AN INVESTIGATION OF THE PERFORMANCE
OF A
STATIONARY SIPHONING TYPE OF ROOF VENTILATOR

by

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A Thesis Submitted for Partial
Fulfillment for the Degree of

MASTER OF SCIENCE
in
MECHANICAL ENGINEERING

Approved:

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Director of Graduate Studies

Virginia Polytechnic Institute
August, 1941

TABLE OF CONTENTS

ILLUSTRATIONS AND TABLES

I. INTRODUCTION

The function of a roof ventilator is to provide a stormproof and weatherproof outlet for vitiated air.

The two natural forces entering into all problems of natural roof ventilation are stack action and wind action. Stack action, also called chimney action or buoyancy, is that action of air flow caused by a difference in the density of the air inside and outside of the structure. If the temperature inside is higher than that outside of the structure, the difference in air density causes the warm air to expel itself from the top of the structure, given a suitable opening, and to draw in cool air at the bottom. This is the well-known principle of draft in a fireplace.

Wind action is that action caused by air in motion. When wind passes around or across an opening without actually entering it, the wind produces a suction at the mouth of the opening. By means of this aspirating action, it is possible to draw air out of a structure, provided the wind velocity is sufficient to create the proper degree of suction at the ventilator opening.

The ventilator which combines the effects of wind action and stack action to produce the greatest evacuation of air under a given set of conditions is considered the most efficient. Throughout this thesis, the terms "effectiveness," "aspirating effectiveness," and "discharge capacity" are used synonymously to indicate the degree to which a roof ventilator fulfills its function of inducing a current of air to flow up through it.

At the present time there is a large number of companies that make roof ventilators. These devices find their widest application in the ventilation of poultry houses and barns, although they have been used successfully in school buildings and other structures (3).

The average purchaser of ventilators lacks the technical knowledge and the laboratory facilities necessary to determine for himself the characteristics of a roof ventilator and is, therefore, an ideal subject for extravagant advertising claims. In this thesis, an effort was made to supply some reliable information regarding the operating characteristics of a number of sizes of one particular type of ventilator.

Although it was impossible to make a complete study of all makes and types of ventilators, it is believed that the results of this investigation will supply useful data to those interested in the type of ventilator tested and will pave the way for similar studies of other makes and types of ventilators.

The author is deeply indebted to a number of individuals and companies for their advice and material help of various kinds. Especial gratitude is due the Shenandoah Equipment Corporation for furnishing equipment without which this investigation would have been impossible. The writer wishes to express his most sincere appreciation to Professor J. B. Jones, Mr. Robert Kulinyi, and other members of the Virginia Polytechnic Institute staff and to Messrs. Chapman, Strickland, and King of the student body whose generous aid has been invaluable in the performance of this work.

II. REVIEW OF LITERATURE

Practically all of the research to date on roof ventilators has been in the nature of comparative tests on various makes of roof ventilators of a given size. Strangely, very little has been done on the testing of a given make of ventilator of various sizes, most investigators adopting the attitude that the effectiveness of a given line of ventilators is some direct function of the size. The specific nature of this function, however, has not occupied much attention in past research.

In 1925, Calderwood and Mack, at the Kansas State Agricultural College Engineering Experiment Station, performed comparative tests on a large number of ten-inch ventilators (4). Their classification of automatic ventilators according to type is one which has been accepted by manufacturers and investigators. They list the classes as:

1. Plain stationary ("no special provision for utilizing the wind velocity in producing additional draft").
2. Stationary siphoning ("principle based on the breaking up of the wind currents and directing them in such a manner as to create a decreased pressure in the upper portion of the ventilator").
3. Plain rotary ("consists chiefly of an elbow supported on a vertical shaft" and rotated by a weathervane fastened rigidly to the top of the elbow).
4. Rotary siphoning (similar to plain rotary with addition of flutes or vanes to establish an ejector action).

Calderwood and Mack studied the features of those ventilators which proved most effective according to their tests and evolved a list of important factors for greatest effectiveness. These are of such significance that they will be quoted verbatim:

> 1. Large projected area exposed to the wind. A large area produced a larger low pressure area and a better exhaust.
> 2. Ample area of the exit passages. The area for the passage of the air leaving the ventilator should be at least as large as the cross-sectional area of the inlet pipe. In the case of the stationary types of ventilators, the area should be larger, as most of the exhaust air passes out of the ventilator on its lee side when the wind is blowing.
> 3. Preventing the entrance of wind. Air which enters the ventilator must be exhausted and unless provision is made for the removal of this additional air or the preventing of its entrance, the capacity of the ventilator is proportionately decreased.
> 4. The straightness of the path of egress of the air. Abrupt turns in the passage of the air introduce friction. The path of the outgoing gases should be as nearly straight as possible. If turns are necessary, they should be smooth and well rounded.
> 5. The freedom of obstruction in the path of egress. The effectiveness of a ventilator may be materially lowered by obstructions. They should, consequently, be eliminated to the greatest possible extent.
> 6. Making use of the vacuum created by the wind. Any provision whereby the vacuum created by the wind is increased or made more effective will produce added ventilator effectiveness.

In connection with item 1 of the foregoing, Mack and Bradley, in 1922, performed tests to determine the effect of the width of storm band on ventilator effectiveness (10). They found that varying the storm band width from 17½ to 21 inches on the same ten-inch ventilator resulted in a corresponding increase in the effectiveness. These results substantiated some similar results published by Mack in 1920 (9).

Dryden, Stutz, and Heald, in 1920, ran comparative tests on a large number of 16-inch ventilators at the laboratories of the National Bureau of Standards, Washington, D. C. (6). In addition to measuring the discharge with no temperature difference at various wind velocities, these investigators compared the resistances to flow of the various ventilators by blowing air through them with a constant-speed electric fan and measuring the discharge. The conclusions drawn from these tests were much the same as those given by Calderwood and Mack (4). These conclusions are quoted on the preceding page.

In 1923, Rowley, in studying the effect of changing the dimensions of a given ventilator, found that there exists a certain optimum diameter of storm band (11). If this dimension is varied in either direction, the draft created by the ventilator is diminished.

Perhaps the most concrete suggestions toward the establishment of a standard code for the testing and rating of roof ventilators were offered by Beals in 1927 (2). He says:

"The claims of some manufacturers are so extravagant, and the arrangement of test equipment used subject to such criticism, that it is necessary, for the protection of manufacturers and users alike, that concerted action be taken to determine upon standard testing apparatus and uniform methods of rating....

"Wind-tunnel tests are preferable to working condition tests because:

1. A laboratory setup of test equipment can be duplicated at any time or place, whereas the circumstances under which a working condition test is made are rarely the same or possible of duplication.
2. A working condition test, to be of any practical value, must be conducted over a long period of time so as to obtain a sufficiently extended range of the various conditions of wind velocities, etc., whereas in a laboratory test, the time element is unimportant.
3. The conditions under which ventilators are installed are so varied, hardly any two being installed under identical conditions, that it seems impossible to conceive of any working test setup that would produce results which could be placed in the hands of an engineer for his information and guidance in the selection of equipment for future projects...."

And in connection with the above, Beals presents an elaborate description, with detail drawings, of a proposed laboratory setup for testing 14-inch ventilators.

It is interesting to note that the test equipment used by the writer is, with minor modifications, the same as that used and recommended by all of the investigators thus far mentioned.

Trent, Groseclose, and Jones point out that tests run with ventilators mounted on a roof are of no practical importance in rating ventilators because it is impossible to control the turbulent air currents around the apparatus, the temperature conditions, and the wind velocity (7). In 1932, these investigators made an attempt to determine ventilator capacities under actual service conditions and were finally forced to resort to wind tunnel tests for the reasons mentioned above. Consequently, the writer wonders what significance can be attached to the data presented by Professor Tuve as a result of his commercial tests, since the tests were run with the ventilators mounted on a roof, and no conditions could be controlled or maintained constant for a sufficient length of time to obtain reliable and duplicable results (14).

The most complete theoretical quantitative discussion of the action of roof ventilators is given in the American Larson Bulletin No. A. I. A. 12k 1 (12). In this treatise are developed equations for the force produced by chimney action and the force produced by the action of the wind. The noteworthy fact in this connection is that "in actual operation the two forces of wind action and stack action do not add together directly but that an additional resistance to air flow is created when both act at the same time. This resistance is equivalent in its effect to a negative force. Hence the net effective force is always <u>less</u> than the sum of the first two forces...." "This negative force," explain the authors, "is the result of a partial blanking-off effect" by the wind, which prevents chimney action from attaining its maximum effectiveness.

Certain other commercial bulletins (8), (13) contain a wealth of descriptive material and practical considerations regarding ventilators if due allowance be made for the fact that they are advertising bulletins.

III. THE INVESTIGATION

Object. The purpose of this investigation is to determine and compare the aspirating effectiveness of 10- to 24-inch sizes of a stationary siphoning type of automatic roof ventilator.

At present, no standard code exists for the testing and rating of automatic roof ventilators. Since the American Society of Heating and Ventilating Engineers is anxious to establish such a code, this investigation might serve the useful purpose of offering suggestions toward that end. A universal apparatus, procedure, and method of presenting test results would help appreciably to eliminate the misleading claims of many ventilator manufacturers. If the ratings were all based on standard tests and standard air, the prospective purchaser would have no difficulty in comparing the performance of the various makes and types of ventilators.

Test Equipment. A wind tunnel was constructed in the Mechanical Engineering Laboratory of the Virginia Polytechnic Institute. The blower end of the tunnel is shown in Figure 1, and the discharge end is shown in Figure 2. At one end of the tunnel were mounted two turbine-driven variable-speed propeller-type fans, capable of producing wind velocities up to seven miles per hour. The mouth of the tunnel was five and one-half feet square. The floor of the tunnel extended six feet lengthwise beyond the sides and top of the tunnel. A stack whose diameter corresponded to the diameter of the ventilator to be tested was placed vertically with its centerline three feet beyond the tunnel mouth. The stack was ten feet long and protruded above the tunnel floor so that the ventilator head was in the center of the area of the mouth of the tunnel (see Figure 3).

