An Outline
OF
Ventilation & Warming,
BY
WM. J. BALDWIN.

WILLIAM J. BALDWIN.

An Outline of Ventilation

—AND—

WARMING,

—BY—

WM. J. BALDWIN, M. AM. SOC. C. E.,
H
Mem. Am. Soc. Mechs. Engs

EXPERT

—AND—

CONSULTING ENGINEER

—IN—

HEATING AND VENTILATION.

(*Copyrighted, 1899.*)

PRICE, ONE DOLLAR.

PUBLISHED BY THE AUTHOR,
No. 106 and 108 BEEKMAN STREET,
NEW YORK.

THE Author is the pioneer writer in America on the subject of Steam Heating.

His work "BALDWIN on HEATING," has reached the 14th edition. Price $2.50.

His work "HOT WATER HEATING AND FITTING" is in the 3rd edition. Price, $2.50.

They are the standard American works of reference on these subjects.

LAST year the author published a little *blue* book, called "Data for Heating and Ventilation," and in its preface he promised to continue his efforts in a similar line at a later date, provided the endeavor he then made was appreciated.

The demand and the appreciation for the "blue" book was greater than his anticipations, and the many letters asking to be remembered when another book was issued, have induced him to produce a *red* book for the year 1899, and call it "An Outline of Ventilation and Warming."

The author has the honor to be the *pioneer* American writer of a book of reference on steam heating, etc. This book known as "Baldwin on Heating" from the press of John Wiley & Sons, has now reached its 14th edition ; something that no other engineering work ever printed in America has attained.

HEATING AND VENTILATION.

Air Necessary for Ventilation of Habitations, Schools, and Public Buildings.

THERE are at least two general classes of circumstances that are the cause of vitiation to the air of habitations, and they may be divided into what can be called controllable and uncontrollable causes.

The controllable causes are those that can be removed by the occupants, or rather prevented by them, with proper attention to personal cleanliness, the cleanliness of the house and its appointments and surroundings, and they consequently cannot come within the province of the architect or engineer (except in a very general way) when providing for the ordinary ventilation of buildings or habitations of any kind.

The uncontrollable causes of the vitiation of the air of buildings or habitations are the natural result of occupation, apart from what individual effort may do, and they should be the ones the architect or engineer is called upon to take into consideration when designing buildings or other habitations.

They are :—

1st. The exhalations from the lungs and transpirations from the skins of animals.

2nd. The contamination due to the products of combustion from lamps, gas burners or other artificial lights with combustion as a result : and

3rd. The vitiation due to any special cause, such as cooking, manufacturing, the laboratory, the etherizing room, the hospital and the disinfecting room.

The first, therefore, is an unavoidable and ever-present cause of vitiation from healthy as well as unhealthy persons, and it forms an ever-constant factor of vitiation per individual, calling for a certain amount of fresh air per hour per person if some common standard of purity is to be maintained, and it is this quantity, whatever it may prove to be, that should form the least quantity that the architect and engineer should be called upon to provide for in ordinary buildings.

In the estimates of fresh air per person by nearly all able writers on the subject, the amount required for respiration and for skin transpirations is all that has been considered in their tables, though reference to the destruction of the air by lighting is not omitted in their writing.

Ventilation, therefore, as spoken of below, will deal only with the amounts of air necessary for the removal of organic contamination due to man in a healthy state, and does not take into special consideration the sick room; defective stoves or furnaces (that leak gases into the air of the house); defective plumbing fixtures or pipes, or *impure cellar air* that finds its way upward through the house, etc., etc., all of which when they exist require a special or preventative treatment rather than a remedial one, and, therefore, all the tables or quantities of air mentioned hereafter are the minimum quantities necessary to keep the air of habitations purified to some "*common standard of comparison*" with the outer air, though in some cases they may be the arbitrary estimates of persons who have been considered good authority on the subject of ventilation at the time they lived and wrote, but may not now be considered ample.

Doctor D. B. Reid, the gentleman who followed Sir Christopher Wren, and the French scientist, Desaguliers, in their efforts to produce something like satisfactory ventilation in the British House of Parliament, in the early part of the present century, was the first person in Great Britain to advocate anything like the necessary amount of air per individual that later research and experience, aided by chemical analysis, has since proved to be necessary.

He made the arbitrary estimate that ten cubic feet of fresh air per minute, or 600 cubic feet per hour, for the respiration of an adult person was, to use his own words, "Certainly quite low enough for average comfort and safety."

Dr. Elisha Harris (New York State Board of Health), while speaking in the light of more recent knowledge on this subject, said, when referring to Dr. Reid's estimate (600 cubic feet), "that with this allowance per capita the air of an apartment would become too vitiated for healthy respiration at the end of an hour," and the question now is, "How very few of us have even this allowance of fresh air where we live and labor?" and the second question then arises, "If this is not ample, what is?"

Able men have considered this subject, and after I have stated briefly their opinions as to the quantities of good fresh air required for different classes of habitations, I will proceed to illustrate the means ordinarily used by competent engineers to obtain ventilation in connection with heating apparatus, as in all cold countries, the two subjects must be considered together.

Some writers always refer to the amount of fresh air required per minute per individual. It is better, however, for many reasons to familiarize ourselves with the amounts required per hour, and, therefore, all reference hereinafter made to quantities of air, will mean the quantity required per hour, unless otherwise especially stated.

General Morin, Director of the Conservatory of the Arts and Trades, Paris, in his able work on warming and ventilating, says: "The amount of air to be changed every hour to preserve the healthful condition of rooms should be, for: Hospitals, 2,119 to 2,472 cubic feet, to be increased to 3,700 during epidemics; surgical wards and lying-in hospitals, 3,532 cubic feet; prisons, 1,766 cubic feet; work-shops, 2,119 cubic feet, to be increased in case of unhealthy trades to 3,532 cubic feet; barracks and theatres (in the day-time,) 1,059 cubic feet; barracks (at night), 1,431 to 1,766 cubic feet; assembly rooms for long sessions, 2,200 cubic feet; hall and lecture rooms, short sessions, 1,059 cubic feet; primary schools, 424 to 530 cubic feet; adult schools, 883 to 1,059 cubic feet.

Peclet, who wrote before Morin, allowed the same for hospitals, 2,120 cubic feet. In theatres, prisons and schools, however, he underestimated, allowing only 300 cubic feet for living rooms and 212 cubic feet for primary schools.

Morin, speaking of his own estimates, remarks that they "*are not at all excessive*," and this Pettenkofer has demonstrated scientifically since

Morin wrote. I would not mention the names of Morin or Peclet at this time, were it not that they were capable and able men in their day, and that hence their estimates are still often looked on as ample by those who have not studied the subject in the light of later experience and experiments.

The error many of the early investigators fell into was that they considered the admission of a measure of air equal to that vitiated as sufficient, or if not sufficient, that two or three times the amount would probably be so.

Tredgold furnishes an illustration of this method of reasoning when he says : "Taking the capacity of an ordinary pair of lungs at 40 cubic inches per respiration, and 20 respirations per minute, he had 800 cubic inches per minute for respiration."

For the transpiration from the skin he estimated that from 12 to 30 grains of moisture was given off in the same time, one minute, and that it would take three cubic feet of air per minute to absorb this moisture, estimating that the humidity or degree of saturation of the air would be sufficiently far from the dew point to allow the air to absorb about ten grains of aqueous vapor per cubic foot. He further estimated that a candle would require about 300 cubic inches of air per hour for its support, and sums up by saying that "four cubic feet per minute or 240 cubic feet per hour was the amount per person necessary for ventilation." In reality, it is not more than one-tenth enough for good ventilation.

The fallacy of such a method of reasoning will be seen if we consider a vessel of clear water into which a small measure of coloring fluid has been discharged, say a bottle of ink into a tub of water. It is very evident that an equal amount of clear water thrown in will not restore the original clearness of the water in the tub, and, in fact, we are justified in saying that *no* amount—at least no practical amount—of water will entirely remove the traces of the ink. It may be diluted to a point of clearness sufficiently good for the purpose to which it is to be put, provided we run into it sufficient clear water, and it is the same with the air of our rooms. The individual turns 240 cubic feet of it as "black as ink" in every hour, and to make it sufficiently good for man to live in, we must add at least ten times as much pure air ; and then we will be taking air into our lungs, air that contains one-tenth of the organic matter that the body gave off previously.

