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HEATING AND VENTILATION OF ST. PAUL'S HOSPITAL, MONTREAL, QUE.

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(Read before the Mechanical Section, 18th January, 1906.)

It is the intention of this paper to describe a system of heating and ventilation at St. Paul's Hospital, Montreal; to outline the ideal aimed at; and to discuss the function and efficiency of the equipment installed.

An ideal system of heating and ventilation should maintain a constant temperature and supply fresh air in large quantities at a proper humidity without dust or drafts. Almost every system of heating is designed to maintain a constant temperature, but very seldom is the humidity given consideration. It is not uncommon to find air in buildings very much dryer than normal pure air, and an explanation is not difficult. Since air saturated at zero degrees will contain about one-half grain of moisture per cubic foot, and at 70 degrees one cubic foot will contain eight grains, it is clear that if air is heated from zero to 70 degrees, the humidity at the higher temperature will be only 6 per cent., and the air will then be dryer than the atmosphere of the Sahara Desert. This extreme dryness is very harmful to the mucous membrane of the human body, and is in a large measure responsible for the prevalence of disease of the nose and throat in cold climates. It is also a noticeable fact that a high temperature is required if persons are to be comfortable with a low humidity. It is well known that a thermometer with moistened bulb will register a lower temperature than a dry bulb thermometer beside it, but it is not generally known that the sensation of heat and cold experienced by people varies rather with the registration of the wet bulb thermometer, than with that of the dry bulb. It is a common error to assume that the dry bulb thermometer gives a true indication of the temperature felt by human beings, and to consider all contradictory evidence as due to the mutability of human nature. Roughly, it will be found that with 55 per cent. relative humidity a temperature of 64 degrees will be as comfortable as a temperature of over 70 degrees, with a relative humidity of 30 per cent. From an engineering standpoint, therefore, we come to the same conclusion as a physician, who, discussing this subject, states that: "So long as we continue to neglect the indoor relative humidity we shall continue to live in unhygienic surroundings, created by any method of heating that is not supplied with means for properly moistening the air. To do this should be as much the purpose of a scientifically constructed heating system as to furnish sufficient heat."*

Any system of ventilation will necessarily add not only to the first cost of a heating equipment, but also to the operating expense. Heat is considered essential because the lack of it at once affects our comfort; while breathing impure air, when one becomes accustomed to it, produces no immediate discomfort. Through ignorance of the fundamental principles much money has been wasted in the past on inefficient or defective methods of ventilation. It is, however, considered poor practice to-day to design a heating system without at the same time making provision for a positive supply of fresh air free from dust or soot, and furnished to the building without drafts in any room. In the State of Massachusetts a law has been in force for several years making it compulsory to supply 30 cubic feet of fresh air per head per minute in all schools and public buildings. The amount of air usually estimated for buildings of different classes is as follows:—

Hospitals (ordinary),	35 to 40	cubic feet	per minute	per person.
Hospitals (epidemic),	80	"	"	"
Workshops, ...	25	"	"	"
Prisons, ...	30	"	"	"
Theatres,..	20 to 30	"	"	"
Meeting Halls, ...	20	"	"	"
Schools (per child),	30	"	"	"
Schools (per adult),	40	"	"	"

*Henry Mitchel Smith, M.D., in a paper before Brooklyn Medical Society, May 15th, 1905.

Fresh air contains about 4 parts carbon dioxide in 10,000, and the presence of 6 to 8 parts in 10,000 is scarcely noticeable, but the presence of 11 parts in 10,000 is distinctly perceptible, and when higher percentages are found the air is sufficiently stale to be not only uncomfortable, but actually injurious. Since an adult breathes about 500 cubic inches of air per minute, and as respired air contains about 3.4 per cent. carbon dioxide, it is clear that approximately 17 cubic inches of carbon dioxide are exhaled per minute, and from this data the following table has been prepared:

Parts carbon dioxide in 10,000.	Cu. ft. of fresh air per minute per person.	Percentage respired air.
4	Infinite	0
5	100	.29
6	50	.58
7	33.3	.87
8	25	1.45
9	20	1.74
10	16.7	2.03
11	14.3	2.32

Common standards of good ventilation are taken as allowing between 6 and 8 parts of carbon dioxide to 10,000 parts of air, and a comparison of the two tables will show that they give about the same results. Allowance should be made for the size of the room and the period during which it is used at a time, for where there is a large space per capita, even if no fresh air is admitted, it will take some time for the air to become polluted.

