

## HEATING AND VENTILATION OF PUBLIC BUILDINGS.

BY THOMAS ELKINTON.

In the sixth month number of *The Student*, for 1888, was published an article furnished by me at the request of the editor on the subject of "Ventilation," which treated of a few general principles, and of their applicability to dwellings and other buildings, but the scope of the article did not cover more than the commencement of the subject and did not touch upon any of the methods of accomplishing the desired results.

It is a hopeful sign that the public mind is becoming more and more awake to our needs for improved ventilation in large buildings and to realize that while good progress has been made in civil and mechanical engineering, and much attention paid to architecture and substantial building, sanitary engineering and hygiene have been greatly neglected.

Probably one reason for so little progress having been made in these matters is that in the first place the problems are really very difficult ones to deal with, and the ability to deal with them, though obtained partially by study, comes better by more extended and continued observation than is usually given to it, and very unfortunately, ventilation is a subject on which one is tempted to enjoy a confidence inversely as the extent of his knowledge.

With every one thus the director of his own ventilation and his own plans of hygiene, the demand for persons skilled in the profession in these lines has heretofore been very limited, and buildings for generations have been erected with but little provision for a proper air supply for the inmates; and, as a result, the hygienic condition of most of our buildings is far from creditable to an age pretending to civilization and refinement.

Professor Morse, in his *Japanese Homes and their Surroundings*, remarks that a Japanese "would look upon the usual

public gatherings of our people in lecture-halls, school-rooms and other closed apartments \* \* \* as filthy in the extreme." A judgment which the sooner we realize as correct, and the sooner we aim to render untrue, the better for our general health.

As a rule, the offices in which business men spend most of their time become very foul when the weather requires the windows closed; lecture-rooms generally dismiss their audiences in profuse perspiration, and with lungs which have been bathed with the exhalations of many others; and court-rooms and other places of mixed assemblages hold their occupants and attenders for hours in an atmosphere totally unfit for the health of human beings.

These evils being apparent to the most careless observer, and the necessity for improvement partially acknowledged, the next step is the arousing of public interest to the point of declining to rest short of their removal, and to publish methods by which this may be effected.

As above intimated, the first idea to dismiss, is that properly heating and ventilating a large building, as it should be done, is an easy thing to accomplish, and that while we must not stop short of good results, far in advance of what we have as an average been heretofore contented with, we must realize that perfection is a matter of the future, or at least not of the immediate present.

He who deals with currents of air finds, in its elasticity, laws of motion, temperature and moisture, features which baffle him at unexpected turns, however long his experience and close his observation.

Experience, however, does teach, and knowledge is power, even when dealing with air, and although we may be but upon the threshold of what we may in the future accomplish in heating and ventilating our buildings, we have already enough at command, if we will but use it, to vastly increase our physical comfort and welfare, and may leave to our successors to improve as they can upon our methods and appliances.

Another matter to be dismissed from the public mind is the idea that heating and ventilation are to be satisfactorily

obtained without paying a reasonable price for both plant and maintenance.

Too often is it the case that the expenditure of a few thousand dollars for matters of architectural effect or decoration of interiors is borne with greater equanimity than the expenditure of an equal amount for the more useful appliances of a good and healthful air supply for the inmates.

It is not well to build and finish offensive to the eye, but much better to fail to please the eye than to fail of an adequate food for the lungs, and to entail consequent impoverishment of the blood.

To heat without ventilation may be done at comparatively little cost, but as the ventilation for large and continuous occupancy means the changing of the volume of air at short intervals, the cost will be greater, though not in proportion to the number of changes and not in proportion to the increased benefit.

Fifty years ago, buildings were heated by stoves and had no provision for change of air beyond the leakage of the doors and windows and the flow of air through the walls. It may be remarked in passing, that a room heated by stoves will remain for a short time surprisingly pure in its condition, because of the rapid transfer of the lower strata to the upper by the currents induced by the hot surfaces of the stoves, but when the volume of the room becomes uniformly bad, as it quickly does, the condition cannot be described in terms of refinement.

No public buildings now are constructed without some recognition of the importance of ventilation, but, as a rule, the recognition is scarcely more than in appearance, providing, as they do, only partial outlets for foul air with scarcely any opportunity for the inflow of pure air, the fact being seemingly constantly overlooked, that while the provisions for the passage of foul air are well enough in themselves, they are of little account without provision for the inflow of pure air.

It is true, windows and doors afford inlets for air, but as the choice between pneumonias and neuralgias and the evils of foul air are not worth discussing, all such sources

of air supply is to be dismissed from a discussion of apparatus adapted to American winters.

Much difference of sentiment exists as to the proper temperature for rooms best promotive of the comfort and health of the occupants, and the ideas of different nations present curious phases.

Curtis tells us that the Chilians, with a climate similar to that of Washington, think that fires in a house are unhealthful, and wear their heavy wraps indoors as well as out, and although coal is cheap and wood abundant, sit in their houses with noses blue and teeth chattering, and at fashionable gatherings women appear in evening dress, with the thermometer between  $40^{\circ}$  and  $50^{\circ}$ . He also states that the mortality from lung and throat complaints is reported to be immense.

