REPORT

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VENTILATION.

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NEW YORK NAVY-YARD, *July* 30, 1879.

SIR: In obedience to the orders of the bureau, we have examined the system of ventilation proposed for ships by Mr. D. C. Green, of No. 88 Liberty street, New York City, and the mechanical apparatus with which he gives it practical effect. Both the system and the apparatus are shown in the accompanying drawing, on which are marked the necessary explanations and references.

The system consists in either exhausting the stagnant air from the compartments of a vessel, in which case fresh air flows in through open hatches or pipes to fill the vacuum, or in injecting fresh air into the compartments, thereby forcing out the stagnant air through open hatches or pipes; or both methods may be employed in combination.

The mechanical means by which these operations are effected is an injector discharging compressed air, the current of which induces a much larger volume than itself of either the stagnant or the fresh air that may surround it.

The compressed air is furnished by an ordinary double-acting air-pump worked by a common steam-cylinder and fitted with a reservoir wherein the air-pressure is maintained practically constant during the strokes of the pump-piston. The air-pump, with its steam-cylinder and reservoir may be placed in any convenient part of the vessel, the compressed air being conveyed by pipes to the injectors. The air-pressure in the reservoir preferred by Mr. Green is from 4 to 5 pounds per square inch above the atmosphere. The injectors may also be placed in any convenient part of the vessel, suitable pipes leading from them to the compartments to be ventilated. But the nearer the air-pump and the injectors are to these compartments, the more economical both in piping and in air-supply will be the ventilation.

What we term the injector consists of two parts, namely: the one, of an automatic valve placed at the end of the pipe which brings the compressed air from the reservoir. This valve is shown in Figure 1 of the accompanying drawing, and is so designed that it can be counter-loaded by a spring or weight to any air-pressure it is desired to employ, its action under this load being such that the air flowing from the valve will always have the pressure for which the valve was loaded, whether the air-supply be great or small from the pump. By this arrangement, the injector working always with a constant pressure of air, the velocity of the air-discharge will be constant also, but the quantity of air discharged will vary with the quantity supplied by the pump, the valve graduating itself to a greater or less area of discharge proportional to this quantity. The valve is, in fact, a peculiar throttle-valve worked automatically by the pressure of the compressed air. It is frictionless when in the vertical position, and has but a trifling friction when horizontal. The valve is placed entirely within the hollow frustum of a cone forming the end of the pipe bringing the compressed air from the reservoir, and consists of a solid frustum of a cone; the two frusta having the inclinations of their conical sides in opposite directions, the sliding of the inner solid frustum out or in within the hollow frustum, under the action of the spring or weight, will increase or decrease the width of the annular space between the frusta which is the area of discharge for the confined air. The valve or inner frustum being counter-loaded by a spring or weight to an equilibrium against a given air-pressure in the reservoir, will automatically assume a position within the outer or hollow frustum that will give the proper area for discharging under that pressure all the air supplied by the pump. If the pump should change the quantity of air supplied in a given time the valve will move automatically to a new position which will give exactly the area required to discharge the new rate of supply under the same pressure. This valve is the novel, and also the important, feature in the mechanical details of the ventilating system employed by Mr. Green, maintaining without supervision an uniform velocity of air-discharge, be the quantity of air discharged what it may. The amount of movement of the valve within the outer hollow frustum is exceedingly small for very great differences in the amount of air-supply during equal times.

The second part of the injector is the receiver, into which the compressed air is discharged by the valve just described. This receiver, lettered S in Figure 2 of the accompanying drawing, is a short, cylindrical pipe, with its two ends formed into frusta of cones; the outer diameter of these frusta is the same as the inner diameter of the pipe containing them; while the intermediate cylindrical portion is, of course, of much less diameter than this pipe. The receiver, together with the valve that discharges compressed air into it, are placed in the ventilating pipe, or pipe through which the stagnant air is exhausted from the compartments of a vessel, or fresh air is delivered into them. The form and dimensions of the receiver, relatively to the valve, exert a marked influence on the economy and the efficiency of the ventilation. The proper proportions can only be determined by careful experiment on a considerable scale.

