose we take the general formula

$$M = K \times 46 \times a^{\left(\frac{T-32}{1.8}\right)} \times \left(a^{\frac{t}{1.8}} - 1\right) + K' \times 0.2024 \times \left(\frac{t}{1.8}\right)^{1.233}$$

in which K is a number which varies with the material of which the walls are constructed, and their mode of construction. In case the wall is solid, K varies with the nature of the surfaces, with the conductive power, with the difference of the internal and external temperature, and inversely as the thickness of the walls. In case the walls are vaulted, or double, that is, have one air space, the value of K as found above, if divided by 2, will give approximately its true value for this case. If the walls have two air spaces, the value of K must be divided by 4, and so on. Or in general, the new value of K will be represented by $\frac{K}{2^s}$, in which s is the number of air spaces. K′ is a number depending on the dimensions and number of air spaces.

The expression $\frac{K}{2^s}$ is obtained as follows. A wall of several thicknesses, enclosing dead air spaces, has remarkable efficacy in resisting the passage of heat, which is commonly attributed to the non-conductibility of the air. But it is obvious that this does not prevent the passage of heat by radiation. The heat radiated by the inner wall, however, is radiated from both sides back into the room as well as outward; consequently but one half is radiated to the second wall. This second wall and each successive wall, in like manner radiates outward not more than one half the heat it receives. Thus the amount of heat passed through the walls decreases in rapid geometric proportion. Mathematically, representing the amount of heat received by the first wall by K, $\frac{K}{2}$ would be the amount radiated to the second wall, $\frac{K}{2^2}$ would represent that radiated through two spaces to a third wall, and, finally, s representing the number of spaces, $\frac{K}{2^s}$, will represent the amount of heat radiated through them. We offer this theory not as an exact solution of the problem of the passage of heat through vaulted walls, for there are several minor elements that will affect the result. But we suggest it as a mode of approximating the truth, and as one important element to be considered in regard to the non-conducting properties of all cellular and loosely compacted substances, with air spaces.

VII.—HEATING APPARATUS.

The great expense in the production of an artificial climate, is that of raising the temperature to summer heat. We seldom consider how dependent our civilization is on the fires by which we are able to keep ourselves in comfortable working condition throughout the year.

Artificial fire is held, by many traditions, to have been the gift of the gods. Among them all, none is more beautiful than that which ascribes to the first use of fires the social habits and civilization of men. The simplest use of fire is that of the savage or wanderer, who lights a fire of sticks in the middle of his hut or tent, leaving an opening at the top for the escape of smoke. Our soldiers in camp improve on this, enclosing their fires in brick, with something like a chimney opening out of the side of the tent, and sometimes the fire itself outside, the smoke and heat passing in a flue under the bottom of the tent. This is somewhat like the ordinary heating of a greenhouse, though there the flues are usually above the floor. The Romans sometimes heated their public buildings in a similar manner, keeping a large fire in a chamber, below or outside of the building, with a broad, gently ascending flue for smoke and hot air, extending the length of the building, just under the tiled floor, and an opening outside for the escape of smoke. Thus they heated, in general, only the floor, but sometimes also in their baths, the sides of the room by hollow tiling. The Chinese, with a somewhat similar arrangement in their best private dwellings, warm also the sides of their rooms and stone seats and couches, the smoke filling their cavities and passing up through flues in the walls to the roof. This heating of the floor is a natural and proper thing in the few cases where it is practicable, if not carried too far. But it is unnatural and objectionable, if the floor is made more than moderately warm, and if relied on as the only means of warming an apartment. In Italy and Spain, where flues are a less constant necessity than in the north of Europe and in our Northern States, the inhabitants still shiver, in winter, over pans of lighted wood or charcoal, placed here and there where they are wanted, or, on a smaller scale, carried about hanging to the ladies' arms, and indeed so inseparable as companions that the ladies call them "*marito*,"—husband.

In northern climates, where fuel is abundant, it is burned lavishly in great open fires, as, until lately, in our own New England, where, in our fathers' houses, great logs of wood were hauled into the enormous fireplaces by a yoke of steers. Nothing can better replace the cheerfulness of sunshine, than a generous open fire. And, though it can never be very economical, because of the escape of heat with the smoke up chimney, many consider, with reason, that for luxury and comfort, they cannot spend their money better in any other way,—especially in consideration of the abundant ventilation it furnishes. The first improvement in the economy of open fires is to have them set out into the room, in iron or stone fireplaces, so as to save some of the heat that would be lost in the chimney stack. The next improvement is to have a chamber back of the fire, through which fresh air may be admitted and passed warmed into the room, to make good the waste of air up chimney, instead of leaving the loss to be made up by cold air stealing in unbidden through cracks, doors, and windows.

The next improvement in point of economy, and the last, is enclosing the fire in a tight stove, set out in the room, with the draft under control by valves. We do not care to mention again the modern innovations of gas stoves, economical as they are in point of heat, because their very economy, in letting no heat escape, is at the terrible expense of health, in keeping the deadly products of combustion in the room. Of stoves the varieties are numberless, and yearly increasing. It would seem invidious to express preference among them. In point of economy, the various stoves themselves differ far less than their management. The main point in a stove or furnace is to learn by experience how to balance the draft in each particular location, so that, with sufficient fire, the least possible amount of heat may escape by the chimney. The regulation of the draft is effected in four principal ways. 1, by checking the entrance of air under the grate. 2, by letting air in directly upon and above the fire. 3, by checking the smoke-pipe with a damper. 4, by letting more or less air into the smoke-pipe behind or above the fire. We mention these different modes of regulation, only to say that they are all efficient, and that it makes little difference, in point of economy, in what way the draft is checked. But in point of salubrity, it is so seldom that the checking of the smoke-pipe by damper or by letting air into it, is managed without sending more or less of the smoke or gas into the room, that we give decided preference, in ordinary cases, to stoves that are regulated only in the admission of air, below and above the fire.*

We are glad to see that the latest stoves are returning to the old-fashioned ways, and discarding the dangerous innovation of interfering with the free escape of the noxious products of combustion. The closing of the draft below the grate is an unexceptionable mode of checking the fire. The admission of air above the fire is advantageous in supplying oxygen for the more perfect combustion of the rising gases, but a small quantity is sufficient for this, and the passage of more over the fire into the smoke-pipe involves loss of heat. This loss, however, is often of small account compared with the gain in ventilation.

Stoves in the room to be warmed, are undoubtedly the most economical means possible of obtaining heat from common fuel; but it is often objectionable to have them in the room, particularly in a large hall with many occupants. They take up much space and are unsightly, and it is impossible to warm a large assembly by them, equally. The next improvement, for obviating these difficulties, is the placing of the stove in a chamber beneath the hall to be heated, and transmitting the heat where it is wanted, by a current of air, taken in cold and passed up warmed. For the first trial of this method of heat-

---

* We should say that we have cured the common evil of escape of gas from a stove regulated by an opening into the smoke-flue, by changing this opening to a position at the very point of entrance of the flue into the chimney; but this might not be effective unless the draft is very strong.

ing, we are indebted to a horticulturist. John Evelyn, an English gentleman, who devoted a long life, closing with the seventeenth century, to gardening and literature, observed plants in hot-houses drooping for want of fresh air, and contrived an elegant arrangement of outside furnace, through which air was passed in pipes into the upper part of his hot-house, the cool and foul air being drawn off to feed the fire, through a flue opening from the floor of the house. His arrangement was highly satisfactory to his plants, and he seems thus to have been the first successful introducer of hot air heating and of downward ventilation.

Evelyn also deserves to have his memory kept green, for his earnest efforts to have London planted with trees and shrubs, as a means of purifying its atmosphere. Only the lime trees of St. James's Park are known to remain as the result of his efforts.

