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An ASABE Meeting Presentation
DOI: 10.13031/aim.201700116
Paper Number: 1700116

Analysis of Available Efficiency and Performance Data for Axial Flow Agricultural Ventilation Fans

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**Written for presentation at the
2017 ASABE Annual International Meeting
Sponsored by ASABE
Spokane, Washington
July 16-19, 2017**

ABSTRACT. *The current ASABE Engineering Practice titled Guidelines for Selection of Energy Efficient Agricultural Ventilation Fans (ASAE EP566.2, ASABE, 2012) provides criteria for selection of energy efficient fans (VER-0.10 = cfm/W at ΔP = 0.10 in of water) and an index to evaluate the flatness of the fan curve (Airflow Ratio). The current engineering practice does not include selection recommendations for small fans (less than 18 inches in diameter), and many large diameter fans that are currently available. In addition, no discussion or reference is provided in the engineering practice to explain the basis for the current recommendations. A statistical analysis was performed using all of the axial flow fan data available (8 to 61 inches in diameter) for the airflow rate (Q-0.10), efficiency (VER-0.10), and airflow ratio (AFR). Comparisons were made to determine the impact of the use of discharge cones on Q-0.10, VER-0.10, and AFR. Use of a discharge cone significantly increased airflow for fans with a diameter of 10 in or larger and significantly improved efficiency for fans with diameters of 16 in and larger. Discharge cones did not provide a consistent improvement in AFR. Instead, AFR was found to correlate negatively with respect to increased fan diameter, and the negative correlation was strongest for fans with discharge cones (R = - 0.822). The results, from the analysis and pooled standard deviations of fan diameter groups were used to develop recommendations for fan selection based on VER-0.10 and AFR, and are provided in Tables 6 and 7.*

Keywords. Agricultural facilities, Animal production, Energy Efficiency, Fan Efficiency, Plant production, Ventilation Fans

Introduction

Agricultural ventilation fans are used to provide the required air-exchange rates for the production of animals and plants in controlled and modified environment buildings. The actual air-exchange rates needed will depend on the animal or plant species, stage of growth, and the season of the year. For example, winter air-exchange rates for animals must provide enough fresh air to supply oxygen for the animals, and remove moisture, carbon dioxide, and other air contaminates generated inside the building. During periods of moderate and high outdoor temperatures, additional fans are needed to remove excess heat from the animals, control interior temperature rise above ambient during hot weather, and to provide the airflow needed for evaporative cooling using foggers or cooling pads. It is not uncommon for the air-exchange requirements during hot weather to exceed minimum ventilation rates by a factor of ten or more. As a result, ventilation fans account for 40% to 80% of the total amount of electricity purchased to operate mechanically ventilated buildings used for animal or plant production. Selection of energy efficient fans, with good performance characteristics, can often reduce ventilation energy requirements by 20% to 30%.

The current ASABE Engineering Practice titled Guidelines for Selection of Energy Efficient Agricultural Ventilation Fans (ASAE EP566.2, ASABE, 2012) provides criteria for selection of energy efficient fans. The two criteria are the ventilating efficiency ratio of the fan operating at a static pressure drop (ΔP) of 0.10 inches of water (VER-0.10, cfm/W), and the airflow ratio (AFR). The static pressure drop of 0.10 inches of water was a good choice since it is a common practice to select fans based on the airflow at 0.10 in of water (Q-0.10). However, it is common for agricultural ventilating fans to operate at system static pressure drops ranging from 0.07 to 0.125 inches of water. The airflow ratio is an index to evaluate the flatness of the fan curve and is defined as (ASABE, 2012):

$$\text{AFR} = \text{Q-0.20} / \text{Q-0.05}. \quad (1)$$

Where,

Q-0.20 = airflow rate at ΔP = 0.20 in of water, and
Q-0.05 = the airflow rate at ΔP = 0.05 in of water.

Obviously no fan can have an AFR of 1.0. However, a fan with a high airflow ratio will be able to provide more air-exchange if required to operate at higher than normal static pressure differences (ΔP = 0.05 to 0.125 inches of water). The ventilating efficiency ratios and values of AFR to recommended for selection of axial flow, agricultural ventilation fans by ASABE (2012) are provided in Table 1.