With a system of forced ventilation there is a tendency to install small ducts, as the available space for ducts is generally limited, and by an increase of pressure the requisite amount of air may be delivered even with small ducts. It is a great mistake, however, to use a high pressure, even though it be available, for at too high a velocity through the ducts a rush of air is distinctly audible, and air entering and leaving rooms at a high velocity will be certain to produce uncomfortable drafts. Some device for cleaning the air supplied is also necessary, for no matter where the inlet is placed there is bound to be mixed with the entering air some dust and soot.

We should then aim to keep a constant temperature at a constant humidity, and to supply pure screened air in positive quantities without creating perceptible drafts.

The equipment at St. Paul's Hospital consists of a motor-driven fan; tempering coils, and heating coils, with their supply and return pipes; ducts for a distribution of air with deflectors for adjustment and dampers for control; thermostats for control of temperatures, and a combined air washer and humidifier for cleaning and moistening the air. The fan is a three-quarter housing steel plate centrifugal with double discharge. It is driven by a direct current motor by means of a chain drive. At full speed it delivers 45,000 cubic feet of air per minute, and by means of a rheostat in the field circuit of the motor two lower running speeds may be used. The coils are of the mitre type, which are usually employed for hot water, as the resistance to circulation is very low, and in this case they are used with low pressure steam for the same reason. Tempering coils are placed between the inlet and sprays to bring the air at least above freezing point. A temperature of 50 to 55 degrees is found necessary in the spray chamber, because the temperature in this chamber affects the humidity, and because some air by-passes the heating stack on the discharge side of the fan, and, therefore, goes to the rooms without a further increase of temperature. The distributing ducts beginning beyond each heating stack carry separately, hot air which passes through the heating coils, and tempered air which goes above them. These ducts are kept separate until the mixing damper is reached, of which a detail is shown in Plate 1. In each duct there is a balanced damper, and the two are joined together by a link, so that when one is open the other is shut, and vice versa. Thus a constant volume of air is supplied at a temperature varying in such a way as to balance the heat losses from the building. In most rooms the dampers are controlled by thermostats, to give a constant temperature, but in some they are arranged for hand regulation.

The air washer and humidifier is shown in detail in figure 1. It consists of a number of spray nozzles in a plane at right angles to the course of the air, and a box of baffle plates which remove the dust and water carried mechanically. The sprays are shown clearly in the drawing, and require no further description, but there are several novel features in the "dry box" which need explanation. In the fan room of the hospital space is very valuable, for every foot is below the ground level, and excavation is expensive. If the cross section of the dry box is to be reduced, we must figure on a higher velocity of air in order to handle the same quantity. In this case a velocity of about 350 feet per minute is used, and the loss in friction is so small as to be almost negligible. Considering that each plate is but two inches long, and the total thickness of the box but 12 inches, it seems impossible that the moisture can be completely removed. A piece of dry paper placed behind the box at any point will show no trace of drops of water, however, nor is there any perceptible moisture on the last bend of the plates. The first bends are purposely left without projec-