These air-heaters, or furnaces, as we call them in this country, are now about as common and well known as stoves. Their varieties are much more numerous than materially different in value. The same observations apply to them as to other stoves, in regard to utility and management. Their air chamber and current require careful and judicious attention. It is enough for us now to recommend in all cases, large, generous air passages, under entire control; as much height as possible in the hot-air pipes; a good degree of equality in the capacity of pipes that are to be used at the same time; abundant evaporation of water; and for rooms that are little used, or remain unoccupied a considerable part of the time, an ample return-pipe from the floor to the bottom of the heater, to be used in extreme weather for warming the air over and over while it is fresh, in place of admitting cold air. For churches, school-houses, and other public halls, this latter method is very advantageous, if care is taken not to have it abused; the cold-air boxes being always open when the rooms are occupied, and thorough ventilation being given after the occupants have left, before the cold-air boxes are closed and the return used. The position of the cold-air box is a matter of great importance. When the outer opening of it is to the leeward, unless the height of the hot-air column is very considerable, there is often no passage of air through, the right way, and sometimes the hot air is drawn through the cold-air box out of doors. To prevent this wrong current, it is well to have in the cold-air box a self-acting valve that will close when the air tends to move the wrong way. To secure a free movement the right way, it is best to take the air in, when it is practicable, from the side of prevailing winds, that is, from the westward. When convenient, it is well to have boxes opening from different quarters, with self-acting valves in each, that one or the other may be sure to work in all winds. Another point of great importance to the right working of any air-heater, is to have in every room the warm air is to enter, a sufficient outlet for the escape of as much air as it is desired to have enter; for, if no air can get out of a room, none will enter. We have known rooms heated by hot-air pipes, that could not be warmed until a window was opened to let air out; then the warm air entered freely.*

It is an objection of some weight against all air-heaters that the temperature of those who depend on them for heat, is maintained almost exclusively by the heated air, instead of by radiated heat, as is mainly the case in sunshine, and by an open fire, and in greater or less degree, with a stove. The disadvantage in this, is the high temperature of the air necessary, which, to one unaccustomed to it, has an unpleasant effect. This is peculiarly the case in a public hall, used only a part of the day. It is common in such a case to let the hall become quite cool in the night. The walls, floor, and furniture then being cold, a very high temperature of the air is necessary when the occupants come together, to make them comfortable. This is easily remedied, in a great measure, by cutting off the supply of cold air to the heaters after the hall has had a thorough blowing out, at night: then, by keeping the fires up and returning the air over and over, through the night, the walls and furniture may be got so warm as to play a considerable and excellent part the next day in keeping the occupants comfortable, without the necessity of their breathing very warm air. If, instead of letting school-rooms and public halls cool down to the freezing point in the night, those who have the care of them would take the

---

* We have nowhere seen these points so carefully considered and attended to as in the furnaces of Mr. Stephen Culver, of Newark, N. Y., a gentleman who has given great attention to the subject, and who puts in an excellent heater with great care and skill.

pains to heat them up to eighty or ninety degrees, the comfort and health of their inmates would be greatly promoted. Nor would the waste of heat be so great as might be supposed. Much the larger part of heat so expended would be required in the morning to heat up the room if it were suffered to get cold. According to Péclet, walls of twenty inches thickness are capable of transmitting but about one-twentieth of the heat they contain, in ten hours of cooling, and they actually lose by transmission much less. There is more loss through windows and cracks. But this can be in a great measure controlled by doubling the windows, and making the rooms tight.

We come now to the consideration of the most important and most successful methods of warming large buildings, namely, those of hot water and steam. As, for the first use of air-heaters, we are indebted to a lover of plants, so too for the first suggestion of steam-heating, we have to thank another devoted horticulturist. In 1652, Sir Hugh Platt published a suggestion that a plant-room might be warmed with the steam from a pot or boiler secured by a cover, and conveyed by a lead pipe to the room. This is considered the first suggestion of steam-heating. The first man to put steam-heating in practice, was James Watt, who in 1784–5 warmed his office with a tinned-iron radiator, in form and dimensions similar to the sheet-iron radiators lately in use, only a little thicker. This was supplied with steam from a boiler below.

In steam and hot water apparatus, we have only new ways of conveying the heat from fires in the basement, or other out of the way place, to the apartments to be warmed. The fires themselves do not differ materially from those of hot-air furnaces. But the heating surface which is exposed to them is the outside of a boiler, filled wholly or partially with water. In the one case the water becomes heated and rises by its lightness, through pipes provided for the purpose, to their uppermost part, whence it descends in returning pipes into the lower part of the boiler. The heating capacity of the arrangement depends on the transmission of the excess of heat from the water through the pipe surface by radiation and conduction. The pipes either traverse portions of the apartments to be heated, or are gathered into banks or coils placed in boxes, through which air is forced, warmed, into the apartments.

When the boiler is filled but partially with water, this, on becoming well heated, is changed into steam. The steam rises in pipes, provided as for the hot water in the former case; but, when well adjusted, condenses into water before it gets back to the boiler to renew the circuit. This fact of condensation is the great means of the heating efficacy of the steam apparatus. For, as nearly one thousand degrees of heat are absorbed and made insensible in changing water into steam, so in condensation of steam into water these thousand degrees of heat are set free again and made sensible; and if the condensation takes place in steam-pipes, when the heat is available for use, the power is very great. Not that any heat is generated from the steam above what is communicated to it by the fire. It is only that, by this alternate absorption and giving up of heat, the steam proves a most excellent conveying medium.

In England, where a mild, artificial heat is all that is required, the hot water method of warming is somewhat extensively used. The heat is eminently mild and agreeable, and the apparatus safely and easily managed. Its chief objections are found to be the slowness with which the changes of temperature, from cold to heat, and the reverse, are effected. This difficulty is still more serious in this country, where we are liable in winter to sudden and great changes.

With steam, great heat can be speedily obtained when once the water has reached the boiling point, and the heat can be suddenly reduced by shutting off the steam; that which is above the gate immediately condensing, and after that the pipes quickly cooling. Steam has also great advantage in efficiency over hot water, in consequence of its much more rapid circulation. This is owing not only to its greater fluidity and ease of motion, but also to the condensation and reduction of volume when it cools, which causes a vacuum, urging on rapidly the advancing steam. Like hot water, steam-pipes are carried into and about the apartments, which they heat both by radiation and by contact with the air, or they are coiled in chambers, through which fresh air is brought and passes heated into the apartments to be warmed. In the latter case the heat is imparted only by contact with the air. Both methods of distributing are largely employed, and often for the same apartment. The advantages of direct radiation are thus secured in some degree, with less power indeed than by open fires, but with much easier general distribution. At the same time, where much change of air is necessary, there is no better mode of warming it than by passing it in contact with coils of steam pipe.

There are various kinds of boilers and radiators for heating, which are commonly classified into low and high pressure arrangements. The low pressure have now both wrought and cast iron boilers and radiators, or expanded pipes, in which the steam is condensed and gives out its heat. Their steam is kept at a pressure of from one to five pounds. The high, as commonly called, but really medium pressure boilers, are always of wrought iron, usually pierced longitudinally with two large flues, or many small tubes, for the passage of the products of combustion and the increase of heating surface, being for the most part just such boilers as are used with steam engines. They are commonly used for mechanical purposes at from sixty to one hundred pounds pressure, but for heating purposes are usually kept at from ten to thirty-five pounds. As between the two systems, it should be stated that steam at twenty pounds pressure has but about 41° of sensible heat more than steam at two pounds. This excess of heat is of very small importance as compared with the amount of diffused heat, evolved at the condensation of steam. The superior efficiency of medium pressure steam is not owing so much to its greater heat, as to its powerful and quick supply of new steam for condensation. It involves also superior economy, from the fact that the same volume of steam at twenty pounds pressure, contains about twice as much useful heat as that at two pounds pressure, because of its greater density; and the radiating surface containing the higher pressure of steam will warm about four times as much air in a given time as that containing lower pressure, both because of the greater heat and the greater rapidity with which this heat is given to the air, and also of the consequent greater rapidity with which air will move in contact with it. Hence but about one-fourth as much radiating surface at twenty pounds pressure is required to distribute a given amount of heat in a given time, as is necessary with two pounds pressure; an item of considerable importance in first cost. To exhibit more fully the relative temperature and volume of different pressures of steam, we present the following table :—

Pressure, Temperature and Relative Volume of Steam to the water that produced it, taking the water as unity or 1.