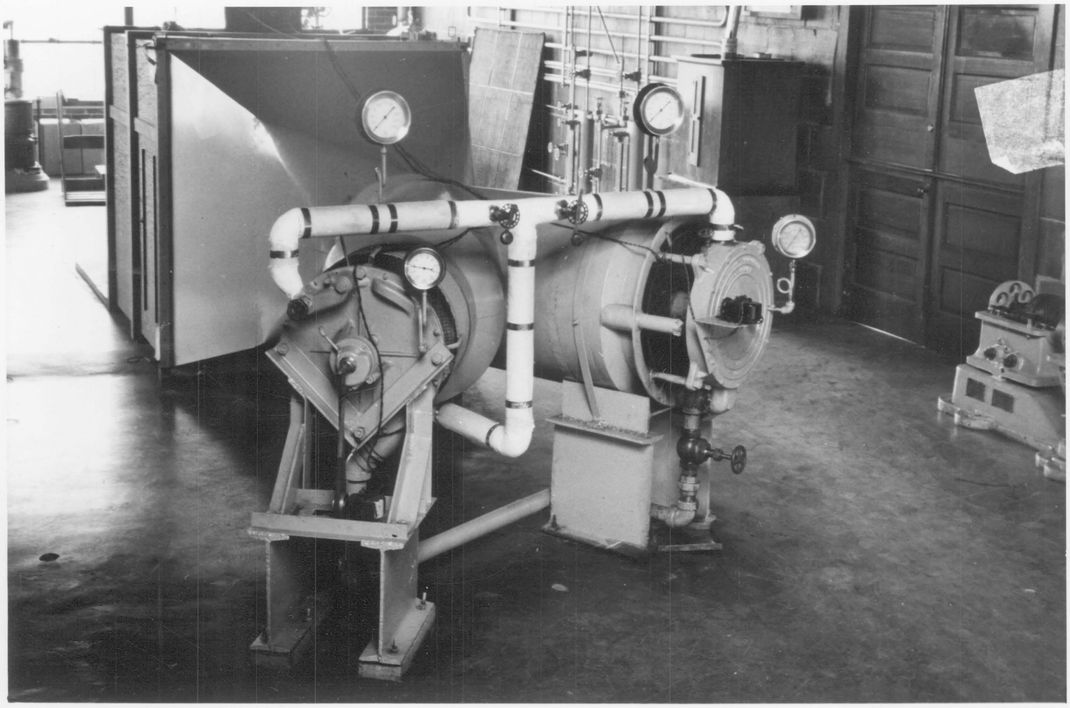


Fig. 1 - VIEW OF WIND TUNNEL FROM BLOWER END

Fig. 2 - VIEW OF WIND TUNNEL FROM DISCHARGE END

Fig. 3 - EIGHTEEN-INCH VENTILATOR MOUNTED ON STACK

IN FRONT OF WIND TUNNEL

The room in which the tunnel and fans were located was large enough to eliminate small disturbances at the ventilator due to drafts caused by the fan suction or to eddy currents caused by the discharged air striking the wall beyond the ventilator.

A great deal of difficulty was experienced in obtaining uniform, parallel flow of the air leaving the tunnel. This problem was solved by placing within the tunnel two fine-mesh screens one foot apart and filling the cross-section near the mouth of the tunnel with tubular straightening vanes five inches in diameter and one foot long. The ends of these tubes are shown in Figures 2 and 3. Visible in Figure 4 is another set of straightening vanes three inches in diameter and one foot long, placed within the tunnel at the blower end. Between these two sets of tubes was mounted a sheet-metal cone with its base facing the tunnel mouth. A pair of adjustable directional vanes, similar to the elevators of an airplane, were fastened to the sides of the cone, and the cone with its vanes could be moved axially to any position inside the tunnel. The cone assembly inside the tunnel is shown in Figure 4. The cone itself avoided a concentration of velocity at the center of the tunnel cross-section by diverting the air toward the sides. The directional vanes could be adjusted to equalize the velocities at the corners of the tunnel mouth. Thus, with the proper setting of the cone assembly, a very uniform, parallel flow of air across the ventilator head could be obtained.

All wind velocities were measured by means of carefully calibrated vane-type anemometers suspended in a vertical plane four inches outside the tunnel mouth (see Figure 2).

The velocities of the air in the stack were measured by means of an Alnor velometer with the duct jet inserted radially in the stack at the vertical

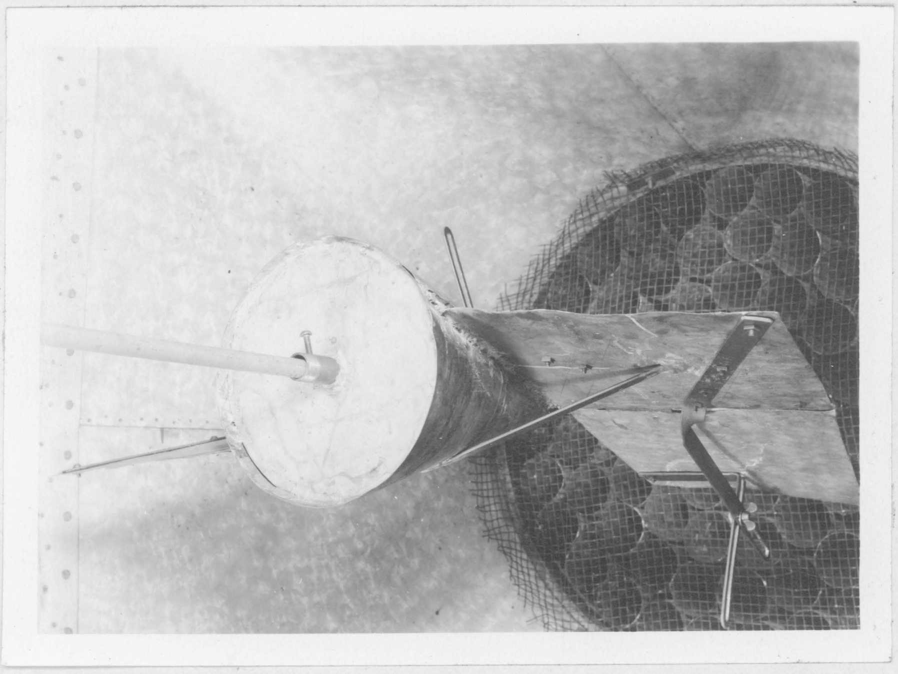


Fig. 4 - EQUALIZING CONE ASSEMBLY

AS SEEN FROM EXIT END OF TUNNEL

mid-point of the stack. The velometer with its jet in the stack is shown in Figures 5 and 6.

Matched hygrometers were used for measuring the wet- and dry-bulb temperatures of the air. One hygrometer was placed in the air stream entering the bottom of the stack, and the other was placed in the wind stream passing over the ventilator.

A calibrated Foxboro instantaneous tachometer was used to determine the blower speeds.

The ventilators tested were all of the same make and were of the stationary siphoning type. The ventilators, shown in Figure 7, were 10-, 12-, 14-, 16-, 18-, 20-, and 24-inch sizes. These sizes were chosen as representing the majority of the ventilators used in practice and because they bore a correct relationship to the proportions of the wind tunnel. Obviously, a very large ventilator placed close to the discharge end of a wind tunnel will show extremely inaccurate results. On the other hand, if a very small unit is tested, the measuring instruments will so obstruct the air passage that equally inaccurate results will be obtained.

Method of Test. The factors governing the effectiveness of an automatic roof ventilator and the items which must be taken into consideration in the choice of a ventilator are so numerous and complex that it was impossible to attempt a complete study. The experiments were thus confined to the determination of the volume of air exhausted per minute by the ventilators. This discharge is affected primarily by the difference in temperature between the air entering the stack and the air blowing across the ventilator and by the velocity of the wind blowing across the ventilator head. In order to make the problem even more specific, it was decided to eliminate the stack

Fig. 5 - EIGHTEEN-INCH STACK WITH VELOMETER AND DUCT JET IN POSITION

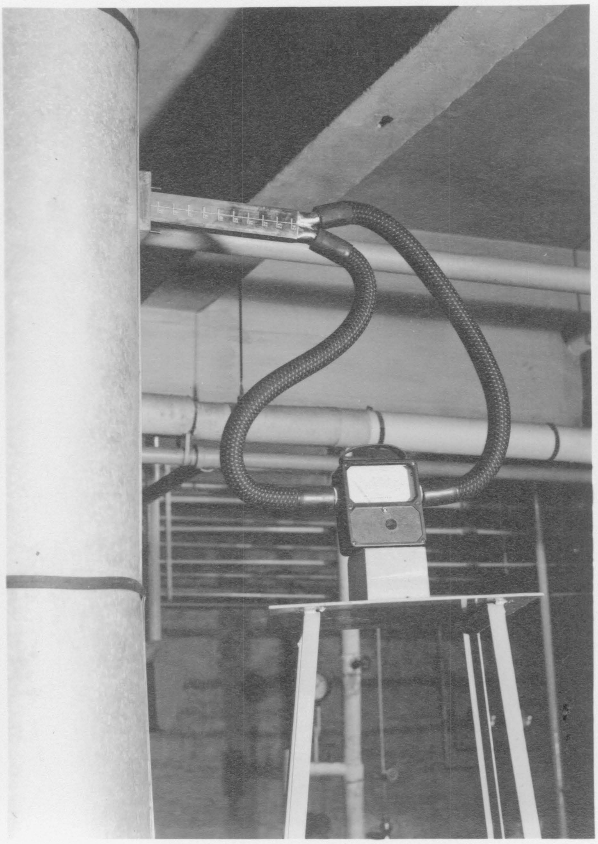


Fig. 6 - CLOSE-UP OF VELOMETER WITH

DUCT JET INSERTED IN STACK

Fig. 7 - 10-, 12-, 14-, 16-, 18-, 20-, AND 24-INCH

VENTILATORS WHICH WERE TESTED

action by maintaining a zero temperature difference and constant humidity between the air entering at the bottom of the stack and that blowing across the ventilator. Any accidental temperature differences which did exist were corrected for analytically.

The calibration of the wind tunnel was carried out in the following manner. For each fan speed, starting with 3000 revolutions per minute and decreasing the speed by increments of 250 revolutions per minute, the position and adjustment of the cone assembly which yielded the most uniform air distribution was determined by trial and error. The cross-sectional area of the tunnel mouth was divided into 64 equal areas by crossed wires which are visible in Figures 2 and 3. Then, with the blowers set at a given speed and with the cone assembly adjusted to correspond to that speed, the wind velocity at the center of each of the 64 small areas was determined by means of an anemometer. These readings were then averaged to determine the average wind velocity issuing from the tunnel. At least three such traverses were run for each fan speed to insure an accurate determination of the wind velocity for any given fan speed. For example, when the fans were rotating at 2750 revolutions per minute, it was found that the wind velocity produced was 6.25 miles per hour. Thus the speed of the wind could be obtained by merely reading the tachometer at the shafts of the turbo-blowers and referring to Figure 8, which is a graphical representation of the results of the calibration.