The early investigators depended largely on the sense of smell as a guide to the vitiation of rooms. It is certainly of considerable help, though conclusions drawn by such means must be as variable within certain limits as the persons who make them.

Morin says that in the Hospital Beaujon, with an admission of 530 cubic feet per bed per hour, there was a "sensible odor." When the admission of air was increased to 880 cubic feet, the odor was "disappearing." His remark on the Military Hospital at Vincennes, with 1,060 cubic feet per bed per hour, was "too little air." With 4,240 cubic feet in the same hospital he said there were "draughts" (because the air was improperly admitted,) and as a compromise between the "draught" and the "smell," he fixed the admission at 2,120 cubic feet and pronounced it "satisfactory."

I will say here that had he admitted the air near the ceiling, he could have avoided the draughts, as the writer has done in the Sloane Maternity Hospital in New York, where over 8,000 cubic feet per bed per hour is admitted in this manner unnoticed by the patients.

With no better guide than the sense of smell, Peclet, in a report on the ventilation of the old Chamber of Deputies at Paris, pronounced 635 cubic feet per head to be "satisfactory," supplementing his remarks with "no odor." The amount of organic matter, therefore, as detected by the nose is very uncertain, especially if one is in the room for any length of time, while on the other hand, the slightest trace of mustiness is detected by a sensitive person on entering from the outer air; and under these conditions Dr. de Chaumont, Assistant Professor of Hygiene, in the Army Medical School at Edinburgh, has shown by a large number of experiments—over 400 analyses—that the sense of smell, carefully employed, does give some idea of the amount of impurity in the air spaces of habitations.

During de Chaumont's experiments, the amount of carbonic acid (CO_2) in the outer air was determined, so that the respiratory impurities were accurately known. Dividing his observations into groups, he found that $1\frac{9}{10}$ parts of carbonic acid (CO_2), due to respiratory impurities was "not noticeable" in 10,000 parts of air; when it reached 4.132 parts in 10,000 the organic matter was "becoming perceptible" to the smell, and that at $6\frac{7}{10}$ parts per 10,000, it was "disagreeable," while at 9 parts (or nearly 1 in 1,000) it was "offensive and oppressive;" "the limit of differentiation by the senses having been reached."

It will thus be seen that when the carbonic acid, due to respiration, etc., has reached 2 parts in 10,000, it is *generally* noticeable, and de Chaumont says, in Parks' *Hygiene*, that "2 parts of *coincident* * carbonic acid per 10,000 of fresh air should be the maximum amount of respiratory impurity admissible in properly ventilated rooms."

Adopting this standard, Parks' *Hygiene* gives the following table of the quantities of pure air per

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*** By coincident he means the amount caused by man in excess of the normal outside condition.**

head that should pass through a room on the basis of $\frac{6}{10}$ of a cubic foot of carbonic acid being exhaled by an average adult person in an hour.

TABLE TO SHOW THE DEGREE OF CONTAMINATION OF THE AIR (IN TERMS OF CO_2) BY RESPIRATION, AND THE AMOUNT OF AIR NECESSARY TO DILUTE TO A GIVEN STANDARD OF .2 PER 1,000 VOLUMES OF AIR, EXCLUSIVE OF THE AMOUNT ORIGINALLY PRESENT IN THE AIR.

Amount of cubic space (= breathing space) for one man in cubic feet.	Ratio per 1,000 of CO_2 from respiration at the end of 1 hour, if there has been no change of air.	Amount of air necessary to dilute to standard of .2 during the first hour.	Amount necessary to dilute to the given standard every hour after the first.
100	6.00	2,900	3,000
200	3.00	2,800	3,000
300	2.00	2,700	3,000
400	1.50	2,600	3,000
500	1.20	2,500	3,000
600	1.00	2,400	3,000
700	0.86	2,300	3,000
800	0.75	2,200	3,000
900	0.67	2,100	3,000
1,000	0.60	2,000	3,000

The $\frac{6}{10}$ of a cubic foot of carbonic acid exhaled is from the experiments of Pettenkofer, who is considered the most trustworthy authority on this subject, and who found by the chemical analysis of the air in experiments on the body of a man 28 years old, weighing 132 pounds, that "in repose" he gave out .00424 cubic feet of carbonic acid reduced to the volume of 32 degrees Fahr. per pound weight of his body; while under "gentle exertion" it was found to be .00591 cubic feet; and that it reached .01227 cubic feet for "hard work;" being nearly in the proportion of 2, 3 and 6 respectively. On the supposition, therefore, that the average weight of the human body is 142 pounds, we have from the above, 142 pounds x .00424 = .602 cubic feet of carbonic acid for a person "in repose;" .9 cubic feet for "gentle exercise," and 1.8 cubic feet for "hard work."

This, then, is the measure of "the vitiation" for healthy persons accepted by the prominent writers and thinkers of the day, and it is from this data that the table was compiled, as I believe, by de Chaumont. The temperature is taken as that of the freezing point of water.

Analysis made in a room under the foregoing conditions (those shown in Table I), would therefore, show 0.0002 of "coincident" carbonic acid, and probably not less than 0.0004 additional carbonic acid for the natural state of the outside atmosphere, making in all about 0.0006 carbonic acid in the air of the room.

It must be distinctly remembered the carbonic acid itself can scarcely be considered an impurity, and from the ventilating engineer's standpoint the excess (the coincident carbonic acid) found to exist within doors, over that existing outside, is only the measure of the organic impurities thrown off by the animal system, and that they exist in proportion to it.

To prevent misconception, the carbonic acid already in the atmosphere was disregarded in the table.

De Chaumont's formula on which it was calculated is $\frac{(P_1 - P)}{P} c = d$, in which P_1 = impurities, or carbonic acid, per 1,000 volumes already in the air-space (c.)

P = admissible limit of the respiratory impurities—that is, 2 parts of coincident carbonic acid in 10,000 of air ; c = air space in cubic feet ; d = amount of fresh air required per hour per individual.

Park points out that for rooms occupied continuously, or for long sessions, that c in the above formula has an apparent importance it does not possess, and substitutes the following simple one, $\frac{e}{P} = d$, in which e = the carbonic acid exhaled per person per hour ; P = the limit of admissible impurities from the lungs, etc. ; d = the required amount of fresh air in cubic feet per hour.

If, then, *e* is taken at the general average of 0.6 cubic feet (according to Pettenkofer), and the limit of coincident carbonic acid at .0002, we have $\frac{0.6}{0.0002} = 3{,}000$ cubic feet per average person per hour, for persons in repose, which will become $\frac{0.6 \times 1.5}{0.0002} = 4{,}500$ cubic feet for gentle exercise, and $\frac{0.6 \times 3}{0.0002} = 9{,}000$ cubic feet for hard work.

On this basis, therefore, of Pettenkofer's .00424 of carbonic acid per pound weight of individuals and the permissible maximum of "coincident" carbonic acid placed at 0.0002, I have constructed the accompanying diagram which shows the whole subject almost at a glance, and enables the architect or engineer to pick out the quantity of air necessary for either children or adults, or for any person from 30 to 170 pounds in weight. The ordinates of the line *a-b* indicate the quantity of air in cubic feet for persons in repose; the line *c-d* for persons gently exercising, and presumably, persons writing or studying; the line *e-f* for persons doing hard work; which line corresponds to the quantity of air ordinarily considered necessary for hospitals.

There is no question in my mind but that children in schools studying, should be classed under the head of "gentle exercise." Their minds are active, and their limbs are always in motion. I therfore consider the line *c-d* as indicating the quantities of air necessary for schools if the standard of purity is to be established or maintained on the addition of but two parts of carbonic acid to 10,000 of air.

DIAGRAM OF THE QUANTITIES OF FRESH AIR NECESSARY FOR VENTILATION:

(ACCORDING TO THE EXPERIMENTS OF PETTENKOFER.)