If it be desired to exhaust a compartment of its stagnant air, the large ventilating pipe must extend from the bottom of the compartment to any point convenient for delivering this air into the atmosphere, the fresh air replacing the stagnant air thus exhausted being delivered into the top of the compartment through hatch openings or a suitable pipe; the pressure causing the replacement being in proportion to the vacuum formed by the injector.

If, on the contrary, it be desired to force air into the compartment, one end of the ventilating pipe must communicate with the atmosphere, while the other end terminates at the top of the compartment. An outlet to the atmosphere must be provided through another ventilating pipe of equal diameter extending from the bottom of the compartment to the atmosphere; or the fresh air may be delivered into the compartment through a ventilating pipe extending to the bottom of the compartment, while the top is open to the atmosphere by means of a hatch or pipe; the stagnant air, in both cases, being expelled by the greater pressure of the fresh air forced in.

Finally, both methods may be employed simultaneously for the same compartment, without additional ventilating pipes. All three arrangements are shown in Figure 2 of the accompanying drawing, which represents a compartment of a vessel, with the steam-cylinder, air-pump, injectors, and pipes necessary for each and all the methods of ventilation proposed.

We witnessed the working of the system of ventilation employed by Mr. Green. The compartment ventilated was 25 feet by 20 feet on the floor and 9 feet in height; and was made reasonably air-tight for the pressure used by means of paper pasted over all its apertures. The steam-cylinder was double-acting, 10 inches in diameter, with 18 inches stroke of piston, and was connected directly to the air-pump, which was also double-acting, 14 inches in diameter, with 18 inches stroke of piston. The pistons were worked at 36 single strokes per minute. The pressure of the compressed air in the air-pipe, just beyond the pump, was 4½ pounds per square inch above the atmosphere; and the injector-valve was counter-loaded to the same.

The greatest diameter of the valve of the injector was 2½ inches, and it was supplied with compressed air through a pipe of 2 inches inner diameter; the receiver into which this valve discharged consisted of a cylindrical pipe, 9 inches in inner diameter and 24 inches in length, with its ends formed into conical frusta of 15 inches extreme diameter and 3 inches length; the entire length of the receiver being 30 inches. It was placed in a horizontal ventilating pipe of 15 inches inner diameter and 10 feet length, forming a communication between the atmosphere and the compartment at one side near the floor.

The outlet from the compartment was near its top, and consisted of a rectangular aperture 18 inches by 18 inches, in which was placed a delicate helical anemometer that recorded the velocity of the outgoing air. Assuming the air-pump to have filled to nine-tenths of its capacity, and taking the *vena contracta* of the rectangular outlet at five-eighths, each volume of air delivered by the pump entrained or induced about twenty-five volumes of external air.

When the pump delivered the same quantity in equal time of the same compressed air directly into the compartment without passing through the injector, for which experiment provision had been made in the apparatus, the difference of effect was very marked, the ventilation being greatly poorer, and the pressure in the compartment falling lower than was required to turn the anemometer, which accordingly remained motionless. In fact, with the same expenditure of power, and the same compression of air in the same air-pump, both as regards density and bulk, twenty-six times the volume of fresh air was thrown into the compartment when the injector was used in connection with the air-pump than when the pump alone was used. This is an immense gain in both the efficiency and the economy of the ventilation. The whole of the additional twenty-five volumes was clear gain, and cost absolutely nothing above the cost of producing the one volume by the direct action of the pump.

The air compressed in the pump is heated to the thermal equivalent of the work done upon it by the compression. With an extended experiment, the temperature of the pump might be thus increased to an objectionable degree, for its loss of heat by radiation might be less than its gain of heat from the compressed air; should such prove to be the fact, the cylinder of the pump could be surrounded by a jacket through which a circulation of cold sea-water could be maintained by a special pump with but little expenditure of power.

