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VENTILATION

OF

BUILDINGS

BY

WILLIAM G. SNOW, S.B.,

MEMBER AMERICAN SOCIETY MECHANICAL ENGINEERS,

AND

THOMAS NOLAN, A.M., M.S.,

FELLOW AMERICAN INSTITUTE OF ARCHITECTS,
ASSISTANT PROFESSOR OF ARCHITECTURE, UNIVERSITY OF PENNSYLVANIA.

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PREFACE.

It has been the desire of the authors to condense into a small compass in the following pages a statement of the general principles of ventilation and of their application to different kinds of buildings.

No claim to originality is made except for the form in which the subject is presented, and due credit is intended to be given for any extracts or quotations from the works of others. The authors of this little book believe that while there are excellent comprehensive treatises and manuals on both the science and the art of warming and ventilating buildings for those who wish to investigate either exhaustively, there is room also for a primer in the subject for those who wish to be told simply and briefly what is to-day considered the best practice.

The subject matter, in about the form here presented, has formed the basis of one part of a series of lectures by the authors in the Department of Architecture of the University of Pennsylvania, the details of that phase of the subject which relates to the mechanics of ventilation having been purposely omitted, as they are discussed in another volume of this series.

It is hoped that the book may prove useful, not only as a popular presentation of the subject for the general public, but also as a suggestive outline in architectural, engineering and other schools in connection with, or as supplementary to courses of lectures which are introductory to the whole subject of the ventilation of buildings.

THE AUTHORS.

PHILADELPHIA,
January, 1906.

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VENTILATION OF BUILDINGS.

I.—GENERAL PRINCIPLES OF VENTILATION.

1. Importance of Ventilation.

Under modern conditions, and with buildings having a tight construction and a relatively small accidental in-leakage of air, the question of providing a sufficient supply of air becomes an important one, especially in the case of rooms which are crowded or occupied continuously for many hours.

As Billings observes:* "It requires the observation of the effects on the health and life of a number of men exposed to such air for a series of months or years, to demonstrate the slow but

* Billings, J. S., "Ventilating and Heating," 1893, Chap. VII., page 120.

certain production of throat and lung troubles, the loss of energy and vitality, and the shortening of life which are thus produced. These observations have been made on soldiers occupying ill-ventilated barracks and operatives working in close workrooms, and comparison of these results has shown that where in any room occupied by human beings there is a definite, unpleasant animal or musty odor, perceived by a person whose sense of smell is of the usual acuteness and who enters from the fresh outer air, the continued breathing of the air producing such odor will be injurious to health."

In certain buildings, where the results of changing from poor to good ventilation have been carefully observed, a marked improvement in the general health of the occupants has been manifest. For example, the records of the United States Pension Bureau state that "just prior to its occupancy of the present thoroughly-ventilated structure, the department was housed in numerous small and poorly-ventilated buildings, under which conditions the sickness of employes entailed an aggregate annual loss of time amounting to 18,736 days. In the new building the loss immediately dropped to only 10,114 days, a reduction of over 45 per cent. When we consider the conditions of yearly salary under which most of these clerks are paid, the financial return from improved ventilation is emphatically evident."

Professor S. H. Woodbridge, of the Massachusetts Institute of Technology, in documents relating to ventilation statistics, states that carefully collected data show that the death-rates have been reduced by the introduction of efficient ventilating systems in children's hospitals from 50 to 5 per cent., in surgical wards of general hospitals from 44 to 13 per cent., in army hospitals from 23 to 6 per cent., and in prisons from 80 to 8 per cent. Even among horses a reduction has been made from 19 to 1.5 per cent. in army stables, while during an epidemic the rate has been reduced fully 80 per cent. by improved methods of ventilation.

2. Composition and Impurities of the Atmosphere.

Atmospheric air is a mixture composed of about 79 parts of nitrogen and 21 parts of oxygen by volume, and in 10,000 volumes there are from 3 to 5 volumes of carbonic-acid gas.

The relative purity of the atmosphere is generally expressed by the number of parts by volume of carbonic-acid gas, expressed by the symbol CO_2, contained in 10,000 parts or volumes of air.

The proportion of this gas contained in the atmosphere may be easily determined by several methods, and it affords a fairly good index of the relative number of micro-organisms present. It is the latter which cause the discomfort and danger to persons who remain for long periods in an atmosphere containing a large proportion of CO_2.

* "It is very improbable that a minute quantity of organic matter contained in the air expired from human lungs has any deleterious influence upon men who inhale it in ordinary rooms. In ordinary quiet respiration no bacteria are contained in the expired air. In the act of coughing or sneezing such organisms may be thrown out. . . . Air is contaminated by minute particles of dust. . . . Experiments in hospital wards showed that in this dust there were micro-organisms including some of the bacteria which produce inflammation and suppuration, and it is probable that these were the only really dangerous elements in this air.

"The experiments made on animals compelled to breathe air vitiated by products of respiration make it improbable that there is any peculiarly volatile poisonous matter in the air expired by healthy men and animals other than CO_2.

* "Expired Air and Problems of Ventilation," Appleton's *Popular Science Monthly*, Feb., 1896. Drs. Billings, Mitchell, and Bergey.

"... Tuberculosis and pneumonia are most prevalent among persons living and working in unventilated rooms. These diseases are caused by specific bacteria which for the most part gain access to the air-passages by adhering to particles of dust which are inhaled, and it is probable that the greater liability to those diseases of persons living in crowded and unventilated rooms is to a large extent due to the special liability of such rooms to become infected with the germs of those diseases.

"The discomfort produced by crowded, ill-ventilated rooms is not due to the excess of CO_2 nor to bacteria, nor in most cases to dusts of any kind. The two great causes of such discomfort—though not the only ones—are excessive temperature and unpleasant odors. The cause of the unpleasant musty odor . . . is unknown. It may be due in part to volatile products of decomposition contained in the expired air of persons having decayed teeth, foul mouths, or certain disorders of the digestive apparatus; and in part to volatile fatty acids given off with or produced from the excretions of the skin.

"... The problem of securing comfort and health in inhabited rooms requires the consideration of the best methods of preventing or disposing of dusts of various kinds, of properly regulating temperature and moisture, and of preventing the entrance of poisonous gases, such as CO, derived from heating and lighting apparatus, rather than a consideration of simply a dilution of air to a certain standard or proportion of CO_2 present."

It will be noted that the opinion expressed in the last paragraph is quite at variance with the opinions favoring the commonly accepted method of maintaining a certain standard of purity, based upon the amount of CO_2 present, by admitting a sufficient volume of fresh air to dilute the foul air to any desired degree.

3. Removal of Dust.

To secure the removal of dust, cheese-cloth stretched on frames is commonly used, but to be effective it is necessary that the area be large, otherwise the cloth will soon become clogged with dust and the flow of air impeded. It is well so to proportion the screen that the velocity of the air through the cloth does not exceed 60 feet per minute.