Table 1. Recommended ventilating efficiency ratios (VER10 = VER at ΔP = 0.10) and airflow ratios (AFR) for ventilation fans. Table 2 in ASAE EP566.2 (ASABE, 2012).

Fan Size, cm (in.)	VER10*, L/s/W (ft^3/min/W)	AFR
45 (18)	4.3 (9.1)	0.75
50 (20)	4.3 (9.1)	0.75
60 (24)	5.6 (11.9)	0.75
90 (36)	5.6 (16.2)	0.70
120 (48)	8.3 (17.6)	0.70
130 (52)	8.3 (17.6)	0.70
152 (60)	10.2 (21.6)	0.68
* VER10 is the fan efficiency @ 25 Pa (0.10 in. H_2O).		

Agricultural ventilation fan manufacturers have responded to the recommendations provided in the preceding (ASABE EP566.1, ASABE, 2008) and current ASABE recommendations (ASABE EP566.2, ASABE 2012) by providing a wide assortment of products that not only meet the minimum fan efficiency standards, but exceed standard recommendations. As a result, the engineering practice has been a successful tool for the promotion of energy efficient ventilation for agricultural production over the last decade. However, the current standard does not include any recommendations for fans with nominal diameters less than 18 inches, and does not provide recommendations for many large diameter fans such as 50, 51, 53, 55, 57, and 61 inches. In addition, no discussion or reference is provided in ASAE EP566.2 (ASABE, 2012) for the rational used to develop the current recommendations.

The objectives of this paper are to: (1) summarize the available data for Q-0.10, VER-0.10, and AFR for all fans of all diameters available from the Bioenvironmental and Structural Systems Laboratory (BESS, 2017), (2) determine pooled variances for Q-0.10, VER-0.1010, and AFR for statistically different fan diameter groups, (3) summarize a statistical analysis of the impact of the use of discharge cones on Q-0.10, VER-0.10, and AFR for the defined fan groups, and (4) suggest recommendations to improve ASAE EP566.2 (ASABE, 2012) based on the results.

Methods

All of the axial flow fan test data for nominal fan diameters ranging from 8 inches to 61 inches that was available from the Bioenvironmental and Structural Systems Laboratory (BESS, 2017) was compiled in a spreadsheet and divided into two groups depending on the use of an aerodynamic discharge cone. The only fans that were not included were fans with three-phase motors since the actual of number of products tested in each category ranged from none for small diameter fans to numbers that were insufficient for statistical inference for larger fans. The data were summarized by determining the maximum, minimum, average, standard deviation (S), and coefficient of variation (CV) for the Q-0.10, VER-0.10, and AFR for fans with and without cones for each nominal diameter. These statistics are summarized for 1357 fan tests in the Appendix (Tables A1 through A4).

The total number of observations available for each fan diameter ranged from 2 for the 8-inch diameter fans to 332 for the 48-inch diameter fans. It was also apparent that the variance (S^2) of Q-0.10, and VER-0.10 increased as fan diameters increased. A sequential F-test for differences in variances of Q-0.10, VER-0.10, and AFR was performed using standard statistical procedures in order to increase the statistical power of the analysis (Steel and Torrie, 1980). The variance of Q-0.10 was used as the primary variance used to establish blocks of fan data by diameter with common variances. The final blocking of the fan data is shown in Table 2 where pooled variances (S_P) for each of the fan performance characteristics and the total error degrees of freedom (EDF), accounting for unequal replication, for each block is also provided. Critical values of F (0.025) as well as the calculated F-values are also provided. The pooled variance for Q-0.10 was significantly different from the smaller fan groups in all cases except for the 48-inch fans. However, the pooled variance of AFR for the 48-inch fans was significantly different from the smaller fan group (*i.e.* 36-inch fans). It can also been seen that the error degrees of freedom for the 7 different fan groups ranged from 35 to 330 providing the best statistical comparisons for the data available.

Table 2. Pooled variances, error degrees of freedom (EDF), and F-test of variances for the blocking of axial flow fan data summarized in the Appendix (Tables A1 through A4).