With a given injector, the efficiency of the *induced* ventilation, or weight of fresh air entrained by the injector into a compartment, without regard to economy in the power producing this ventilation, will be in the ratio of the velocity of the air issuing from the injector, and of some function of the mass of air injected in equal times. This mass, with the same injector and pressure, will be in proportion to the width of the annular opening made by the valve. Air compressed to two atmospheres above zero discharges into the atmosphere with a velocity of 1,173.61 feet per second, and this velocity remains constant at all higher pressures; therefore, any increase of pressure in the pump beyond 15 pounds per square inch above the atmosphere would not cause any increase in the efficiency of the *induced* ventilation. Under the pressure of 4½ pounds per square inch above the atmosphere, as adopted by Mr. Green, air rushes into the atmosphere with the velocity of 649.61 feet per second, which is a reduction of 44.65 per centum below the maximum in the efficiency of the induced ventilation, but with a great increase in the practicability of the system and ease in managing it, together with an enormous increase of economy in the power-cost of the ventilation produced. At the low pressure of 4½ pounds per square inch above the atmosphere, but little difficulty would probably be experienced from the heating of the air produced by its compression.

The weight of air, other things equal, received by the compartment through the injector from the pump, will, with equal speed of pump piston, of course, be the same, let the degree to which the air is compressed be what it may, the breadth of the annular space made by the valve through which the compressed air is discharged being necessarily reduced, automatically, proportionally to the pressure. The efficiency of the *direct* ventilation, therefore, as this air-supply may be called, with the same injector, as far as the weight of air furnished directly from the pump is concerned, will not be affected by the degree of compression; but the expenditure of power producing the compression will be in the direct ratio of the degree of compression, twice the compression requiring twice the power. Hence, the less the compression the greater the economy with which the ventilation is produced for all pressures over 15 pounds per square inch above the atmosphere; below that, the cost is no longer *pro rata* with the compression, the effect of the lessening velocity of the induced air current entering now as a factor. It has been shown that all the increased ventilation which could be obtained by increasing the air-pressure in the pump from 4½ to 15 pounds per square inch above the atmosphere would be what was due to the difference in the effluent velocities in the two cases, namely, 649.61 and 1,173.61 feet per second, or 44.65 per centum of the induced ventilation; but this would be obtained at an increased power-expenditure in the ratio of $\left(\frac{15+4\frac{1}{2}}{15} : \frac{15+15}{15}\right)$ 54 per centum.

Both the efficiency and the economy of the ventilation produced by injecting air into a compartment with pressures from 4½ to 15 pounds per square inch above the atmosphere is from 4 to 5 per centum greater than that obtained by exhausting the air, because, in the former case, the direct ventilation is utilized, while in the latter it is not.

The system of ventilation proposed by Mr. Green is not original, except so far as relates to the particular form of his automatic valve. This system, as applied to the ventilation of compartments, seems to have been first suggested by Mons. Mondésir, and was afterwards proposed by Mons. Decante to the French Government for the ventilation of the French Horse Transports, as appears from an account in the July, 1872, number of the Revue Maritime et Coloniale. It is highly recommended by Mons. J. B. Fonssagrives, retired chief of the Medical Department of the French Marine, in the second edition, published in 1877, of his classical "Traité d'hygiène navale."

The same system was applied in 1863 by the presiding officer of this board to the furnaces of an experimental boiler in the New York navy-yard, for the purpose of forcing the combustion. In this case, however, steam was used as the injecting vehicle instead of air, on account of the facility with which it could be obtained under considerable pressure from the boiler itself, without requiring additional apparatus to produce the compression. The mingled steam and air, in very small proportion of the former to very large proportion of the latter, were delivered into the front of the closed ashpits of the boiler by means of ordinary injectors encircled by conical tubes. At the same date an experiment was tried with the same object on the same boiler, by forcing or blowing atmospheric air up the chimney through an injector by means of an ordinary Dimpfel blower. Although this blower delivered air of very slight pressure, the result was, in measure, satisfactory; but the air of this low pressure was so wanting in velocity that the apparatus would be too bulky for use on board a vessel. Circumstances prevented the continuance of these experiments which were to have been extended, varied, and enlarged, and which might otherwise have produced results of value in connection with the ventilation of naval ships, as they were being made in the right direction.

The only vessels to which a complete system of ventilation has been applied in the United States Navy were the monitors. This system was also devised by the presiding officer of this board, and was first applied by him at the Washington navy-yard to the original historic Monitor shortly after her action with the Merrimack, and afterwards to all the iron-clads, from a general design furnished by him. It consisted in drawing, by means of ordinary Dimpfel blowers, the atmospheric air down an armored pipe extending from the deck to a level with the top of the turrets, and then blowing it into the different compartments of the vessel at large through horizontal pipes of adequate cross-section provided with the necessary registers; the stagnant air thus forced out of the compartments escaped up the turrets.