Sometimes the air is washed, by causing it to pass through a coke-filter over which water trickles; and in other cases the air is brought in contact with fine sprays of water from specially designed nozzles.

4. Testing the Quality of the Air.

Several methods have been employed to determine directly the number of micro-organisms present in air.

*"The first is known as Hesse's method,

* Sir Henry E. Roscoe, "A Lecture on Ventilation of Schools," 1889.

in which a solid medium is used for the nutrition of the micro-organisms. The principle of this method consists in drawing a known volume of air through a long, wide tube, the inside of which is coated with Koch's nutrient gelatine peptone. As the air passes through the tube the micro-organisms settle on the jelly, and in the course of a few days develop into colonies, which become visible to the naked eye and can be counted. The second method is that proposed by Carnelly, the air being aspirated through a sterilized conical flask also containing solid sterilized jelly. The micro-organisms fall on the surface of the sterilized jelly, and in a few days the separate colonies due to each special organism make their appearance, and can be counted. In the third method, that of Percy Frankland, the air is drawn through a glass tube containing two sterilized plugs of glass wool, which are afterward transferred to a flask containing sterilized gelatine."

As these methods are rather too refined for ordinary work, the carbonic-acid test has become the recognized one, owing to the ease with which it can be made, and to the fact that the results show closely enough for practical purposes the quality of the atmosphere.

One of the best methods of making this test is to take six clean, dry bottles, with tight stoppers, having a capacity of respectively 100, 200, 250, 300, 350, and 400 cubic centimeters; a glass tube having a capacity of exactly 15 cubic centimeters to a given mark; and a bottle of perfectly clear, fresh lime-water, as the apparatus required. The bottles are to be filled with the air to be examined by means of a bellows or a hand-ball syringe. To the smallest bottle 15 cubic centimeters of the lime-water are to be added, the cork put in, and the bottle well shaken. If turbidity appears, the amount of carbonic acid will be at least 16 parts in 10,000. If no turbidity appears, the bottle of 200 cubic centimeters is to be treated in the same manner; turbidity in this will indicate 12 parts in 10,000. In similar manner, turbidity in the 250 cubic centimeter bottle will indicate at least 10 parts in 10,000; in the 300, 8 parts; in the 350, 7 parts; and in the 400, less than 6 parts. The ability to conduct more accurate analyses can be acquired only by special study and a knowledge of chemical properties and methods of investigation.

Other apparatus and tests are employed which are more convenient than the preceding, and give fairly close results.

In the air tests designed by Dr. Fitz of Harvard University, a measured volume of a colored solution known as phenolph thalein is placed in a tube. This tube, of telescopic pattern, when elongated brings a known volume of air in contact with the liquid.

The thumb is placed over the end of the tube, which is then shaken. If the color in the liquid does not disappear, the telescopic portion is pushed down to release the air, and again drawn out in order to bring a fresh volume in contact with the liquid. This operation is repeated until the color in the liquid disappears.

The tube is graduated, the marks indicating cubic centimetres, and a table accompanies the apparatus showing the number of parts of CO_2 in the air corresponding to various volumes required to cause the disappearance of color in the liquid. Dr. Fitz considers air containing 14 parts of CO_2 in 10,000 very bad; 9 parts, bad; 7 parts, fair, and 5 parts, good.

Another convenient test, giving approximately correct results, is that made by the use of what is known as "Wolpert's apparatus."

5. Proportion of Carbonic-Acid Gas.

An average adult at rest exhales about 480 cu. in. of air per minute. Woodbridge puts it at 15 cu. ft. per hour. Of this, about four per cent. is CO_2, which, though heavier than the surrounding air when at the same temperature, tends to rise because of the higher temperature gained by passing through the lungs. In addition to the exhalation from the lungs, there is given off from the body considerable vapor, which must be absorbed by the surrounding air.

One function of ventilation is to so dilute the air of occupied rooms that the proportion of CO_2 is kept within certain limits.

Ventilation may be considered good when the number of parts of CO_2 in a room does not exceed from 6 to 7 parts in 10,000. With 8 parts, the air appears close to one entering from out-of-doors. When the CO_2 exceeds 10 parts in 10,000, the quality of the air is noticeably bad, and produces a feeling of weariness in a person breathing it for some time. Continuous breathing of musty air, that is, air noticeably close-smelling to a person entering from out-of-doors, reduces the vitality of persons breathing it, and renders them more susceptible to disease.

6. Amount of Air-Supply Necessary.

The volume of fresh air that must be supplied to keep the air in the room at a certain degree of purity may be readily computed. For example: What volume of air must be supplied to an occupied room to prevent the CO_2 from exceeding 7 parts in 10,000? Taking as a basis the commonly accepted figures of 0.6 cu. ft. as the amount of CO_2 given off per person per hour, and 4 parts in 10,000 as the proportion of CO_2 in the outside air; if the fresh air admitted absorbs 3 parts to reach the standard of 7 parts as explained above, 3 cu. ft. of CO_2 is taken up, which is equal to that given off by $3 \div 0.6 = 5$ persons. That is, 10,000 cu. ft. of air must be admitted per hour to 5 persons, or 2000 cu. ft. per hour per person in order that the number of parts of CO_2 in 10,000 shall not exceed 7.

By similar computations, 6000 cu. ft. per hour per person will be found necessary to dilute the air to 5 parts of CO_2 in 10,000 parts, 3000 cu. ft. to dilute it to 6 parts, 1000 cu. ft. for 7.33 parts, 1500 cu. ft. for 8 parts, and so on.

Where gas-lights are used, an additional supply of air must be provided, since the vitiation of air caused by each jet is as great as that caused by five or six men.

The air-supply commonly accepted as sufficient for different classes of buildings is shown by the following table:

Class of building.	Cu. ft. per hour per occupant.	Cu. ft. per min. per occupant.
Hospitals..........	4000–6000	66–100
Court-rooms	2000	33
Legislative halls..	2000	33
Theaters...........	1500–1800	25–30
Halls..............	1000–1200	17–20
Churches..........	1000–1200	17–20
Schools............	1800–2400	30–40

*"The quantities of air which should be furnished by ventilating means cannot be safely based solely on the number of those to occupy the rooms to be provided for. . . . The smaller the per capita space, the less the per capita air-supply must necessarily be made. On the other hand, the larger the per capita space, the greater the per capita supply required to maintain the agreeable if not the wholesome quality of the air. The most active and dangerous impurity in the air of occupied enclosures is the matter of organic nature, called effluvia, thrown off by the body through its pores. That matter rapidly changes in character, passing through a fermenting and decomposing to a putrescent condition. The longer it is retained within a room, the worse its odor becomes and the more morbific its condition. The aims of ventilation should be, as far as practicable, to limit atmospheric impurities to

*** Prof. S. H. Woodbridge in Conn. School Document No. 13, 1898.**

the location of their origin, and to reduce the quantity and the time of retention of such impurities within an inclosure to a minimum. In proportion as the per capita space of an inclosure is greater, the quantity of such matter contained in it is larger, the time of its retention longer, and its character more offensive and harmful. It follows, therefore, that the more sparsely occupied rooms of a building are those to which the largest per capita supply should be furnished.