Pressure per Square Inch.	Temperature.	Volume of water being 1.	Pressure per Square Inch.	Temperature.	Volume of water being 1.
Pounds.	Fahr.	Number.	Pounds.	Fahr.	Number.
1, ...	102.9	20,954	41, ...	269.9	662
2, ...	126.1	10,907	42, ...	271,4	647
3, ...	141.0	7,455	43, ...	272.9	634
4, ...	152.3	5,695	44, ...	274.3	620
5, ...	161.4	4,624	45, ...	275.7	608
6, ...	169.2	3,901	46, ...	277.1	596
7, ...	176.0	3,380	47, ...	278.4	584
8, ...	182.0	2,958	48, ...	279.7	573
9, ...	187.4	2,676	49, ...	281.0	562
10, ...	192.4	2,427	50, ...	282.3	552
11, ...	197.0	2,222	51, ...	283.6	542
12, ...	201.3	2,050	52, ...	284.8	532
13, ...	205.3	1,903	53, ...	286.0	523
14, ...	209.0	1,777	54, ...	287.2	514
15, ...	213.0	1,669	55, ...	288.4	506
16, ...	216.4	1,572	56, ...	289.6	498
17, ...	219.6	1,487	57, ...	290.7	490
18, ...	222.6	1,410	58, ...	291.9	482
19, ...	225.6	1,342	59, ...	293.0	474
20, ...	228.3	1,280	60, ...	294.1	467
21, ...	231.0	1,224	61, ...	294.9	460
22, ...	233.6	1,172	62, ...	295.9	453
23, ...	236.1	1,125	63, ...	297.0	447
24, ...	238.4	1,082	64, ...	298.1	440
25, ...	240.7	1,042	65, ...	299.1	434
26, ...	243.0	1,005	66, ...	300.1	428
27, ...	245.1	971	67, ...	301.2	422
28, ...	247.2	939	68, ...	302.2	417
29, ...	249.2	909	69, ...	303.2	411
30, ...	251.2	882	70, ...	304.2	406
31, ...	253.1	855	71, ...	305.1	401
32, ...	255.0	831	72, ...	306.1	396
33, ...	256.8	808	73, ...	307.1	391
34, ...	258.6	786	74, ...	308.0	386
35, ...	260.3	765	75, ...	308.9	381
36, ...	262.0	746	76, ...	309.9	377
37, ...	263.7	727	77, ...	310.8	372
38, ...	265.3	710	78, ...	311.7	368
39, ...	266.9	693	79, ...	312.6	364
40, ...	268.4	677	80, ...	313.5	359

Pressure, Temperature, &c.—Concluded.

Pressure per Square Inch.	Temperature.	Volume of water being 1.	Pressure per Square Inch.	Temperature.	Volume of water being 1.
Pounds.	Fahr.	Number.	Pounds.	Fahr.	Number.
81,	314.3	355	96,	326.6	305
82,	315.2	351	97,	327.3	302
83,	316.1	348	98,	328.1	299
84,	316.9	344	99,	328.8	296
85,	317.8	340	100,	329.6	293
86,	318.6	337	105,	333.2	281
87,	319.4	333	120,	343.3	249
88,	320.3	330	135,	352.4	224
89,	321.1	326	150,	360.8	203
90,	321.9	323	165,	368.5	187
91,	322.7	320	180,	375.6	173
92,	323.5	317	195,	382.3	161
93,	324.3	313	210,	388.6	150
94,	325.0	310	225,	394.6	141
95,	325.8	307	240,	400.2	133

For the low pressure system it is claimed that the heat, by greater distribution through the thickness and extended surface of the cast-iron radiators, comes in contact with the air to be warmed at a lower degree than from wrought iron pipes, which alone are used with high pressure steam. This is assumed to be an advantage, because of the tendency of high heat to burn and render offensive the particles of decomposing matter and of dust that fill the air. Opinions conflict as to there being any unpleasant effect on air heated by hot steam pipes; and, if such effect is admitted, there is great doubt whether the healthfulness of the air is not increased, rather than diminished, by the burning of particles already noxious. Another advantage claimed for the low pressure heaters, is the fact that the weak cast-iron boilers in common use will crack and burst harmlessly, instead of being liable to violent explosion. It is also true that a wrought-iron boiler of the same strength would burst with even less injury to surrounding objects than the cast-iron. However, this sense of security from low pressure boilers, is of value, and also the feeling, whether well founded or not, that the air is wholesome as well as agreeable. And, besides, the low pressure heaters are so arranged as to be in some degree self-regulating, making the care of them, on a small scale, little more difficult than that of a hot-air furnace. For these reasons they are well approved in many first-class dwellings, and in some more public buildings. For buildings of large size, however, wrought-iron boilers have the advantage of single large fires, in place of the numerous small ones used for low pressure cast-iron boilers; they can be run at high or low pressure, as the weather demands; their operation is more speedy and certain; the first cost, in proportion to power, less; and in the opinion of practical men they are more economical in fuel, as well as equally safe under similar circumstances.

Whatever heating apparatus is to be employed for any large service, it is necessary first to calculate the number of cubic feet of air to be warmed per hour, the temperature required, the out-door temperature to be expected, and the amount of cooling surface, in glass and cold walls, to reduce the temperature of the air. From these elements it is a matter of scientific calculation to determine how much surface of grate, of iron exposed to the fire, and of radiating pipe, will be necessary to secure the temperature required. The many failures in such calculations are attributable to inexperience and to a desire to save in first outlay, overlooking contingencies, and balancing hopes of extraordinary success against figures, rather than to any inherent difficulty in the calculation, based, as it may be, on scientific and experimental knowledge.

In regard to the practical use of heating apparatus in the public and other large buildings of this country, it is probably safe to say that more than three-fourths of them, including hotels, hospitals, factories, theatres, &c., are heated by steam at a pressure considerably above twenty pounds. In view of the fact that the first attempts to distribute heat through the agency of water, were made with water alone, or with steam at a low pressure; and also of the fact, stated above, that steam at a medium or high pressure has, at the present time, been very generally adopted, we are bound to conclude that the practical experience of heating-engineers has convinced them that steam at a medium pressure has decided advantages over low-pressure steam, or hot water, for the economical and satisfactory heating of large buildings. In small buildings, it is seldom that any one would wish to use steam of high or medium pressure; but hot water and low pressure steam are often used and give good satisfaction.

The chief advantages of steam and hot water heating over hot-air furnaces, are, 1. Entire security against the escape of deleterious gases from the combustion chamber into the air that is to be breathed; 2. The means of bringing, with little loss and small space, the heat to radiating surfaces where the heat is wanted, at any distance from the fire: this advantage, however, is possessed in high degree by steam alone; not efficiently by hot water; 3. The real, or supposed, benefit of heating air by surfaces that can be raised only to a moderate temperature; that is, not much, if any, over 212°.

VIII.—VENTILATING APPARATUS.