The Englishman, too, sits in his large parlor with a small grate, and considers himself comfortable with the thermometer in the fifties.

The proper temperature for every individual is probably that at which he is most comfortable, and this will vary with the physical condition and manner of dressing; one who dresses very warmly needs but little for wraps, and will be oppressed with a temperature agreeable to one who makes more difference between indoor and outdoor wear.

As "comfortable" points, however, are not in use on the thermometer scales, we must express ourselves by the degrees marked upon them, and in practice an average amount of comfort may be secured in our latitude by about  $65^{\circ}$  for audience chambers, where the occupants sit with their wraps,  $69^{\circ}$  to  $70^{\circ}$  for schools, and  $1^{\circ}$  or  $2^{\circ}$  higher for parlors, with elderly people in the family.

Heating a building is generally attended to so far as providing against its being too cold, but the regulation of the temperature to provide against overheating and for the supply of a proper volume of pure air, are points which are very seldom secured.

Omitting for the moment the regulation of the temperature and considering the volume, and without citing all the authorities as to what constitutes a proper air supply *per*

*capita*, it may be briefly stated that they vary from ten cubic feet to sixty feet per minute, the lower estimate, however, being based upon the theory of each one in an audience receiving at each inhalation a supply of pure air, and discharging it where it cannot be again used, a condition only possible out of doors in a stiff breeze.

Sixty cubic feet of air *per capita*, per minute, for an audience, school-room, or class-room, with much more for the sick-room and the hospital, will, it is to be hoped, at an early day be acknowledged as the requirement for good ventilation, but in the present stage of education in these matters it is probably, as a matter of expediency, better not to state the scientific requirement, but, in order not to defeat the rising tide of healthful sentiment, name forty cubic feet per minute *per capita* as a satisfying quantity for the time.

Forty cubic feet *per capita* per minute means for a class-room with thirty, 1,200 feet per minute; for a parlor of fifty visitors, 2,000; for a school-room of 100, 4,000; for a lecture or court-room of 500, 20,000; and for an audience of 1,000, 40,000 cubic feet; and lastly, for the larger audience of 2,500, 100,000 cubic feet of air per minute, as the requisite air supplies for a moderate estimate of the human needs when thus assembled.

How many of the buildings of the day are thus furnished with an air supply like this, or anywhere approximating it.

Doubtless, these figures are startling to such as have not considered them, but they are not unreasonable, even if we have lived for many years with but one-fourth or less of the supply, when we have been at lectures and elsewhere in large audiences and crowded rooms.

Suppose each of our heads were encased for a minute in an air-tight box less than three and one-half feet dimension for each side, or forty cubic feet capacity, and had taken about a dozen full inspirations and expirations of our lungs, would we not deem it proper to have a fresh box at the expiration of that minute, especially if, instead of having the air-tight box exclusively for our own use, we were sharing our exhalations with a neighbor, and in turn were partaking of the exhalations of his lungs?

An audience room for 1,000 seats on floor and galleries would be about sixty feet wide, eighty feet long and twenty-five high, and contain 120,000 cubic feet, and the introduction of 40,000 cubic feet per minute would change the entire volume once in three minutes, or twenty times per hour, a change which it is to be hoped the future will deem little enough, but is immensely in advance of the average present usage, which probably often does not change more than three or four times per hour, if even that frequently. For reasons which I cannot explain, unless it be that for the same percentage of vitiation, the unpleasant odor developed is less when the air is quickly changed than when it is slowly changed, I am inclined to the view that there will, for large, crowded rooms, be the same apparent sweetness, on a less inflow *per capita*, than in a smaller room with fewer in it. Thus in a class-room of thirty, with at least twenty feet *per capita* of inflow, the room has seemed more foul to me than a lecture-room crowded by an audience of 500 persons did with the same supply *per capita*, or 10,000 cubic feet per minute, and I am satisfied that a sitting-room with three or four occupants and closed doors will not remain pleasant short of sixty cubic feet per minute air supply, and that a class-room requires forty feet *per capita*, and that a larger audience will be equally comfortable with a little less; but without explaining these differences, I would have the air supply whenever possible up to these requirements.

The degree of temperature and the volume of air per minute to be maintained having been fixed upon for our needs, further details remain to be considered.

There are probably but a few buildings in existence in this country in which, on continued occupancy by large assemblies, the temperature does not, in a short space of time, rise to an uncomfortable degree, even, it may be, so much as 20° in the course of an evening or single session, and be maintained at these points, although the closing of registers and radiator valves has discontinued the source of applied heat. Apart from the heat of the lamps and gas lights, the main source of increased heat comes from the

audience, each one of whom is a human stove of  $98^{\circ}$  temperature, radiating what with a few in a room is scarcely perceptible, but with many produces a great increase, and hence it is that while for the warming of a room in cold weather previous to its occupancy the incoming air must be at a comparatively high temperature, it must be greatly reduced after the human stoves have occupied the room and their wraps and outside clothing, cooled by the weather before reaching the room, have become of the same temperature as the room.