Nominal Fan Diameter Group (in)	Pooled Variance – S_P^2 Q-0.10 (cfm ^{2})	VER - 0.10 ([cfm/W] ^{2})	AFR	EDF	Critical Values [a] F (0.025)	Calculated F-Values [b] Q-0.10 F-cal	VER - 0.10 F-cal	AFR F-cal
8 to 16	77,415	1.854	0.0159	57	1.789	2.610*	1.039	1.460
18	202,067	1.926	0.0109	35	1.790	2.753*	1.465	1.809*
20 & 25	556,369	2.822	0.0060	113	1.377	4.951*	1.492*	2.780*
36	2,754,688	4.210	0.0168	283	1.254	1.778*	1.413*	2.094*
48	4,897,255	2.980	0.0080	330	1.287	1.125	1.278	2.253*
50 to 52	5,510,865	3.807	0.0036	181	1.300	1.428*	1.523*	3.507*
53 to 61	7,871,410	5.798	0.0125	324				

[a] Critical F values at the 95% level using the EDF of the of the next larger fan diameter group as the numerator and the EDF of the smaller fan diameter group as the denominator.

[b] F-cal = (larger variance / the smaller variance), used to determine if at least one variance in the next larger fan diameter group was significantly different from the smaller fan diameter group.

The pooled variances along with the pooled EDF were used to perform t-tests at the 95% and 99% levels of probability to determine if use of a discharge cone had a significant impact on the mean values of Q-0.10, VER-0.10, and AFR. The pooled variances shown in Table 2 were also used to assist in developing recommendations for target values of VER-0.10.

The standard error of a difference was calculated using the following standard equation (Steel and Torrie, 1980):

$$SE\ (Y_1\text{-}Y_2) = S_P\ [(1/n_1) + (1/n_2)]^{0.5}. \quad (2)$$

Where,

$SE\ (Y_1\text{-}Y_2)$ = the standard error of the difference between two means being compared, Y_1 and Y_2,

S_P = the pooled standard deviation = $[S_P^2]^{0.5}$,

n_1 = Number of observation for Y_1, and

n_2 = Number of observation for Y_2.

The means for Y_1 and Y_2, correspond to the mean values of Q-0.10, VER-0.10, and AFR for each size of fan with or without a discharge cone. The values used for Y_1, n_1, Y_2, and n_2, are tabulated in the Appendix.

The calculated value of t, t-cal, was calculated as (Steel and Torrie, 1980):

$$t\text{-cal} = (Y_1 - Y_2) / SE\ (Y_1\text{-}Y_2). \quad (3)$$

Results

The impact of using a discharge cone on the airflow rate at 0.10 inches of static ΔP (Q-0.10) is shown for fan diameters ranging from 8 to 61 inches in Table 3. The range of airflow rates observed is provided (minimum to maximum Q-0.10) along with the average values of Q-0.10 for fans with and without cones. The results of the t-test is also indicated next to the mean Q-0.10 for fans with cones. Means accompanied by a single asterisk signify a significant difference at the 95% level of probability and means with two asterisks were significantly different at the 99% level.

Table 3. Impact of discharge cones on the airflow of axial flow fans operating at ΔP = 0.10 inches of water (Q-0.10).

Nominal Fan Diameter (in)	Minimum Q-0.10 (cfm)	Maximum Q-0.10 (cfm)	Average Q-0.10 No Cone (cfm)	Average Q-0.10 With Cone (cfm)
8	240	521	381	NA [a]
9	613	1070	926	1060
10	680	1530	1054	1530 *
12	780	2260	1319	1778 *
14	1500	2610	1841	2203 *
16	2050	3580	2572	2943 **
18	2060	4720	3279	4004 **
20	2630	5290	3885	4638 **
24	4090	7510	5433	6117 **
25	4340	7420	4340	6591 *
36	6940	15840	9364	10951 **
48	12700	26800	17488	20986 **
50	15700	30400	20844	22991 **
51	21300	31900	22625	26263 *
52	17100	29800	21450	25334 **
53	16300	28100	20536	23270 **
54	16300	34800	20443	27050 **
55	20600	34400	NA	26249
57	20100	31480	NA	26809
60	25600	32400	NA	29171
61	21600	29900	24350	26575

[a] NA = no data available

* Significantly different at the 95% level.