In conducting the actual ventilator tests, a ventilator was placed over the corresponding stack mounted at the end of the tunnel, and the speed of the blowers was regulated by throttle valves to produce the desired wind velocity. The velocity of the air induced through the stack was obtained by making standard four-, six-, or eight-point traverses (depending on the diameter

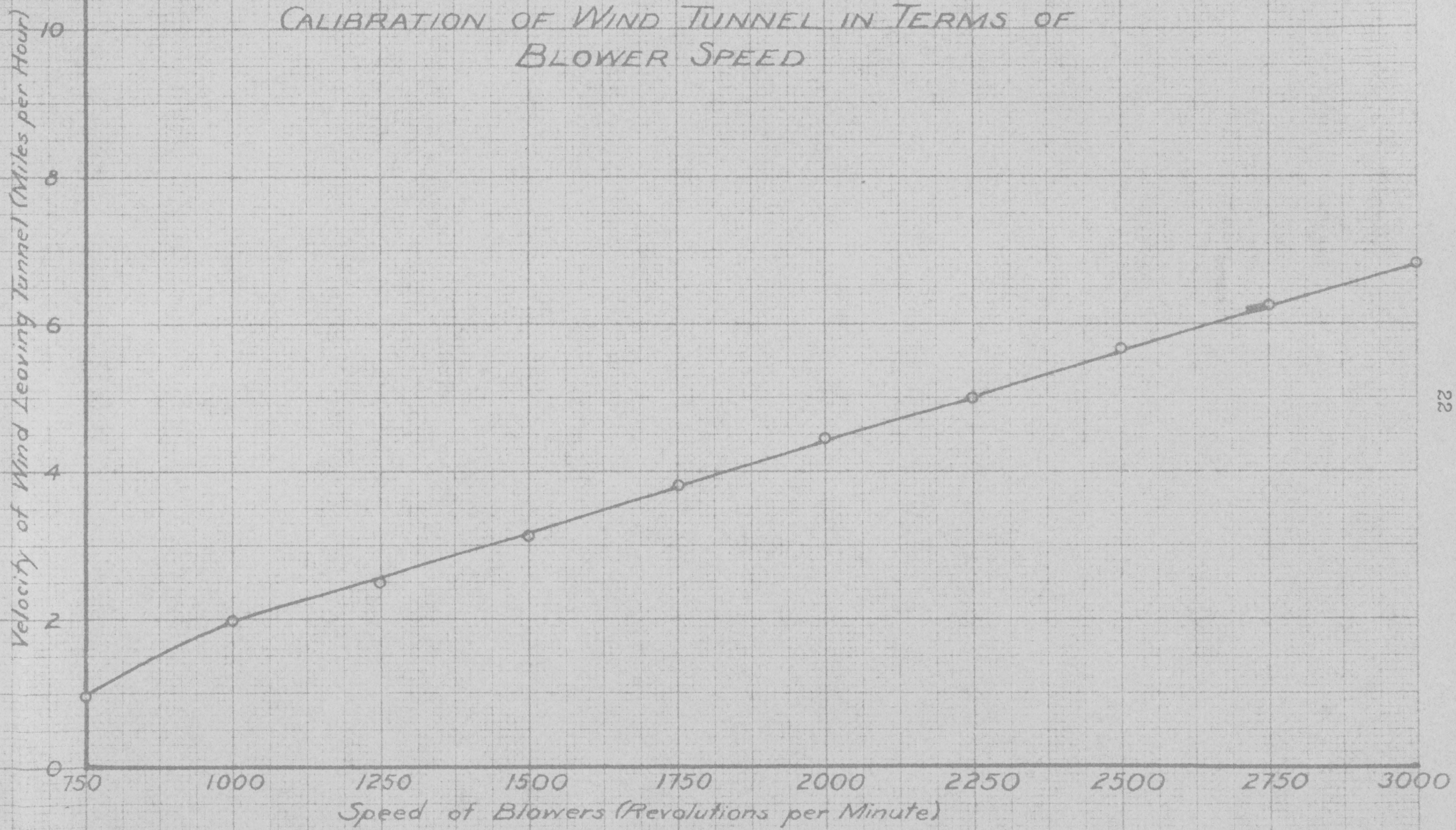


Fig. 8 - WIND TUNNEL CALIBRATION

E.M. Simons
July, 1941

of the stack) with the velometer duct jet. The readings on each traverse were taken with the duct jet at the mid-points of concentric equal annular areas, as recommended by the American Society of Heating and Ventilating Engineers for pitot tube traverses (1). Two traverses at right angles to each other were made for each blower speed. This procedure was carried out at least twice for each ventilator in order to ascertain whether or not the results were duplicable. Since the velometer reads velocities directly in feet per minute, and since the air velocity in the stack fluctuated slightly, it was necessary to observe and average these fluctuations over a period of time for each point in the traverse.

A second series of tests were run to determine the volume of air induced through an open stack when no ventilator was mounted on it. These tests were carried out in exactly the same manner as the tests with the ventilators, but each stack was raised so that its upper end was located opposite the center of the tunnel opening. The results secured in this latter case are referred to and recorded as "Open Stack."

Test Results. The observed data are presented in Tables I to XIV, inclusive. Tables I to VII, inclusive, give the data for the tests conducted with the ventilators mounted on the stacks, each table being for a different size of ventilator. Tables VIII to XIV, inclusive, give the same data for the runs with the plain open stacks at the end of the tunnel. For each traverse, the actual velometer readings and their average are given. In addition, the hygrometer readings for both the air leaving the tunnel and the air flowing in the stack are recorded.

Table XV gives the composite results for all the ventilators and open stacks tested. Each velocity listed represents the average as determined by two traverses taken at right angles to each other. Each value under the heading "Corrected Discharge" represents the volume of standard air ($70^{\circ}F$ and 29.92 inches of mercury barometer) induced through the stack with no friction in the stack and no difference in temperature between the air entering the stack and the air leaving the wind tunnel. Figures 9 and 10 are a graphical illustration of the relationship between corrected discharge and wind velocity for the various ventilators and open stacks.

Table I

OBSERVED DATA FOR 10-INCH VENTILATOR

July 26, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)					Temperatures (^{o}F)			
	1	2	3	4	Average	Tunnel Room		Stack Room	
						Dry	Wet	Dry	Wet
	Traverse No. 1								
6.82	225	240	240	250	239	101	79	89	77
6.25	200	215	220	215	213	99	79	89	77
5.68	170	190	200	200	190	100	79	89	76
5.00	175	185	165	165	173	99	79	88	76
4.44	140	145	160	150	149	99	78	87	75
3.80	125	130	140	140	134	98	78	87	75
3.12	110	125	120	125	120	96	77	86	75
2.50	60	60	75	95	73	95	77	87	75
	Traverse No. 2 (at right angles to traverse No. 1)								
6.82	210	225	250	250	234	97	78	86	75
6.25	185	195	225	225	208	97	78	86	75
5.68	170	175	200	200	186	96	77	86	75
5.00	155	160	180	185	170	95	77	86	76
4.44	120	130	160	165	144	95	77	85	75
3.80	100	120	145	135	125	94	77	86	76
3.12	80	95	110	130	112	93	77	85	75
2.50	65	60	75	60	65	94	77	86	75

Barometer--28.07 inches of mercury
Average dry bulb temperatures:
Tunnel--97°F
Stack---87°F

Table II

OBSERVED DATA FOR 12-INCH VENTILATOR

July 26, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)					Temperatures (°F)			
	1	2	3	4	Average	Tunnel Room		Stack Room	
						Dry	Wet	Dry	Wet
	Traverse No. 1								
6.82	205	220	210	210	211	91.5	76.5	81.0	73.5
6.25	195	200	200	200	199	92.0	76.5	81.0	73.5
5.68	170	175	185	185	179	91.5	76.5	81.0	74.0
5.00	150	160	165	165	160	91.0	76.0	81.0	73.5
4.44	130	135	130	140	134	90.5	76.0	80.0	73.0
3.80	105	105	105	120	109	89.0	72.5	79.5	72.5
3.12	75	80	75	100	82	89.0	75.5	79.5	72.5
2.50	60	60	70	80	67	89.0	75.0	79.5	72.5
	Traverse No. 2 (at right angles to traverse No. 1)								
6.82	200	210	225	250	221	90.0	75.0	79.0	72.0
6.25	180	180	215	210	196	90.5	75.0	79.5	72.0
5.68	140	160	190	205	174	90.0	75.0	79.0	72.0
5.00	120	140	170	185	154	90.0	75.0	79.0	72.0
4.44	110	120	145	165	135	89.5	75.0	79.5	72.0
3.80	105	100	115	150	117	89.0	75.0	80.0	73.0
3.12	75	75	95	105	87	89.0	75.0	79.0	72.5
2.50	60	65	85	95	76	89.0	75.0	79.0	72.5

Barometer--28.11 inches of mercury
Average dry bulb temperatures:
Tunnel--90°F
Stack---80°F

Table III

OBSERVED DATA FOR 14-INCH VENTILATOR

July 17, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)					Temperatures (°F)			
	1	2	3	4	Average	Tunnel Room		Stack Room	
						Dry	Wet	Dry	Wet
	Traverse No. 1								
6.82	175	190	220	240	206	87	72	76	68
6.25	160	165	215	220	190	87	72	75	69
5.68	150	160	190	205	176	85	71	74	67
5.00	120	125	170	185	150	85	70	74	67
4.44	105	95	145	165	128	84	70	74	67
3.80	75	80	110	140	101	83	69	74	67
3.12	60	75	85	120	85	83	69	74	67
2.50	55	55	75	80	66	83	69	73	66
	Traverse No. 2 (at right angles to traverse No. 1)								
6.82	200	215	230	220	216	91	74	84	72
6.25	190	200	215	215	205	92	74	85	73
5.68	165	180	195	200	185	90	73	84	72
5.00	140	165	170	175	163	89	73	84	73
4.44	155	140	150	155	150	89	73	83	72
3.80	140	130	145	150	141	88	73	82	71
3.12	100	100	100	120	105	87	73	81	72
2.50	75	60	80	80	74	86	72	82	73

Barometer--28.00 inches of mercury
Average dry bulb temperatures:
Tunnel--87°F
Stack---79°F