As we are considering only the problems of cold weather, we dismiss as dangerous and barbarous the relief of overheated rooms by the opening of doors and windows to the outside air, and can allow of no arrangement but that which supplies the place of the outgoing impure air with that which is fresh and has been properly warmed.

Considering next the principles to govern the arrangements for the exit of foul air from occupied apartments, there has been more or less controversy as to whether ventilation should be from top or bottom, with the probably now well-accepted result that both are correct, according to circumstances.

In a room with few occupants, the greater part of the air exhaled from the lungs cools and falls to the floor, being also increased in specific gravity by the impurities added to it in the process of breathing, and hence for sitting rooms and chambers, the floor line (not the line above the wash-board, as mechanics often insist and too many architects allow) is the proper level for the foul air outlets.

Doubts have been expressed by well-informed men as to the necessity and importance of floor ventilation; but besides the obvious advantage of drawing off the layer of cool air apt to rest upon the floor level, the experiments of the late John M. Whitall, some years ago in the sick wards of the Philadelphia Hospital, by which he found that as he lowered the outlet for foul air by successive steps until he placed them at the floor line, he lowered the sick rate of the ward, demonstrates too conclusively to admit of cavilling

the importance of floor-line ventilation for rooms of small occupancy.

It is true, a portion of the lung exhalations are volatile, and to be found at the top of the room, and for these and the heated gases from lamps and gas-lights a small outlet at the ceiling would be correct; but as open registers at the ceiling would on ordinary occasions be but an outlet for pure air, and a waste of fuel in consequence, it is safe to dispense with them in ordinary sitting-rooms and chambers and trust to the dilution of the upper strata by the warm air rising from the registers to the ceiling and thence falling to the floor and passing out at the floor-line vents.

For parlors, however, where large companies are to be occasionally entertained, it is better to provide ample ceiling ventilation for reasons presently stated, but to be careful to keep them closed ordinarily.

The volatile exhalations which are found at the top of the room become more worthy of attention as the occupancy increases in numbers, and they become perceptible "odor" to visitors from the fresh air, and the question arises, Which is the lesser evil, to provide for their removal at the risk of wasting pure air and fuel and destroying the floor ventilation, or to endure the slight odor, which, if the air supply is at all reasonable, is not serious in itself?

With the usual risks of unskilful handling of registers by careless or indifferent attendants, it is probably better to dispense with the ceiling ventilation, but with skilful and interested caretakers, it would probably be as well in class-rooms and similar rooms to have ceiling registers, with rigid rules for closing them when the rooms are not occupied, taking care also that the ceiling outlets shall at best not exceed in area one-fourth of that at the floor line.

In large and crowded rooms, like lecture and court-rooms and meeting-rooms, the problem again changes. In these cases the air supply will or should be much below that of the temperature of the human stoves, and from these human stoves are continually ascending currents of heated air, carrying with them the exhalations of the lungs, and for such rooms, when sufficient inflow of air is supplied, the



ventilation may safely be at the ceiling; providing, however, a trifling outlet at the floor for circulation purposes when warming the room previous to occupancy, at which time the ceiling outlets should be closed.

Allusion may here be made in passing, to what has doubtless surprised many who have attempted to relieve rooms which were originally constructed devoid of ventilation facilities, by adding ventilation at the top or by the pulling down of windows. They have reasoned that if a room was overheated, the hot air at the top would escape if opportunity was offered, and they reasoned correctly to that extent, but they overlooked the fact that for all the air that escaped there must be an equal volume to take its place; and hence in the room described, the supply would come in just where it went out, or rather a stream of hot air would go out one portion of the opening and a stream of cold air pass in the other part. As air does not heat quickly from itself, a chilling body of cold air, whether from ventilator or window top, falls upon an audience, and as they are previously overheated, the sudden blast is a source of danger to them, and the last state of the audience is worse than before.

An old-fashioned meeting-house in Philadelphia, constructed in the beginning of the century, without ventilator appliances, was altered some thirty or more years ago by the addition of central ventilators in the ceiling, opening with cupola and slat-work through the roof, but they were unavailable in cold weather for reasons above mentioned.

A year or more ago, I tried the experiment of covering one of the ceiling openings with a sheet of metal perforated with small holes not exceeding one-fourth of an inch in diameter, knowing that although the cold air must come through some of the apertures as the heated air passed through other apertures, yet I had a hope that as the incoming currents were finely divided streams, they would, in passing toward the floor, twenty-five feet distant, become so nearly the temperature of the room as to become harmless as to temperature. I was, however, disappointed and the device proved useless; it might have worked if the heated

air had gone out at alternate apertures with those at which the cool air came in, but the probabilities are that the outgoing currents massed at one-half the plate and the incoming at the other, and the latter joining together as they fell, made the operation of the ventilator about the same as if no perforated plate had been used. Very likely, if I had carried alternate tubes to within eight or ten feet of the floor, with the hot-air apertures between the pipes, there might have been better success in the result.