This was a very simple system, and it acted with great efficiency, giving the vessels perfect ventilation. They had no natural ventilation whatever, and depended wholly on the artificial ventilation for habitability. The blowers were driven through belts by small steam-cylinders, and were geared to make five revolutions to each double stroke of the steam-pistons.

It is, of course, possible with this system to perfectly ventilate any vessel, so that in absolute efficiency it is equal to the best which can be devised; but economically it is greatly inferior to the system by injectors, requiring a very much greater expenditure of power and very much bulkier piping.

With the injector system there is the same small steam-cylinder as with the blower system, but it directly works an air-pump which replaces the blower. The quantity of atmospheric air to be compressed in the pump being only from 4 to 5 per centum of what has to pass through the blower, the expenditure of power is proportionally less. With the blower, air-pipes of the full capacity for the air required for the entire ventilation have to start from the blower, but proceed with diminishing area of cross-section from register to register. With the injector only a small pipe for the compressed air is used, even when starting from the pump, and it too has a diminishing area of cross-section from injector to injector. The money cost of the apparatus in the two cases will not differ to any extent of practical importance, but the enormous reduction in the bulk of the ventilating pipes is of the first consequence on board ship, as is also the equally large reduction in the coal cost of the power expended on the ventilation. In either case the cost of the ventilation in coal is not material, so that for ship's use the great advantage of the injector system is in the very greatly less bulk of its apparatus.

If artificial ventilation is to be generally adopted in naval vessels, then an exhaustive series of experiments should be made with the injector system, to ascertain the best proportions for the apparatus, and the laws governing its application. Such experiments would be costly in time and money, but they would be found true economy in the end. The same remarks apply to the blower system, little or nothing concerning which is known, as relates to the absolute efficiency obtainable by it, or to the cost in power of the ventilation produced with it. The two systems appear to be the best, or, rather, the only ones practicable on board ship. The blower has the advantage of extreme simplicity, but the disadvantage of greater bulk of apparatus and greater power-cost for the production of a given ventilation. The injector system has the advantage of a less bulky apparatus and less power-cost for the production of a given ventilation, but the apparatus is more complicated and more delicate. The absolute power-cost of producing a given ventilation with either system, and, consequently, the absolute money cost, are at present unknown.

The system employed by Mr. Green has not yet been patented, the case still pending before the Patent Office, so that the particular points of originality which may be allowed by that office have not been determined. It is impossible, however, to sustain a claim to the system of ventilating by injectors, and the patentable portion will probably be confined to the use of the particular automatic counter-loaded throttle-valve hereinbefore described. Any other valve producing an equivalent effect, or the use of an ordinary throttle-valve depending for adjustment on manipulation by an attendant, can be employed without either legal or moral invasion of Mr. Green's rights.

The effect of Mr. Green's valve is to maintain always the same pressure of compressed air at the point of discharge into the receiver, let the speed at which the compressing air-pump works be as variable as it may, owing to variations in the boiler-pressure. With a constant boiler-pressure the air-pump would work at a constant speed, and always supply the injector with compressed air of the pressure to which an ordinary throttle-valve might be regulated, which latter being once adjusted would require no further attention. In this case the ordinary throttle-valve would be in every way as efficient as Mr. Green's valve. Now, a sufficiently near uniform pressure of steam for practical purposes upon the piston of the small steam-piston driving the air-pump, can be obtained by means of a "governor" applied to the throttle-valve of each cylinder; and with a uniform pressure upon the steam-piston the air-pump piston would have with its invariable load a practically uniform speed, so that equally good results can thus be obtained without the use of Mr. Green's valve, from an ordinary throttle-valve throttling the air-pressure. Mr. Green's valve, however, is a most elegant and appropriate device for accomplishing the purpose, and accomplishes it perfectly without the assistance of other apparatus.

As an essential portion of this subject we have calculated and placed in the following table the velocities in feet per second with which air

2 V

compressed to the tabular pressures flows into the atmosphere. In thus flowing, compressed air follows two entirely different laws, according as the compression is less or more than that of two atmospheres above zero.