Table IV

OBSERVED DATA FOR 16-INCH VENTILATOR

July 16, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)							Temperatures (°F)			
	1	2	3	4	5	6	Average	Tunnel Room		Stack Room	
								Dry	Wet	Dry	Wet
6.82	180	180	190	225	240	240	209	86	74	75	70
6.25	160	160	155	200	215	220	185	87	74	76	70
5.68	150	155	165	190	200	205	178	84	73	75	70
5.00	125	130	140	165	185	190	156	84	72	75	70
4.44	100	100	90	125	165	160	124	84	73	75	70
3.80	90	90	90	120	145	140	112	85	73	75	70
3.12	70	70	65	75	100	110	82	84	73	75	70
2.50	55	50	60	70	80	80	68	84	73	75	70
	Traverse No. 2 (at right angles to traverse No. 1)										
6.82	210	220	215	225	225	210	218	86	73	80	71
6.25	190	200	190	200	195	180	193	87	73	80	71
5.68	175	175	180	180	180	190	180	87	73	81	72
5.00	155	170	170	160	160	155	162	87	73	83	72
4.44	125	140	140	135	135	125	133	87	73	82	71
3.80	110	100	100	80	105	85	97	85	71	83	71
3.12	85	95	90	70	75	85	83	86	71	83	71
2.50	70	80	60	45	70	65	65	87	72	82	71

Barometer--28.10 inches of mercury
Average dry bulb temperatures:
Tunnel--86°F
Stack---77°F

Table V

OBSERVED DATA FOR 18-INCH VENTILATOR

July 12, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)							Temperatures (°F)			
	1	2	3	4	5	6	Average	Tunnel Room		Stack Room	
								Dry	Wet	Dry	Wet
6.82	275	275	260	200	200	180	235	90	75	80	72
6.25	245	250	235	195	200	175	217	91	75	79	71
5.68	230	240	215	180	150	165	197	90	75	80	71
5.00	210	215	205	145	135	150	177	89	74	78	71
4.44	195	195	165	125	120	145	157	88	74	78	71
3.80	165	165	155	95	110	110	133	87	73	77	70
3.12	150	145	125	85	80	85	112	86	73	77	70
2.50	105	115	90	60	60	75	84	87	73	77	70
1.99	75	70	50	30	20	45	48	87	73	77	70
	Traverse No. 2 (at right angles to Traverse No. 1)										
6.82	210	220	235	250	250	215	230	85	71	79	69
6.25	190	210	220	225	240	225	218	83	70	76	68
5.68	180	185	200	205	200	180	192	83	70	77	68
5.00	155	185	175	185	185	175	177	83	70	77	68
4.44	130	150	160	165	170	155	155	81	69	75	67
3.80	135	125	150	145	125	120	133	79	69	75	67
3.12	105	120	100	105	100	110	107	83	70	78	68
2.50	90	75	85	90	80	75	83	77	67	74	65
1.99	70	60	55	10	75	10	47	78	68	75	68

Barometer--28.08 inches of mercury
Average dry bulb temperatures:
Tunnel--86°F
Stack---77°F

Table VI

OBSERVED DATA FOR 20-INCH VENTILATOR

July 11, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)							Temperatures (°F)			
	1	2	3	4	5	6	Average	Tunnel Room		Stack Room	
								Dry	Wet	Dry	Wet
6.82	225	235	230	225	225	210	225	92	74	83	72
6.25	220	200	205	215	220	205	211	91	74	83	72
5.68	185	190	195	190	190	185	189	90	73	83	71
5.00	150	165	160	160	175	175	164	90	73	83	71
4.44	145	145	155	155	155	160	153	89	73	82	71
3.80	125	100	120	115	145	125	122	89	73	82	71
3.12	95	100	95	85	105	105	98	88	73	82	71
2.50	70	70	60	75	75	75	71	88	73	81	71
1.99	20	25	20	50	40	55	35	87	73	81	71
	Traverse No. 2 (at right angles to traverse No.1)										
6.82	190	195	210	265	270	245	229	97	77	92	77
6.25	175	175	205	235	225	225	208	94	76	92	77
5.68	160	155	165	205	210	205	183	95	77	92	77
5.00	150	135	155	195	185	180	167	93	77	93	77
4.44	125	110	130	155	155	155	138	92	76	91	77
3.80	115	100	105	150	150	155	129	92	76	90	76
3.12	80	75	85	120	145	125	105	91	76	89	76
2.50	60	55	50	70	100	85	70	90	75	88	75
1.99	50	25	60	65	80	70	58	89	75	87	75

Barometer--27.98 inches of mercury
Average dry bulb temperatures:
Tunnel--92°F
Stack---86°F

Table VII

OBSERVED DATA FOR 24-INCH VENTILATOR

July 5, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)									Temperatures (°F)			
	1	2	3	4	5	6	7	8	Average	Tunnel Room		Stack Room	
										Dry	Wet	Dry	Wet
	Traverse No. 1												
6.82	190	205	195	210	235	225	210	220	211	83	82	81	73
6.25	190	175	175	190	200	205	205	205	193	82	81	79	72
5.68	165	155	140	165	175	190	195	195	173	81	80	79	72
5.00	130	135	135	145	160	165	170	170	151	81	80	79	72
4.44	115	100	90	90	120	135	130	130	114	81	79	80	73
3.80	70	80	80	75	90	105	115	115	91	84	83	80	73
3.12	65	60	60	55	55	70	60	80	63	83	82	82	75
	Traverse No. 2 (at right angles to traverse No. 1)												
6.82	240	240	230	230	195	175	175	150	204	94	71	84	70
6.25	200	210	210	210	175	150	145	125	178	89	68	83	66
5.68	200	190	195	190	160	135	150	120	168	93	70	84	67
5.00	180	180	175	185	130	110	100	100	145	92	70	83	67
4.44	135	150	160	150	105	85	80	80	118	89	69	83	67
3.80	130	130	140	115	90	70	75	60	101	94	71	83	67
3.12	115	100	125	100	65	70	50	60	86	93	71	84	67

Barometer--28.11 inches of mercury
Average dry bulb temperatures:
Tunnel--88°F
Stack---82°F

Table VIII

OBSERVED DATA FOR 10-INCH OPEN STACK

July 26, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)					Temperatures (°F)			
	1	2	3	4	Average	Tunnel Room		Stack Room	
						Dry	Wet	Dry	Wet
	Traverse No. 1								
6.82	170	180	210	210	193	95	79	87	76
6.25	165	175	195	195	183	95	79	87	77
5.68	135	145	175	185	160	95	79	88	77
5.00	125	135	160	180	150	94	78	87	77
4.44	105	130	150	150	135	95	77	88	77
3.80	85	105	130	130	113	95	77	88	75
3.12	85	90	110	115	100	96	77	87	77
2.50	75	85	90	100	88	95	74	88	73
	Traverse No. 2 (at right angles to traverse No. 1)								
6.82	170	175	185	185	179	101	78	89	75
6.25	165	170	180	180	174	101	78	89	75
5.68	150	160	165	170	161	100	77	89	74
5.00	135	140	160	165	150	98	77	88	75
4.44	125	140	160	155	145	99	78	89	75
3.80	115	130	130	145	130	97	77	88	74
3.12	100	110	115	120	111	98	78	88	76
2.50	95	85	95	85	90	97	77	88	75

Barometer--28.08 inches of mercury
Average dry bulb temperatures:
Tunnel--97°F
Stack---88°F

Table IX

OBSERVED DATA FOR 12-INCH OPEN STACK

July 26, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)					Temperatures ($^{\circ}F$)			
	1	2	3	4	Average	Tunnel Room		Stack Room	
						Dry	Wet	Dry	Wet
	Traverse No. 1								
6.82	175	190	195	220	195	95.0	79.0	85.5	76.0
6.25	165	165	195	205	183	94.5	78.5	85.0	76.0
5.68	125	150	160	165	150	93.5	78.5	84.5	76.0
5.00	125	140	155	170	147	95.0	77.5	83.5	75.5
4.44	110	120	145	140	129	92.5	77.5	84.0	76.0
3.80	100	100	120	140	115	92.0	77.0	84.0	76.0
3.12	75	90	120	125	103	92.5	77.0	83.0	75.0
2.50	70	70	85	100	81	91.7	77.0	83.5	74.0
	Traverse No. 2 (at right angles to traverse No. 1)								
6.82	160	170	165	165	165	92.0	77.0	81.0	73.5
6.25	155	155	155	165	158	92.0	77.0	81.0	74.0
5.68	150	155	160	160	156	92.0	77.0	81.0	73.5
5.00	155	155	160	165	159	91.0	77.0	81.5	73.0
4.44	150	150	160	165	156	91.5	74.5	81.5	73.0
3.80	140	140	145	150	144	91.5	74.5	82.0	75.0
3.12	110	105	110	115	110	91.0	76.5	82.5	74.0
2.50	95	95	90	105	96	92.0	77.0	83.5	74.0

Barometer--28.08 inches of mercury
Average dry bulb temperatures:
Tunnel--93°F
Stack---83°F

Table X

OBSERVED DATA FOR 14-INCH OPEN STACK

July 18, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)					Temperatures (°F)			
	1	2	3	4	Average	Tunnel Room		Stack Room	
						Dry	Wet	Dry	Wet
	Traverse No. 1								
6.82	160	140	160	170	158	96.5	72.0	87.0	70.0
6.25	140	140	150	160	148	96.5	72.0	87.0	69.0
5.68	140	140	150	155	146	95.0	71.0	86.0	68.0
5.00	140	135	160	160	149	95.0	72.0	86.0	69.0
4.44	145	125	140	140	138	94.0	72.0	87.0	70.0
3.80	120	100	120	135	119	95.0	73.0	88.0	71.0
3.12	95	95	100	135	106	94.0	73.0	87.0	71.0
2.50	90	80	80	90	85	94.0	73.0	88.0	73.0
	Traverse No. 2 (at right angles to traverse No. 1)								
6.82	105	115	160	170	138	85.0	70.0	80.0	69.0
6.25	105	115	160	170	138	86.0	71.0	81.0	70.0
5.68	105	115	150	170	136	86.0	71.0	80.0	70.0
5.00	115	100	140	160	129	86.0	71.0	80.0	70.0
4.44	100	100	140	150	122	85.0	71.0	81.0	70.0
3.80	95	100	135	140	117	87.0	72.0	84.0	72.0
3.12	80	75	110	135	100	88.0	73.0	84.0	72.0
2.50	60	60	90	100	78	88.0	73.0	85.0	73.0