I was lately shown another plan for relieving an oppressive lecture-room of heated air and supplying it with fresh air, but it too was a failure, and I consider all attempts at ventilation and air supply as misspent means and labor, unless they comprise ample facilities for warming or tempering the inflowing air when the weather is cold.

Coming now to the consideration of the methods of heating rooms and buildings, the use of stoves and direct radiators placed in rooms must be discarded, because of their furnishing no air supply to the rooms. Some advantages have been supposed to arise from radiated heat, because affording sensible warmth and admitting of cooler air for breathing, but less stress is now laid upon this than formerly, and it is of no practical account for large audiences.

Openings are sometimes made adjacent to the ordinary direct steam radiators in rooms, but their action is uncertain, as, at times when the wind is unfavorable, the air will pass out through the openings instead of into the rooms, and when the weather is very cold and the wind favorable for the air supply, the portion of steam surface presented to the current of air is inadequate for its warming, and the aperture is closed because the room cannot be kept warm enough on account of the cold current.

Hot-air furnaces are an advance upon stoves, because all the heating done by them is accompanied by a volume of air of greater or less amount, and for years to come, for many private and some public buildings of moderate size, hot-air furnaces will probably be used, and within reasonable limits may answer a fairly satisfactory purpose.

The besetting shortcoming of the day, however, is that the furnaces for buildings, whether private or public, are altogether inadequate in capacity for the work that ought to be done, and the air supply to the furnace and the flues for conducting the air to the rooms are seldom half the size they should be. The consequence is that many buildings cannot be warmed in zero weather by their furnaces, the air supply is never sufficient for the occupants, and as the furnaces are often necessarily forced and without water evaporation, the air is supplied at a high temperature, and the floating particles in the air being burned upon the overheated surfaces, the quality of the air furnished to the living rooms is baked, unpleasant and unwholesome.

It will be urged that larger furnaces will cost more to erect and run, which is true as to first cost, but, within certain limits, not true as to maintenance, because it is quite as expensive to run a small furnace beyond its capacity as it is to run a furnace better proportioned to the work.

In building flues for inflow and outflow, it is not well to build smaller than twelve inches square because of friction, the total area, I think, should equal one-third of a square foot for every 1,000 cubic feet of contents. This will bring controversies between owners and builders; but I have a hope, future owners and builders will be willing to plan their flues first and adapt the balance of the house to them. In large buildings flues eighteen inches square are a good size.

With furnaces or any other method of heating, there should be provision for changing the temperature of separate apartments, without such regulation of the furnace as inconveniences other parts of the house, or the closing of registers and restricting the air supply. This has seldom been attempted. Two cases of private houses are within my knowledge, in which the air was taken at will from the top of the furnace or from the bottom, but the mechanical work was at fault in one case and the flues too small in the other to be wholly successful; but these are matters which experience can quickly cure.

In the case of lecture or other rooms of sufficient size to require one or more furnaces for their especial warming, a

simple device will greatly relieve the overheating. This I accomplished for a meeting-house in Philadelphia by having large openings made in the furnace chambers above the drums and causing the doors to these openings to be worked by the Johnson heating regulating apparatus, which at the same time worked the draught of the furnaces.

Thermostats placed in the meeting-room, being set at a given point, the operation is that when the temperature of the room rises above this point, the draughts of the furnaces are closed, thus reducing the fire, and air is admitted to the furnaces above the drums and passes up into the room only partially heated until the temperature falls to the regulation point, when the cool-air opening is then closed, the air follows the usual course through the heating chamber and the draught is put on the fire.

The foul-air ventilation is at the ceiling, and the apparatus works very well for an appliance made to an ordinary furnace; and all lecture-rooms, heated in the usual way by furnaces, could be greatly improved in this way at a moderate expense, although no furnaces of the old patterns are probably of sufficient capacity and air supply to meet the proper demands of an audience.

The best furnaces for capacity and the best arrangement of heating and ventilating by hot-air furnaces that have as yet come to my knowledge, are the Rutan hot-air furnaces and the Rutan arrangement of flues, furnished and planned by Smead, Wills & Co.

These furnaces are so arranged that the cold air passes at will under the furnace or through it, or partially in each way, and the sizes of the flues are in accordance with a suitable provision for the ventilation of the building.

With the ordinary steam apparatus, indirect heating or placing the radiators at the base of flues is relied on for the purpose of warming the air before it enters the room, and the flow of air through the flues is relied on for the air supply. The current is thus dependent somewhat upon the amount of steam supply to the radiators, and somewhat upon the suction or pull of the foul air or ventilating flues of the building.

This indirect system answers partially well for dwellings and rooms of but few occupants, but is totally inadequate for the wants of class-rooms and rooms of many occupants, as the diminished temperature required when the rooms are full curtails the ascending force where the most air is wanted, and moreover, as the outside temperature approaches the inside requirements, all the systems of natural draughts depending upon the difference in weight of the outside and inside columns of air completely fail of their desired efficiency.