"Considering only the permanent effects upon health, an individual air-supply of 1000 cu. ft. per hour furnished to a crowded audience-hall having but 100 cu. ft. of space per capita, may be regarded as giving as good ventilation as a 3000 cu. ft. per capita supply of air per hour furnished to a school-room having a 300 cu. ft. per capita space."

7. Draughtiness.

The frequency with which the air in a room may be changed depends upon the possibility of introducing it without causing draughts.

With wall registers overhead, it is difficult to change the air oftener than every five or six minutes. Even then, great care must be taken to thoroughly distribute the supply. This is done in many cases by means of "diffusers" attached to the registers. These devices are made of vertical strips of metal, which are set at different angles and thus cause the air discharged through the register to spread out over a larger area.

In regard to draughtiness, it may be said that experiment has shown that a velocity of air of $1\frac{1}{2}$ ft. per second is not perceptible to the senses, and a velocity of 3 ft. per second causes no discomfort.

Accordingly, in seating spaces, care must be taken to prevent air-currents from exceeding the higher velocity stated.

In school-buildings and halls, into which the air may be introduced at a temperature above that of the room and at a point considerably above the heads of the occupants, no uncomfortable draughts need be felt. The air will pass across the ceiling until the exposed walls and windows are reached, when it will become chilled, descend to the floor and be drawn through the seating space to the vent openings located near the floor.

The greatest difficulty in preventing draughts occurs in the case of a supply of air from above, which must be brought in at a temperature below that of the room, as in the case of a crowded hall having little or no exposure. In such cases the air must be brought in through numerous openings of relatively small size.

8. Compulsory Ventilation.

Massachusetts was the pioneer in the matter of compulsory ventilation. In that State the Department of Inspection of Factories, Workshops, and Public

Buildings demands that the following requirements be guaranteed in the specifications accompanying plans submitted to the Department for approval:

1. The apparatus must, with proper management, heat all the rooms, including the corridors, to 70° F. in any weather.

2. With the rooms at 70° F. and a difference of not less than 40° between the temperature of the outside air and that of the air entering the room at the warm-air inlet, the apparatus must supply at least 30 cu. ft. of air per minute for each scholar accommodated in the rooms.

3. Such supply of air must so circulate in the rooms that no uncomfortable draught will be felt, and that the difference in temperature between any two points on the breathing plane in the occupied portion of a room will not exceed 3°.

4. Vitiated air in amount equal to the supply from the inlets must be removed through the vent outlets.

5. The sanitary appliances must be so ventilated that no odors therefrom will be perceived in any portion of the building.

The laws of Pennsylvania require that schoolhouses shall have in each class-room at least 15 sq. ft. of floor space and not less than 200 cu. ft. of air space per pupil, and shall provide for an approved system of heating and ventilation by means of which each class-room shall be supplied with fresh air at the rate of not less than 30 cu. ft. per minute for each pupil, and warmed to maintain an average temperature of 70° F. during the coldest weather.

The New York State requirements are practically the same, and provide in addition that the facilities for exhausting the foul or vitiated air shall be positive and independent of atmospheric changes.

9. Space Per Occupant of Rooms.

The space provided per occupant is obviously an important matter, and, as noted, is one of the provisions in the laws governing the ventilation of schools. The larger cities guard the welfare of tenement-house dwellers by demanding certain capacities, heights, and window areas of rooms. Thus in Philadelphia it is required that

"Every habitable room in every such tenement-house shall be of such dimensions as to contain at least 700 cu. ft. of air. Every habitable room in every such tenement-house shall be in every part not less than eight feet in height from floor to ceiling; . . . the total window space for one room shall not be less than twelve square feet."

The Boston Building Laws require that

"Every room in every tenement or lodging house hereafter built, and in every building hereafter altered to be used as such, shall not be less than eight feet in height in the clear in every story, except that in the attic it may be less than eight feet high for one half the area of the room. Every such room shall have one or more windows on an open air-space with an area at least one tenth as great as that of the room. The top of at least one window on such air-space in each room shall be at least seven feet six inches from the floor, and the upper sash of the same window shall be movable."

The New York City requirements are as follows: The height of rooms must be not less than eight feet, and the total area of window or windows in every room communicating with the external air shall be at least one tenth of the superficial area of such room; and the top of one, at least, of such windows shall not be less than seven feet six inches above the floor, and the upper half, at least, shall be made so as to open the full width.

Every habitable room of a smaller area than one hundred superficial feet, if it does not communicate directly with the external air, and is without an open fireplace, must be provided with special means of ventilation, by a separate air-shaft extending to the roof, or otherwise, as the board of health may prescribe.

In all tenement-houses hereafter constructed, and buildings hereafter converted to the purposes of a tenement-house, each room must have a separate window opening to the outer air.

Each water-closet room must have a window opening to the outer air, and such water-closet inclosure, if provided with a ventilating flue or duct, may have the window opening on any court or shaft containing at least twenty-five square feet in area.

Certain minimum requirements abroad are stated in the following schedule:

Kind of building.	Cubic space per head in cu. ft.	Authority.
General school-rooms (minimum allowed)	130	London School Board.
Graded schools (minimum allowed)	117	" " "
Dundee board school, average	152	
Common lodging-house (sleeping-rooms)	300	Local Govt. Board.
British army barracks (minimum)	600	Army Regulations.
Prisons, seldom under	750–800	Parkes' "Hygiene."
Non-textile workrooms	250	Factory Act.
Army horses (minimum)	1600	Army Regulations.
" " (in infirmary)	1900	" "

In this country the per capita space in churches is generally 300 cu. ft., or more. Schools have about 200 cu. ft. and ordinary halls frequently have only 100 cu. ft., or even less.

10. Cost of Ventilation.

The relatively great cost of ventilation is due not only to a loss of heat accompanying the escape of air through the vent-flues greater than would be the case if they were not provided, but it is also due to the fact that in the case of mechanical ventilation, a considerable part of the expense is chargeable to the operation of the fans, driven by engines or motors.

The relative cost of steam and gas engines, electric and water motors, depends upon a variety of conditions, such as the steam-pressure, quality of gas, voltage, and water-pressure. In a general way, however, for apparatus of 10 horse-power or less, the gas-engine costs much more than any of the others. The steam-engine and the electric motor do not differ greatly in first cost, and the water-motor, in comparison with the others, is very inexpensive.

As to the running expense, gas-engine makers claim a consumption of from 15 to 17 cu. ft. of gas per effective horse-power. With small gas-engines under ordinary working conditions, the consumption is likely to be double this amount, or more, costing with dollar gas four or five cents per horse-power per hour.