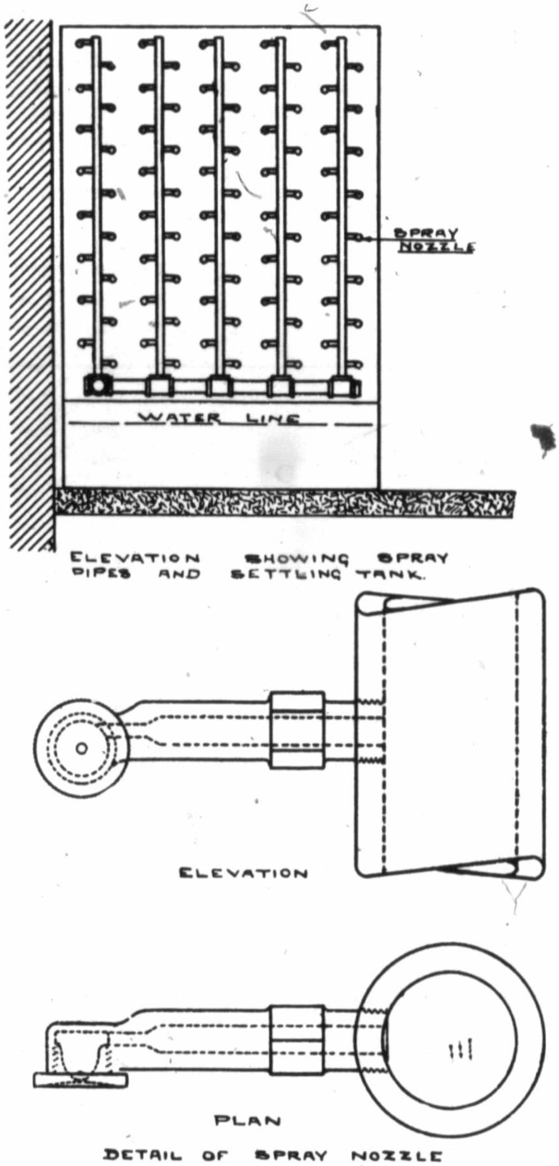

SPRAY NOZZLE
WATER LINE
ELEVATION SHOWING SPRAY PIPES AND SETTLING TANK.
ELEVATION
PLAN
DETAIL OF SPRAY NOZZLE

FIG. 1.

tion to allow a film of water to form, and it is this film which collects most of the moisture and all dust or soot. The first projection prevents most of this film from being carried through, and the remaining projections remove thoroughly whatever water may remain. While we may depend upon the film to remove all water carried mechanically, the moisture carried by absorption is on the contrary increased to an amount dependent chiefly on the velocity

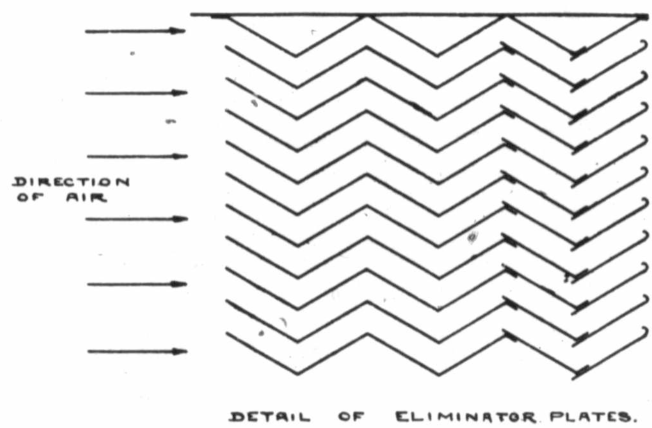


FIG. 2.

of air through the plates. At any given running speed of the fan this velocity is constant, and the relative humidity of air leaving the baffle plates at full speed remains nearly constant at 80 per cent., independent of the relative humidity of the entering air. If the temperature of the spray chamber is kept at 55 degrees, each cubic foot will carry 80 per cent. of 4.85 grains or 3.88 grains of water, which will give a constant humidity of a little more than 55 per cent. when the air is warmed to 65 degrees. The temperature in the spray chamber is kept constant by a thermostat, which operates a by-pass damper below the tempering coils, admitting enough cold air to reduce the temperature as required. The air in the tempered air ducts will remain at 80 per cent. humidity, and the air in the hot air ducts will enter the room at a low relative humidity, but in either duct 3.88 grains are carried by each cubic foot of air, which corresponds at 65 degrees to a humidity of 55 per cent., and if the rooms are kept at this temperature the humidity will be practically constant.