Without dwelling at greater length in illustrating these points, because they are probably obvious to all who of later years have examined the subject and have had experience in contending with the practical solution of heating and ventilating problems, I think it may safely be stated that the time has come for, and the state of sanitary engineering education warrants, the abandoning of all reliance upon natural draughts in the ventilation and air supply of all large buildings or rooms of crowded occupancy of whatever character, private or public, with perhaps occasional exceptions of single rooms opening directly at the top.

This point being reached, there remains only the consideration of its alternative, or forced ventilation.

Forced ventilation may be secured by artificially heating the exhaust flues or shafts, or by exhaust fans, either of which plans will withdraw the foul air from the respective rooms, and thus induce an inflow of pure air to the rooms at the inlet. In some cases, perhaps, this is the most convenient method that can be adopted.

A minus condition to a room, however, will induce currents from all openings, as well as those intended for the air supply; but the leakage from windows and doors of cold air, as well as the quickening of the currents of air cooled by direct contact with the windows and walls, are undesirable.

The minus condition may also, in many cases where the inlets and outlets of the rooms cannot be placed advantageously, result in a direct passage of the pure air to the outlets without distribution through the room, thus making thoroughfares of wholesome atmosphere, but leaving great masses of stagnant air between them.

Ventilation shafts, if of much size, and of a height to be effective, are expensive, and the cost of maintaining the upward current by applied heat is not economical, for the experts tell us that one pound of coal will accomplish twice the work in moving air when expended as power that it will accomplish when expended as heat; and, further, the construction of exhaust shafts is often incompatible with the convenient arrangement for large buildings, excepting by increasing the number of them and largely adding to the cost of construction.

On the other hand, a plenum condition of a room, or that resulting from having the fresh air forced into the rooms, obviates some of the disadvantages of the minus or exhaust system, for the pressure being upon all parts of the room, the cold air is pressed against at all the cracks or leaking places of doors, windows or elsewhere, instead of being encouraged to enter; and, again, an open door from either out-of-doors or a cooler hall or room, is not the means of having rude blasts of shivering air enter the room, disagreeable and dangerous to the inmates. For hospitals and other places, where it is desirable that even small portions of air from a room should not be allowed to pass into other parts of the building, it may be needful to assist the exhaust flues of the rooms by artificial means; but for all ordinary buildings, such as school-houses, lecture-rooms, etc., when properly arranged with vent for each of the rooms, the plenum system will, without doubt, be sufficient and most desirable.

Fans have long been used for producing forced ventilation in buildings and keeping the rooms in the plenum condition, and if properly constructed and proportioned to the work, and properly supplemented with suitable air conduits, are the best means of accomplishing the object in view.

In many large buildings it has been the practice to use a simple wheel of large diameter, with curved flanges or vanes at the circumference displacing large volumes of air, and driving the same into basement corridors or ducts, from which the air passes through the radiators at the base of flues leading to the various rooms of the building.

As a rule, the current of air from wheels of this character forcing the air into large corridors becomes of very little effect at a comparatively short distance from the wheel, partly from the construction of the wheel not being the best for exerting pressure upon the current, partly from the leakage of the duct or corridor, and partly because from the size of the corridor any pressure from outside winds upon exposed apartments would be sufficient to drive back the currents and prevent them from entering the rooms, by cushioning upon the air in the corridor or the supplying duct.

Practically, therefore, the fans thus constructed and arranged are of little value, and in one instance of a large institution within my knowledge, the superintendent ceased to use the fan, and made openings at intervals into the corridor for an air supply, thus returning to the ordinary indirect heating system depending only upon natural draughts. Buildings arranged in this manner would be very much improved by constructing a by-pass or valve work at the base of each flue, by which the air could at will be made to pass through the radiators or around them for the controlling of the temperature in the rooms above, or if a simple regulating apparatus was provided by which the steam supply to the radiators governed the temperature.

The most effective apparatus that has yet been devised for heating and ventilating large buildings of which I have any knowledge, is by the use of an ordinary pressure blower attached to a heating chamber through which it forces the air, and from which the heated air is conducted in air-tight piping of proper proportions, branching off to the various rooms in the building.

For the heating surfaces of the heating chamber the usual steam pipes and coils will answer, but the heating chamber which much more favorably impresses me is one recommended to me by George W. Storer, of 149 North Third Street, Philadelphia, to whom I am indebted for having first called my attention to the efficiency and economy of applying to schools and public buildings the system I am now attempting to describe and recommend—a system

which, it is to be observed, has been generally adopted of late years for warming large industrial establishments, but without the detail needful for use where the buildings are divided into many apartments.

The heater built and used by G. W. Storer consists of two tiers of the ordinary pin radiators, through which the air to be warmed is forced by the blower.

There is an advantage in banking the heating surfaces of a building in one mass, as it puts the control of the steam upon a single valve, if desired, rather than upon a multitude distributed all over the building; for although this does not relieve from care of blast gates and registers at the respective rooms, the care of management of the latter and the cost of repair are much less than for steam valves.

I am also disposed to believe that the loss of heat in carrying the heat to a distance is less than by a ramification of steam pipes all over the building, notwithstanding the superior carrying power of steam, but I apprehend there has not sufficient experience been had to determine this point with certainty.