It is not uncommon for small low-pressure steam-engines to take from 50 to 75 lbs., or even as much as 100 lbs. of steam per horse-power, equivalent to from 7 to 14 or more lbs. of coal per horse-power per hour, and costing from $1\frac{3}{4}$ to $3\frac{1}{2}$ cents per horse-power per hour. If the exhaust steam is utilized, however, it matters not how much steam the engine consumes, since the exhaust steam is practically as good for heating purposes as live steam.

A common meter-rate for electric motors is equivalent to about 10 cents per horse-power per hour, which, with the discount based upon a sliding scale, according to the power used, is not far from 8 cents per horse-power per hour for a motor of moderate size.

Power developed by water-motors at ordinary city rates varies, according to the pressure, from 30 to 40 cents per horse-power per hour,—a prohibitive rate. Of course, the higher the pressure the less the consumption of water, and the lower the cost.

From the preceding, it may be said that to develop each horse-power per hour would cost roughly, exclusive of attendance, 5 cents with gas, 3 cents with steam when the exhaust is not utilized, 10 cents with electricity, and 40 cents with water, these figures being based upon small machines under ordinary working conditions.

Of these machines, the electric and water motors are the least noisy, and also require the least attention. With the gas-engine very careful treatment is necessary to muffle the exhaust. The steam-engine, if of heavy pattern, low speed, and in proper adjustment, will run practically without noise; but the pulsations of the exhaust should be diminished, by allowing the steam to escape into a reeciver or equalizing-chamber before passing to the exhaust-pipe leading to the roof.

11. Humidity.

The humidity or moisture in the atmosphere is commonly expressed in terms of relative humidity; that is, complete saturation, or the "dew-point," corresponds to a relative humidity of 100. A fair average humidity, in what is considered fine weather, in northern latitudes, is about 70. In certain sections of the country it is often much lower, and in others much higher; and in heated rooms it frequently falls to one third of the above. Whether or not these low humidities work injury to persons exposed to them, is a question in regard to which the opinions of investigators differ.

To whatever extent it may affect the health, it is a pretty generally accepted fact that air which is too dry in heated rooms causes sensations which are not as agreeable to a healthy person as air containing a greater amount of moisture. Since evaporation cools the air, and the rate is more rapid when it is dry than when it is moist, it follows that to secure the same degree of comfort the temperature must be kept at a higher point when the humidity is low than when it is high.

To increase the relative humidity artificially, evaporating pans or fine sprays of water are employed. The former in their simplest forms are the little pans with which most furnaces are equipped, but which, in fact, have little effect upon the large volume of air passing through the heater. The capacity of air to absorb moisture increases rapidly with a rise in temperature. For example, air at 70° F. will absorb approximately eight times as much moisture as air at 15° F. Hence if the air at the latter temperature had a relative humidity of 70, it is quite evident that a large amount of water would have to be evaporated to give the same relative humidity to the air in the rooms. To evaporate a pound of water, 1000 heat-units, in round numbers, are required; and since only from 8000 to 9000 heat-units can be utilized per pound of coal burned, it is readily seen that to increase, to any extent, the relative humidity of air supplied to a building, an amount of coal must be burned to evaporate the water far in excess of what, at first thought, would be considered necessary. The cost of artificially raising the relative humidity in rooms to that corresponding to June weather is not the only drawback, experimenters having found that with a relative humidity in rooms of much over 30, and an outside temperature of 0° F., the windows become thickly coated with frost, due to the condensation of moisture on them.

12. Cooling the Air.

For cooling air on a small scale, ice may be conveniently employed. Each pound in melting absorbs about 142 heat-units; and since 1 heat-unit absorbed from the atmosphere will lower the temperature of approximately 55 cu. ft. of air 1° F., it is a simple matter to compute how much ice must be melted to cool a given volume of air a certain number of degrees.

Chilling the air reduces its capacity for absorbing moisture, and increases its relative humidity.

An excess of humidity causes discomfort, and hence air-supply systems are sometimes arranged to pass the air over trays of chloride of calcium, which has a strong affinity for moisture, and to thus dry the air, after passing it over the ice and before allowing it to enter the rooms.

For large plants a refrigerating machine should be used, with brine at a very low temperature circulating through coils, over which the air is forced or drawn by fans.

* Professor Woodbridge states that "either of two methods may be followed for making the treated [chilled] air salubrious and agreeable. The whole quantity of air cooled may be

* Report on Heating and Ventilation of the Senate Wing, U. S. Capitol, Washington, Dec. 14, 1895.

brought down to so low a temperature as to precipitate the necessary moisture for drying it, and then warmed again by artificial heating to the temperature and dryness essential to comfort; or a part only of the air may be so sharply chilled as to remove the weight of moisture necessary to insure dryness, and this chilled and dried air may then be passed on and mixed with the untreated part, resulting in the drying and cooling of the entire volume of air."

The capacity of refrigerating machines is commonly expressed in "tons of ice-melting capacity in 24 hours," one ton refrigerating effect being equivalent to 284,000 heat-units. One ton of coal should produce at least 13 tons of refrigeration, based upon ice-melting capacity; and one ton of refrigeration should be produced by the expenditure of not over 1.2 engine horse-power.

13. Testing Systems of Ventilation.

In addition to testing the quality of the air, as previously explained, it is often necessary to determine the volume of air entering or leaving a room. For this purpose an anemometer, or air-meter, is used, by means of which the velocity at the register may be determined. Knowing this, and knowing the area through which the air must pass, the volume is readily determined.

Air-pressures may be determined by means of the ordinary U tube, one end being connected with the duct or flue, and the other with the atmosphere, the difference in pressure being indicated by the difference in level of the water in the two legs of the tube. This reading of pressure differences in inches of water may be readily transformed into pressure in ounces by multiplying by .578—this factor being the equivalent, in ounces, of the pressure due to a head of one inch of water.

The humidity of the air may be ascertained by a hygrometer, an instrument provided with two standard thermometers—one, the dry bulb, showing the temperature of the air, the other, the wet bulb, the temperature due to evaporation. When the air is saturated no evaporation takes place and the thermometers read the same. The dryer the air, the more rapid the evaporation of water from the wet bulb, and the lower the temperature of that thermometer, in comparison with that of the dry bulb. The greater the temperature difference, the lower the relative humidity.

A table is provided with these instruments, showing the relative humidity corresponding to various temperature differences.

For determining temperatures in ordinary ventilating work, good standard thermometers are all that are necessary.