Barometer--28.02 inches of mercury
Average dry bulb temperatures:
Tunnel--90°F
Stack---85°F

Table XI

OBSERVED DATA FOR 16-INCH OPEN STACK

July 19, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)							Temperatures (°F)			
	1	2	3	4	5	6	Average	Tunnel Room		Stack Room	
								Dry	Wet	Dry	Wet
6.82	150	150	140	150	150	150	148	92	73	85	72
6.25	130	110	130	115	120	125	122	90	73	85	72
5.68	125	125	120	105	120	120	119	87	72	84	72
5.00	100	120	120	110	120	115	114	86	71	83	71
4.44	110	120	115	120	110	125	117	85	71	82	70
3.80	75	100	95	90	105	100	94	86	72	82	70
3.12	75	70	70	85	85	75	77	88	73	83	78
2.50	70	55	60	55	65	70	70	89	74	83	71
	Traverse No. 2 (at right angles to traverse No. 1)										
6.82	115	110	110	150	165	165	165	89	74	79	71
6.25	105	105	110	150	160	160	132	89	74	79	71
5.68	105	100	110	140	155	155	128	89	74	79	71
5.00	100	95	105	140	160	155	126	89	74	78	70
4.44	100	85	100	120	140	150	116	89	73	79	70
3.80	90	80	85	110	120	125	102	90	74	82	71
3.12	60	65	65	80	105	100	79	90	74	82	71
2.50	55	60	55	70	85	80	68	89	74	82	72

Barometer--28.00 inches of mercury
Average dry bulb temperatures:
Tunnel--89°F
Stack---82°F

Table XII

OBSERVED DATA FOR 18-INCH OPEN STACK

July 21, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)							Temperatures (^{o}F)			
	1	2	3	4	5	6	Average	Tunnel Room		Stack Room	
								Dry	Wet	Dry	Wet
6.82	205	210	200	180	170	160	188	87	69	83	68
6.25	185	195	185	170	160	150	174	87	69	82	68
5.68	150	155	145	130	115	100	132	88	70	88	67
5.00	150	140	140	135	110	110	131	89	70	83	68
4.44	140	140	140	120	105	110	126	90	70	84	68
3.80	110	115	115	120	100	85	108	89	70	85	69
3.12	115	110	100	85	75	90	96	90	70	84	68
2.50	100	100	80	80	70	75	84	90	69	84	67
	Traverse No. 2 (at right angles to traverse No. 1)										
6.82	150	155	155	140	120	115	139	94	71	85	68
6.25	145	140	145	140	145	150	144	94	71	84	66
5.68	155	150	150	120	120	120	136	93	70	84	67
5.00	160	155	140	115	115	125	135	92	69	85	68
4.44	120	150	130	110	110	100	118	91	69	85	67
3.80	120	115	115	110	95	85	107	90	68	84	65
3.12	106	110	105	70	75	70	89	90	69	86	67
2.50	90	80	80	75	65	65	76	90	69	84	67

Barometer--28.19 inches of mercury
Average dry bulb temperatures:
Tunnel--90^{o}F
Stack---84^{o}F

Table XIII

OBSERVED DATA FOR 20-INCH OPEN STACK

July 21, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)							Temperatures (^{o}F)			
	1	2	3	4	5	6	Average	Tunnel Room		Stack Room	
								Dry	Wet	Dry	Wet
6.82	180	175	190	170	180	185	180	92	70	83	67
6.25	170	175	180	195	170	170	176	93	70	83	68
5.68	130	130	150	150	135	135	138	92	69	82	65
5.00	135	140	145	150	140	150	143	92	69	82	65
4.44	125	130	140	120	140	130	131	92	69	82	66
3.80	70	105	120	110	110	110	104	91	69	83	67
3.12	105	95	100	100	100	105	101	92	70	82	66
2.50	55	60	75	75	65	55	64	93	71	84	67
	Traverse No. 2 (at right angles to traverse No. 1)										
6.82	130	125	160	170	170	170	154	94	71	83	67
6.25	110	110	140	155	155	155	138	94	71	83	67
5.68	120	120	140	160	165	160	144	94	71	83	67
5.00	120	110	130	140	125	135	127	92	70	84	67
4.44	100	110	115	150	160	155	132	92	69	83	67
3.80	75	85	90	100	110	105	94	91	69	83	67
3.12	75	70	75	100	105	100	88	94	77	84	67
2.50	50	50	50	70	70	60	58	93	71	84	67

Barometer--28.14 inches of mercury
Average dry bulb temperatures:
Tunnel--93^{o}F
Stack---83^{o}F

Table XIV

OBSERVED DATA FOR 24-INCH OPEN STACK

July 21, 1941

Wind Vel. mph	Velometer Readings at Traverse Points (fpm)									Temperatures (°F)			
	1	2	3	4	5	6	7	8	Average	Tunnel Room		Stack Room	
										Dry	Wet	Dry	Wet
	Traverse No. 1												
6.82	175	170	165	160	125	100	75	95	133	88	70	76	65
6.25	165	165	165	160	125	100	85	100	133	91	70	78	65
5.68	160	160	160	155	125	100	100	90	131	91	70	79	66
5.00	155	160	160	150	115	90	70	85	123	91	71	79	66
4.44	150	160	160	155	100	100	75	75	122	92	71	79	66
3.80	130	125	135	105	90	70	70	65	99	92	71	79	66
3.12	125	110	110	100	75	65	70	60	89	92	71	80	66
	Traverse No. 2 (at right angles to traverse No. 1)												
6.82	125	160	160	150	150	150	150	150	149	88	70	76	65
6.24	140	140	135	110	130	130	140	150	134	84	68	73	64
5.68	145	145	125	110	120	140	135	125	131	83	67	73	64
5.00	130	125	105	105	105	125	120	100	115	83	67	73	63
4.44	120	120	115	120	110	115	135	130	121	84	67	73	64
3.80	80	75	75	75	70	75	80	90	78	81	67	71	63
3.12	75	80	85	65	60	75	75	75	74	81	67	71	63

Barometer--28.13 inches of mercury
Average dry bulb temperatures:
Tunnel--87°F
Stack---76°F

Table XV

RESULTS OF VENTILATOR TESTS

Wind Vel. mph	Size of Ventilator (Inches)							Size of Open Stack (Inches)						
	10	12	14	16	18	20	24	10	12	14	16	18	20	24
	Observed Velocity Induced in Stack (Average fpm)													
6.82	237	216	211	217	233	227	215	186	180	148	142	164	167	141
6.25	211	198	198	195	218	210	190	179	171	143	127	159	157	134
5.68	188	177	181	181	195	186	174	161	153	141	124	135	141	131
5.00	172	157	157	155	177	166	147	150	153	139	120	133	134	123
4.44	147	135	139	128	156	146	119	140	143	130	117	122	132	121
3.80	130	113	121	106	133	126	101	122	130	118	98	107	99	95
3.12	112	85	95	84	110	102	86	106	107	103	78	93	94	82
2.50	69	72	70	63	84	71	--	89	89	82	66	80	61	--
	Corrected Discharge (cfm)													
6.82	186	259	331	448	562	784	1253	162	202	240	371	490	634	928
6.25	166	238	310	402	527	725	1107	157	192	232	332	474	595	882
5.68	147	212	284	374	470	643	1013	141	171	229	324	---	554	864
5.00	136	187	245	320	427	575	858	132	171	225	315	397	518	810
4.44	115	162	219	265	376	505	694	122	161	211	306	364	501	798
3.80	102	136	190	219	320	436	588	107	145	192	257	321	376	626
3.12	88	102	150	173	266	352	502	93	119	167	204	279	357	540
2.50	55	87	110	130	203	246	---	79	100	132	173	240	231	---