Both hot and tempered air ducts are made of galvanized iron of the following gauges:—

All pipes of less than 5 feet circumference, of No. 26 guage; 5 to 8 feet circumference, of No. 24 gauge; 8 to 10½ feet circumference, of No. 22 gauge; 10½ to 13¼ feet circumference, of No. 20 gauge; 13¼ to 19 feet circumference, of No. 18 gauge; above 19 feet circumference, of No. 16 gauge.

The cross section at any point of the air ducts is designed to give a constant friction per foot of length, and each branch is designed to receive its proportionate supply, though the amount of air it receives will depend largely upon the angle at which it leaves the main duct, and at this point a deflector is installed to permit careful adjustment when taking an anemometer test.

There are four separate buildings to be heated, and the ducts run through tunnels to three of them. Hot and tempered air are carried in separate ducts from the coils and by-pass until close to the opening into each room, where mixing dampers are located as shown in the plate. As soon as possible after passing the dampers a gradual increase of 50 per cent. in the area of the duct is made, which makes the velocity of air entering so low that there is no perceptible draft. No register faces are used, but the iron of the duct is flanged back against the wall and covered with a plain wood border. This arrangement gives a neat appearance, and by doing away with registers gives ready access for cleaning, and an unobstructed flow of air.

The vent flues all have dampers, which are, in most cases, kept partly closed to ensure a slight plenum in the rooms. All vent flues lead to the attic, in which there are two ventilating towers with movable louvres. The louvres are made of a waterproof silk, with a rod at top and bottom to keep its shape. The top rod is stationary in a frame, and the bottom rod is light enough to allow air to escape, but heavy enough to fall back in place if there is a tendency for air to enter.

It is noticeable that in such a ventilating system there are many adjustments to be made, but most of these are made when testing, and are then left permanently in a fixed position. After all deflectors and dampers are set no change can be made in the amount of air supplied, except by varying the speed of the fan, and this can only be done from the switchboard. Thermostatic dampers in most rooms keep the temperature variation within one degree. Another set of thermostats placed in the fresh air inlet are adjusted to close off one coil of the heating stacks at 10 degrees above zero, a second at 20 degrees, and a third at 30 degrees. Similarly one section of the tempering coils closes when the out-door temperature is 35 degrees, and the other closes at 60 degrees. The temperature regulation is thus taken care of, and since, as already explained, the humidity is controlled automatically, the only attendance that is required is the occasional cleaning and oiling of motor, fan, and pumps.

The operating expense and first cost of such a system of heating and ventilation will be higher than for a system of direct steam piping designed for heating alone. While accurate data for comparison are not available, an examination of the formulae will show the reason for the difference found in practice.

A common formula for the loss of heat from a building is

$$H = \left(\frac{n\,c}{55} + K\,G + K^1\,W \right) t$$

where

H = Loss of heat in B. T. U. per hour.

n = Number of times air is changed per hour.

c = Cubical contents of building in cubic feet.

G = Area of exposed glass surface in square feet.

W = Area of exposed wall surface in square feet.

t = Difference of temperature between air inside and air out of doors.

K and K^1 = Co-efficients for the loss of heat in B. T. U. per square feet per hour through glass and wall respectively.

An average value of K is 1, and of K^1 ¼, so that a general formula would be*

$$H = \left(\frac{n\,c}{55} + G + \tfrac{1}{4}\,W \right) t$$

In this formula $(G + \frac{1}{4}W)\,t$ expresses the heat lost by radiation through walls and windows. This loss would be the same for either a direct steam system or an indirect heating system if the temperature in the room were uniform. To heat a building satisfactorily with direct steam it is necessary to place much of the radiating surface along outside walls. As the air back of and above these coils or radiators will be hotter than air in the body of the room, the loss by conduction is proportionately increased. Obviously, with an indirect system there is a saving, as the hot air pipes are carried on inside walls and the temperature is practically uniform.