14. Ventilation and Acoustics.

*"The arguments sometimes urged against the upward ventilation of auditoriums because of the alleged interference of such ventilation with their acoustic properties are for the most part fallacious and groundless. Sound-waves are disturbed by traveling through air of unequal density. When air lacks homogeneity, because of decided inequalities of temperature or moisture, the travel of sound is affected in somewhat the same manner as is that of light when it passes through heated air rising from a stove or other heat source. Heated air rising in mass and in column form from a floor register through the cooler air of a room, or cold air falling in reversed fashion from a ceiling opening through the warmer air of a room, presents an obstacle to the even movement of sound-

* Prof. S. H. Woodbridge in Report on Heating and Ventilating, House of Representatives, 1899.

waves. When, however, the movement is diffused and the air temperature is approximately even throughout the whole mass, that slow movement, whether upward or downward, has no appreciable effect on sound-travel."

II.—DIFFERENT SYSTEMS OF VENTILATION.

1. Systems of Ventilation.

The fireplace is the simplest example of exhaust ventilation, and the furnace the simplest means for securing a supply of warm fresh air.

With other systems the heat of the fire is first transferred to a medium, water or steam, which in turn warms the air passing to the rooms.

In the furnace system the air is heated by direct contact with cast-iron or steel-plate surfaces, cold air being brought into the space between the body of the furnace and the casing by a box or duct connected with the outdoor air.

Of course if cellar air is used, the fresh-air supply feature is, to a very great extent, lost, the supply depending upon the tightness of basement walls and windows against the in-leakage of fresh air.

The indifference of the dwellers in houses heated by furnaces, in many parts of the country, to the importance of having a cold-air box for a fresh-air supply, is simply astounding, and can be explained only by assuming a widespread ignorance of the bad effects on health from the long-continued breathing of cellar air.

The *indirect* steam or hot-water system works on the same general principle as the furnace, and it possesses several advantages and has a wider range of application. Buildings which would require several furnaces are easily heated by a single boiler, the benches of indirect radiators being placed near the base of the flues, thus avoiding the relatively long pipes common in furnace heating. With the latter, the longer the pipes the more sluggish the flow of air and the greater the chance of failure in heating rooms on the exposed sides during strong winds.

Direct-indirect, as its name implies, is a compromise between *direct* heating with radiators in the rooms, and indirect heating with radiators suspended from the basement ceiling and incased in galvanized iron or wood, and with cold-air and warm-air ducts connected with the spaces below and above these radiators.

This direct-indirect system is a great improvement in point of ventilation over the direct system, but falls far short of the indirect system in positive results.

The greatest difficulty with the direct-indirect method is experienced in mild weather, when a constant supply of fresh air equivalent to that required in cold weather cannot be admitted without over-heating the room, since it must pass up over the radiating surface.

If the steam is shut off, the air enters at the outdoor temperature, which may be too cold for comfort in the room.

With this method of heating, the rooms on the windward side of a building are excessively ventilated, while those on the lee side receive a less generous supply of fresh air on account of the tendency to a vacuum condition existing on that side.

Ordinary indirect systems, commonly called "gravity" systems, depend solely on the difference in the temperatures of the air in the flues and the air outside, to cause the desired velocity. This difference varies with changes in the weather, and consequently the flow of air is not constant, becoming more sluggish as the weather grows milder. Winds also seriously affect its flow. To overcome these faults the "blower" or "fan" system is used.

In the oft-quoted words of the late Robert Briggs, "If air is wanted in any particular place, at any particular time, it must be put there, not allowed to go. . . . No other method than that of impelling air by direct means, with a fan, is equally independent of accidentally natural conditions, equally efficient for a desired result, or equally controllable to suit the demands of those who are ventilated."

The "fan" system is more expensive than others, both in first cost and in running expense, but the results are far superior to those attainable by any other method.

In manufacturing buildings the "blower" system is installed rather as a heating system than as a ventilating system. When there is a surplus of exhaust steam, the greater steam consumption of this system beyond that required by direct radiation is of no moment. The system is generally arranged in its simplest form with a single system of hot-air ducts with dampers at the outlets.

Manifestly this system would be too crude for use in a building in which fans are installed primarily to secure a nearly constant air change.

In such cases the system is commonly arranged in one of three ways:

1. A main heater with tempered air

by-pass and with mixing-dampers at the entrance to ducts.

2. A main heater arranged to supply air at approximately 70° F. to the rooms which are to be heated by direct radiation.

3. A main heater to supply air at from 60° to 70° F. to the ducts leading to reheaters placed near the base of the flues.

System "1" is a modification of the old double-duct system with mixing-dampers at the base of flues, and is commonly used in connection with some method of temperature regulation.

If hand control is necessary, the double-duct system, one for hot air and one for tempered air, may be used to advantage, since the regulating chains connected with the mixing dampers may then lead directly to the rooms.

System "1" is very simple in its arrangement, but when this method is used the temperature of the rooms is affected by winds more than it is with either system "2" or "3," since the windward rooms being under greater pressure from without than the others, secure a smaller supply of air than similar rooms on the unexposed sides. The air will follow the lines of least resistance. The heating surface being concentrated in one place, there is little circulation of warm air when the fan is not in use, and the building, therefore, becomes colder at night and requires a longer time to warm up in the morning than it does with either system "2" or "3."

System "2" has been widely adopted. The heating and ventilating systems are entirely separate, and sufficient radiating surface is installed to warm the rooms independently of the air-supply. In buildings used for certain purposes, where a "shut-down" would be very serious, this system possesses an advantage from the fact that in the event of any trouble with the fan, the ventilation only is affected, while the heating goes on without interruption.

This system is particularly effective

in rooms used intermittently, such as assembly-halls in school-buildings. The rooms are kept warm by direct radiation at a minimum cost, and when they are occupied, the fresh-air supply ducts and foul air exhaust ducts are put into use.

System "3" may be installed at less expense than system "2," and it is somewhat more positive than system "1," possessing the advantage of conducting only tempered air through the ducts instead of air at a higher temperature, as in system "1," which suffers a greater heat loss by radiation. System "3" is naturally more affected by winds than is system "2," in which radiators are placed in the rooms; but since the reheaters, or "supplementary heaters," as they are called, are placed near the rooms which they are to heat, there is less trouble in heating exposed rooms during high winds than is experienced when system "1" is used.

2. Fans and Blowers.

W. F. Butler, in the little treatise on Ventilation which this one supersedes, states that Dr. Desaguliers in 1723 was called in to ventilate the House of Commons, and that after an unsuccessful attempt by means of heated flues which were not properly used, invented a centrifugal wheel or blowing-machine arranged to force the air either into or out of the House as required.

The type of fan commonly used for forcing air through a system of ducts is known as a "blower," and consists of a wheel of the paddle type incased in a steel-plate housing. The fan-wheel is generally made with radial blades, but in the best work these are curved in order to reduce the whirring noise caused by rapid rotation.

The type of fan described is used to force the air through long lengths of ducts and pipes without an excessive consumption of power.

The chief advantage this type of fan possesses over the propeller or disk type is that it delivers a large volume of air against considerable pressure with a consumption of power small when compared with that required by the latter type.

These are used, as a rule, in connection with short ducts of large area, in which the velocity is low, or they are connected with vertical vent-flues.