** Significantly different at the 99% level.

The results in Table 3 indicate that use of a discharge cone increased the Q-0.10 airflow significantly for all fans with a diameter of 10 inches or greater. All of the 55, 57, or 60 inch fans tested by BESS were equipped with discharge cones. While 61-inch fans with cones provided more airflow the difference was not statistically significant due to the limited number of observations as shown in Table A4.

As would be expected, the increase in airflow provided by a discharge cone coincided with an increase in fan efficiency as indicated by the results for VER-0.10 provided in Table 4. In general, addition of a cone provided a significant increase in VER-0.10 for fans with nominal diameters of 16 or more inches. The only exceptions were for 20, 25, and 61 inch fans. The lack of statistical significance for the 61 inch fans is due to the relatively low number of data sets (Table A4). The lack of significance for the 20 and 25 inch fans was unexpected, but may be due to the fact that market demands are typically higher for 18, 24, and 36 inch fans as compared to 20 and 25 inch fans. The lack of market demand would be a likely reason for manufacturers to limit development of efficient products in these diameters.

The comparison of airflow ratios for fans with and without discharge cones is provided in Table 5. The statistical comparisons indicate that use of a discharge cone did not have a significant impact on AFR for most fan diameters. Other factors related to fan design, such as motor quality, and fan rpm had a greater impact on AFR.

In general, fan rpm decreases with fan diameter and fan efficiency typically increases. Correlation of the mean AFR values shown in Table 5 with respect to fan diameter indicated that for all fans (with or without cones) AFR was negatively correlated with respect to diameter with an R of - 0.594. Correlation of AFR values with respect to diameter for fans with cones indicated a stronger negative correlation as indicated by R = - 0.822. Therefore, AFR is a performance index that should be considered independent of fan efficiency. High values of AFR should be given preference in the selection of all fans to provide the flattest fan curve possible.

Table 4. Impact of discharge cones on the ventilating efficiency ratio of axial flow fans operating at ΔP = 0.10 inches of water (VER-0.10).

Nominal Fan Diameter (in)	Minimum VER-0.10 (cfm/W)	Maximum VER-0.10 (cfm/W)	Average VER-0.10 No Cone (cfm/W)	Average VER-0.10 With Cone (cfm/W)
8	3.6	5.9	4.8	NA [a]
9	4.2	5.6	4.7	5.3
10	3.9	8.6	5.6	5.1
12	5.2	9.6	7.6	8.4
14	6.6	12.6	8.6	9.4
16	7.7	13.2	8.8	11.5 **
18	7.5	13.0	9.7	10.7 *
20	7.7	12.6	9.9	11.0
24	8.2	17.1	11.0	13.6 **
25	8.3	16.0	13.8	12.8
36	9.0	20.8	14.6	15.4 **
48	12.7	23.8	16.2	18.9 **
50	12.8	24.5	16.6	19.0 **
51	15.0	23.6	16.1	19.6 **
52	12.0	24.8	15.2	19.1 **
53	14.8	26.6	18.2	20.5 **
54	13.6	27.4	17.2	20.2 **
55	14.0	28.7	NA	19.9
57	15.3	24.5	NA	19.9
60	16.1	21.7	NA	18.7
61	17.5	24.4	18.7	21.5

[a] NA = no data available
* Significantly different at the 95% level.
** Significantly different at the 99% level.

Table 5. Impact of discharge cones on the airflow ratio (AFR) of axial flow fans.