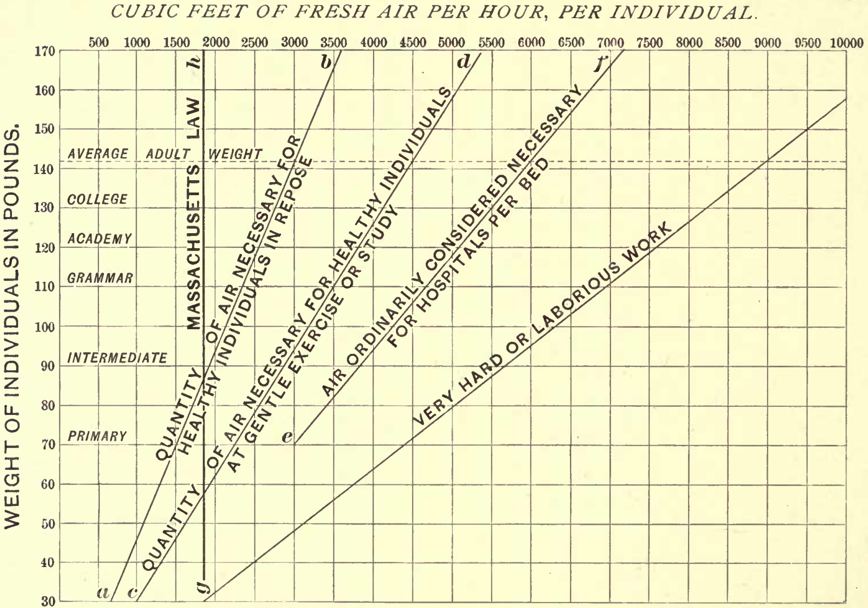

FIGURE I.

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The vertical line *g-h* shows the air required for schools under the Massachusetts law, and it has been added to the diagram for comparison. The line is vertical because weight of persons is not considered. It is equivalent to maintaining a "standard of purity" whose excess of carbonic acid would be about 4 parts in 10,000 of air, when the weight of the scholar is 120 lbs.

All permanent reforms, however, have come slowly, and therefore if the persons in charge of our public schools will only adopt the lowest of the standards shown in this diagram, and advocated by Morin, Wyman, de Chaumont, Billings, Parks, Pettenkofer, and, in short, every man who has studied the question carefully, we will be making a great stride towards perfection, and a wonderful improvement over the present state of affairs in many countries.

It will result in brighter and healthier children. They will learn faster and grow larger, and the teachers who have to live in the same atmosphere with them will be improved, physically and otherwise, as well as the children. Sore throats will disappear, and sick headaches will be the exception, not the rule.

HEATING.

BOILER : In warming by steam or hot water, the boiler is generally the first consideration.

Horse-power : What is known as the "boiler-maker's horse-power" is usually taken at 15 square feet of surface, in *fire-tube* boilers, such as the horizontal multi-tubular boilers.

The makers of large diameter (4 inch) *water-tube* boilers place a horse-power at between 11 and 12 square feet of surface ; though recent practice is beginning to place it at 10 square feet.

These, of course, are arbitrary ratings, and will vary with the conditions of draught, the proportion of grate to boiler, and surrounding conditions, but they are nearly correct for average conditions, and form good practice.

Centennial horse-power : The centennial horse-power of a boiler is that quantity of surface that will evaporate 30 pounds of water from a temperature of 100 degrees Fahrenheit, to steam at 70 pounds pressure, regardless of the boiler surface that it requires to accomplish it.

Mechanical Engineer's Horse-Power: The mechanical engineer's horse power is the evaporation of 33 pounds of water from a temperature of 212 degrees Fahrenheit to steam at 80 pounds pressure, which is nearly the same as the centennial horse-power.

Evaporation in Boilers: The evaporation of water in boilers is ordinarily found to be between 2 and 3 pounds of water per hour, per square foot of surface, under ordinary conditions of setting. A boiler can be forced to the evaporation of 4 or 5 pounds of water per square foot of heating surface, but it is always attended with waste in fuel; the greatest economy being obtained at between 2 and 3 pounds of water per square foot of surface, per hour.

Boiler Maker's Horse Power: When the boiler maker's horse-power is taken at 15 square feet of heating surface, it is only necessary that it shall evaporate 2 pounds of water per hour, per square foot, to make steam equal to the centennial horse-power.

Limit of Economy: When the boiler maker's horse power is taken at less than 15 square feet, the evaporation, of course, must be greater than 2 pounds per square foot, and when the boiler maker's horse-power is placed as low as 10 square feet per horse-power, the evaporation to accomplish the centennial horse-power must be 3 pounds of water per square foot per hour; when it has probably reached the working limit of economy.

Grate Surface to Boiler Surface:
Boiler Surface to Grate Surface:

The ratio of grate surface to boiler surface varies between (1) of grate to fifty (50) of heating surface, to one (1) to thirty (30), for horizontal multi-tubular fire-tube boilers; while for the ordinary 4 inch water-tube boiler, the ratio is about one (1) to thirty-five (35); the ratio for the well-known Babcock & Wilcox Water Tube Boiler being from 1 to 35, to 1 to 40.

For the cast-iron heating boilers, it will vary between one (1) of grate to thirty (30) of heating surface, running down to less than one (1) to ten (10), in some types of cast iron boilers.

As a general thing, the greater the proportion of heating surface to grate, the greater the economy in the burning of fuel.

Coal Burned per Square Foot of Grate: There is an idea that the most economical consumption of coal is obtained when it is burned on grates at the rate of between 8 and ten pounds per hour per square foot of grate. This, however, was obtained from a series of experiments, under boilers whose grate surface held about a constant relation to the heating surface, so that the economic relation between coal and grate will vary with the relation between the area of the grate to the area of the heating surface of the boiler.

In ordinary practice, however, it may be stated, that the economic limit in factory boilers, and where steam is made in large quantities for power, may be placed at 15 pounds of coal per square foot of grate per hour; the range for power boilers being from 10 to 15 pounds of coal per square foot of grate per hour.

In the matter of heating boilers, the conditions are very different. In heating boilers, the ratio of grate to heating surface of boiler is larger than for power boilers, while the ratio of consumption of coal per square foot of grate will drop down to as low as 2 and 3 pounds of coal per hour. The reason of this is that the furnaces are made larger so as to hold a large body of coal and maintain heat for long periods (8 to 12 hours) without attention, with scant draught and slow combustion.

Relation of Chimney to Grate Surface: In power boiler practice, an arbitrary rule says that when a chimney is 100 feet high, it should be 1/8 of the grate area in its (the chimney's) smallest cross section. This seems to work fairly well for boilers down to about 50 horse-power, but with smaller boilers, the proportion of the chimney (under such an empirical rule) should have an excess of about 50%, and it is good practice, never to provide a chimney of less than one square foot of cross section for boilers for heating apparatus.

Draught in Chimney: The intensity of draught in a chimney varies directly as the square root of the height of the chimney (temperatures remaining constant,) so that corrections may be made according to this rule, for chimneys as they vary in height. In other words, when the height of the chimney is 100 feet, the intensity may be considered as 10; while at 150 feet, the intensity will be but 12½; while for 50 feet, it will be 7; so that the relation between chimney areas and grate areas will vary inversely as the square root of the height.

Evaporation in Boilers per pound weight of Fuel: There is sufficient heat in a pound of good coal to evaporate 14 pounds of water, provided all the heat of the coal can be utilized.

In practice, however, there is only sufficient heat utilized to evaporate between 10 and 11 pounds of water to produce draught. In burning fuel, the heat that is carried off with the products of combustion and below the temperature of the steam is lost, except insofar as it makes draught, or is utilized to warm the feed water.

Proportioning Boilers: In proportioning boilers when the work to be done is known, first determine the rate of combustion per square foot of grate most desirable, say about 15 pounds per hour; then determine the size of the entire grate on the assumption that you can evaporate 10 pounds of water per hour per pound of coal, which is the equivalent of 150 pounds of water per square foot of grate; then, having the entire horse-power required, say 100, at 30 pounds of water per horse-power, or a total of 3,000 pounds of water per hour, it will require just 20 square feet of grate for such a boiler.

In determining the surfaces of boilers, it is better not to consider the question of ratio of heating surface to grate surface, but of heating surface to the water to be evaporated.

Taking the water, therefore, at 3,000 pounds per hour, and 3 pounds of water per square foot of heating surface as a maximum evaporation, the heating surface of the boiler would just equal 1,000 square feet, which should be increased to 1,500 square feet when the evaporation is to be only 2 pounds of water per square foot of surface per hour.