It is very important in using this type of fan to see that the resistance interposed to the passage of air through the ducts is slight, as it consumes an excessive amount of power, and delivers a relatively small volume of air when operating against considerable friction or pressure.

It is not uncommon to see propeller fans installed where blowers should be used, and vice versa. It is very important that a proper selection be made if economy in operation is to be secured. Blowers should be used for long ducts or with high velocities; propeller fans for short ducts and low velocities. The latter are used chiefly for exhausting air, although they may be employed to advantage for supplying air to buildings of relatively small size.

3. Plenum and Exhaust or Vacuum Systems of Ventilation Compared.

The plenum system is a pressure system designed to force air into a building, creating a slight pressure therein, and overcoming to a certain extent the in-leakage of cold air.

The air-supply may be taken from a source the surroundings and condition of which are known, thus insuring its purity, and when necessary this air may be filtered by passing it through cheese-cloth screens.

The exhaust or vacuum system is a system of ventilation designed to exhaust the air from a building, creating a tendency toward a slight vacuum therein.

With the exhaust method alone, the

air which takes the place of that drawn from the rooms, comes from uncertain sources which may not be favorable to a pure supply.

It is a common mistake to suppose that with the exhaust system all the air required to take the place of that removed will flow in or be drawn in through the flues leading from furnaces or indirect radiation when these systems of heating are used. As a matter of fact, the air which is to take the place of that removed, tends to follow the lines of least resistance, and much of it is drawn in around doors and windows, causing uncomfortable draughts.

On the other hand, all the air supplied with a plenum system will not pass out of the room through the vent-flues provided for the purpose, but instead, much of it will pass out around windows and doors, especially if theso happen to be on the lee side of the building.

The above considerations lead naturally to the conclusion that the best arrangement is to combine the plenum and exhaust systems, using a supply fan of greater capacity than the exhaust fan in order that the air of the room may be under a slight pressure, thus preventing, in a measure, the in-leakage of cold air.

4. Aspirating Coils Versus Exhaust Fans.

The removal of foul air from rooms is generally accomplished by means of aspirating coils placed in the flues. These to be effective should be placed as near the opening into the flue as possible.

Where the flues are small this cannot be done readily, and the flues must be collected in the attic in a chamber in which is placed the aspirating coil.

This should be made up of pipes placed in an inclined position to avoid cutting down the flue area, and so arranged that all the air will pass across them.

Coils strung around the sides of the air chamber or shaft, leaving a large open space in the middle, are comparatively ineffective.

Since the flue action sought is merely that of a chimney, the higher the column of hot air, the greater the "pull" and the velocity of the air in the flue. Accordingly, it is desirable that all vent-flues should have sufficient height and area of discharge, or should be equipped with aspirating coils to provide for the required volume of air when the outdoor temperature is from 40° to 50° F.

The mistake is often made of installing aspirating coils in large buildings, where electrical exhaust fans would be far more efficient and at the same time less expensive to operate in the handling of a given volume of air.

The delivery of air by a fan is not affected to any great extent by atmospheric changes, as is the case with an aspirating coil, which, with a rise in the outside temperature, has less and less effect in causing a flow of air.

A fan is decidedly more efficient than a steam coil for moving air, and while its first cost is greater than the coil, that fact should not be allowed to stand in the way of its introduction in good-sized buildings, as the saving in operation over the heat wasted by a coil would soon make up for any difference in the cost of installation.

5. Downward Ventilation.

The downward method of ventilation is, in the great majority of cases, the only practicable one. In general, the most effective and economical ventilation in which the air is chilled during its passage through a room, is by the downward system. The air entering at the warm-air inlet rises to the ceiling. To distribute this air and make it effective in ventilating, it must be brought down to the seating space before escaping to the ventilating-flues. With rooms having outside exposure, such as school-rooms, the air entering at the warm-air inlet after passing across the ceiling and coming in contact with the cold outside walls, becomes somewhat chilled and descends to the floor, the continuous inflow of fresh air increasing this action. With inlets and outlets properly placed with reference to the exposed walls, this method gives very satisfactory results when a sufficient volume of fresh air for dilution is supplied.

In rooms having little or no exposure, the entering air must be admitted at a temperature below that of the room, otherwise the heat given off by the occupants will more than offset the loss of heat through the walls, and will cause a rise in temperature beyond the point of comfort. The heat given off by each person is practically the same as that produced by a burning candle.

In case it is necessary, for the reasons above stated, to introduce the air at a temperature of from 10 to 15 degrees below that of the room, great care must be taken in the arrangement of openings to avoid objectionable down-draughts.

The air-currents must be broken up and finely divided, otherwise downward currents of cold air will be felt in different parts of the room. This condition will not occur with the downward system, except in cases where the air must be admitted at a lower temperature than that at which it is desired to maintain the air of room. No trouble from down-draughts need be experienced in rooms where the loss of heat through the walls and glass is greater than the heat given off by the occupants, since in such rooms the air must be admitted at a temperature considerably in excess of 70° F., and, therefore, will not have a tendency to descend at once to the floor, but will gradually fall as it becomes chilled along the exposed walls.

With the downward system, as applied in theaters and halls, the warm air exhaled from the lungs is met by the descending currents of air entering at or near the ceiling. This mixture of the two must be re-breathed before it can reach the ventilating openings placed in or near the floor; whereas, with the upward system, the exhalations are carried at once toward the outlets in the ceiling.

Effective downward ventilation of audience-rooms is practicable, if a sufficient volume of air is used for the purpose and if inlets and outlets are properly located. To secure the best results, the inlets must be arranged as stated above, and the outlets located in the immediate vicinity of each occupant. To prevent vitiated air from the gallery and balconies reaching the main floor, the foul air discharge openings from them must have a stronger exhaust action than those in the main floor.

In regard to the volume of air to be supplied with this system, Mr. A. R. Wolff in a pamphlet on The Ventilation of Buildings, recommends an air-supply of 3000 cu. ft. per occupant per hour; but states that for theaters having a large space per capita, and in which the atmosphere is perfectly fresh at the outset, and where the space is occupied for only two or three hours at a time, the air-supply may be safely reduced to 2000 to 2500 cu. ft. These amounts range from about 33 to 50 cu. ft. per minute, as against 20 cu. ft. per minute for excellent results with the upward system.

The downward system is very ineffective in giving relief in hot and muggy weather, and is out of the question for rooms in which smoking is to be indulged in. It is, therefore, important when possible to so arrange the downward system of ventilation that it may be made reversible to provide for these conditions. The German House of Parliament is arranged with such a system, operated as follows: For an hour or so before occupancy, warm air is admitted at the top and drawn out at the bottom. As the chamber is filled, the system is reversed. Tests on the down-draught system showed the air in the room to be very oppressive, especially in muggy weather, whereas when the air was let in at the bottom, after being moistened in its passage through the warming chamber, it was found to have no unpleasant effects whatever.