Less radiating surface for the cubic contents of the building is required when the radiators are concentrated in a chamber arranged as just described than when they are distributed around at the different rooms, and the mains and returns are dispensed with, and the cost of steam fitting much reduced. The total cost of the heating plant of a building by this method, notwithstanding the expense of blower engine and piping for the hot-air ducts, is but little if any more than a plant of the ordinary type of indirect steam heating.

The reason that less heating surface is required for the same work is because a radiator filled with steam under ordinary arrangement can only affect the temperature of the quantity of air which comes in contact with it, but is capable of heating a much larger volume than comes to it when influenced only by natural draughts.

An illustration of the capacities of these pin radiator heaters may be mentioned in the results of experiments in



1887 with a small model in which each tier consisted of three pin radiators, or six in all, the air being forced with a small blower of six-inch outlet.

When the air was forced through the heater under a pressure of four and one-half inches of water, or say with a velocity of over 7,000 feet per minute, the temperature of air was raised from  $20^{\circ}$  to  $163^{\circ}$ , or  $143^{\circ}$ ; and with the air pressure of two inches of water, or over 5,000 feet per minute, the temperature was raised to  $180^{\circ}$ , or  $160^{\circ}$ . High-pressure steam, or forty pounds to the square inch, was used in both these experiments.

With ten pounds of steam on the heater, and air pressure two inches of water, the temperature of the air delivered was  $147^{\circ}$ , or  $127^{\circ}$  of elevation of temperature.

A model of this size is not to be altogether depended upon for calculations of a large plant, but the great heating capacity of the heater properly proportioned cannot fail to be apparent, as also the fact that if two tiers of pin radiators are kept filled with steam it will be impossible for air to get past the radiators at any velocity for convenient use for heating purposes, without being sufficiently warmed.

In a larger heater containing sixteen radiators in each tier, I purposely covered one-half the radiators as well as could conveniently be done in order to test certain points respecting the retardation by friction, thus exposing only eight radiators in each tier to the air supply of sixteen inches in diameter.

With so small a radiating surface and so large a pipe, the temperature was raised  $118^{\circ}$  with an air pressure of one and one-half inches of water, or a velocity of over 4,000 feet per minute; and  $130^{\circ}$  with one-half an inch pressure, or velocity of (say) 2,500 feet per minute, or a delivery of (say) 3,000 cubic feet per minute—the outlets not being quite equal in area to the sixteen-inch opening. This experiment must not be taken for a basis of close calculations, because the radiators which were covered over were filled with steam at the same time, and probably contributed something to the temperature, although little or no air passed through them.

Making all allowances, however, and counting the heating surface of the pin radiator at practically eight to eight and one-half square feet, though nominally greater, the heating power is very apparent.

In another series of experiments with the heating apparatus, in which the full capacity, however, was not tested, the water of condensation was weighed.

The aggregate experiments extended over an hour and three-quarters, the temperature was raised  $100^{\circ}$  on an average, the quantity of air passed through the heater was 472,508 feet, and the condensation was  $558\frac{1}{2}$  pounds of water—or reducing this to an hour, the volume of air was 270,000 cubic feet and 319 pounds of water.

Allowing the very low estimate of six pounds of water to one of coal, we have fifty-three pounds of coal as the equivalent of work, or in other words, one-half pound of coal per hour raised 2,700 cubic feet of air  $100^{\circ}$  in temperature. This is a very fine showing, and six pounds is a very small allowance for the evaporation power of the coal, but there must be a liberal counting on radiation of heat at the boiler before the steam reaches the heating chamber.

Heavy pressures of air are not desirable for ordinary purposes of heating and ventilation, both on account of the strong currents to be handled at the rooms and the apparent loss of heat at the point of delivery from expansion into the room. This, perhaps, is not serious, but care must be taken to have ample capacity of blower and engine for maintaining an air supply in time of storms, when the pressure on exposed sides of a building tends to neutralize the air supply for that part of a building. This difficulty is well known in ordinary methods of heating, and it is owing to the inability of the old-fashioned wheel fans heretofore described, and the modern radial fans known as the wing-fan pattern, to maintain a pressure upon a building, that pressure blowers, such as are constructed for heating and ventilation purposes, are to be preferred, and in fact they are, I think, the only kind of sufficient reliability to be recommended.

Heating plants have long been designed and used essen-

tially upon the plan here recommended, but have not been entirely successful, probably solely through the want of liberality in their proportions, but these are defects which observation will make apparent. It will also require time to bring the system into favor, as it will probably be condemned—as it has been by those, who, upon greater knowledge of its merits, have adopted it.

Future experience will, no doubt, greatly perfect the details; but enough is already known to warrant the venturing upon suggestions.

I recommend taking a uniform pressure of one-quarter of an ounce as the force of the air supply in the main piping, and having the blower capacity per minute at that pressure equal to one-tenth the cubical contents of the building to be heated and ventilated.