For the first case, the effluent air at the moment of entering the atmosphere has the pressure of one atmosphere above zero, let its compression in the compressing vessel be what it may between the limits of one and two atmospheres above zero, so that the weights of air discharged within these limits, other things equal, are in the direct ratio of the tabular velocities, which velocities are themselves in the ratio of the square roots of the differences of the atmospheric pressure and the pressures of the compression, both counted from zero and at constant temperature.

For the second case, the effluent air at the moment of entering the atmosphere has exactly the same velocity let its compression be what it may above the limit of two atmospheres above zero; the velocity being uninfluenced by any greater compression than two atmospheres above zero, and consequently constant, the temperature being supposed constant. But, in this case, the effluent air at the moment of entering the atmosphere has exactly half the pressure to which it was compressed in the compressing vessel; consequently, for all compressions above that of two atmospheres above zero, the weight of compressed air flowing into the atmosphere, other things equal, will be in the direct ratio of the compressions above zero.

In making the calculations, the height of a homogeneous column of air of average composition, including aqueous vapor and carbonic-acid gas, weighing one pound per square inch, has been taken at 1457.6525 feet; and $2g$. has been taken at 64⅓. The atmospheric pressure has been taken at 14.688 pounds per square inch, or at 29.92 inches of mercury.

Table of the velocities with which air compressed to the tabular pressures flows into the atmosphere.

Pressure of the compressed air in the compressing vessel in pounds per square inch above zero, at constant temperature.	Pressure of the compressed air in the compressing vessel in pounds per square inch above the atmosphere, at constant temperature.	Velocity with which the compressed air flows into the atmosphere in feet per second.	Relative weights of compressed air discharged in equal times into the atmosphere, from the same orifice.
15.688	1	306.23	1.0000
16.688	2	433.07	1.4142
17.688	3	530.40	1.7320
18.688	4	612.45	2.0000
19.688	5	684.75	2.2361
20.688	6	750.10	2.4495
21.688	7	810.20	2.6457
22.688	8	866.14	2.8284
23.688	9	918.69	3.0000
24.688	10	968.33	3.1621
25.688	11	1015.64	3.3166
26.688	12	1060.80	3.4640
27.688	13	1104.12	3.6055
28.688	14	1145.80	3.7416
29.376	14.688	1173.61	3.8324
29.688	15	1173.61	3.8731
30.688	16	1173.61	4.0036
31.688	17	1173.61	4.1340

We have been particular in the announcement of the foregoing *true* laws governing the flow of compressed air into the atmosphere, and in the making of the corresponding computations, because these laws are not correctly given in treatises on the dynamics of elastic fluids.

Very respectfully, your obedient servants,

B. F. ISHERWOOD,
Chief Engineer, U. S. N.
THEO. ZELLER,
Chief Engineer, U. S. N.
HENRY L. SNYDER,
Chief Engineer, U. S. N.

Engineer-in-Chief WM. H. SHOCK, U. S. N.,
Chief of the Bureau of Steam Engineering,
Navy Department.

COMMANDANT'S OFFICE, *Navy-Yard, New York.*

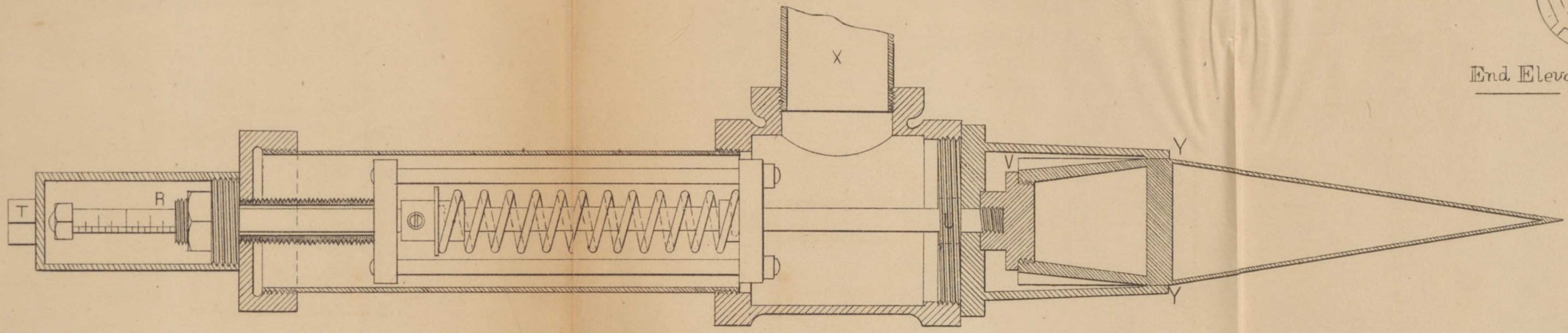
Forwarded July 31, 1879.