Nominal Fan Diameter (in)	Minimum AFR	Maximum AFR	Average AFR No Cone	Average AFR With Cone
8	0.77	0.88	0.83	NA
9	0.67	0.92	0.86	0.91
10	0.48	0.94	0.81	0.92
12	0.46	0.91	0.64	0.85 *
14	0.32	0.89	0.68	0.83
16	0.57	0.89	0.80	0.83
18	0.29	0.91	0.76	0.87 **
20	0.68	0.90	0.82	0.86
24	0.54	0.91	0.77	0.80
25	0.63	0.89	0.63	0.84
36	0.28	0.89	0.67	0.86 **
48	0.28	0.87	0.71	0.76 **
50	0.59	0.88	0.75	0.76
51	0.53	0.86	0.78	0.76
52	0.57	0.87	0.77	0.78
53	0.09	0.85	0.69	0.67
54	0.25	0.92	0.63	0.78 **
55	0.61	0.84	NA	0.75
57	0.34	0.84	NA	0.70
60	0.56	0.78	NA	0.69
61	0.34	0.72	0.57	0.52

[a] NA = no data available
* Significantly different at the 95% level.
** Significantly different at the 99% level.

Recommendations

Based on the analysis of the available axial flow fan data for VER-0.10 and AFR recommendations were developed for the selection of energy efficient fans for the wide range of air-exchange rates used in agricultural production facilities. In general, it is desirable select a fan that provides the needed airflow with the highest VER-0.10 and AFR available. However, a minimum target value is needed in practice.

The available data for mean values of VER-0.10 provided in the Appendix, and pooled variances shown in Table 2 were used to develop minimum targets for VER-0.10 to define energy efficient fans. The target VER-0.10 value was selected based on adding 0.25 to 0.5 times the pooled standard deviation to the mean VER-0.10 for a particular diameter grroup. Then the percentage of the available fans that met or exceeded the target VER-0.10 was determined. The goal was to develop a target VER-0.10 that was met by at least 20% of all fans in a diameter group. For most fan sizes the criteria were met by setting the target VER-0.10 equal to the mean + 0.5 S_P. In two cases the fraction of S_P added to the mean was adjusted up or down to meet or exceed the population compliance goal (20%). The results or this process is shown in Table 6.

Table 6. Recommended minimum values of VER-0.10 for selection of energy efficient axial flow fans

Nominal Fan Diameter (in)	Mean VER-0.10 (cfm/W)	Target VER-0.10 (cfm/W)	Percent of Population that meet the Target
8 to 10	5.0	5.7 = Mean + 0.5 S_P [a]	20
12 & 14	8.5	9.2 = Mean + 0.5 S_P	26
16 to 20	11.1	11.5 = Mean + 0.33 S_P	24
24 & 25	13.5	14.3 = Mean + 0.5 S_P	27
36	15.4	17.0 = Mean + 0.54 S_P	29
48	18.9	19.3 = Mean + 0.5 S_P	21
50 to 52	19.2	20.2 = Mean + 0.5 S_P	23
53 to 61	19.9	21.1 = Mean + 0.5 S_P	33

[a] S_P is the square root of the pooled variance of VER-0.10 shown in Table 2 for each fan size class.

Selection of a fan with a sufficiently flat fan curve is important to maintain the needed air-exchange rates while operating fans at higher than normal values of ΔP. A high AFR is also an index of the quality of the overall fan design. It was determined that AFR was negatively correlated with fan diameter, and that fan data within groups (maximum and minimum values) indicate that fans with the highest efficiencies (VER-0.10) can have low values of AFR. Recommended minimum values for AFR were set for the four fan diameter ranges shown in Table 7. The grand mean AFR for the range of fan diameters is shown with the recommended values of AFR that ranged from 0.70 for fans with diameter of 48 inches or more to 0.80 for small fans (8 to 16 in).

Table 7. Recommended minimum values of AFR for selection of energy efficient axial flow fans

Range of Nominal Fan Diameters (in)	Grand Mean AFR for Range of Fan Diameters	Recommended Minimum AFR
8 to 16	0.81	0.80
18 to 36	0.79	0.75
48 to 55	0.74	0.70
57 to 61	0.64 (cones only)	0.70

The recommendations suggested in Tables 6 and 7 are not vastly different from the values in the current engineering practice (Table 1). However, they are more comprehensive for the range of fan sizes used in a wide variety of agricultural production facilities, and they are based on the VER-0.10 and AFR values obtained by a large portion of the available axial flow fans. The target values also provide values that will encourage manufacturers to make greater, yet attainable, improvements in fan performance and efficiency. The result long-term would be less electrical energy used to produce animal and plant products and possible enhanced profit margins for producers.