We cannot better preface a consideration of the various modes of applying power to the work of ventilation than with the following quotation from Tomlinson's Rudimentary Treatise on Warming and Ventilation, London, 1858, by which it will be seen that bees are the original mechanical ventilators:—

"Reaumur remarks, 'Ce que la Nature apprend est sçu de bonne heure;' and as Nature is the best as well as the earliest teacher, we take our first example, in the history of ventilation, from the lower animals; and we venture to assert that a more difficult, or, apparently, more hopeless problem, does not exist in our rooms and crowded assemblies, our mines and ships, than in the case about to be proposed.

"Imagine a dome-shaped building, perfectly air-tight, except through a small hole at the bottom, capable of containing thirty or forty thousand animals, full of life and activity, every portion of the enclosed space that can be spared being filled with curious machinery; the problem is, how to warm and ventilate such a space so as to maintain a proper temperature, and yet to give to every individual within it a proper supply of air.

"Now this is the condition of a common bee-hive, and we may remark, that if, with all our machines, and contrivance, and scientific resources, the combined operation of warming and ventilating a room be difficult or unsatisfactory, how infinitely more so must be that of a small bee-hive, crowded with bees, the greater part of the interior filled up with combs of waxen cells, and only one small opening for the ingress and egress of the inhabitants, or for the escape of foul air and the entrance of fresh.

"In a common hive, there is absolutely no other door or window, or opening, than this small entrance hole; for, on taking possession of a new hive, the bees stop up all the cracks and chinks, with a resinous substance named propolis, for the purpose of keeping out insect depredators; and the proprietor, with the same object, generally plasters the hive to the stool, and, in order to keep off the rain, covers it with a heavy straw cap, or turns a large pan over it.

"It must not be supposed that, because the vitality of insects is greater than that of warm-blooded animals, bees are not affected by the same agencies which affect us, for they are so, and in a similar manner; they fall down apparently dead, if confined in a close vessel; they perish in gases which destroy us; they perspire and faint with too much heat, and are frozen to death by exposure to too much cold.

"Huber introduced some bees into the receiver of an air-pump. They bore a considerable rarefaction of the air without any apparent injury; on carrying it further, they fell down motionless, but revived on exposure to the air. In another experiment, three glass vessels, of the capacity of sixteen fluid ounces, were taken; 250 worker bees were introduced into one, the same number into another, and 150 males into the third. The first and the third were shut close, and the second was partially closed. In a quarter of an hour, the workers in the close vessel became uneasy; they breathed with difficulty, perspired copiously, and licked the moisture from the sides of the vessel. In another quarter of an hour, they fell down apparently dead. They revived, however, on exposure to the air. The males were affected more fatally, for none survived; but the bees in the vessel which admitted air did not suffer. On examining the air in the two close vessels, the oxygen was found to have disappeared, and was replaced by carbonic acid; other bees introduced into it perished immediately. On adding a small portion of oxygen gas to it, other bees lived in it, but they became insensible instantly on being plunged into carbonic acid, and revived on exposure to the air; they perished irrecoverably in nitrogen and hydrogen gases. Similar experiments, performed with the eggs, the larvæ and the nymphs of bees, proved the conversion of oxygen into carbonic acid in all three states. The larvæ consumed more oxygen than the eggs, and less than the nymphs. Eggs, put into foul air, lost their vitality. Larvæ resisted the pernicious influence of carbonic acid better than the perfect insect would have done, but the nymphs died almost instantly therein.

"These, and many other analogous experiments, prove that the respiration of bees has a similar vitiating effect upon a confined atmosphere as the respiration of larger animals, and that bees require constant supplies of fresh air, in the same manner as other living creatures. They also require their dwellings to be kept moderately cool. When, from any circumstance, such as exposure to the sun, overcrowding, or the excitement caused by fear, anger, or preparation for swarming, the temperature of the hive is greatly raised, the bees evidently suffer. They often perspire so copiously as to be drenched with moisture; and on fine summer nights, thousands of them may be seen hanging out in festoons and clusters, for the purpose of relieving the crowded state of the hive.

"On inquiring into the method adopted by the bees for renewing the air of the hive, Huber was struck by the constant appearance of a number of the workers arranged on each side of the entrance hole, a little within the hive, incessantly engaged in vibrating their wings. In order to see what effect a similar fanning would produce on the air of a glass receiver containing a lighted taper, M. Senebier advised him to construct a little artificial ventilator, consisting of eighteen tin vanes. This was put into a box, on the top of which was adapted a large cylindrical vessel of the capacity of upwards of 3,000 cubic inches. A lighted taper, contained in this vessel, was extinguished in eight minutes; but, on restoring the air and setting the ventilator in motion, the taper burned brilliantly, and continued to do so as long as the vanes were kept moving. On holding small pieces of paper, suspended by threads, before the aperture, the existence of two currents of air became evident; there was a current of hot air rushing out, and at the same time a current of cold air passing in. On holding little bits of paper or cotton near the hole of the hive, a similar effect was produced; they were impelled towards the entrance by the in-going current, and when they encountered the out-going current, they were repelled with equal rapidity.

"These two currents are established in the hive by the fanning motion of the bees' wings. The worker bees perform the office of ventilators, and the number, at one time, varies from eight or ten to twenty or thirty, according to the state of the hive and the heat of the weather. We have frequently watched their proceedings with interest. They station themselves in files, just within the entrance of the hive, with their heads towards the entrance, while another and a larger party stand a considerable way within the hive, with their heads also towards the entrance. They plant their feet as firmly as possible on the floor of the hive, stretching forward the first pair of legs, extending the second pair to the right and left, while the third, being placed near together, are kept perpendicular to the abdomen, so as to give that part a considerable elevation; then uniting the two wings of each side by means of the small marginal hooks with which they are provided, so as to make them present as large a surface as possible to the air, they vibrate them with such rapidity that they become almost invisible. The two sets of ventilators, standing with their heads opposed to each other, thus produce a complete circulation of the air of the hive, and keep down the temperature to that point which is fitted to the nature of the animal. When a higher temperature is required at one particular spot, as, for example, on the combs containing the young brood, the nurse bees place themselves over the cells, and, by increasing the rapidity of their respirations, produce a large amount of animal heat just where it is wanted. The carbonic acid and other products of respiration are got rid of by ventilation.

"The laborious task of ventilating the hive is seldom or never intermitted in the common form of hive, either by day or by night, during summer. There are separate gangs of ventilators, each gang being on duty about half an hour. In winter, when the bees are quiet, and their respiration only just sufficient to maintain vitality, the ventilating process is not carried on; but by gently tapping on the hive, its inmates wake up, increase the number of their respirations, and, consequently, the temperature of the hive, to such a degree that the air becomes intolerably hot and vitiated. To remedy this, a number of worker bees go to the entrance of the hive and begin to ventilate the interior as laboriously as in summer, although the open air be too cold for them to venture out.

" Bearing in mind the fact that the animal frame is a true apparatus for combustion, we can understand how bees regulate the temperature of their hive ; when greater heat is wanted, they increase the rapidity of their respirations, or, in other words, they burn more carbon ; but they get rid of the products of combustion, and also prevent the heat from accumulating, by the process of ventilation. Bees, in general, maintain a temperature of 10° or 15° above that of the external air ; but, at certain periods, this temperature is greatly increased. Mr. Newport observed, in the month of June, when the atmosphere was at 56° or 58°, that the temperature of the hive was 96° or 98°. This high temperature arose from the nurse bees incubating on the combs, and voluntarily increasing their heat by means of increased respiration. In winter, on the contrary, when only just-sufficient heat is required to maintain vitality, less carbon is burnt, and the temperature of the hive is accordingly low. In one observation by Mr. Newport, at 7.15 A. M., on the second of January, 1836, when there was a clear, intense frost, and the thermometer in the open air stood a little above 17°, a thermometer, permanently fixed in the hive, marked a temperature of 30°, or two degrees below the freezing point. The bees were roused by tapping on the hive, and in the course of sixteen minutes, the thermometer rose to 70°, or 53° above the temperature of the external air. On another occasion, when the temperature of the hive had been raised to about 70°, the external air being at 40°, the bees soon cooled it down to 57°, by their mode of ventilation, and kept it at that point as long as the hive continued to be excited.