The latter size boiler would probably have 30 square feet of grate, and if it is only worked up to 100 horse-power, would burn but 10 pounds of coal per square foot of grate per hour, while the ratio of the heating surface of the boiler to the area of the grate still remains 50 to 1, which in the judgment of the writer, is about the economical limit.

CONDENSATION IN RADIATORS: It has been shown that the evaporation in boilers is between 2 and 3 pounds of water per square foot of surface per hour.

It is also well known by the experiments of competent engineers (see "*Baldwin on Heating*," page 298) that the condensation in radiators varies from $\frac{1}{4}$ to $\frac{3}{10}$ of a pound of steam (water) per hour, for low pressure steam (1 to 5 pounds,) such as is used in heating, all of which established a fact that in determining the size of a boiler for a heating apparatus, it is well to provide boiler sufficient to evaporate one pound of water for every 3 to 4 square feet of heating surface in the building.

To have the boiler sufficiently large beyond question, so as to cover condensation in mains, etc., it is well to consider, therefore, one pound of water to every 3 square feet of heating surface, as the average condensation in the radiators and the evaporation in the boiler.

Therefore, by dividing the radiating surface taken in square feet within the building by 3, we have the condensation in pounds of water per hour, and dividing the product by 30, we have the capacity of the boiler in centennial horse-power.

These conditions are for direct radiation only.

For indirect radiation, by natural draught, the condensation is about twice as great as for direct radiation, and with modern fan systems, the condensation in the radiator is about four times as great; while with hot blast high pressure work, the condensation may reach six times as much as for direct radiation. The latter, however, is not desirable, and is not good practice in warming buildings, though it may do for drying purposes.

One pound of condensation per square foot of heating surface is a liberal allowance for fan or forced ventilation work, so that the relation between surface of boiler and heating surface is in the proportion of from 2 of radiation (condensing surface) to 1 of boiler (heating surface), to 3 of radiation to 1 of boiler, according as the boiler is made to do more or less work.

The foregoing on boilers, grates, chimneys, evaporation, condensation, etc., gives a general idea of what may be called the "elastic limit" of the heating question, and to go much further would be to enter the domain of engineering, which is obviously not the intention of this work.

Rules and methods, however, to provide ready and approximate data for the architect or designer who desires to find the first things necessary for the installation of a steam heating or ventilating apparatus, are within the scope of these articles, and I know no better way than to present some of the preliminary ones used in the drawing office of the writer.

They are for heating and ventilating work for which practical and nearly accurate rules are required. They are all based on strictly scientific and engineering data, but they are divested of all unnecessary refinement, which for ordinary purposes would only add complication to the task, without getting very much nearer the actual truth.

To use these rules, the writer and the reader, should warm a building together.

When a set of plans are placed on the drawing boards, the first consideration is to determine the amount of condensation of steam that has to go on within a building, when that building is to be properly warmed by the particular method of heating or of heating and ventilation that the owner or the architect may desire to adopt.

It may be asked, "Why is the question of condensation the first consideration?" and in reply I will say, that it furnishes us with the first item of data on which to base all our other calculations. For instance, when we find the amount of cooling or condensation that is to take place within a building in the coldest weather, we can then readily find the amount of water that it will be necessary to evaporate to do this work. Having the amount of water that is to be evaporated, we can then obtain in any order we please, the size of the boiler necessary to evaporate the water; the amount of coal or other fuel that will evaporate the same water; the size of the grate on which to burn the coal; the size and height of chimney necessary to supply air for combustion; the size of the radiators necessary to condense the steam; the size of pipes necessary to convey steam or hot water to the radiators; and all other attendant data which will develop as we proceed.

CONDITIONS FOR A SCHOOL: Take, for instance, an ordinary primary school building of eight rooms, with say fifty children to a room, and our problem is to warm and ventilate this building so as to comply with what is known as the Massachusetts Law, which law provides that each occupant of the room has to receive a quota of thirty cubic feet of air per minute, which is equivalent to 1,800 cubic feet of air per hour per child. This, therefore, on the basis of the minimum quantity of air allowed by law, making no allowance for the teacher, will call for the admission of 90,000 cubic feet of air per hour to the school room. Some allowance, however, should be made for the teacher, and also some for a factor of safety, so that it is both reasonable and safe for an architect or a designer to assume that he sould provide at least for the admission and the warming of 100,000 cubic feet of fresh air each hour to each of the eight principal rooms of the school building.

QUANTITY OF AIR REQUIRED: This will call for 800,000 cubic feet of air per hour for the class rooms alone, and at least 200,000 cubic feet additional should be provided for ventilation for the other parts of the building. Therefore, an eight room primary school will require about 1,000,000 cubic feet of air per hour for its proper ventilation.

Usually, enough warmth can be admitted with this quantity of air to keep the rooms properly and equitably warm, although it is customary to use additional direct radiation in the halls, etc., and in very cold climates, a little direct radiation in the form of long coils underneath the windows.

Having now discovered the quantity of air necessary for the building, we have next to consider what its temperature should be as it passes through the registers.

It is usual to maintain a temperature of 70 degrees Fahr. within a room. It is a common thing to provide in specifications "that the room shall be warmed to 70 degrees Fahr. when the thermometer outside is at zero." If the air passes the registers, however, at 70 degrees Fahr., it will not maintain the temperature of the room at 70 degrees, as a certain amount of cooling goes on within the room, due to walls and windows. It is known, however, that should the air pass the registers at a temperature of 100 degrees, (giving the Massachusetts quantity of air) that it is somewhat more than sufficient to maintain the temperature of the room at 70 degrees, after the building is dry, even when the temperature outside is at zero. It is also known that air passing the registers at 80 to 85 degrees (giving the Massachusetts quantity, say 100,000 cubic feet per hour for the room described) will not maintain the temperature of the room at 70 degrees, when the temperature outside drops much below 40 degrees.

According to three (3) different theoretical rules (which it is not necessary to go into here) and assuming average conditions of walls and windows with light on two sides of such a room as we have selected, I have found that the air should enter the room at 27 degrees; 16 degrees; and about 13½ degrees respectively above that at which the room is to be maintained; but my experience has been such that I place it at 30 degrees plus—that is, 70 degrees plus 30 degrees ; and therefore base all my calculations for school work on an increase of 100 degrees above zero as the lowest safe temperature for which I provide means to warm the air.

Air Units : Having therefore determined that the building requires 1,000,000 cubic feet of fresh air per hour warmed 100 degrees, we have as a result, 1,000,000 cubic feet x 100 degrees Fahr. = 100,000,000, which of course is 100,000,000 cubic feet of air warmed 1 degree, and which we may call 100,000,000 "Air Units," the air unit being the equivalent of warming one cubic foot of air one degree Fahr. If now we divide these Air Units by 50, we have reduced the same to a value of 2,000,000 Heat Units ; the Heat Unit being the equivalent of warming one pound of water 1 degree.

The Air Unit, however, above adopted, is an arbitrary unit, and to be correct should be based on warming a cubic measure of air at some *constant* temperature, say at 32 degrees or at zero, or the warming of some *constant* weight of air, irrespective of its temperature or bulk. For our purpose, however, the divisor 50 is approximately correct, and is obtained thus :—

One pound of air at 32 degrees Fahr. under a pressure of an atmosphere of 29.9 inches of mercury, will occupy a space of 12.38 cubic feet, and its specific heat is .2379 ; the specific heat of water being unity. In other words, a pound of water requires 4.2 times as much heat to increase its temperature one degree Fahr. as a pound of dry air does ; so that the warming of 4.2 pounds of air 1 degree is the equivalent of cooling one pound of water 1 degree. We have thus, one pound of air at 32 degrees Fahr., occupying a space of 12.38 cubic feet x 4.2, which equals 52 cubic feet, or the bulk of air at a temperature of 32 degrees that can be warmed by 1 Heat Unit. This, as will be noted, is for air at 32 degrees. Now, if the air instead of being 32 degrees is zero, following the same method of reasoning as we have above, its bulk will be 48.6 cubic feet for each Heat Unit ; and a temperature of 14 degrees above, its bulk is 50 cubic feet ; while at 70 degrees Fahr. it will be 56.2 cubic feet. This therefore gives the range of bulk for air between zero, the coldest outside temperature on which calculations are usually made, to 70 degrees, the temperature of the room, and shows why 50 can be taken as a proper divisor without appreciable error.