Conclusions

A total of 1357 fan data sets were obtained from the Bioenvironmental and Structural Systems Laboratory (BESS, 2017). Data for the airflow (Q-0.10) and ventilation efficiency ratio (VER-0.10) at an operating pressure difference of 0.10 inches of water, and the airflow ratio (AFR) were statistically analyzed to determine the impact of using a discharge cone on fan performance and efficiency. An F-test of variances was used to place the data in blocks with common variances to facilitate a more powerful t-test. The statistics were also used to develop recommendations for VER-0.10 and AFR of the selection of fans ranging in size from 8 to 61 inches. The primary conclusions are given below.

- Discharge cones provided significantly more airflow for fans with a diameter of 10 inches or more, and significantly higher ventilation efficiency ratio (VER-0.10) for fan diameters of 16 inches or more.
- A table of recommended target values for VER-0.10 (Table 6) was developed based on means and fractions of the pooled standard deviation for eight fan diameter groups.
- The mean AFR of all fans was found decrease as fan diameter increased. Correlation of AFR with respect to diameter for all fans with or without cones gave an R of - 0.594. The correlation between AFR and fan diameter for fans with discharge cones was - 0.822. It was concluded that AFR, an important fan performance index, should be grouped separately from fan efficiency.
- A table of recommended values of AFR (Table 7) was presented using four fan diameter groups.
- It is recommended that ASABE consider the results of this study to improve EP566.2 (ASABE, 2012).
- In general, use of the recommendations from this analysis will meet or exceed the current ASABE recommendations.

Acknowledgements

The work in this study was supported by a USDA-NRCS project entitled: Improving Energy Efficiency in South Carolina Animal Facilities and Greenhouses: A Partnership for Education, Outreach, and Technology Adoption, and Clemson University Extension.

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Appendix – Summary of Fan Data Obtained from BESS Laboratory

Table A1. Summary of Fan Data (@ ΔP = 0.10 inches of water) for Axial Flow Fans with Diameters from 8 to 16 inches. Data obtained from BESS Laboratory April 2017 (BESS, 2017).

Nominal Fan Diameter (in)		FANS WITHOUT CONES Q-0.10 (cfm)	VER - 0.10 (cfm/W)	AFR	FANS WITH CONES Q-0.10 (cfm)	VER - 0.10 (cfm/W)	AFR
8	Maximum	521	5.9	0.88	NA	NA	NA
	Minimum	240	3.6	0.77			
	Average	**381**	**4.8**	**0.83**			
	S [a]	198.70	1.626	0.078			
	CV (%)	52.2	34.2	9.4			
	n [b]	2					
9	Maximum	1063	5.1	0.92	1070	5.6	0.91
	Minimum	613	4.2	0.67	1050	4.9	0.90
	Average	**926**	**4.7**	**0.86**	**1060**	**5.3**	**0.91**
	S	184.60	0.319	0.105	14.14	0.495	0.007
	CV (%)	19.9	6.8	12.3	1.3	9.4	0.8
	n	5			2		
10	Maximum	1390	8.6	0.94			
	Minimum	680	3.9	0.48			
	Average	**1054**	**5.6**	**0.81**	**1530**	**5.1**	**0.92**
	S	286.23	1.851	0.192			
	CV (%)	27.2	33.2	23.6			
	n	5			1		
12	Maximum	1790	9.6	0.91	2260	9.1	0.89
	Minimum	780	5.2	0.46	1470	7.4	0.82
	Average	**1319**	**7.6**	**0.64**	**1778**	**8.4**	**0.85**
	S	363.06	1.359	0.179	313.80	0.643	0.028
	CV (%)	27.5	18.0	27.8	17.7	7.6	3.3
	n	8			5		
14	Maximum	2210	11.00	0.87	2610	12.6	0.89
	Minimum	1500	6.6	0.32	1790	6.7	0.75
	Average	**1841**	**8.6**	**0.68**	**2203**	**9.4**	**0.83**
	S	212.16	1.522	0.227	291.82	2.104	0.047
	CV (%)	11.5	17.7	33.3	13.2	22.3	5.7
	n	8			10		
16	Maximum	2953	11.2	0.86	3580	13.2	0.89
	Minimum	2050	7.7	0.57	2550	10.2	0.77
	Average	**2572**	**8.8**	**0.80**	**2943**	**11.5**	**0.83**
	S	268.11	0.947	0.086	258.89	0.995	0.044
	CV (%)	10.4	10.7	10.7	8.8	8.6	5.3
	n	11			10		