The expression $\frac{n\,c}{55}\,t$ is an allowance for the heat required to warm air which enters around doors and windows and through the walls. In a building 50 feet high, with an indoor temperature of 70° in zero weather, there would be a pressure inwards against the wall at the ground level of about one-half pound per square foot. Through openings at top and bottom air, with a free passage,

* Prof. R. C. Carpenter, Heating and Ventilating Buildings, Chap. III.

would flow at a velocity of over 3,000 feet per minute. The friction of the course that such a current of air takes in an ordinary building reduces the above figures, but in any room, if the upper sash of a window is lowered, and the lower sash raised, air will flow in at the bottom and out at the top at a comparatively high velocity. When the sashes are shut air still comes in through crevices, and through the walls, and, unless the construction is exceptionally tight, unpleasant cold drafts will be formed.

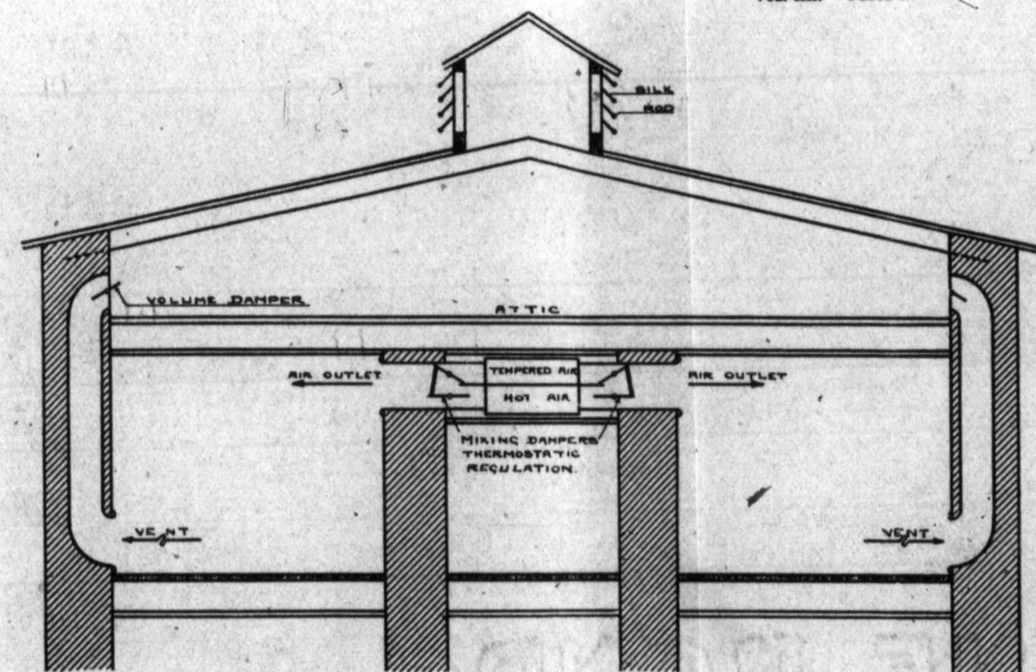
The volume of air which thus passes through the building by filtration must be heated to the temperature maintained. An estimate of the volume which is to be heated must be made, and with proper allowance for the nature of the construction the value of n (the number of air changes per hour) is for corridors, 3; for churches and assembly rooms, 2 to 2½; for ground floor rooms, 2 to 3; and for second floor rooms, 1½ to 2.

With an indirect system of heating the expression $\frac{n\ c}{55}\ t$ gives the B. T. U. required for ventilation alone. With a direct steam heating system the infiltration of air might be considered as ventilation, but the amount is uncertain and inadequate, and any advantage of ventilation received is more than offset by the injurious effect of the drafts formed. With an indirect system all entering air is heated before it goes to the rooms, and there is no leakage around doors and windows, for a plenum is formed by the fan, which reverses the natural tendency and causes an outward flow of air. If the fan were to take its supply of air back from the rooms no plenum would be formed, and there would be an infiltration of air as with direct steam heating. If part air is taken from out of doors and part returned there is a proportion at which, if a window is opened on a still day, no perceptible flow of air will take place in either direction. This is the condition when the same amount of air is taken from out of doors as would otherwise enter by infiltration. When so operated, although ventilation to the extent of about two air changes per hour is supplied, the cost of operation will be a minimum, and will be the same as for direct steam heating.