BRITISH HEAT UNITS: We have found above, therefore, that for every million cubic feet of air admitted to the building in an hour (or any time) and warmed 100 degrees, that we will have to furnish steam equal to 2,000,000 British Heat Units in the same time. To warm this quantity of air the equivalent of 2,000,000 Heat Units, we will have to cool a quantity of steam equal to 2,000,000 Heat Units, and here again another average divisor of 1,000 may be used without appreciable error, by which we obtain the amount of steam necessary to be condensed (or water to be evaporated), and the answer will be in pounds weight of steam or water; which, in the instance we have cited, is the equivalent of 2,000 pounds weight of steam condensed, or 2,000 pounds of water evaporated to steam in a boiler.

HEAT UNITS IN ONE POUND OF STEAM: Let

us now see how this divisor of 1,000 is obtained. If we evaporate one pound of water from a temperature of 212 degrees (under our ordinary pressure of atmosphere) it requires 965 Heat Units to accomplish the evaporation, and to turn the water into steam at a pressure just above the atmosphere (according to Ragnault's tables) and if we look at any of the tables of the heat of steam, we will find that the *latent* heat of vaporization decreases with an increase of pressure, but that the *sensible* heat increases, and that the sum of the sensible and latent heat of steam above 212 degrees forms a nearly constant quantity, increasing slightly with the increase of pressure, so that at ten pounds pressure it is the equivalent of 974 Heat Units, and at forty pounds pressure it is the equivalent of 989 Heat Units, while at one hundred pounds pressure it is the equivalent of 1,004 Heat Units. I follow this line of reasoning on the assumption that we always cool the water in the return pipes to 212 degrees, or something below it.

In low pressure apparatus it cools considerable below 212 degrees, so that it is only necessary to cool it to 178 degrees to extract the whole 1,000 Heat Units from it. Therefore the divisor of 1,000 (Heat Units) is obtained by cooling one pound weight of steam from say one pound pressure above atmosphere to water at a temperature of about 178 degrees in the return pipes, and which would become but 1,004 heat units if we cool the steam from one hundred pounds pressure to a temperature of 216 degrees in the return pipes. Therefore, the divisor of 1,000 is not empirical, but founded on correct science.

If we therefore divide our 2,000,000 Heat Units by our constant of 1,000 (the Heat Units in a pound weight of steam) we find that we have to condense just 2,000 pounds weight of steam at any ordinary pressure, to supply our 2,000,000 Heat Units, necessary to warm the 1,000,000 cubic feet of air 100 degrees Fahr.

HORSE-POWER: Having now discovered that we require to evaporate 2,000 pounds of water or condense 2,000 pounds of steam, we divide this 2,000 by 30, and get the result in Centennial horse-power; which is equivalent to 66.6 horse-power.

This, therefore, gives us the boiler capacity we have been looking for.

COAL: After having found our boiler, it becomes necessary to approximate the amount of coal that we may have to burn, so that we may be able to estimate our expense and also arrive at the size of our grate. Having the amount of water that it is necessary to exaporate, say 2,000 pounds, a simple method indeed is to divide the weight of water in pounds by another constant divisor of ten (10) and the result is the weight of good coal that will be burned to evaporate that quantity of water. This ten (10) is also a slightly variable quantity, and will vary from *eight* to *eleven* with different types of boilers and kinds of coal. I use the *ten* for all ordinary calculations. Therefore, if we divide the 2,000 pounds of water by *ten*, it shows that we have to burn about two hundred (200) pounds of coal per hour to warm 1,000,000 cubic feet of air 100 degrees in the same time.

GRATE: Having found the amount of coal to be burned, it then becomes necessary to establish the size grate necessary to burn this coal. It has been said before that in burning coal under large boilers when a fireman is in attendance, that the greatest results in economy have been obtained when the coal has been burned at the rate of about nine pounds per hour per square foot of grate. For a low pressure apparatus in house work or school work in the care of janitors, and any apparatus that is made automatic and that will have to run for long periods without attention, four to five pounds of coal per hour per square foot of grate is ordinary practice; hence the large proportion of grate in small boilers. Again, with high pressure power boilers, twelve to one, and even higher, is not considered bad practice. This question, therefore, admits of great latitude, but for boilers for all ordinary large buildings (power boilers) ten to one and twelve to one, becomes a good rule. In other words, divide the amount of coal by ten or twelve, and you have the square feet of grate necessary and proper to burn it under average conditions of practice.

The ten to one would give us twenty square feet of grate for a sixty-seven horse-power boiler, which is rather a larger grate than a sixty-seven horse-power horizontal boiler would require, and where ten may be a good ordinary divisor, twelve will probably be nearer the ordinary and every-day practice, when circumscribed by local conditions.

CHIMNEY: The next question to consider is that of the chimney necessary to burn the amount of coal required. The chimney, when accurate data is required, should be calculated by the amount of coal to be burned and the height of the chimney, but this is a complex question in itself, and we have no room for it just here.

A common old rule for proportioning the size of the chimney for the grate, is to take one-eighth of the grate area, and call it "chimney." Nothing was said about the height of the chimney, and at the best it is but a crude approximation, and often disappointing with short chimneys. It is one of the questions for an educated engineer when much is at stake.

RECAPITULATION.

We may now review the whole of the foregoing matter in the following simple manner by an arithmetical example, thus :

(1) 1,000,000 cubic ft. air passing through building in an hour.
× 100° Fahr. air is warmed (0. to 100 F.)
50)100,000,000 Air Units.
1000)2,000,000 Heat Units required in an hour.
10)2,000 lbs. water to be evaporated in boiler or steam condensed in apparatus per hour.
12)200 lbs. coal required per hour.
8)16.6 sq. ft. of grate (minimum.)
2.075 sq. ft., size of chimney 100 ft. high.

The above speaks for itself.

If now we desire to find only the Centennial horse-power of the boiler, we divide the number of pounds of water to be evaporated per hour by *thirty*, thus :

(2) 30)2,000 lbs.
66.6 horse-power.

BOILER SURFACE: If again we desire to know the square feet of surface that such a boiler should have, to furnish 66.6 horse-power with ease, we may take "the boiler maker's rule" of allowing fifteen square feet of surface per horse-power (which is the usual amount provided in horizontal multitublar boilers) and we have the following simple example:—

(3) 66.6 horse-power of boiler.*
15 sq. ft. per horse-power.
999 sq. ft. of surface in boiler.

which is practically 1,000 square feet of surface for such a boiler.

The foregoing simple data, therefore, establishes the amount of air necessary for the school; the temperature at which provision should be made to warm it; the total (British) units of heat necessary to warm the air; the amount of water necessary to be made into steam (or steam to be condensed into water); the amount of coal required to be burned per hour; the reasonable size of the grate on which

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*This boiler would be capable of being worked up to about 100 Cen. H. P.

to burn the coal; the size of the chimney necessary for the same; the power of the boiler in nominal horse-power, and the number of square feet of fire and flue surface in the boiler.

The above is for indirect or fan work for school buildings, hospitals, etc.

DATA FOR DIRECT RADIATION.

The heating or direct radiating surfaces of a building should be proportioned to the cooling surfaces, with of course an additional arbitrary allowance for air leakages or accidental ventilation and a fixed additional allowance sufficient to warm the air admitted or carried off when systematic ventilation is provided.

The cooling surfaces of a building are the outside walls and windows and in cases of churches often the roofs. The judgment of the designer will suggest other cooling surfaces when they exist. The partition walls between warmed rooms of course should not be considered, and the cubic contents of a room play little or no part in the matter.

It has been found that after the walls of a building are dry, that a square yard of wall will cool about as much air as a square foot of glass.

This, of course, is an approximation, differing with different construction, a furred wall passing less heat than one with the plaster on the hard wall. The ranges, however, are probably between 5 square feet and 10 square feet to 1; that is, a wall may be so poor that 5 square feet of it will cool as much air as a square foot of glass, or it may be so good that it will require 10 square feet of it to cool as much as 1 square foot of glass.

Now, it has also been found, that ½ square foot of average direct radiating surface, at low pressure steam (1 or 2 pounds) will about offset the cooling of 1 square foot of glass in an ordinary window, in zero weather, without much wind when the radiators are properly disposed, so that with this data, we can approximate the direct heating surface for building, by allowing ½ square foot of radiator for each square foot of the windows and for each 5, 7 or 10 square feet of wall, as in our judgment we deem proper. To this, however, must be added often as much as 50% additional for accidental ventilation, through window and door leakages, for fireplace, and even for the movement of air through the walls of a building under wind pressure. Evaporation from walls of a new building is an important factor of cooling, especially in the first winter.