[a] Non-pooled standard deviation of the data for a nominal fan diameter, with or without cones.
[b] n = number of fans for which data were available for each nominal fan diameter, with or without cones.

Table A2. Summary of Fan Data (@ ΔP = 0.10 inches of water) for Axial Flow Fans with Diameters from 18 to 48 inches. Data obtained from BESS Laboratory April 2017 (BESS, 2017).

Nominal Fan Diameter (in)		FANS WITHOUT CONES			FANS WITH CONES		
		Q-0.10 (cfm)	VER - 0.10 (cfm/W)	AFR	Q-0.10 (cfm)	VER - 0.10 (cfm/W)	AFR
18	Maximum	4120	12.2	0.90	4720	13.0	0.91
	Minimum	2060	7.5	0.29	3000	8.1	0.82
	Average	**3279**	**9.7**	**0.76**	**4004**	**10.7**	**0.87**
	S [a]	517.55	1.227	0.153	382.97	1.510	0.022
	CV (%)	15.8	12.6	20.0	9.6	14.1	2.6
	n [b]	17			20		
20	Maximum	4890	12.1	0.90	5290	12.6	0.90
	Minimum	2630	7.7	0.68	3760	9.0	0.80
	Average	**3885**	**9.9**	**0.82**	**4638**	**11.0**	**0.86**
	S	733.82	1.567	0.068	446.75	1.288	0.037
	CV (%)	18.9	15.9	8.3	9.6	11.7	4.3
	n	18			12		
24	Maximum	6910	14.4	0.89	7510	17.1	0.91
	Minimum	4090	8.2	0.54	4640	9.2	0.63
	Average	**5433**	**11.0**	**0.77**	**6117**	**13.6**	**0.80**
	S	848.61	1.432	0.115	703.99	1.747	0.061
	CV (%)	15.6	13.0	15.1	11.5	12.9	7.6
	n	28			52		
25	Maximum				7420	16.0	0.89
	Minimum				5610	8.3	0.79
	Average	**4340**	**13.8**	**0.63**	**6591**	**12.8**	**0.84**
	S				958.98	2.517	0.077
	CV (%)				14.5	19.7	9.1
	n	1			8		
36	Maximum	14460	18.7	0.87	15840	20.8	0.89
	Minimum	6940	9.0	0.34	7500	9.6	0.28
	Average	**9364**	**14.6**	**0.67**	**10951**	**15.4**	**0.86**
	S	1452.66	1.926	0.133	1795.08	2.139	0.127
	CV (%)	15.5	13.2	19.8	16.4	13.9	14.8
	n	120			165		
48	Maximum	22600	19.2	0.87	26800	23.8	0.87
	Minimum	12700	12.7	0.28	15500	14.6	0.39
	Average	**17488**	**16.2**	**0.71**	**20986**	**18.9**	**0.76**
	S	1938.99	1.494	0.115	2349.92	1.841	0.072
	CV (%)	11.1	9.2	16.2	11.2	9.8	9.5
	n	118			214		

[a] Non-pooled standard deviation of the data for a nominal fan diameter, with or without cones.
[b] n = number of fans for which data were available for each nominal fan diameter, with or without cones.

Table A3. Summary of Fan Data (@ ΔP = 0.10 inches of water) for Axial Flow Fans with Diameters from 50 to 55 inches. Data obtained from BESS Laboratory April 2017 (BESS, 2017).