Another point to be borne in mind in downward ventilation is that if the system is to be used in summer, the air passing through the ducts in the attic space is likely to become so heated that it is rendered unfit for use.

6. Upward Ventilation.

Another method of ventilation consists in removing the impurities instead of diluting them. This is the upward system. The heat given off by each person sitting in a room causes an upward current in the surrounding air. If, then, an ample supply of pure air is admitted at each seat, in such a manner that it will cause no uncomfortable draught, the space occupied by each person will be continuously and thoroughly flushed, and all impurities given off will be carried up with the ascending current of air toward the ceiling, at which point the foul air will be removed through suitable openings. These openings should connect with ducts leading either to exhaust fans or to flues in which are placed aspirating coils. This method of ventilation is generally employed in theaters and legislative halls, where the seats are fixed in position.

With upward ventilation, where each person is provided with an individual air-supply and all impurities are at once removed, a smaller volume of air is necessary than with the downward system, where the atmosphere is maintained at a certain degree of purity by dilution.

It is important in either the upward or the downward system that the volume of air supplied should exceed that of the air removed by exhaust fans, so that the air in the rooms will be under a slight pressure; otherwise cold air will be drawn into the building through doors and windows, causing draughts, or, in the case of theaters, smoke will be drawn in from the foyer and smoking-rooms.

It is important that the ceiling be kept at a higher temperature than the air of the room, as in the case of ceilings chilled by skylights or roofs the air coming in contact with them becomes cooled and falls toward the floor in objectionable draughts.

These down-draughts may be overcome by placing coils or radiators near the ceiling to intercept them, or by slightly warming the attic space.

The coils referred to may generally be hidden from view by placing them above cornices.

III.—THE VENTILATION OF DIFFERENT CLASSES OF BUILDINGS.

1. Residences.

In dwellings, furnaces or indirect steam or hot-water radiation furnish the desired supply of air, provided the ducts are properly arranged. In order to heat houses efficiently in severe weather by either of these systems, it is necessary to change the air in them about once every fifteen minutes, thus giving an ample supply to the usual number of occupants. In fact, many systems are arranged to have the stories above the first heated by direct radiation, dependence for fresh air being placed upon open windows in the sleeping-rooms.

One great advantage of a warm-air system, whether a furnace or an indirect steam or hot-water apparatus, is that the rooms cannot be heated without at the same time supplying them with air, which, if the basement ducts are properly arranged, is relatively pure air.

The direct-indirect system, in which the radiators are located in the rooms and connected with cold-air ducts leading through the walls, gives a limited air-supply; but it does not give as great a supply as in the case of indirect heating with all the surface in the basement, and with cold-air ducts leading to and warm-air ducts leading from the "benches" or "stacks" of indirect radiators.

The "blower" system is seldom installed in ordinary residences, although it is not uncommon in the larger ones in our principal cities, particularly New York. In the latter class of buildings, even where the system is not used throughout, it is advisable to adopt it for the ball-rooms and for those rooms likely to be occasionally well filled with guests.

2. School Buildings.

In small school buildings having from four to six rooms, the furnace system, when properly installed, gives good results at about one half the first cost of the indirect steam system, which is the one commonly used in buildings ranging in size from those having the number of rooms stated, to those having from twelve to sixteen rooms.

Larger buildings should have mechanical ventilation, and if proper attendance can be assured, such a system may be appropriately used in buildings having as few as eight rooms.

The details of furnace heating in school buildings differ from those followed in dwellings. The flues are much larger in proportion to the space heated, and horizontal runs are practically eliminated by placing the furnaces directly at the base of the flues.. Furthermore, the heat is controlled by mixing-dampers, which regulate the temperature of the air without seriously affecting the volume delivered.

The air discharged from the rooms should be made to pass through flues the air-flow in which is accelerated by a heater or by steam coils, otherwise the flow will be very sluggish in mild weather, since the velocity depends upon the difference in the temperatures of the air inside and outside of the flue.

Indirect steam-heating systems are arranged somewhat in the same manner as furnaces, benches of radiators taking the place of the latter at the base of the flues, and mixing-dampers being used to control the air temperature.

Each vent-flue should have an aspirating heater, placed as short a distance above the opening from the room as possible, for the lower the heating-coil with reference to the top of the flue, the greater the velocity of air created. It is of course sometimes necessary to group the flues in the attic in an aspirating chamber, but this method is not so effective as the one just described.

Assembly-halls used intermittently should be heated by direct radiation, and the air-supply and ventilation should be shut off except when the hall is occupied.

The coat-rooms should be heated by direct radiation and should have ample exhaust ventilation. The principal toilet-rooms should receive very careful attention in the planning of a system, and positive exhaust ventilation should be provided. It is not advisable to force air into such rooms, since it may leak out again into others; but with direct radiation for heating, and with a strong exhaust ventilation, the flow of air is bound to be *into* them. All ventilating flues should be connected with an exhaust fan, or should have steam coils supplied by a small steam boiler to maintain heat in them during mild weather when the main boiler is not in use.

3. Churches.

Small churches are generally heated by furnaces, which furnish a supply of air, and possess an advantage from the fact that the heating may be quickly accomplished, and that when no longer needed, the fires may be allowed to go out. No care need be taken to prevent freezing, as is the case with steam and hot-water systems.

For larger buildings the "fan-furnace" system is used, giving a more positive air-supply than with simple furnaces. The indirect steam system gives good results in buildings of this class; and the best results are usually obtained by having the warm air enter through registers placed either at the ends of pews or in the walls about 7 feet above the floor.

The exhaust ventilation takes place through openings in the front of the platform, the space below it being connected with an exhaust duct.

Fan systems may be arranged in such

buildings in a variety of ways, the general methods being about the same as those described for school buildings. One of the simplest methods is that of forcing the supply of tempered air through supplementary heaters placed at the base of flues, these flues terminating at registers in the window-sills or walls. The air-supply is thus delivered around the entire periphery of the room, and is then drawn through the seating space to properly located openings in the ends of the seats, or in the front of the platform. An exhaust fan is connected with the ducts leading from these openings.

A very simple but effective method of supplying air to churches is that of using the entire space under the auditorium as a "plenum" chamber, tightly caulking or weather-stripping the basement windows and other places where the air would be likely to escape, forcing a liberal supply of fresh tempered air into this space and allowing it to escape through openings which are located under the seats in a manner similar in general arrangement to that in which they are disposed in theaters. The details for church work, however, are somewhat different from the arrangement in theaters, as the air issues from a long slot in the lower side of ducts placed immediately under the seats where they do not show. Vertical supply connections are made with these ducts at the ends of the pews. Of course there is considerable leakage of air when this method is used, but this is not a serious matter, as the ventilating apparatus is in operation for only a few hours each week. Its simplicity commends it. The heating of an auditorium which is supplied with air in the manner described is accomplished by direct radiators located, as a rule, in recesses provided under the windows, these radiators being screened by ornamental register faces.