" By this process of ventilation also, bees get rid of noxious odors in the hive. Huber found that, on introducing into the hive some penetrating vapor, disagreeable to the bees, they always increased the amount of ventilation, until they got rid of it. Humble-bees adopt the same method of dispelling pernicious odors ; but it is remarkable, that neither their males, nor those of domestic bees, seem capable of using their wings as ventilators. 'Ventilation is therefore,' says Huber, 'one of the industrial operations peculiar to the workers. The Author of nature, in assigning a dwelling to those insects where the air can hardly penetrate, bestows the means of averting the fatal effects which might result from the vitiation of their atmosphere. Perhaps the bee is the only creature intrusted with so important a function, and which indicates such delicacy in its organization.' " In confirmation of these facts we are informed by bee-keepers that they have observed the lines of bees at the entrance of the hive, but, not knowing their purpose, have called them only sentinels.

A man ordinarily renders unfit for respiration and incapable of supporting life, not less than two cubic feet of air in a minute. If now this air could be seized and carried off at once by itself, it would be easy to calculate how much fresh air would need to be supplied to each person, and thus to the whole number of occupants of a hall. But it is impracticable to take away the vitiated air by itself alone, because of its almost instantaneous diffusion in all the air about it. The best that can be done is to remove all the air about the person, foul and mixed, with such rapidity that in the fresh air coming to take its place, there will be no diffusion of the foul air worthy of notice. Now the quantity of air that must be removed each minute from the neighborhood of an individual, to effect this practical degree of purity, will depend on a variety of circumstances that will differ in different cases. In the House of Commons, it has been found to vary from ten to sixty cubic feet a minute. This extreme demand is doubtless attributable in part to the want of purity of the out-of-door air in that locality, and in part to the mode of ventilation used, by which the air entered at the bottom and went upwards through the carpet and in contact more or less with the occupants before it came to be breathed. Downward ventilation would doubtless satisfy the members with a much smaller quantity of air, than would upward ventilation. Various authorities give an average of about twenty cubic feet a minute, as required in most cases, by each member of a legislative assembly. This amount would probably be an excessive allowance under downward ventilation in ordinary times, but it would hardly be safe to reckon upon less as the amount which there should be capacity to furnish, and there would no doubt be times when twenty feet would be found none too much. This amount, it should be understood, is not mere guess-work, but is that which is determined by many experiments to be what an audience has required and has not been satisfied without.. In the Hall of Representatives and in the Senate Chamber of the Capitol in Washington "each individual in either hall is supplied with fifty cubic feet of air per minute in summer, and twenty-five feet per minute in winter; assuming the Hall of Representatives to contain two thousand persons, and the Senate Chamber sixteen hundred." "The foul air is discharged from the roof through reticulations in the ceiling;" the warm air being forced in through and near the floor by means of fans. Mr. Thomas U. Walter, architect of the Capitol extension, who has given us these facts, believes the supply to be in excess of all means of contaminating the air, and certainly it should be more than sufficient if advantageously distributed. In fact, however, there has been so much complaint that a Commission has been charged with the matter, and is now making elaborate investigations. It seems to us a reasonable inference, that, as was concluded in the parallel case of the House of Commons, the fault is not in the amount, but in the theory and mode adopted, namely, of upward ventilation.

Twenty cubic feet a minute for each of three hundred persons is six thousand feet of air a minute to be taken out of the hall, and its place to be supplied with fresh air. It is evident that this is no small matter, and that if a constant and regular movement is to be depended on, some special power is necessary to do the work. We could cite all the principal writers on ventilation, to prove that no large hall can be properly ventilated without some such power. In the Capitol at Washington two large iron fans, driven by steam power, are used for each wing, one for each hall, and one for each set of committee rooms. One iron fan, fourteen feet in diameter, similar to that used by M. Combe, in the ventilation of the Belgian Mines, is used to force air into the Free City Hospital of Boston; it is driven by an engine of about ten horse power. A fan, driven by an engine of twenty horse power, is used to force air into the Boston Custom House. Steam power fans are also used, as we understand, at the hospitals in Taunton, Worcester and Northampton, in this State; at Augusta, Maine, at Utica and Brooklyn, New York, and at the Music Hall in Philadelphia;

and doubtless in many other public buildings with which we are unacquainted. Those we have cited will suffice to show the fact that power on a large scale is found necessary, whenever thorough ventilation of large buildings is attempted.

The various expedients employed for effecting the change of air in an apartment naturally fall into three classes. First, those which depend only on the natural movements of the air, and attempt only to direct and facilitate their operation. Second, those which obtain their power by the simple application of heat or of steam jets to a column of air. Third, those which move the air by mechanical power.

The first class embraces every variety of chimney cap or cowl, and studied modifications in form and size of air passages. Of cowls nearly all are good that we have seen, and useful in their place. Their purpose is always to open free passage to air and smoke in one direction, and to prevent any passage the wrong way. They are of use only in utilizing or counteracting the effect of the wind. Consequently they are of no avail, but rather an obstruction, when there is no wind, and they are sufficient only in cases where there is draught enough in still weather, but where some protection is needed from high winds to facilitate the exhaustion of air that might otherwise be forced by wind down the shaft. Preventing the ingress of the wind, or taking advantage of it as a power, is all that any so called ventilator, in the shape of a chimney cap, can ever do, unless it is used with two or more flues together, one cap towards the wind to carry fresh air down, and another turned from the wind to bring foul air up. This arrangement does some service when the wind blows, and even without wind, when there is much difference of temperature between indoors and out, which will cause a downward current in one, and an upward in the other. It serves a good purpose when applied to a room which has no other convenience or opportunity for letting out the foul air and taking in fresh, as in the hold or forecastle of a ship. The air, however, that is let in by this means is the cold outer air, that enters only to mix with the foul air and cool it, so that in part it sinks to be breathed over again, or to turn immediately and come out again through another flue. Where, as in all modern halls of any pretension to salubrity, warm fresh air is introduced, a single chimney or ventilator flue for the escape of the foul air is much better, as then its place is supplied with warm air instead of cold.

We have shown in the following cuts representative cowls of some of the best classes of those which have come to our notice.

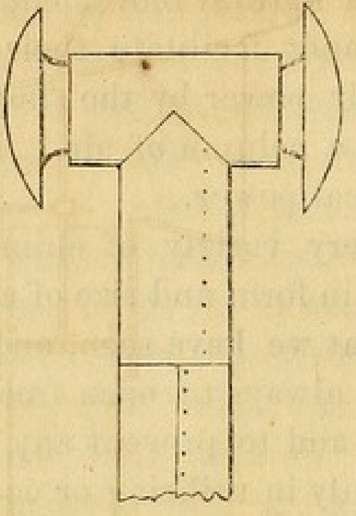


Fig. 1.

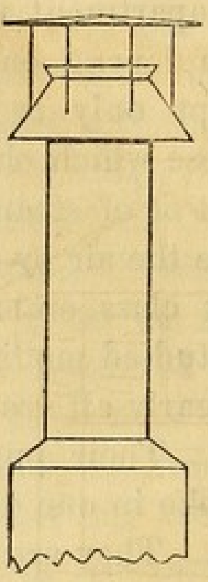


Fig. 2.

Fig. 1 is a fixed cap with two opposite horizontal outlets, each of which is protected from wind that would blow into it, by a shield outwardly convex. A similar shield is often applied to vertical outlets.