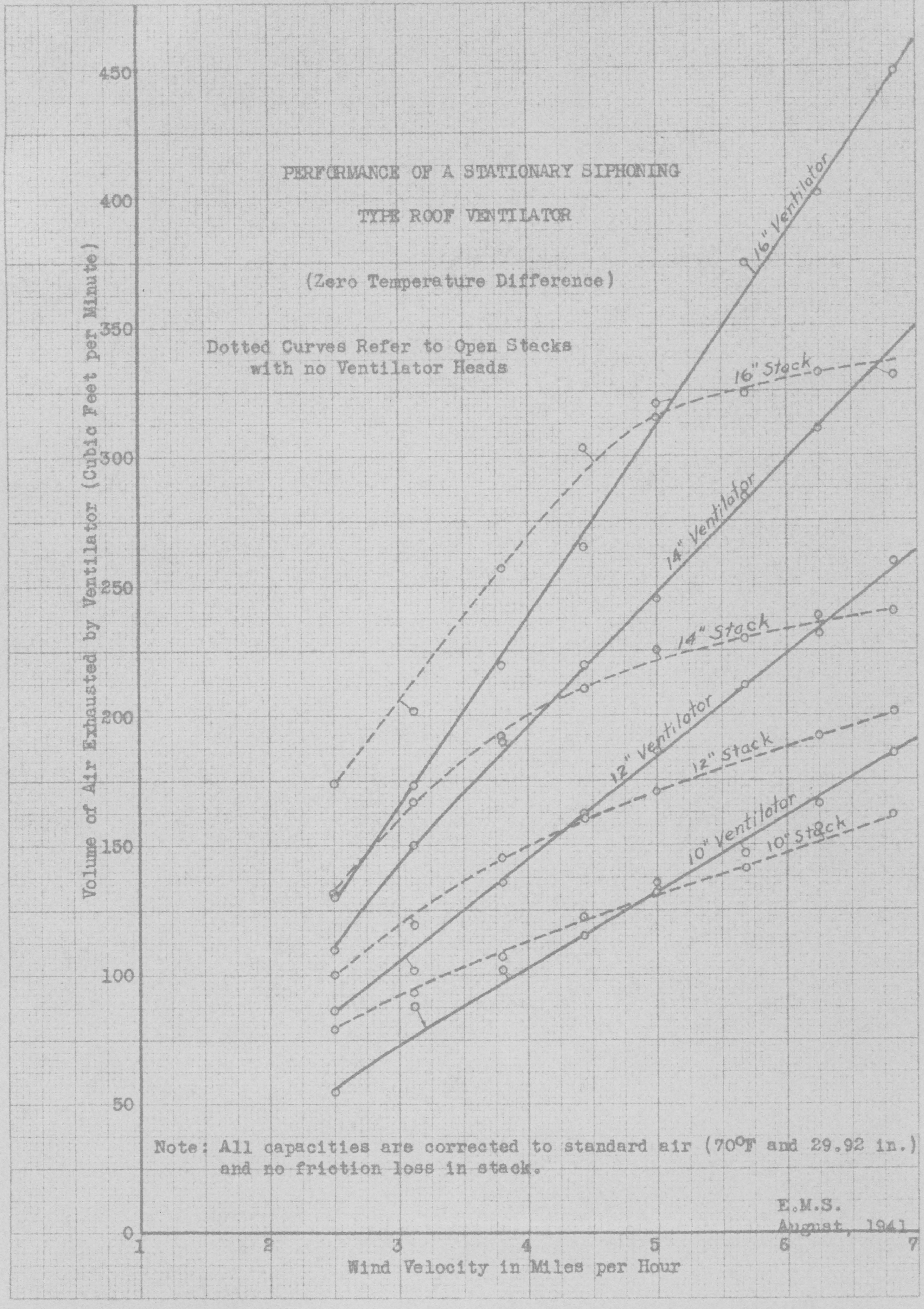


Fig. 9 - PERFORMANCE OF 10- TO 16-INCH VENTILATORS AND OPEN STACKS

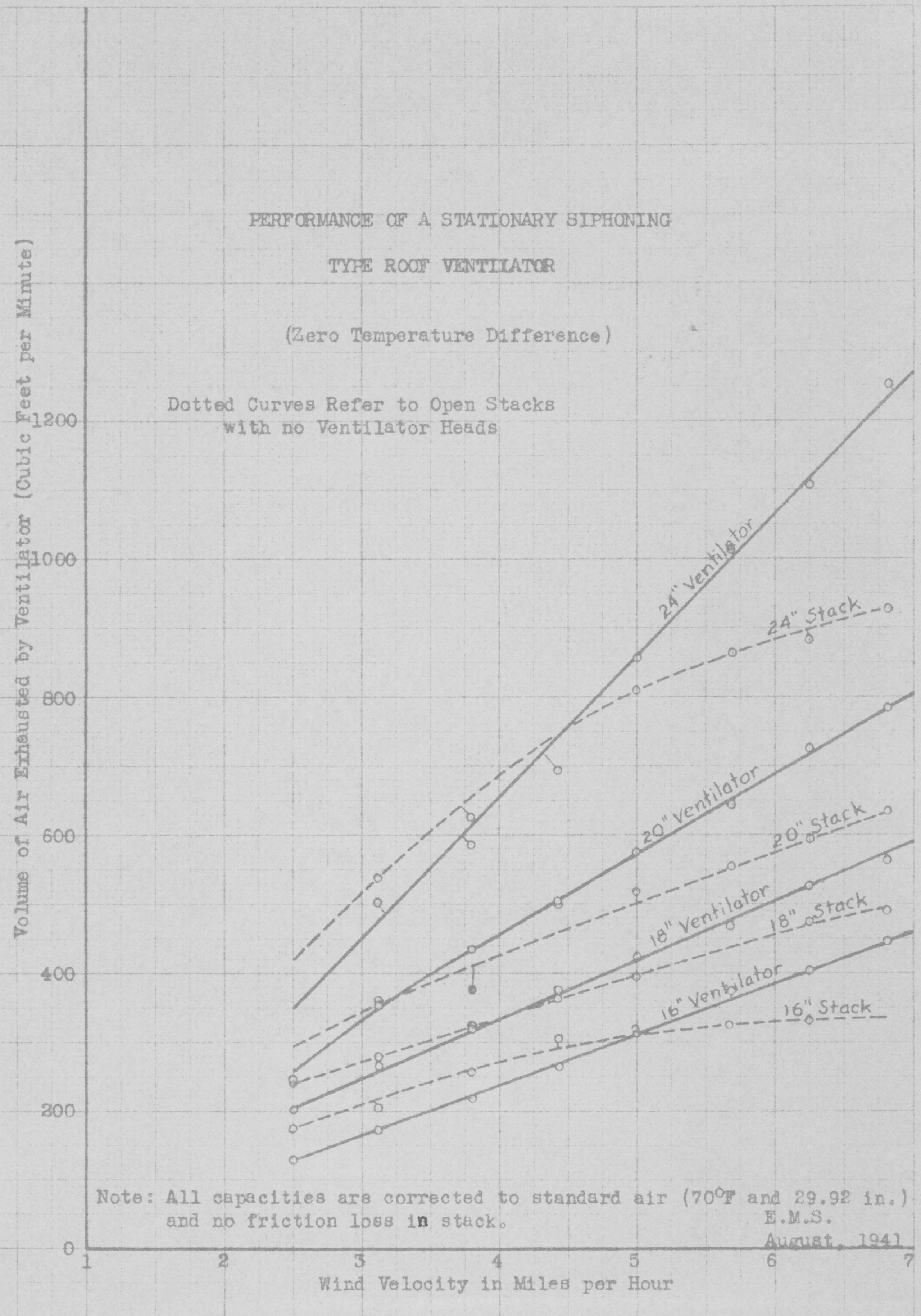


Fig. 10 - PERFORMANCE OF 16- TO 24-INCH VENTILATORS AND OPEN STACKS

IV. DISCUSSION OF RESULTS

The corrected discharge capacities presented in Table XV and plotted in Figures 9 and 10 are based on the following conditions:

1. That there is no difference in temperature between the tunnel air and the stack air and, consequently, that no chimney action exists.
2. That there is no friction in the stack itself.
3. That the air flowing through the stack is at a temperature of 70°F and a barometric pressure of 29.92 inches of mercury.

Since it was difficult to maintain the first of the above conditions during the tests and impossible to maintain the latter two, it was necessary to correct the results to conform to all three conditions. The method of applying these corrections is illustrated by the following explanation and sample calculations, using the data for the first run on the 14-inch ventilator (see Table III).

The average of the induced velocities as found by two traverses at right angles to each other is 211 feet per minute, or 3.52 feet per second. The actual velocity head, then, is

$$\begin{aligned} h_1 &= \frac{V^2}{2g} \\ &= \frac{(3.52)^2}{64.4} \\ &= 0.1925 \text{ feet of free air.} \end{aligned}$$

The <u>Heating Ventilating Air Conditioning Guide</u> (1) gives the theoretical draft intensity of a natural draft chimney with a circular section as

$$D = 2.96\, H\, B_o \left(\frac{W_o}{T_o} - \frac{W_c}{T_c} \right), \qquad \text{(I)}$$

where

D = theoretical draft, inches of water

H = height of chimney, feet

B_o = barometric pressure, inches of mercury

W_o = density of air, pounds per cubic foot

W_c = density of chimney gases, pounds per cubic foot

T_o = absolute temperature of atmosphere, degrees Rankine

T_c = absolute temperature of chimney gases, degrees Rankine.

From the laws for perfect gases,

$$W_o = \frac{P}{RT_o} \quad \text{and } W_c = \frac{P}{RT_c},$$

where

P = absolute pressure, pounds per square foot

R = gas constant = 53.3 for air.

Solving for W_o and W_c,

$$W_o = \frac{(28.00)(0.491)(144)}{(53.3)(460 + 87)}$$

$$= 0.0680 \text{ pounds per cubic foot}$$

$$W_c = \frac{(28.00)(0.491)(144)}{(53.3)(460 + 76)}$$

$$= 0.0690 \text{ pounds per cubic foot.}$$

Substituting known values in Equation (I) and converting inches of water to feet of free air,

$$h_2 = (2.96)(10)(28.00)\left(\frac{0.0680}{547} - \frac{0.0690}{536}\right)\left(\frac{1}{12}\right)\left(\frac{62.4}{0.0690}\right)$$

$$= -\ 0.2453 \text{ feet of free air.}$$

Equation (I) gives the air-moving force produced by the buoyancy of a column of air in the stack when the temperature of the gases inside the stack is higher than that of the wind across the top. If, however, the temperature of the air inside the stack is lower than that of the air across the top (as was the case in these tests), then the measured discharge under these reversed temperature conditions is actually less than that which would have resulted had no temperature difference existed. The fact that h_2 comes out negative indicates that the reversed temperature difference hampers the air movement through the stack by necessitating the lifting of air of greater density. Thus, the velocity head that would have existed had no temperature difference been present is the sum of the measured velocity head, h_1, and the absolute value of the draft pressure as calculated from Equation (I). Consequently, the velocity head corrected for temperature difference is $(0.1925 + 0.2453) = 0.4378$ feet of free air.

The following equation for friction loss in a round air duct is given in the Heating Ventilating Air Conditioning Guide (1):

$$h_L = 1.1 \frac{L}{C \; D^{\frac{9}{7}}} \left(\frac{V}{4005}\right)^{\frac{13}{7}} , \qquad \text{(II)}$$

where

h_L = loss of head, inches of water

L = length of pipe, feet

C = 50 for heating and ventilating ducts

D = diameter of pipe, feet

V = velocity of air, feet per minute.

It should be noted that this formula is based on standard air, and for other conditions, the friction varies directly as the air density. Substituting known values in Equation (II), correcting for the air density, and converting inches of water to feet of free air,

$$h_3 = \frac{(1.1)(10)}{(50)(1.167)^{9/7}} \left(\frac{211}{4005}\right)^{13/7} \left(\frac{1}{12}\right)\left(\frac{62.4}{0.0690}\right)\left(\frac{0.0690}{0.0748}\right)$$

$$= 0.0529 \text{ feet of free air.}$$

It is obvious that the observed velocity would have been greater had no friction existed in the stack. Thus, the velocity head corrected for friction and temperature difference is

$$h = 0.4378 + 0.0529$$

$$= 0.4907 \text{ feet of free air.}$$

The corrected velocity may now be calculated directly from $V = \sqrt{2gh}$. Thus,

$$V = 60\sqrt{(2)(32.2)(0.4907)}$$

$$= 337 \text{ feet per minute.}$$

The quantity of free air flowing is obtained by multiplying this velocity by the cross-sectional area of the stack, or

$$Q = AV$$

$$= \frac{\pi}{4}\left(\frac{14}{12}\right)^2 (337)$$

$$= 360 \text{ cubic feet of free air per minute.}$$

This discharge may be corrected to standard air by the application of the characteristic equation for perfect gases. Thus, the final corrected discharge is

$$Q' = (360)\left(\frac{28.00}{29.92}\right)\left(\frac{530}{536}\right)$$

$$= 331 \text{ cubic feet per minute of standard air.}$$

Although the wet bulb readings are not used in arriving at the discharge capacities, they were taken with the original intention of correcting the observed velocities to a standard dry-bulb temperature of 70°F and a relative humidity of 40 per cent. That the humidity correction is insignificant may be seen from the following example, using the data from the first traverse in Table I.