Nominal Fan Diameter (in)		FANS WITHOUT CONES Q-0.10 (cfm)	VER - 0.10 (cfm/W)	AFR	FANS WITH CONES Q-0.10 (cfm)	VER - 0.10 (cfm/W)	AFR
50	Maximum	24000	18.9	0.82	30400	24.5	0.88
	Minimum	15700	12.8	0.66	18000	14.0	0.59
	Average	**20844**	**16.6**	**0.75**	**22991**	**19.0**	**0.76**
	S [a]	2225.05	1.769	0.050	2529.20	2.066	0.070
	CV (%)	10.7	10.7	6.7	11.0	10.9	9.2
	n [b]	18			76		
51	Maximum	24100	17.1	0.81	31900	23.6	0.86
	Minimum	21300	15.0	0.74	20300	16.9	0.53
	Average	**22625**	**16.1**	**0.78**	**26263**	**19.6**	**0.76**
	S	1340.09	0.991	0.033	2699.43	1.943	0.069
	CV (%)	5.9	6.1	4.2	10.3	9.9	9.0
	n	4			19		
52	Maximum	24000	17.6	0.82	29800	24.8	0.87
	Minimum	17100	12.0	0.68	18400	13.3	0.57
	Average	**21450**	**15.2**	**0.77**	**25334**	**19.1**	**0.78**
	S	3171.22	2.664	0.064	2027.85	1.852	0.045
	CV (%)	14.8	17.6	8.3	8.0	9.7	5.8
	n	4			66		
53	Maximum	24900	22.5	0.82	28100	26.6	0.85
	Minimum	16300	14.8	0.52	16800	16.6	0.09
	Average	**20536**	**18.2**	**0.69**	**23270**	**20.5**	**0.67**
	S	2514.82	1.966	0.103	2917.09	2.090	0.174
	CV (%)	12.2	10.8	14.9	12.5	10.2	26.2
	n	22			64		
54	Maximum	26400	19.8	0.83	34800	27.4	0.92
	Minimum	16300	13.6	0.48	17100	14.5	0.25
	Average	**20443**	**17.2**	**0.63**	**27050**	**20.2**	**0.78**
	S	3520.35	2.073	0.145	2602.48	2.306	0.076
	CV (%)	17.2	12.1	23.1	9.6	11.4	9.8
	n	7			136		
55	Maximum	NA	NA	NA	34400	28.7	0.84
	Minimum				20600	14.0	0.61
	Average				**26249**	**19.9**	**0.75**
	S				3103.70	3.099	0.068
	CV (%)				11.8	15.6	9.0
	n				59		

[a] Non-pooled standard deviation of the data for a nominal fan diameter, with or without cones.
[b] n = number of fans for which data were available for each nominal fan diameter, with or without cones.

Table A4. Summary of Fan Data (@ ΔP = 0.10 inches of water) for Axial Flow Fans with Diameters from 57 to 61 inches. Data obtained from BESS Laboratory April 2017 (BESS, 2017).

Nominal Fan Diameter (in)		FANS WITHOUT CONES			FANS WITH CONES		
		Q-0.10 (cfm)	VER - 0.10 (cfm/W)	AFR	Q-0.10 (cfm)	VER - 0.10 (cfm/W)	AFR
57	Maximum	NA	NA	NA	31480	24.5	0.84
	Minimum				20100	15.3	0.34
	Average				**26809**	**19.9**	**0.70**
	S [a]				2892.10	2.387	0.137
	CV (%)				10.8	12.0	19.7
	n [b]				29		
60	Maximum	NA	NA	NA	32400	21.7	0.78
	Minimum				25600	16.1	0.56
	Average				**29171**	**18.7**	**0.69**
	S				2049.97	1.977	0.075
	CV (%)				7.0	10.5	10.9
	n				7		
61	Maximum	27100	19.8	0.69	29900	24.4	0.72
	Minimum	21600	17.5	0.44	22700	19.2	0.34
	Average	**24350**	**18.7**	**0.57**	**26575**	**21.5**	**0.52**
	S	3889.09	1.626	0.177	3712.48	2.241	0.206
	CV (%)	16.0	8.7	31.3	14.0	10.4	39.4
	n	2			4		

[a] Non-pooled standard deviation of the data for a nominal fan diameter, with or without cones.
[b] n = number of fans for which data were available for each nominal fan diameter, with or without cones.