Fig. 2 is Emerson's fixed cap, which has done and now does probably more service, in this neighborhood, than all others. It consists of the base of a cone, up through which is the outlet, protected by a circular plate placed horizontally a few inches above the cone. Its action is to divide and turn aside the wind that blows across it, preventing any from blowing down the opening, while a partial vacuum on the lee side favors the exit of its contents. With the cone reversed this cap is used effectually for the forcing of air downwards through its pipe, by the action of the wind. With the addition of the small inverted cone, this cap was found by a committee of the Boston Academy of Arts and Sciences to be the best in use.

Fig. 3 is a pyramidal cap hung at the apex, a few inches above the shaft, in such a manner that the wind, blowing, will force down the side next to it and close that side of the opening, while the leeward side will be opened wider for the exit of air or smoke.

Fig. 4 is Espy's Ventilator, a horizontal cone, swinging with apex to the wind by the wind's action on a vane attached to the larger end, dividing the wind and creating a partial vacuum at the mouth.

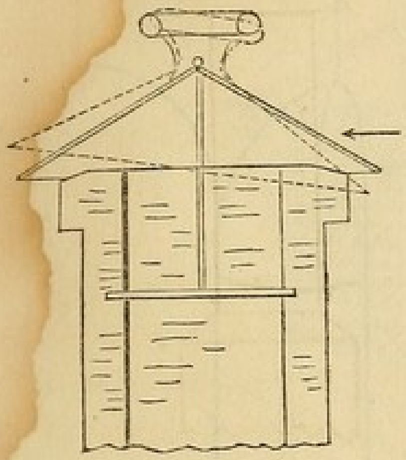


Fig. 3.

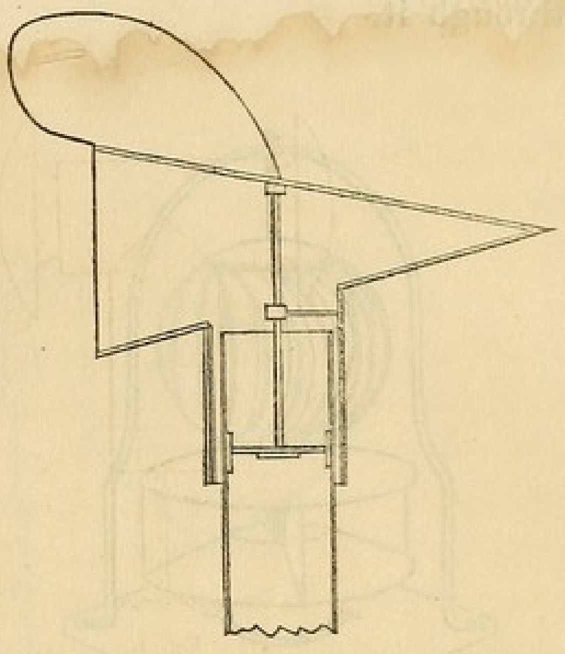


Fig. 4.

Fig. 5 is a swinging horizontal cylinder with vane like Espy's cone, but with the addition of a cone, whose mouth, opposite to the outlet, opens to the wind and passes it out as a jet through a small tube at its apex into the centre of the outlet. The force of this jet stimulates the passage of air or smoke through the outlet; a similar cap has been found by experiments in Philadelphia the best there in use.

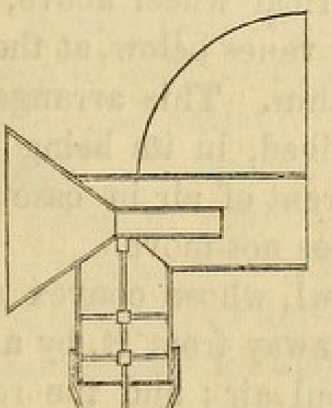


Fig. 5.

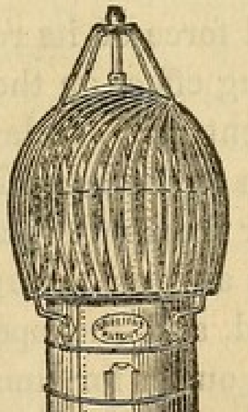


Fig. 6.

Fig. 6 is an English device, lately patented in this country, for lifting air or smoke out of a shaft by means of the Archimedean screw, which is kept in motion by the action of the wind on a hemispherical wheel at the top. This cap has a certain effect, as long as it turns easily, while the wind blows. At other times it is more or less of an impediment to any passage through it.

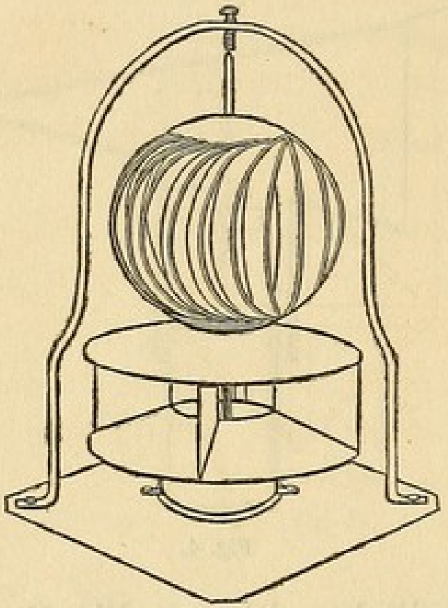


Fig. 7.

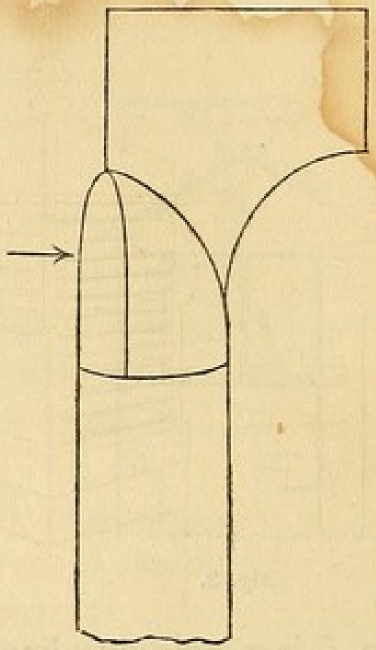


Fig. 8.

Fig. 7 is a patented cap not yet in use, which revolves by the action of the wind on its spherical wheel above, and, by the centrifugal force of its revolving vanes below, at the outlet, has an expelling effect on the air within. This arrangement is an improvement on that last described, in its being no material obstruction to the ascending current of air in case the cowl is clogged, or from other causes does not move.

Fig. 8 is a common cap or cowl, whose convex side is kept to the wind, and the open side away from it, by a vane, when used as an outlet for smoke or foul air; and the reverse, as in the cut, when used for the reception of outer air.

Fig. 9, taken from Morin's French treatise on ventilation, is Muir's improvement on Watson's ventilator. It consists of a square box with a roof and openings on the four sides. Its peculiarity consists in vertical partitions that divide it into four compartments, through one or more of which to windward, fresh air is supposed to descend, while the foul air passes up and out through the leeward openings. This is the only cap which, acting alone, has a direct effect when there is no wind blowing, it serving even in still air to change the air of a room of a temperature different from that of outer air, in the same way that two distinct openings would, through one of which the cooler air will descend while the warmer ascends through the other.