Having found or established the radiating surface, it is then necessary to know what the condensation within a radiator amounts to.

Horizontal coils of plain pipe, well distributed, have the highest efficiency as direct heaters. Then come the simple types of vertical radiators, when not of too great a height. The higher a radiator is, the lower its efficiency per square foot of surface, and thirty-six or thirty-eight inches has been established as a fair limit of height, so as to prevent an unnecessary waste of floor room, with reasonable economy in iron and in cost.

Without going into the matter in detail, therefore, it is only necessary for me to say that in horizontal one inch pipe in wall coils, the condensation per square foot of surface is found to be about .3 of a pound of water per square foot per hour for low pressures (one or two pounds pressure of steam) and that it decreases to about .25 of a pound of water per square foot per hour for the average types of radiators.

Taking the value, therefore, of a pound of steam at 1,000 Heat Units, we have 300 Heat Units per square foot of surface for coils, which in some cases, run a little over this, and 250 Heat Units per square foot of surface for average radiators. The condensation, however will vary and increase with an increase of pressure of steam, and numerous experiments have demonstrated that the condensation in different types of radiators and coils can be reduced to the equivalent of 1.66 Heat Units per degree difference, between the temperature of the air of the room and the temperature of the steam, per square foot of heating surface, for the poorer types, to about 2.25 Heat Units for the more efficient direct radiators and coils.

Assuming, therefore, that we have a radiator of 100 square feet in a room at 70 degrees, with a pressure of steam at one pound, or 215 degrees, we have a difference of temperature between the steam and the air of the room of 145 degrees, and should the type of radiators or coils be unknown to us, other than that the building is to be warmed by direct radiation, it is reasonable to assume that we may average the loss of heat per square foot of surface per degree difference of temperature at two Heat Units, which is my usual practice (unless I know exactly what type the radiators are to be) and which gives us a total loss of heat of .290 Heat Units per square foot of surface, for a radiator of 100 square feet, therefore the loss of heat is equivalent to 29,000 Heat Units, or say the condensation of twenty-nine pounds of steam, while for a building of 1,000 square feet of surface, it will amount to 290,000 Heat Units, and so on.

For the sake of easy calculation, therefore, we will assume that we have a building with 10,000 square feet of radiation, and desire to find the boiler, etc. we may proceed as follows :

(4) 10,000 sq. ft. of radiation in building.
290 Heat Units lost per sq. ft. per hour
1,000)2,900,000 Total Heat Units.
10)2,900 lbs. Water to be evaporated or steam to be condensed per hour.
12)290 lbs. coal required per hour.
8)24.16 sq. ft. of grate.
3.2 Area of chimney in sq. ft. 100 feet high.

The horse-power of the boiler and the surface in square feet can be found as shown before in examples (2) and (3).

APPROXIMATE RULES.

Simple approximate rules based on the forgoing are :—

HEAT UNITS.

(1.) Having the cubic feet of air to pass through a building in an hour, and warmed 100 degrees Fahr., multiply it by two (2) and the answer is in *Heat Units.*

POUNDS WEIGHT OF STEAM.

(2.) Having the cubic feet of air to pass through a building in an hour, and warmed 100 degrees Fahr., desiring the weight of steam required to warm same, divide by 500, and the answer is in *pounds weight of steam.*

COAL REQUIRED.

(3.) Having the cubic feet of air to pass through a building in an hour, and warmed 100 degrees Fahr., and requiring the amount of coal to be burned per hour, divide by 5,000, and the answer is in *pounds weight of coal.*

SIZE OF GRATE.

(4.) Having the cubic feet of air to pass through a building in an hour, and warmed 100 degrees Fahr., and requiring the grate area, divide by 60,000, and the answer is in *square feet of grate.*

SIZE OF CHIMNEY.

(5.) Having the cubic feet of air to pass through a building in an hour, and warmed 100 degrees Fahr., and requiring the chimney 100 feet high, divide by 500,000, and the answer is in *square feet of cross sectional area of chimney.*

REQUIRED HORSE-POWER.

(6.) Having the cubic feet of air to pass through a building in an hour, and warmed 100 degrees Fahr., and requiring the horse-power of the boiler, divide by 15,000, and the answer is in *horse-power.*

BOILER SURFACE.

(7.) Having the cubic feet of air to pass through a building in an hour, and warmed 100 degrees Fahr., and requiring the number of square feet of heating surface in boiler, divide by 1,000, and the answer is in *square feet.*

VENTILATION THROUGH THE MEANS OF INDIRECT RADIATION.

One cannot fully appreciate ventilation unless they have been entirely without it.

In rudely built habitations, there is a larger degree of accidental ventilation than is ordinarily supposed.

In well-built modern residences, the construction is often so good that it will hold water, hence the greater necessity for systematic ventilation.

A case in point comes to the writer, in which a grand New York residence was so air tight that the air to supply the grate fires had to come down the register flues, and when the fires were out, the air often came down some of the chimneys and passed to other chimneys or to the vent flues. In the kitchen of this house the air had to come down the ventilating flue of the hood of the range to supply the range fire until a window was opened. The kitchen floor was tiled and the walls and ceiling were marble.

This building was warmed by direct radiation with the exception of one indirect heater for main hall, which, of course, did not admit sufficient air to supply the fireplaces.

In determining the quantity of air required for a private residence, it may be said that the engineer has no data to go by. The residence may be large, and the number of persons to occupy it may be small, and an average of two persons to a room would be too high for any kind of private residences, excepting perhaps, the poorer apartment houses or tenements.

There is probably therefore nothing left to the designer but to assume that two persons will occupy a bed-room, and that such bed-rooms will average some two to four thousand cubic feet of air in good residences.

According to such a supposition therefore it would be only necessary to change the air in one of these rooms once or twice in the hour to give each person something like two thousand cubic feet of fresh air per hour, and if the whole house was treated in the same proportion, the change of air would be once in one-half hour to once in an hour, which when compared with school or hospital ventilation appears exceedingly small, though about the same per capita.

My object, therefore, in assuming conditions for a private house similar to those just given, is to show that it will not require such excessively large flues as some persons suppose, to secure very good ventilation in private houses.

The general deduction therefore to be drawn from the foregoing is, that when sufficient warm air is entering or leaving a private residence to keep the house sufficiently warm to be comfortable in cold weather, that it is reasonable to assume that the house is receiving sufficient fresh air to ventilate it to a reasonable standard of purity.

The air entering the house is the vehicle of the heat. It is evident, of course, that the air is taking sufficient heat from the indirect radiators or the furnace to keep the house warm, and this fact alone is presumptive evidence that sufficient air is coming in for ventilation. This diction has been questioned, still, I am forced in repeat it here, as I know it to be a fact, at least for private residences.

This holds true for air entering the room at the registers up to a temperature of from 140 to 150 degrees, and by finding the amount of heat that will be lost through the walls and windows of the building, one may estimate the amount of heat that is carried into the room or the building, by finding the number of cubic feet of air that it would be necessary to warm from the temperature the room is to be maintained at, to the temperature at which the air passes the registers. Therefore, without the use of an anemometer, a close estimate of the quantity of air that enters a room can be made, with no other data than the temperature of the room, the temperature at which the air passes the registers and the loss of heat through the walls and windows, the latter found in the usual way.

This line of reasoning will also carry us considerably further, and it can be always used in approximating the amount of air passing into a school room without the use of an anemometer. For instance ; if the outside temperature happens to be zero, the temperature of the school room 70 degrees, and the temperature of the air passing the registers 80 degrees, it is reasonable to assume that that room is receiving a quantity of air per child equal or exceeding the quantity required by the Massachusetts Law.

It is also as reasonable to assume when it is found that the outside temperature is 30 or 40 degrees (average conditions for winter weather in the neighborhood of New York) and that the air is found passing the registers considerably above 100 degrees, (and that it is necessary to maintain a temperature so high to keep the room warm) that it is not receiving sufficient air per capita to ventilate it to a standard of purity that is now considered sufficient by any reliable authority.