In other words, for a building of 500,000 cubic feet contents, the blower should deliver 50,000 feet per minute when running at a speed equivalent to one-quarter ounce pressure, and taking for the equivalent velocity of the air 2,000 feet per minute at the points of exit as the basis of all calculations for the delivery of volume instead of the theoretical velocity of 2,584 feet.

The blower should not be calculated upon this basis at its maximum capacity, but should be capable of being driven at a velocity increasing the air supply to an ounce or more pressure if required.

The basis herein recommended indicates a capacity to change the air in the whole building every ten minutes on a normal speed, which, while not covering all that may be wanted in special rooms, is so far in advance of the prevailing usage as to answer for a beginning at this stage of the science, especially as the surplus power can be held as a reserve.

In practice, the whole of a building is seldom used at once, so that the full capacity will seldom be invoked, and the rooms not in use will, of course, not be drawing upon the air and warmth supply, and hence special rooms may be changed once in five or three minutes if so arranged.

It is a property of air currents from a blower that the

closing off of part of the outlets does not clog the blower, as it really runs the easier, the wheel in the case simply slipping in its own air supply; and as the exhaust steam of the engine is utilized in the heating chamber, the cost of producing the currents and pressure upon the building is very slight.

Great care is needed in the piping for this system, as the engineers and architects accustomed to planning and the mechanics skilled in the workmanship are at present very few; the tendency of the former being to pipe on too small a scale, and the latter to be abrupt in their angles and rough in their work.

As the details must vary with every building, only general principles can be enunciated, and these may require modification in special cases, but the following may be of service as a guide:

The blower being of the capacity indicated, the main pipes leading from it must maintain the full cross-section of the area of the outlet of the blower, until the diverging branches to the various rooms of the building have reduced the demand upon the main, when the main may be reduced in section, care being taken not too reduce too rapidly; small branch pipes of great length are quite undesirable; it is better to so divide the mains as to keep as great a mass of the heated air together as circumstances will allow.

The number of branch pipes to each room will depend on the size and circumstances of the room. One pipe, of eleven inches diameter, discharging at one-fourth ounce pressure would deliver over 1,300 cubic feet per minute, but two pipes of eight inches each would deliver about the same, and by being at different points in the room, secure a better distribution. Unless for small rooms or closets, less than six-inch outlets are not desirable.

The area of the branch pipe or pipes to a room must not be less than one square foot for every 20,000 cubic feet capacity of the room, for changing the air once in ten minutes, and of course must be greater for crowded rooms.

As a rule, the blast pipes should not enter directly into the room, but should open into flues or pipes at the rooms

of four times their area, in order to reduce the velocity of the inflow at the room. This refers more particularly to registers or inlets at the sides of the rooms, eight feet from the floor, as with this arrangement I have had no inconvenience whatever from currents, although the smaller pipe within the flue delivered air at the quarter-ounce pressure, or 2,000 feet per minute velocity.

Where this enlarged flue cannot be had for expanding the current, it may, however, do to run some risks of currents. Thus, in a certain lecture-room not originally constructed for this system, I have, through the flues, as I found them, driven three overhead streams of air, delivering not less than 10,000 feet per minute, at a velocity of 2,500 feet per minute, the currents reaching to the opposite wall, fifty feet distant, with but a moderate annoyance from currents in the room; and this annoyance a little change of delivery places will probably remedy.

Round pipes are better than square pipes, a circular pipe one foot diameter delivering air more satisfactorily than a pipe one foot square, with the saving both in mechanical construction and in the material proportional to the relative circumference, or nearly twenty-five per cent.

Corners must always be turned on a perfect curve. I have seen the delivery of pipes almost destroyed by an abrupt turn, although the outlet area was maintained. It follows also that branches must always diverge from mains at an acute angle, and never at  $90^\circ$ , to ensure full delivery.

For large audience rooms liable to be closely packed, the best method of entering the fresh air is through the floor by small orifices, so numerous and of such area that a steady flow passes steadily upwards, without serious draught, to the outlets at the roof or ceiling.

Many audience chambers, however, cannot have the use of the basement or room beneath for the necessary piping or reservoir of air, and in that case, recourse must be had to the sides of the room and the outlets above the heads of the occupants eight or ten feet from the floor, as may seem best, according to the height of the room.

As all machinery is liable to accident, the heating

chamber and blower should be duplicated in cases where a delay in heating would be inconvenient. Thus for a building of 1,000,000 cubic feet capacity, instead of one large wheel of 100,000 cubic feet per minute capacity, two of 50,000, with their respective heating chambers, would be better, placing them contiguous to each other, and arranging so that one could do the work of the other when temporarily necessary. This could readily be done by speeding up above the regular speed, and being satisfied for the time with a little less air supply as a whole.

The fan and heater and piping constitute the main portions of the plant, but other details are of great importance for controlling the temperature of the rooms to be heated without varying the air supply.

In the case of large audience rooms, the simplest plan would be to let one blower ordinarily be in service only for that room, and regulate the temperature by the steam valve of the heating chamber, either with automatic apparatus controlled by a thermostat in the chamber, or, if an apparatus is used which will indicate the temperature of the chamber in the engine-room, the hand of the engineer can, without much care, keep a steady temperature.