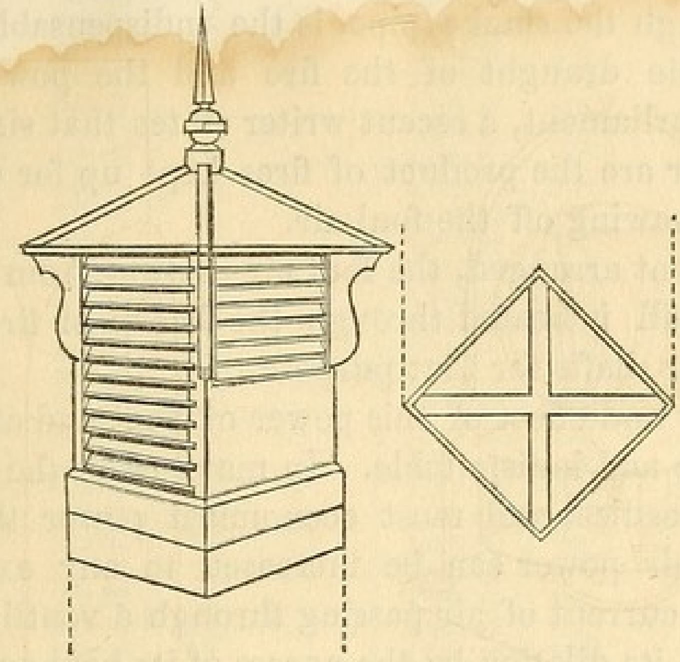


Fig. 9.

It is, therefore, nearly equivalent to two well protected openings in the roof, but with the disadvantage of their being close together. In rare instances, where space is wanting, it may be an advantage to have them close together, but the nearer the points of inlet and outlet of air in a room, the less ventilation will be effected. Great claims of merit for this as a ventilator and as a "system of ventilation," have been set forth in England, and in this country where it is sold as Robinson's ventilator. But it amounts to nothing more than this double opening, and its effect changes to that of a single opening when a door or window is opened, as found by experience in both countries. In its best operations it can only serve to let out foul air and to let in an equal amount of cold fresh air, like the opening of one or two windows.

After all, the best possible appliance to a flue depending only for its efficiency on the motion of the wind, fails entirely at the very time, in still weather, when its services are most needed; and to depend upon such appliances for the ventilation of a public building, is like depending on chance rides to accomplish a journey, instead of taking the cars.

SECOND. The application of fire or of steam-jets to a column of air to obtain power of draught by its rarefaction, is in common use. In mines it is used for their ventilation. For blast furnaces it is employed, through tall chimneys, to give them a strong draught. In all locomotives, the jet of exhaust steam puffing through the smoke pipe, is the indispensable means of increasing the draught of the fire and the power. In the Houses of Parliament, a recent writer states that six bushels of ashes an hour are the product of fires kept up for the express purpose of drawing off the foul air.

As at present arranged, the foul air passing from the Representatives' Hall is heated through the backs of fire grates set in the foul air shafts for that purpose.

The theory and effect of this power of heat and of the steam-jet are simple and indisputable. In many cases the one or the other is the readiest and most economical power that can be had; and their power can be increased to any extent. The velocity of a current of air passing through a ventilating shaft, depends upon its dilation by the excess of its heat over the heat of the external air, and, friction aside, it is equal to $8 \sqrt{h}$, h, being the difference in the height of the column in the ventilating flue, above that of a column of external air having the same weight.

The following table shows the dilation of air in proportion to increase of temperature, and from it the value of h can be taken in any case where the temperature of the air in the ventilating flue, and the out-door temperature are given; thus:— temperature of outer air 10°; temperature of air in flue 212°; height of flue 100 feet; the dilation of air from 10° to 212° is shown by the difference in the numbers opposite those several temperatures, and is $1,364.86 - 955.38 = 409.48$. As this is the dilation for 1,000 feet, move the decimal point three figures to the left for the dilation of one foot; we have now .40948 to be multiplied by the height of flue, which we assume in this example to be 100, and the result, 40.948, is the value of h.

Expansion of Air.

Temperature. Degrees, Fahr.	Relative Volume.	Temperature. Degrees, Fahr.	Relative Volume.	Temperature. Degrees, Fahr.	Relative Volume.
0,	935.12	51,	1,038.52	101,	1,139.86
1,	937.14	52,	1,040.55	102,	1,141.89
2,	939.17	53,	1,042.58	103,	1,143.91
3,	941.20	54,	1,044.61	104,	1,145.94
4,	943.23	55,	1,046.64	105,	1,147.97
5,	945.25	56,	1,048.67	106,	1,149.99
6,	947.28	57,	1,050.70	107,	1,152.02
7,	949.31	58,	1,052.73	108,	1,154.05
8,	951.33	59,	1,054.76	109,	1,156.08
9,	953.35	60,	1,056.79	110,	1,158.11
10,	955.38	61,	1,058.82	111,	1,160.13
11,	957.41	62,	1,060.85	112,	1,162.16
12,	959.43	63,	1,062.88	113,	1,164.19
13,	961.45	64,	1,064.91	114,	1,166.22
14,	963.48	65,	1,066.94	115,	1,168.25
15,	965.51	66,	1,068.97	116,	1,170.28
16,	967.53	67,	1,070.99	117,	1,172.31
17,	969.55	68,	1,073.01	118,	1,174.34
18,	971.58	69,	1,075.05	119,	1,176.37
19,	973.61	70,	1,077.07	120,	1,178.40
20,	975.64	71,	1,079.09	121,	1,180.43
21,	977.67	72,	1,081.11	122,	1,182.45
22,	979.70	73,	1,083.14	123,	1,184.48
23,	981.73	74,	1,085.17	124,	1,186.51
24,	983.76	75,	1,087.19	125,	1,188.54
25,	985.79	76,	1,089.22	126,	1,190.57
26,	987.82	77,	1,091.25	127,	1,192.60
27,	989.85	78,	1,093.28	128,	1,194.63
28,	991.88	79,	1,095.30	129,	1,196.66
29,	993.91	80,	1,097.33	130,	1,198.69
30,	995.94	81,	1,099.36	131,	1,200.72
31,	997.97	82,	1,101.38	132,	1,202.75
32,	1,000.00	83,	1,103.41	133,	1,204.78
33,	1,002.03	84,	1,105.44	134,	1,206.81
34,	1,004.06	85,	1,107.47	135,	1,208.84
35,	1,006.09	86,	1,109.50	136,	1,210.87
36,	1,008.12	87,	1,111.52	137,	1,212.90
37,	1,010.15	88,	1,113.54	138,	1,214.93
38,	1,012.18	89,	1,115.56	139,	1,216.96
39,	1,014.21	90,	1,117.58	140,	1,218.99
40,	1,016.23	91,	1,119.60	141,	1,221.02
41,	1,018.25	92,	1,121.62	142,	1,223.05
42,	1,020.27	93,	1,123.65	143,	1,225.08
43,	1,022.30	94,	1,125.68	152,	1,243.34
44,	1,024.33	95,	1,127.70	162,	1,263.61
45,	1,026.36	96,	1,129.72	172,	1,283.88
46,	1,028.38	97,	1,131.75	182,	1,304.05
47,	1,030.40	98,	1,133.77	192,	1,324.32
48,	1,032.43	99,	1,135.80	202,	1,344.59
49,	1,034.45	100,	1,137.83	212,	1,364.86
50,	1,036.48				

THIRD. It has, however, been proved by experiment, that where much power is required, the same amount of fuel can be more economically expended through a steam engine and a blower, than by direct application of the heat to a column of air.

Dr. Ure observes:—

*

"That it has been ascertained that a power equivalent to one horse in a steam engine, will drive at the rate of eighty feet per second, a fan, the effective surfaces of whose vanes and whose exhaling conduits have each an area of eighteen inches square, equal to that of a large steam boiler chimney; the velocity of air in the chimney, produced by a consumption of fuel equivalent to the power of twenty horses, was no more than thirty-five feet per second, while that of the fan, as impelled by the power of one horse, was sixty-six feet per second. Hence it appears that the economy of ventilation by the fan is to that by the chimney draughts, as 66 × 20 is to 35, or 38 to 1. It is obvious, therefore, that with one bushel of coal consumed in working a steam-impelled eccentric fan, we can obtain as great a degree of ventilation, or we can displace as great a volume of air, as we could with thirty-eight bushels of coal consumed in creating a chimney draught. Economy, cleanliness, and compactness of construction, are not, however, the sole advantages which the mechanical system of ventilation possesses over the physical. It is infallible even under such vicissitudes of wind and weather as would essentially obstruct any chimney draught ventilation, because it discharges the air with a momentum quite eddy-proof, and it may be increased, diminished, or stopped altogether, in the twinkling of an eye, by the mere shifting of a band from one pulley to another. No state of air without, no humidity of air within, can resist its power. It will impel the air of a crowded room, loaded with vesicular vapors of perspiration, with equal certainty as the dryest and most expansive."