MIXING VALVES: As indirect steam radiators or furnaces will warm the air that passes over their surfaces any place from 130 to 180 degrees it then becomes necessary, if ventilation is to be maintained, that the air connot be admitted to the room at its initial temperature, and that some means must be provided for cooling it, (or changing its temperature) to meet the requirements of the day or the hour, and called "mixing" or tempering.

Endeavors have been made to accomplish this in several ways, one of which was to use hot water, and try and regulate the temperature of the water to the conditions of the day.

Another was to control the valves on the steam coils automatically, so that when the room passed the normal temperature, the coils were shut off and when it fell a few degrees, the valves were again opened.

This applies to either steam or hot water, though principally to the former, and gives fair results, the objection to it in the case of steam being that it often results in cracking in the pipes at the times the valves are opened.

All things considered then, the mixing or switch valve which is nothing but a shunt in the air pipe, gives probably the best results.

Figures No. 1 and No. 2 show two modifications of the switch valve in connection with a cold air inlet pipe, a radiator, a register and a school room, all of which can be operated by hand, "*b*" being the switch or shunt and "*a*" being the chain or pull; which may be operated in various manners, the simplest of which is shown in the illustration. This requires the attention of the teacher.

Figure No. 2 shows the method and valve used with automatic control, such as the "Johnson Thermostatic Regulation."

There are two ordinary butterfly dampers, ("*b.*" "*b.*") so arranged that the cold air will pass through the under one and the warm air from the radiator through the upper one; the thermostic contrivance ("*T*") opening and closing the valves and admitting alternately warm and cold air to the flue where it mixes and then escapes into the room. Of course, the prime object of a "switch-valve" is to be able to change the temperature of the air, while keeping the quantity of air admitted to the room *constant*. When a person closes the ordinary hot air register of an ordinary heating apparatus to *modify* the temperature of the room, *he cuts off the air supply*, and this is the great defect in most indirect heating apparatus.

POSITION OF HEAT REGISTERS: The question is often asked—"Where should the warm air register be in a room?" and this may be answered broadly by saying, it matters little where it is, provided it will not cause inconvenience to the occupants. In private houses, it is generally placed near the floor, and of preference, it should be near the coldest side of the house. The floor system probably can only be tolerated where the air enters at a comparatively high temperature, and reduced quantity, and for this reason in the case of schools and hospitals, it is found that modern practice always places the register above

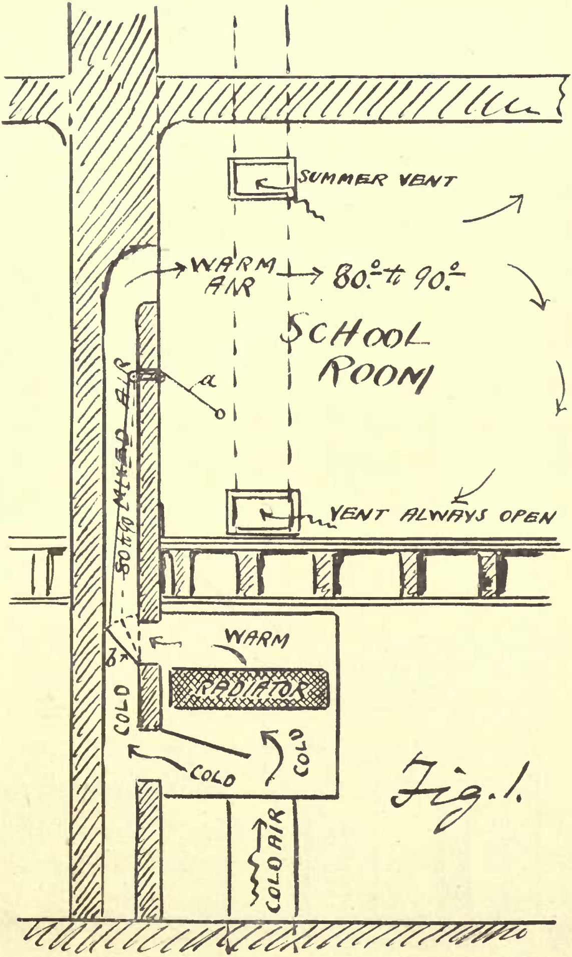
SUMMER VENT
WARM AIR
80° to 90°
SCHOOL ROOM
a
SOFT MIXED AIR
VENT ALWAYS OPEN
b
WARM
RADIATOR
COLD
COLD
COLD
COLD AIR

Fig. 1.

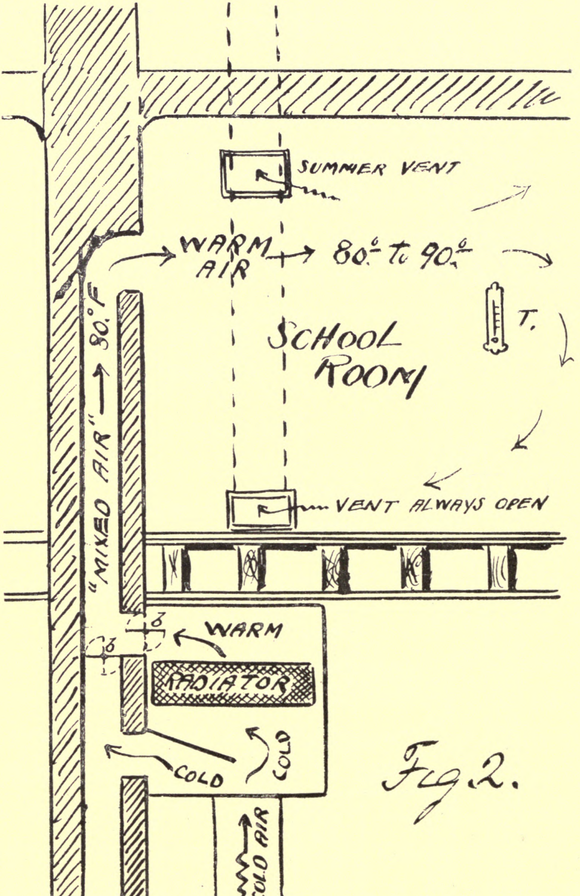
SUMMER VENT
WARM AIR
80° to 90°
T.
SCHOOL ROOM
"MIXED AIR" → 80° F
VENT ALWAYS OPEN
WARM
RADIATOR
COLD
COLD
COLD AIR

Fig. 2.

the head-line, as the quantity of air sufficient for school or hospital ventilation cannot, as a general thing, be admitted near the floor, on account of its low temperature, without inconvenience to the occupants. Seven (7) to eight (8) feet, therefore, is considered the proper level for the lower edge of the heat register in schools and hospitals.

When the register is above the head-line, it also permits of a smaller sized register than could be tolerated at the floor. It has been said that 1½ feet per second is about the velocity at which air should enter a school or hospital without causing draught.

This is not the case, however, when air is admitted above the head-line, 1½ to 2 times the area of the flue being good practice, with a velocity of 4 to 6 feet per second through the register.

School rooms are generally planned with windows on two sides, and many seem to think that the warm air register should be placed in one of the side walls as near a window front as possible. It is shown, however, with some degree of confidence, that this is not at all necessary. When the warm air from a register enters a room at a high register, the air is projected some distance into the room. It then finds the ceiling, and begins to move across the ceiling in the direction of the windows and outer walls, down which it flows and returns across the floor, to concentrate again at the outlet or vent register. This produces a rolling motion or local circulation which tends to mix the air, and without making an assertion as to which is the best position, I will simply say, that when the air is delivered very close to the windows, it begins to fall and pass across the floor, and were it not that it does not immediately pass out, simply a proportion of it passing out and part of it diffusing and getting into the general circulation of the room, I would say that near the window was not the best place to admit it. When the warm air is admitted near the rear wall or through the rear wall, it finds the ceiling, passes to the windows, passes down, passes across the floor and apparently does more to produce mixing and diffusion than if admitted at the front. The register in either posiion, however, being 4 or 5 feet from the ceiling, generally discharges air sufficiently low and with sufficient velocity to disturb the entire amount of air just above the head-line. It is then taken into the circulation before explained and carried to the floor-line, each person thereafter being a means of mingling the floor air with the ceiling current again ; the body supplying the heat to produce the upward current. This motion is shown by the diagram.