The weight of one pound of dry air plus moisture at 70°F dry-bulb temperature and 40 per cent relative humidity is 1.0062 pounds. The weight of one pound of dry air plus moisture at the test conditions (87°F dry-bulb temperature and 70°F wet-bulb temperature) is 1.0118 pounds. The correction factor is 1.0118/1.0062, or 1.0056. Since the guaranteed accuracy of the velometer is only 97 per cent, it would be pointless to apply a 0.56 per cent correction to a value which is already subject to a 3 per cent error.

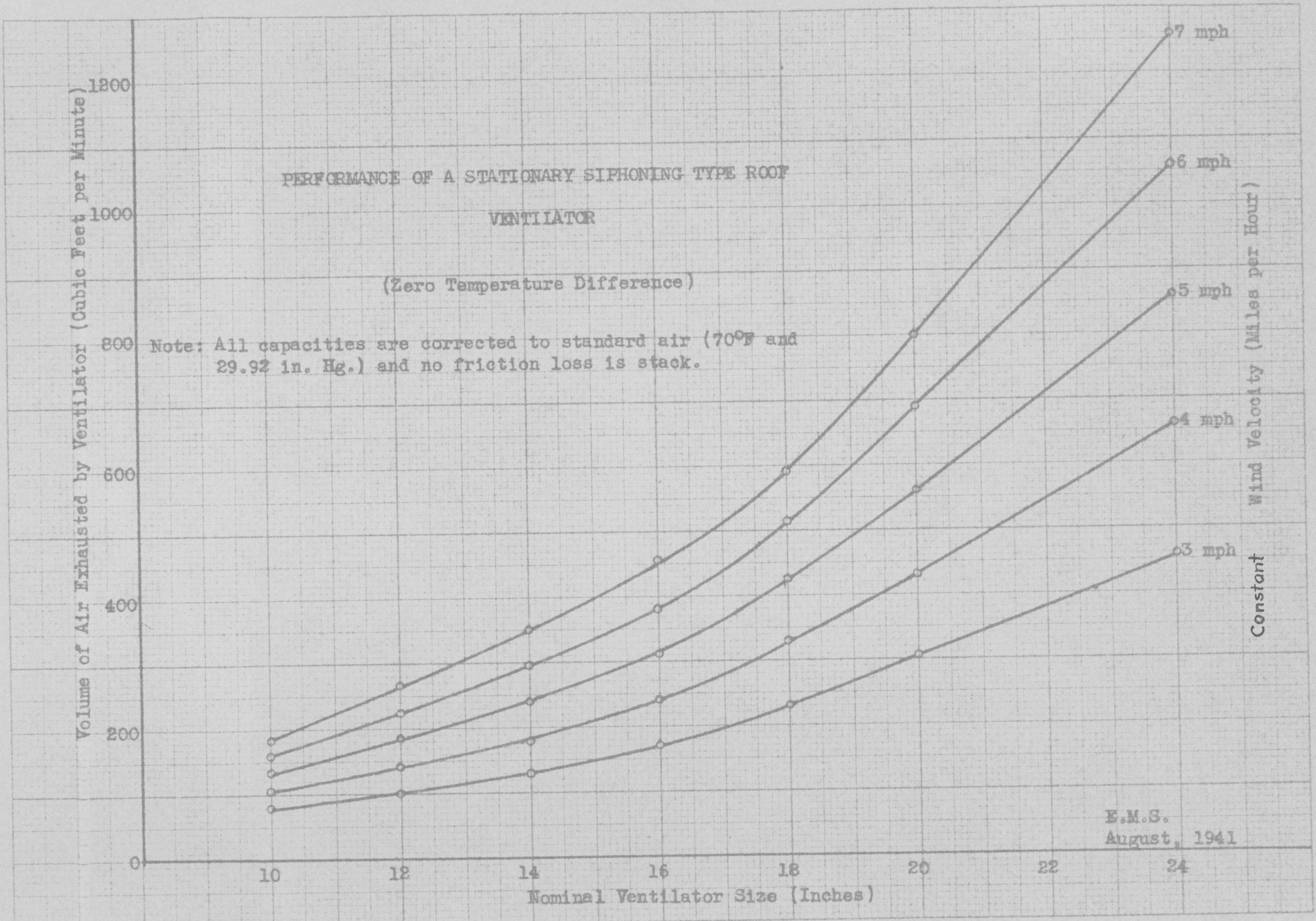
One source of possible error in the test results is the difficulty of reading an accurate average of the fluctuations of the velometer needle. As a check on the accuracy with which this average could be determined by watching the needle for a period of time, several traverses were run taking fifty readings at a given point and averaging these to determine the air velocity at that point. The velocities determined by this method agreed very closely with those determined by averaging the fluctuations by eye.

A study of the curves in Figures 9 and 10 shows that under the test conditions, the relationship between discharge capacity and wind velocity for any given ventilator is approximately linear. During the course of the tests, however, it was noted that there is a tendency for the discharge to drop off sharply at low wind velocities. Thus, when no temperature difference exists, a minimum wind velocity of between one and two miles per hour is required to counteract the effects of friction in the ventilator passages and to start the air moving up the stack. The increase in the slopes of the curves at low wind velocities can be accounted for by the fact that a greater percentage of the total air-moving force is used up to counteract the effects of friction.

The fact that the curves in Figures 9 and 10 diverge as the wind velocity is increased indicates that, while straight-line equations are approximately correct for the capacities of all the ventilators, the constants are different for each size of ventilator. Therefore it is obvious that the data obtained from a test on any one of a series of ventilators of similar make will not suffice to calculate the capacities of the entire line.

In comparing the discharges by an open stack and by a ventilator mounted on the stack, it is seen that below a wind velocity of about 4.5 miles per hour the open stack discharges more air than the ventilator, whereas above this wind velocity the ventilator shows better exhaust capacity than the open stack. The reason for this crossing of the curves is the fact that at low wind velocities, the siphoning action of the ventilator is more than offset by the friction in the devious passages through which the air must flow. At the higher wind velocities, however, the coefficient of friction is reduced, the aspirating action is more effective, and the ventilator shows far better performance than the open stack. Also, the flatness of the open stack curves at high wind velocities may be attributed to a partial blanking-off effect due to the converging streamline flow of wind currents around the opening. Practical use of the open stack as a ventilator for regions where the prevailing wind velocities are low would be impossible because no means are provided to prevent down-drafts from blowing into the stack and no cap and storm band are present to keep the elements out of the stack.

In Figure 11 is presented an interesting series of curves which show the relationship between discharge capacity and ventilator size at wind velo-



PERFORMANCE OF A STATIONARY SIPHONING TYPE ROOF VENTILATOR

(Zero Temperature Difference)

Note: All capacities are corrected to standard air (70°F and 29.92 in. Hg.) and no friction loss is stack.

E.M.S.
August, 1941

Fig. 11 - VENTILATOR CAPACITIES AT VARIOUS WIND VELOCITIES

cities of three, four, five, six, and seven miles per hour. The data used to plot Figure 11 were read directly from the curves of Figures 9 and 10.

In order to determine the equations of the curves in Figure 11, various combinations of logarithmic and arithmetic coordinates were tried. The only one that gave approximately straight lines is the semi-logarithmic arrangement shown in Figure 12, where the discharge is plotted to a logarithmic scale.

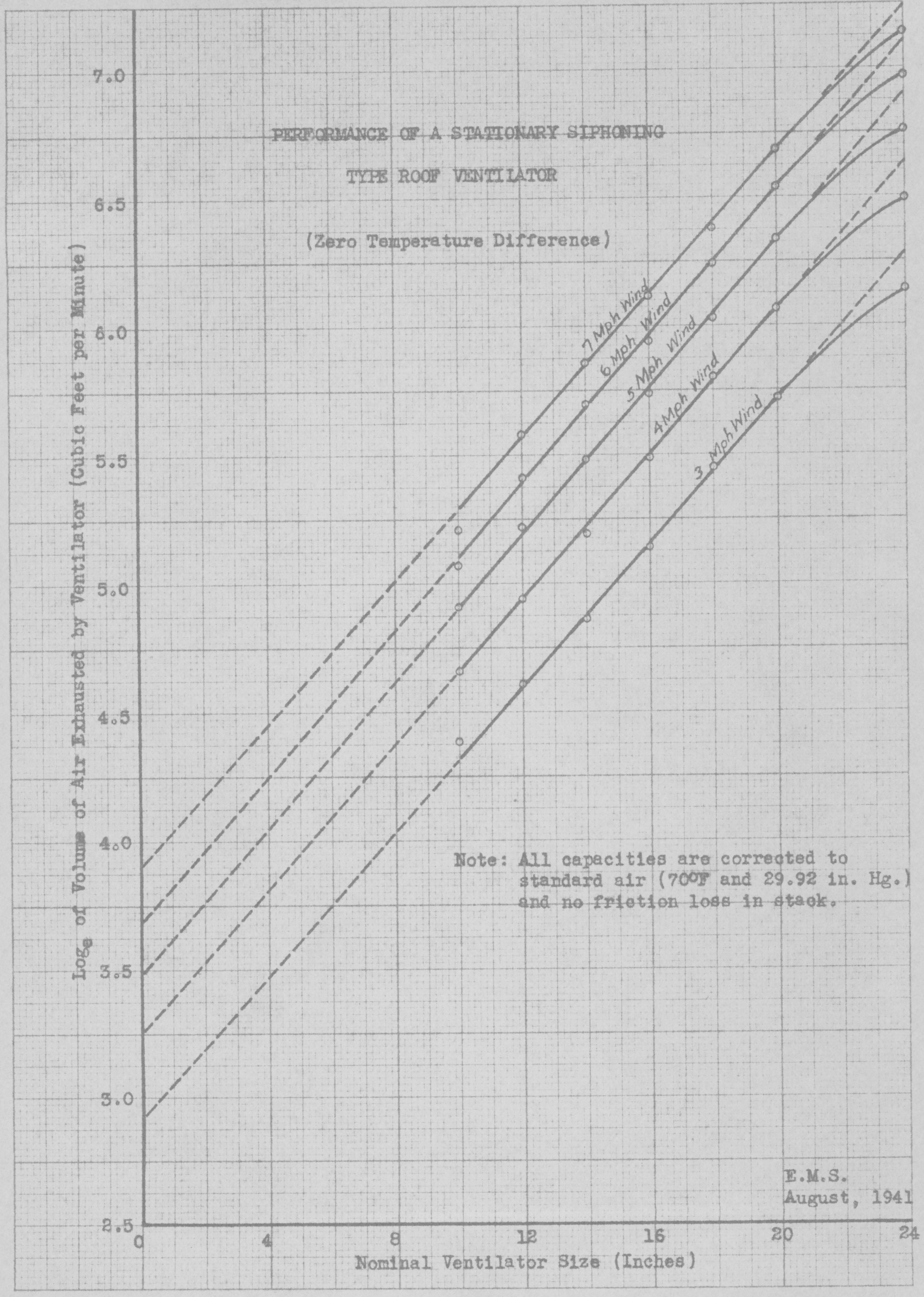
The only points which do not fall on the straight lines are those which represent the discharge by the 24-inch ventilator. The consistency with which these points fall below the straight lines suggests that the experimental capacities determined for the 24-inch ventilator might be lower than the true capacities. A possible explanation is the fact that the ratio of the projected area of the storm band of the 24-inch ventilator to the area of the mouth of the wind tunnel is relatively high.