This, however, will not be available where several or many rooms are to be heated by the air from the same main pipe.

To meet this case in a building where the basement was not required for other purposes, I devised a simple application of the principle of induction.

In this building the main warm-air pipe starts from the heating chamber with a diameter of fifty-four inches and passes through the central corridor of the basement, branching out to flues on either side and diminishing in diameter to about eighteen inches at the extreme end.

The branch pipes of six, eight and more and less inches enter the flues for the rooms and terminate in the base of these flues with a short pipe above the elbow, the hot-air pipe being furnished with a blast gate worked by a lever in the class-room. The flue is about four times the area of the blast pipe, and at the base on the other side of the corridor

hall has a valve door, which, when open, admits air from the basement around the blast pipe.

The cool-air valve is also worked by a lever in the classroom, and the flue opens into the classroom eight feet from the floor.

The air in the main pipe is intended to be kept at a steady pressure of one-quarter of an ounce and at a temperature according to the weather to afford sufficient heat in any part of the building.

With the blast gates wide open, a flow of warm air enters the room in a volume sufficient to change the volume of the room once in ten minutes, but when the room becomes heated to whatever degree is desired, say 68° or 70°, the hot-air pipe is slightly closed and the cool-air valve is opened.

By this operation the warm air is slightly curtailed, but, as it is still rushing in with considerable force and is surrounded with cooler air from the opening of the cool-air valve at the base of the larger flue, by the principle of the injector or by induction, it carries up a greater volume than has been shut off from the warm-air pipe.

It requires but little care to so adjust the valves as to vary the temperature at will, without diminishing the volume.

This plan, however, would not be available in buildings in which the basement was wanted for occupancy, or where, owing to surrounding buildings or for other reasons, it was not easy to obtain the supply of cool or tempered air at every flue.

These contingencies can be met by doubling the piping system, carrying hot air through one system and tempered air through the other, and entering the branches from both into the flue or directly into the rooms and regulating the inflow by suitable valves.

In this arrangement the heating chambers must be arranged to supply the air at the respective temperatures required.

Flues are the better for being in inside walls, rather than outside, and no fears of good distribution need be enter-

tained, because both inlets and outlets are on the same side of the room.

Where the walls do not admit of good-sized flues, offsets in the room should be endured rather than small flues.

Offsets may be reduced to a minimum by using metal.

Registers should be dispensed with when the inflow is regulated by other valves, and an opening with a neat border and lining will soon be as sightly to the practical eye as registers.

Fans should be run by their own engines, in order that the air delivery may be controlled according to the occupancy of the building, without reference to connections with other machinery.

Moisture should be added to the air after warming. In one case where I failed of sufficient quantity with a large surface of boiling water, I found a steam-jet to answer.

Specially exposed rooms must be borne in mind and specially provided for. Thus in an institution, the newest part of which is warmed on the system described, the temperature was not satisfactory for three rooms very much exposed, the pipes to which were small and carried in outside walls, but all defects were cured by an increase of the air supply.

In conclusion, the object of this is more for the purpose of inciting investigation and much-needed improvements in the ventilation of public buildings, and places where audiences gather and business men spend their time in business hours, than to present a basis for technical contention.

The methods particularly recommended may not be applicable to all existing buildings, though there are but few buildings in and near Philadelphia, however recent their erection, but that greatly need improvements in ventilation. With those who cannot suspend their judgment long enough to understand what is being explained to them without expressing either an adverse opinion or a description of some other system, it is a thankless task to discourse, but those who have worked sufficiently in the practical work of heating and ventilation to realize the real intricacies



of the problems presented, and which vary with every building, everything bearing upon the subject is patiently considered, and with an interest that pertains to seekers for further knowledge.

At the end of ten years, after taking an interest in **matters** pertaining to ventilation, I felt I was further back than at the **beginning**, and at the end of twenty years had made but little **progress**. At the present time, some ten years later, I am only at the point of starting fresh, hoping, however, to give some impetus to the cause, and particularly to incite others to go on to more perfect work.

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## ON THE LONGITUDINAL RIVETED JOINTS OF STEAM-BOILER SHELLS.\*

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BY JOHN H. COOPER.

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The initial statement to the English Lloyd's rules for steam boilers is embodied in the following words: "The strength of circular shells to be calculated from the strength of the longitudinal joints," which assures us that this part of the boiler should be properly proportioned.

To these rules a memorandum is added: "In any case where the strength of the longitudinal joint is satisfactorily shown by experiment to be greater than given by this formula (Lloyd's), the actual strength may be taken in the calculation."

Later on, Lloyd's rules (under the head of "Periodical Surveys," regarding the examination of boilers after they have been several years in service) say: "The safe working pressure is to be determined by their actual condition."

These statements lie in the line of practical efficiency, and point to the necessity of providing material in accordance with the requirement of the load to be carried.

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\* Read at the Nineteenth Meeting of the American Society of Mechanical Engineers, and revised by the author for publication in the JOURNAL from advance-sheets of the *Transactions*.