POSITION OF VENTILATING REGISTERS : Where should the ventilating registers be in a room? The opinion prevails among the best informed, that if we are confined to one vent register, it is best to withdraw the air from a room close to the floor and almost below where the air is admitted ; certainly in the same wall. This seems to favor school construction in a general way.

A floor register should be at the floor ; not in the floor, but in the side wall at the floor ; and to obtain the best results, should cut down through the baseboard with its lower edge level with the floor. An endeavor should also be made to have the floor ventilating register as wide and as low as possible. When flues are large, they require large registers, which means with the ordinary form of register, that the air is passing out under the upper edge of the register at between 18 and 30 inches from the floor, often leaving a cold stratum of air at the floor, causing cold feet to children. When the construction will permit, the register should never be more than 16 inches in height, with the longest diameter across the flue. This, however, is rarely permissible in ordinary wall construction, so that it is sometimes necessary to leave out the fret-work entirely, using nothing but a frame, and finish into the air flue with plaster or iron in the case of schools.

Is it necessary to have a ventilating register near the ceiling in schools? Some authorities think it is not, though very few designers dare to leave it out altogether, and for this reason there is generally a compromise, by putting a somewhat smaller register than the one used at the floor in the vent flue near the ceiling, with chains and valves so that it may be closed. Of course, in winter time, this register should not be left entirely open. If it does, it results in robbing the room of both heat and fresh air. It is therefore provided with means of closing it, and the responsibility of closing it remains with the teacher. In summer time, of course, it may be opened with advantage.

Hospitals should be provided with registers near the ceiling as well as at the floor, so that "flushing" could be resorted to at times, even if the ceiling registers were not kept constantly open.

To prevent too great a loss of heat at the ceiling, however, the designer should use some discretion in proportioning the ceiling registers, so that too much of the heat and fresh air would not escape that way; if the registers are neglected.

Doctor Dalton, Dean of the College of Physicians & Surgeons, at the time the first Sloane Maternity Hospital was built, when working on the matter with the writer, came to the conclusion that the ceiling registers should all be omitted. It was found, however, in certain small confinement rooms, that when chloroform was used, particularly at a time when the gas was burning, that ceiling registers were an absolute necessity, the formation of clorine gas being a result of the combination of chloroform with the products of combustion ; the excess of which gas had to be drawn away at the ceiling to make the rooms useful. This, at least, is a case where ceiling ventilation was an absolute necessity, so that when the second part of the building was constructed, ceiling ventilation was provided in all the rooms and wards, their use being left to the judgment of the doctors.

In auditoriums where fresh air is admitted in large quantities, through many small places underneath the seats we find another condition which always requires ceiling ventilation.

FORCED VENTILATION (FANS): The term "forced ventilation" signifies that the air is forced into a building with a fan or blower.

The disc fan, which is nothing but a screw propellor, will move large quantities of air under very slight resistance—a pressure equal to a ¼ of an inch of water being about the maximum. It cannot be used to advantage when forcing air through a system of sheet iron flues that have any considerable length.

The centrifugal fan, which is a paddle-wheel, and which sends the air off the edge of the blade by centrifugal force, is used as an intermediate pressure fan, controlling air pressures between ¼ inch of water pressure and 2 inches of water pressure; the inch of water pressure being, of course, a wind pressure capable of sustaining a column of water one inch in height.

This class of fans can be run at a speed capable of sustaining these pressures without undue noise. The same type of fan housed, and run at very high speeds are called pressure blowers, and for air pressures other than ventilation can be used successfully up to about 4 ounces. The objection, however, to using any type of centrifugal fan for high pressures is the enormous expense for maintenance when the volocities are high, the power required increasing in a ratio between the square and the cube of the velocities. The economical limit for centrifugal fans therefore, can be placed at about one inch of water pressure, and no ducts for carrying air through buildings should be designed that would require a greater pressure to move the air successfully through them ; ½ inch of air pressure forming probably the best reasonable practice.

The housed centrifugal fan or blower when throwing air from the tip of the blade, sends it against the case, where it rebounds and has to be carried around by the paddle wheel to the delivery port; which results in a great waste of power. For this reason, duplex cone fans of the centrifugal type, which discharge the air in a forward direction, being a compromise between the centrifugal fan and the propeller fan, will move more air at less cost than any other type of centrifugal fan. They have the advantage of delivering large quantities of air with comparatively slow velocities, thus doing away with annoying air vibrations which are carried through the air passages. They are capable, when run at the same speed as the housed blower, of delivering air at as high pressures, and when it is desirable to run them at slow speeds, by simply widening the blades, they secure increased quantities of air at very much less cost of power expended than housed fans. They are now fast coming into use, their value being fully recognized.

PLENUM VENTILATION.

When the air is forced into the building, it is generally known as "plenum" ventilation, for the reason that the pressures are slightly above the atmosphere, causing the air to escape, not only by the systematic vent flues, but often by any accidental opening. By this method, the engineer is able to *select* the place from which he takes his air supply.

EXHAUST VENTILATION.

Exhaust ventilation is that in which fans are placed at the top of the house, or in the ventilating flues, lessening the pressure within the building, producing a slight vacuum. It is sometimes necessary to exhaust buildings in this way, but exhaust ventilation should never be used entirely to the exclusion of plenum ventilation, for the reason that if one produces a slight vacuum in the building, air will enter through all openings, thus preventing the engineer from selecting or controlling the air supply; and the writer has known cases in his own practice, where exhaust ventilation was capable of drawing the air from the soil pipes through the trap in the water-closet fixtures. In like manner, if there are accidental leaks in the sewerage or soil pipes of the building, contaminations are sure to enter. The same applies to cesspools and drains or neighboring contaminations of any kind; while with plenum ventilation, the air of the building is made to enter the accidental breaks in the sewer pipes and *pass out of the building* through the *accidental* openings.

When the two systems have to be used in combination, the plenum system should have such a preponderance, that there would be no chance of the vacuum system drawing foul air into the building.

There should probably be an exception to this rule in the case of dissecting rooms, laboratories, or other exceedingly foul sections of a building. It sometimes becomes necessary to exhaust these parts of the building, or at least to have less pressure in them than in the other rooms, so that the foul air or smells will not pass from the dissecting rooms to the remainder of the building, but rather press *into* the dissecting rooms or laboratories.

WM. J. BALDWIN.

CARD BY THE AUTHOR.

THE author offers his services as an Expert and Designer of heating, cooling and ventilating plants and general engineering.

He has had thirty years experience, both practical and theoretical, with a thorough knowledge of all the minutia of detail of construction. His experience enables him to assure economy, both in design and maintenance.

Below are a few of the buildings for which he has furnished plans, specifications, etc.

Vanderbilt Memorial Hall (Yale College,) New Haven, Conn.
The (new) College of Physicians and Surgeons of the City of New York.
The Vanderbilt Clinic, New York.
The Sloane Maternity Hospital, (old and new,) New York.
The W. & J. Sloane Carpet Store, New York.
Lawyers' Title Insurance Co.'s Office Building, New York.
Hanover Fire Insurance Co.'s Office Building, New York.
The Metropolitan Telephone and Telegraph Co.'s Office Building.
Mechanics Bank Office Building, Brooklyn.
Exchange Office Building, New Haven, Conn.
New Laboratory, College Physicians and Surgeons, N. Y.
Wm. J. Syms Operating Theatre, (Roosevelt Hospital,) N. Y.
Columbia College Medical Department (easterly and westerly extensions).
American Theatre, New York.
Manhattan Co.'s and Merchants' Bank Office Building.
The Importers' & Traders' Bank.
U. S. Army Barracks and U. S. Army Mess Hall, David's Island, New York Harbor.
George Street Public School, New Haven, Conn.
Norton Street Public School, New Haven, Conn.
Public School, No. 3, Paterson, N. J.
Lemair Schwartz, Factory Building, N. Y.
Messrs. Abraham & Straus, Great Department Store, Brooklyn.
Leggett Office Building, Brooklyn.
Ellis Island U. S. Emigrant Station, N. Y. Harbor.
Madam De Hirsch Home for Working Girls, New York.
"No. 7 Wall Street," Building of W. Wheeler Smith, Architect.
Robert Hoe Building, New York.
Hundreds of other large buildings and residences throughout the United States.
Consulting Mechanical Engineer Electric Subway Companies, N. Y.

☞ ***TERMS FURNISHED ON APPLICATION.***