W. W. QUEEN,
Captain Commanding.

FIGURE 1.

SECTION OF VALVES [A B, C, Figure 2]

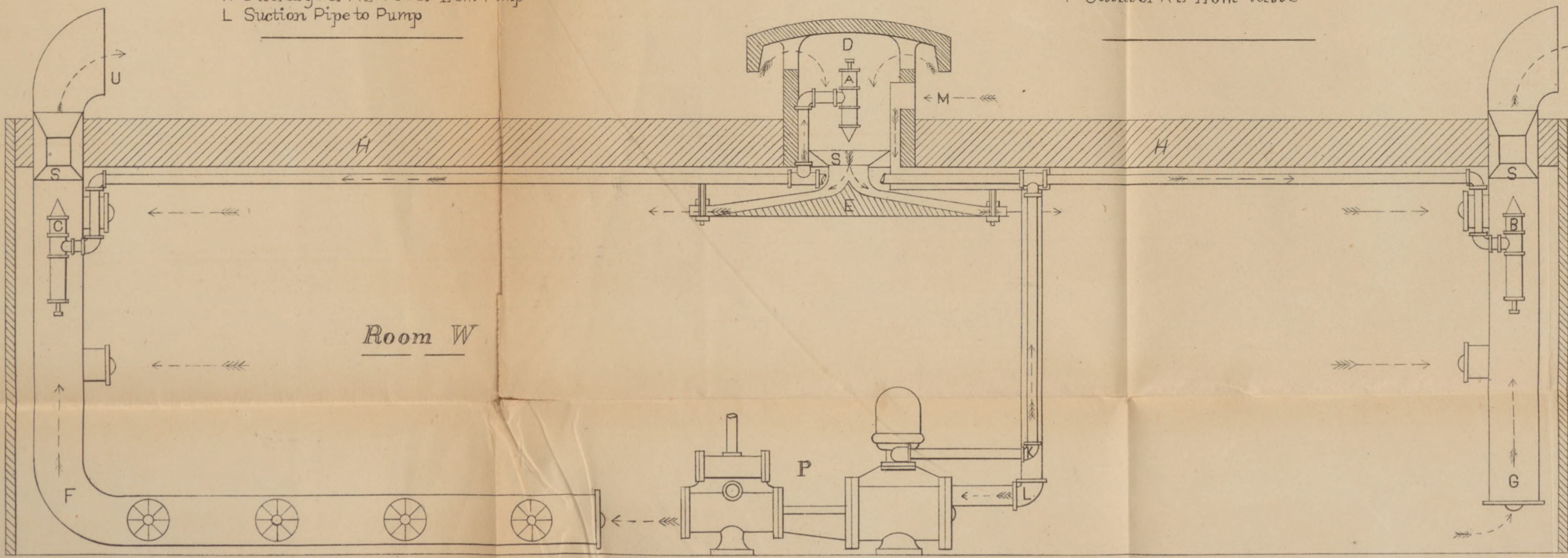
End Elevation at V



ABC Air Valves
D Air Inlet
E Air Distributor
F Exhaust with Pipes to Rooms
G Exhaust without Pipes to Rooms
HH Deck
P Pump
K Discharge of Air Power from Pump
L Suction Pipe to Pump

V Outside Air to Suction L
SSS Adjutable Air Pipes
N Steel Spring
R Rod or Tube for Adjusting Pressure
T Cap Covering End of Valve Stem
U Bearing at U for Valve Stem
X Air Inlet to Valve
Y Outlet of Air from Valve

FIGURE 2



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