A supply of two air changes per hour is not sufficient for a hospital, and the fan takes its entire supply of air from out of doors, giving an air change in from 6 to 8 minutes, or 8 to 10 air changes per hour.

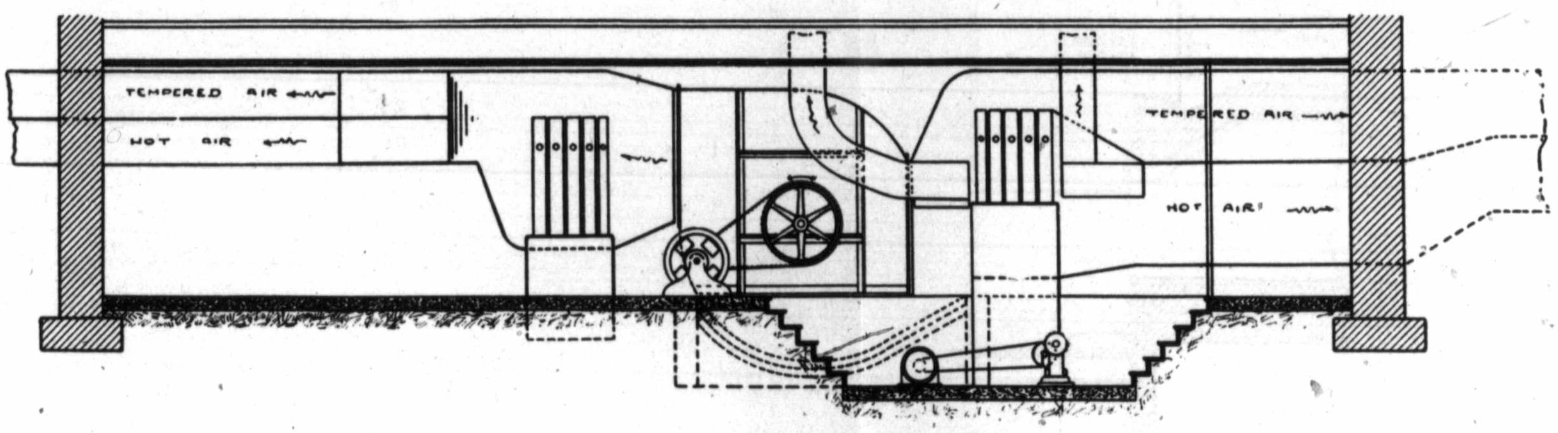
The cost of fuel for ventilation alone may be easily estimated. Assuming an average temperature of 30° from Dec. 1st to March 1st, the coal required to supply 3,000 feet of air per capita per hour can be calculated from the formula $H = \frac{n\ c}{55} t$, which becomes $H = \frac{3000}{55} + 30 = 1636$ B. T. U. per hour. In a hospital ventilation is supplied day and night, giving a total requirement of 3,533,760 B. T. U. per capita for three months. In schools the plant would be in operation only eight hours per day, requiring but one-third this amount. Assuming an evaporation of nine pounds of steam per pound of coal, the coal required during the three months stated would be about 450 pounds per capita for hospitals, and 150 pounds per capita for schools.

CAN. SOC. C. E. TRANSACTIONS
VOL. XX. PLATE 1.