There have been numerous forms of air pumps or blowers used for the propulsion of air. A hundred years ago a large fan, propelled by man power, was in use for the ventilation of the House of Commons.

Dr. Arnott contrived an air pump, which has been used with good results in hospitals, worked by man or water-power. There are also several kinds of power-blowers in constant use in this country, sometimes for ventilating purposes, but oftener for forcing air into furnaces to increase the fires, for which they are now considered indispensable where much power is required. Nearly all those which have been used for ventilation depend, for their power to move air, upon the centrifugal force with which the air leaves the outer end of the revolving blades. In some of these fans the sides are fixed and the blades only revolve; in others, one side only is fixed, while the other revolves with the blades attached. For the purpose of exhaustion, the air is usually taken from enclosed channels into the middle of the fan, and is discharged freely at all points of the circumference. For the purpose of forcing, it is usually taken freely at the middle, and is discharged through enclosed channels from the circumference. Occasionally fans are arranged to both take and discharge air through enclosed channels.

We have used a fan for ventilation which consists of an enclosed cylinder, having through the axis a solid shaft, to which is attached a blade or fan extending from the axis to the circumference. Over a part of this shaft is a hollow shaft, to which is attached another blade or fan, also extending from the axis to the circumference; both shafts extend outside of the cylinder, and are driven by any convenient power, the alternate motion being given by simple gear. While in operation, one blade stands as a partition between the opening for the ingress of air and that for its egress, and the other moves forward, pushing all the air out of the cylinder before it, the cylinder being filled again with air coming in behind the revolving blade from the supply pipe. On completing the revolution this blade takes its place as a partition, while the other revolves, and thus acting alternately they discharge the cylinder twenty or thirty times a minute, more or less, as required. The value of this, over other fans, consists mainly in its slow motion and economy of power, and in its accurate measurement of the amount of air supplied.

IX.—CONCLUSIONS; IN APPLICATION TO THE STATE HOUSE.

From the foregoing considerations we conclude,—

1. That the supply to the occupants of the State House of fresh air, suitably tempered in heat and moisture, in such abundance as will obviate the necessity of their ever breathing over the same air twice, is an object paramount to any considerations of trouble or expense.

2. That the most efficient, reliable, economical and comfortable mode of heating the building is by steam at a pressure of twenty pounds or more; the heat to be distributed by steam pipes to every part of the building, and to be communicated to the rooms, in part by air warmed by contact with the pipes, and forced in, and in part directly by radiating pipes in the rooms.

3. That, for the purpose of forcing in and controlling a constant and sufficient supply of fresh air at every point, we would recommend the use of a large fan-blower, of slow motion, driven by steam power. As at present arranged, the degree of ventilation which can be obtained in the Representatives' Hall, depends upon the difference in the temperature of the air in the ventilating flues, and that of the air out of doors. There is a limit to the amount of heat which can be applied to the air in the flues, and consequently the change of air in the hall is less in proportion to the increased warmth of the outer air. It is probable that on a very cold day, the quantity of fresh air supplied to the hall might amount to four cubic feet per minute for each of three hundred persons; but if the outer air should approach in temperature nearly to that of the air in the ventilating flue, there would be no change, and ventilation would cease. We have seen that it is deemed necessary to supply twenty cubic feet of air per minute for each individual, to insure health and comfort, and provision should be made to supply this amount to six hundred persons in the Representatives' Hall, and to a large number occupying other parts of the building. We consider the application of mechanical power therefore, to be indispensable, both on account of its necessity for forcing in this large amount of air, and because we cannot be sure that under unfavorable circumstances the ventilation would not otherwise entirely cease.

4. That, for the exhaustion of the foul air at every point, we would recommend a similar blower, driven by the same power; or, if this prove impracticable, we would provide for the application of heat to the escaping air at all necessary points.

5. That the best place for the introduction of air, at least in the principal halls, is in or near the ceiling; and the best place for the exhaustion of the foul air is through the floor.

6. That the orifices for admitting and for exhausting the air should be ample, and as well distributed as practicable.

7. That the provision for the admission of warm air should be accompanied, for each room, with provision for the supply and mixture, previous to entrance into the room, at the pleasure of the occupants, of as much cool air as will keep the temperature at the most satisfactory point, without diminishing the supply of fresh air.

As regards the amount of power necessary to accomplish the full heating of the building, we must say that all that is known practically and scientifically on this subject, will not enable one to determine the exact ratio for all cases, between grate area, fire surface, radiating surface, and the space to be warmed. Each building has circumstances peculiar to itself, which will modify the general rule. It is needless to specify all the circumstances which weighed on our minds in arriving at the conclusions given below, but it may be stated that they result from as careful a consideration of the subject as could be given to it in the time which has been allowed.

That portion of the State House which is used, and should be warmed and ventilated, contains about 722,000 cubic feet, divided as follows :—

Used by the Executive Departments, ...	318,100
Senate and Representative Halls and Galleries, .	169,900
Committee-rooms and other rooms for the use of members of General Court, ...	94,550
Halls, Corridors, &c., used by the public, . . .	139,450
	722,000

To warm this space satisfactorily at all times, would require, we think, about 14,400 square feet of radiating surface in the channels and in the rooms. About 2,400 square feet of fire-surface would be required to keep this radiating surface up to a proper temperature in severe weather; this amount of fire-surface in boilers is commonly rated at 160 horse-power. We should set four boilers, of forty horse-power capacity each, in a vault below the present surface of the ground, at the west end and outside of the building, making no change in the present external appearance of either building or grounds.

Fresh air, to supply the waste, we should take from the west end of the building, and carry it through channels built in the space now used as a cellar, and leading thence to the several rooms, by action of a ventilating fan set within the channel near the outer wall of the building; these channels we should expand into mixing chambers near the rooms, and, before the entrance into the mixing chambers, make the channels double, placing in one portion coils of steam pipe, so that into the mix ing chamber will come both hot and cold air, to be mixed at pleasure. The pipes for the supply of steam and return, we should carry through the air channels, to economize the heat. The vitiated air we should take by the shortest practicable course from the rooms to the dome; that from the rooms in the body of the building on the north side, including the Library, through the spaces back of the niches on the north side of the Representatives' Hall; that from the Representatives' Hall through spaces back of the niches on the south side of the hall; that from the east wing, over the Senate Chamber, through the roof into the dome; and that from the west wing through the roof in a similar manner, making special provision in each room, where practicable, to take away by independent channels the products of combustion from the gas used for lighting. In the dome we should collect all the foul air into one large shaft, terminating in or near the cupola, to deliver the air at the highest practicable point. Automatic check valves should be placed in the foul air pipes to prevent any accidental back currents, and also valves for regulating the amount of air passing from each room.

For moistening the air, it would be well to throw steam, to some extent, into the air before it comes to the radiating surface, so as to increase the capacity of the air to take and convey heat; and additional provision should be made for supplying moisture in each mixing chamber, so that the amount for each room may be regulated independently of the others.

We find, on examination, that the plan, as thus roughly indicated, for warming and ventilating the State House, is feasible; but it may be found economical to warm and ventilate some of the less important and isolated committee-rooms by independent means; if so, a heater of sufficient capacity should be placed in the room arranged to warm fresh air from out-doors, and a ventilating flue warmed by the escaping products of combustion from the heater, arranged for conveying away the air of the room.