With the forced-air supply issuing through openings under the seats as described, no ventilating flues whatever are required, as the air will readily escape through the crevices in walls and ceilings.

By the use of electric fans the very desirable results of a forced-air supply and exhaust ventilation may be obtained even in small churches. The initial outlay is not great where good results are considered necessary, and the running expense, even with a high rate charged for electric power, amounts to but little, since the apparatus is in use for so short a time each week.

The air-supply per occupant in churches need be only about two thirds of that required for schools, since the amount of space per person is much greater and the period of occupancy is considerably shorter. Twenty cubic feet of air per minute per occupant is considered a fair allowance.

4. Halls and Court-rooms.

Small assembly-halls may be efficiently ventilated by the indirect system, with the ducts furnished with mixing-dampers; and the exhaust ventilation may be effected through heated flues. If the hall is large enough to warrant it, electric supply and exhaust fans should be provided.

In legislative halls with fixed seats, mechanical ventilation is generally provided and arranged in the same manner as for upward ventilation in theaters, the fresh air being admitted near the seats, through openings in the risers to the several tiers, or in the desk-supports.

5. Theaters.

In the ventilation of theaters by the upward system, the space under the auditorium is used as a plenum-chamber, and there are openings under the seats or in perforated chair-legs. In this way each person receives an individual air-supply, which, after passing over him, ascends to the ceiling, where the vitiated air is drawn off by means of an exhaust fan.

Such systems require only about twenty

cubic feet of air per occupant per minute to give good results. The air exhaled from the lungs, being warmer than the surrounding air, rises, and with the upward system the exhalations are removed without being again brought into contact with the occupants. Particular attention must be paid in theater ventilation to the exhaust ventilation of foyers and smoking-rooms, in order to insure an *inward* current of air into these rooms through doorways or other openings.

It is practically impossible to secure proper ventilation of theaters without employing fans.

6. Hospitals and Asylums.

In the heating and ventilating of hospitals, furnaces are rarely employed except in buildings of very small size.

The direct-indirect system is of course preferable to direct radiation for this service, as in cold weather a good air-supply can be secured. In mild weather, however, it is difficult to obtain an adequate air-supply without overheating the rooms.

The plain gravity indirect steam or hot-water system affords a simple and fairly effective method of supplying air to buildings not large enough to warrant the use of a complete mechanical system. Mixing-dampers should be provided. If electric fans can be employed in combination with indirect radiation, the system will be more effective, and especially so in mild weather.

With any of the above systems for supplying air, exhaust ventilation should be provided by means of either heated flues or fans.

In the main wards the air may be admitted through openings below the windows and between the beds, and exhausted through several large fireplaces or through openings near the floor.

A more perfect distribution of the air is secured by placing a vent-opening under each bed. Such openings, if used, should be located a few inches above the floor, to prevent their becoming clogged with dust, as would be the case with floor registers.

The blower system is particularly effective in hospitals where a continuous and large volume of air is necessary. This system is commonly arranged in conjunction with direct radiation, the latter being sufficient to heat the building, and the blowers supplying tempered air to the rooms. With this arrangement, in case anything should happen to the blower, engine, or motor, while it would interrupt the ventilation, it would not affect the heating. The temperature of the air-supply and that of the rooms should be controlled by thermostats.

The blower system may also be arranged with supplementary heaters, and in certain cases the double-duct system, with mixing-dampers, may be employed.

For the heating of hospitals for the insane, the registers should be of special design known as the "asylum" pattern, and operated by means of a key. The fret-work on such registers is designed to prevent the inmates from passing their fingers through the register-faces.

Floor registers must never be used in such rooms. The inlet registers should be placed 6 or 7 feet above the floor, and the vent registers near the floor. It would be out of the question to place radiators in rooms occupied by insane patients, unless such radiators were placed above reach, or were screened.

7. Office Buildings.

Provision is rarely made for the proper ventilation of office buildings. Direct-indirect radiation is not infrequently installed, giving, under certain conditions, a reasonable supply of air to rooms having few occupants. Exhaust ventilation of toilet-rooms by means of fans is generally provided. The rooms below grade require careful attention, a change of air in engine-rooms and boiler-rooms once in every five minutes being not too frequent. This is accomplished by mechanical means, both as to the supply and the discharge, unless a space around the smoke-stack is provided. The ordinary vertical-flue arrangement cannot be used in modern office buildings, because in the lower stories there are generally few partitions, and the windows are so large that insufficient available space is left for flues.

The corridor system in connection with blowers overcomes this difficulty.

In this system the air-supply is taken from the roof or from a court or area; fans in the basement discharge this air to a system of ducts placed above false ceilings in the corridors; registers discharge warm air near the ceiling line of each office; and circulation is maintained through the rooms by means of register-faces placed near the floor and connecting with the corridors, from which the air escapes up the stairways and elevator-shafts, or through toilet-rooms, to openings at the top of the building.

A more perfect and at the same time

a more expensive system is one in which radiators are used in each room to counteract the loss of heat through the walls and windows, and in which a supply of air at about 70° F. is brought in to provide for ventilation. This system is, however, far more expensive, but the heating of the building, especially during high winds, is more uniform than with the ordinary blower system introducing air to the rooms at a temperature of from 110° to 130° F.

8. Department Stores.

At certain seasons of the year the modern department store requires such a large supply of fresh air, that it can be secured in no other practicable way than by the use of fans.

The fresh air is drawn by basement fans from the roof or from openings some distance above the sidewalk, in order that it may be reasonably free from dust.

It is not customary to install fresh-air flues and vent-flues in the upper stories, because, owing to the large window area, it is almost impossible to find space for them. These stories are generally heated by direct radiation. The blower system permits a better arrangement for heating the vestibules than any other, as re-heaters having a large amount of surface, and through which air is forced and heated to a high temperature, may be placed in the basement. This air is then discharged through registers or screens into the vestibules, where it becomes mixed with the incoming cold air. It is practically impossible to provide too liberally for heating these spaces, as at certain seasons, which are generally the coldest ones, the doors are kept practically wide open by the crowds surging in and out.

9. Manufacturing Buildings.

The simplest arrangement of the blower system in manufacturing buildings consists in locating the fan and heater at about the middle of the shop, discharging the heat through galvanized-iron ducts suspended overhead and leading toward the ends of the building, and having a series of outlets through which the hot air is discharged against the walls. This air is then drawn back to the heater and is "rotated." A fresh-air connection should be made with the outside of the building, to be used when necessary for ventilation.

Blower systems in shops are not generally installed for the purpose of ventilating them, but are used primarily for heating. In textile mills and other factories several stories in height, flues may be carried up on the outside brick walls with outlets on each floor, the blower forcing hot air into the base of these flues through underground ducts.

This makes a very convenient system, and presents a better appearance than one in which galvanized-iron ducts are strung about the rooms; but the system must, of course, be incorporated into the general building plans.

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