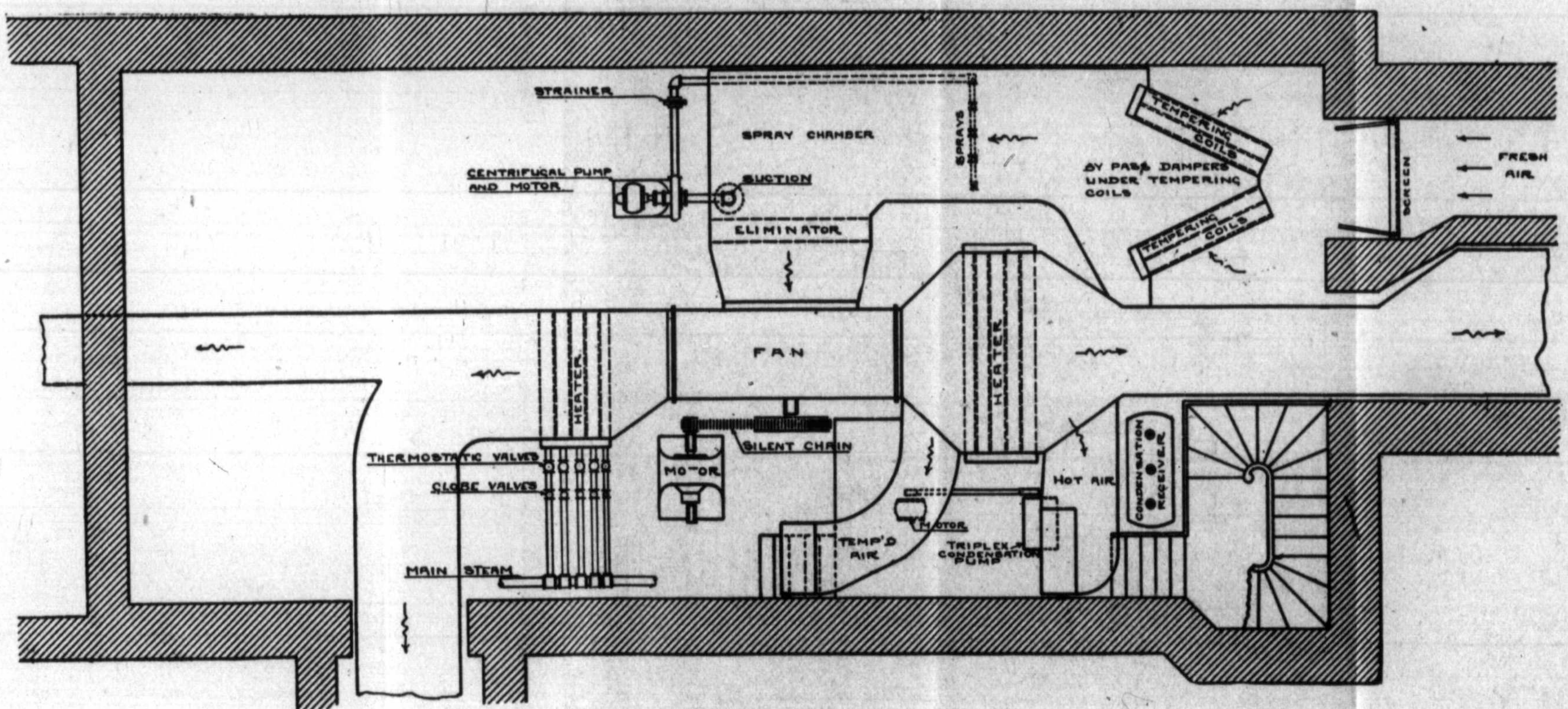


ELEVATION

CAN. SOC. C. E. TRANSACTIONS
VOL. XX. PLATE 2.



ELEVATION


STRAINER
SPRAY CHAMBER
SPRAYS
CENTRIFUGAL PUMP AND MOTOR
SUCTION
ELIMINATOR
TEMPERING COILS
BY PASS DAMPERS UNDER TEMPERING COILS
TEMPERING COILS
SCREEN
FRESH AIR
HEATER
FAN
HEATER
SILENT CHAIN
MOTOR
THERMOSTATIC VALVES
GLOBE VALVES
MAIN STEAM
TEMP'D AIR
MOTOR
TRIPLEX CONDENSATION PUMP
HOT AIR
CONDENSATION RECEIVER

PLAN