After extrapolating the lines in Figure 12 to obtain the intercepts, the following equations were found:

Wind Velocity Miles per Hour	Equation
3	$\log_e Q = 0.142\ D + 2.98$
4	$\log_e Q = 0.142\ D + 3.22$
5	$\log_e Q = 0.142\ D + 3.47$
6	$\log_e Q = 0.142\ D + 3.71$
7	$\log_e Q = 0.142\ D + 3.88$

Q = discharge, cubic feet per minute.

D = nominal size of ventilator, inches.



PERFORMANCE OF A STATIONARY SIPHONING

TYPE ROOF VENTILATOR

(Zero Temperature Difference)

Note: All capacities are corrected to standard air (70°F and 29.92 in. Hg.) and no friction loss in stack.

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Fig. 12 - VENTILATOR CAPACITIES AT VARIOUS WIND VELOCITIES

The exponential form of these equations is

$$Q = e^{(0.142D + C)} ,$$

where C is a constant which depends on the wind velocity.

V. CONCLUSIONS

The results of this investigation, while not as thoroughly conclusive in some respects as might be desired, seem to indicate the following facts with a considerable degree of certainty:

1. At a low wind velocity, an open stack with no ventilator mounted on it is more effective than the same stack with a ventilator. However, with higher wind velocities across the top, the stack equipped with a ventilator shows greater exhaust capacity than the open stack.

2. Under the conditions maintained in these tests, the relationship between the capacities and sizes of the ventilators tested is given by the equation

$$Q = e^{(0.142\,D + C)},$$

where C is a constant which depends on the wind velocity.

3. The relationship between discharge capacity and wind velocity across the top of a ventilator is approximately a straight line, except at very low wind velocities (below two miles per hour), where the discharge seems to drop off rapidly for a small decrease in wind velocity.

4. An examination of the confusing and diversified catalog ratings published by ventilator manufacturers and a study of the work of previous investigators reveal a crying need for the establishment of a standard code for the testing and rating of roof ventilators.

5. The effectiveness of a given roof ventilator in a wind tunnel test depends primarily upon the following factors:

a. Velocity of the wind blowing across it.

b. Difference in temperature between the air being exhausted and the air surrounding the ventilator.

c. The degree to which the passage of air through the ventilator is obstructed. From this standpoint, a straight open vertical pipe is the ideal ventilator, but considerations of weatherproofness prohibit its use.

d. The relationship of the area of the exit passages to the area of the window opening in the structure to be ventilated. It was found by observation that unless the area of the atmospheric opening in the room to be ventilated was at least as great as the cross-sectional area of the stack, the effectiveness of the ventilator under test was seriously reduced.

VI. SUMMARY

Tests were performed to determine and compare the aspirating effectiveness of 10- to 24-inch sizes of a stationary siphoning type of automatic roof ventilator.

The basic principles of ventilator design were studied critically, and suitable apparatus and methods of carrying out the tests were designed accordingly. One series of tests consisted of mounting a ventilator on a ten-foot stack at the mouth of a calibrated wind tunnel, and by measuring with a velometer the velocity of the air traveling up the stack, determining the volume of air drawn through the stack while winds of from two to seven miles per hour were blowing across the ventilator. The second series of tests was identical with the first, except that the ventilator was removed and the wind was directed across the open end of the stack. Stacks and ventilators of sizes 10, 12, 14, 16, 18, 20, and 24 inches were tested. All test results are based on zero difference in temperature between the wind tunnel air and the stack air and on no friction loss in the stack. The capacities listed are for standard air at 70°F and a barometric pressure of 29.92 inches of mercury.

The tests revealed several interesting facts. The open stacks were found to be more effective than the ventilators when the wind velocity across the ventilators was less than about 4.5 miles per hour; but the ventilators proved better than the open stacks at wind velocities above 4.5 miles per hour. For the series of ventilators tested, the relationship between discharge capacity and wind velocity across any given ventilator was found to be approximately linear. It was observed that small disturbances in the air currents around the ventilator head seriously affect the discharge and that for maximum effectiveness, it is necessary to have ample window opening in the room to be ventilated.

VII. SUGGESTIONS FOR FUTURE STUDY

Although the scope of this investigation and the methods employed in conducting it gave a considerable quantity of reliable data of importance, the writer feels that there is a vast amount of additional work to be done in the field of automatic roof ventilators.

One of the shortcomings of the work as a whole is the fact that only one make of ventilator in a limited number of sizes was tested. The information secured as to the performance of this type of ventilator cannot be applied in full to ventilators of another design unless tests are performed to justify such application.

Experimental methods and apparatus were sufficiently accurate and reliable for the work in hand, but as the tests progressed, a number of items were observed which might be revised to simplify the procedure required to obtain reliable and duplicable results. The more important changes which might be incorporated in future work of this nature are as follows: (a) Redesign wind tunnel to provide uniform distribution of wind velocity without the necessity of setting the cone assembly for each speed; (b) Employ means of controlling air temperatures in both tunnel room and stack room; (c) Provide a method of accurately measuring and varying area of fresh air inlet opening in stack room; (d) Provide ample and controlled outdoor openings for the blower suction and for the tunnel discharge; (e) Provide a means of directing the wind on the ventilator at a controlled angle in order to study the influences of up-drafts and down-drafts on ventilator performance; (f) Employ a fan which would give a wider range of wind velocities.

As regards suggestions for future study, the following recommendations are offered: (a) Conduct tests on a number of different types of ventilators over a wide range of sizes; (b) Investigate the resistance to the flow of air through each ventilator; (c) Compare the ventilators as to efficiency, general construction, and durability; (d) Carry out experiments to determine the effect of varying certain dimensions of a given ventilator; (e) Investigate the effectiveness of ventilators under various conditions of temperature difference; (f) Study the effects of up-drafts and down-drafts on ventilator performance; (g) Determine the effects of sloped roofs, parapets, and building walls in the vicinity of the ventilator; (h) Determine the quantitative relationship between discharge and chimney action, discharge and aspirating action, and discharge and a combination of chimney action and aspirating action; (i) Determine experimentally the maximum ratio of projected ventilator area to area of wind tunnel mouth for reliable wind tunnel tests.

To carry out all of the above recommendations in a satisfactory manner would, of course, entail the expenditure of a considerable sum of money and an immense amount of time without any guarantee of a commensurate return in the form of useful information. If the performance of ventilators under actual service conditions is seriously affected by small disturbances (as appears to be the case), highly refined test procedure would be a waste of time.

VIII. BIBLIOGRAPHY

(1) American Society of Heating and Ventilating Engineers, Heating Ventilating Air Conditioning Guide. P. 182, pp. 543-560, pp. 639-648, p. 768, A. S. H. & V. E. New York. 1940

(2) Beals, G. D., "A Proposed Set-Up For Testing Automatic Roof Ventilators." The Heating and Ventilating Magazine, Vol. 24, No. 5, pp. 59-61, May, 1927

(3) Beals, G. D., "Public Building Ventilation with Automatic Roof Ventilators." The Heating and Ventilating Magazine, Vol. 25, No. 2, pp. 501-509, Feb., 1928

(4) Calderwood, J. P. and Mack, A. J., "Comparative Tests of Automatic Ventilators." Kansas State Agricultural College Eng. Exp. Sta. Bul. No. 14, April, 1925

(5) Calderwood, J. P., Mack, A. J., and Bradley, C. J., "Comparative Tests of Roof Ventilators." Journal A. S. H. & V. E., Vol. 28, No. 5, pp. 189-197, July, 1922

(6) Dryden, H. L., Stutz, W. F., and Heald, R. H., "Some Comparative Tests of Sixteen-Inch Roof Ventilators." Journal A. S. H. & V. E., Vol. 27, No. 2, pp. 67-74, March, 1921

(7) Groseclose, F. F., Jones, W. B., and Trent, C. E., "An Investigation of the Relative Efficiency of Automatic Ventilators." A thesis for the degree of M. S. at the Virginia Polytechnic Institute, June, 1932 (Not in print)

(8) Hirschman, W. F. Co., Inc., "Roof Ventilators and Auxiliary Equipment." (Commercial) Bul. HV-21, W. F. Hirschman Co., Inc., Buffalo, N. Y., 1938

(9) Mack, A. J., "Recent Tests on Automatic Ventilators." Journal A. S. H. & V. E., Vol. 26, No. 9, pp. 849-853, Dec., 1920

(10) Mack, A. J. and Bradley, C. J., "Recent Tests on Automatic Ventilators." The Heating and Ventilating Magazine, Vol. 19, No. 4, pp. 36-38, April, 1922

(11) Rowley, F. B., "Comparative Tests of Roof Ventilators." Journal A. S. H. & V. E., Vol. 29, No. 1, pp. 39-44, Jan., 1923

(12) The American Larson Ventilating Co., "The American Larson Roof Ventilator." (Commercial) Bul. A. I. A. 12k 1, The American Larson Ventilating Co., Pittsburgh, Pa., 1936

(13) The Swartwout Co., "Controlled Air Circulation." (Commercial) Bul. 205, The Swartwout Co., Cleveland, Ohio

(14) Tuve, G. L., "Description of Test Methods and Formulas as given in a report on Roof Ventilators Conducted for The Burt Manufacturing Company In the Laboratories of Case School of Applied Science." July, 1934. (Not in print)