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Standardized Static Pressure Curves for Air Conditioning Fan Selection

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Abstract- The head loss due to friction and duct fittings, as well as the velocity regain, in nine common low velocity air conditioning ductwork arrangements are analyzed to obtain system static pressure heads. A set of curves of static pressure versus fan discharge were thus obtained. Such curves can be used repeatedly for fan selection for different installations.

Keywords- *Static pressure curves, Air conditioning fan*

I. INTRODUCTION

As an alternative to duct system total pressure, which is the sum of the velocity pressure and static pressure [1], the static pressure is sometimes used in conjunction with the fan discharge rate, as a criterion for air conditioning fan selection.

Usually, head loss calculations are carried out to obtain static pressure for varying fan discharge rates. A graph of static pressure against fan discharge is then plotted and superimposed on a set of fan characteristic static head versus discharge curves. The points of intersection of this set of curves with the system head curve indicate the particular fan to be selected, taking into consideration the variations of fan efficiency with discharge. The procedure is well explained in available literature [2].

For the busy design office, this procedure, involving series of calculations and plotting of curves, is somewhat cumbersome; hence the need for ready-made static head curves which would serve as time savers. Such ready-made curves can be obtained by standardizing some duct parameters which affect system performance, for a given set of representative duct configurations. This paper highlights a method of obtaining such ready-made curves.

II. DUCT CONFIGURATIONS FOR ANALYSIS

The static pressure heads are analyzed for varying index lengths of an air conditioning ductwork serving a floor of a hotel building (Figure 1). The analysis is carried out for duct runs ABC, ABCD…, and ABCDEFGHIJKL as independent installations; whence the following parameters are adopted.

a. Each wall-mounted supply outlet delivers 0.15 m^3/s of conditioned air.
b. The head loss through each supply outlet is obtained from a manufacturer's catalogue [3] as 25 N/m^2 (2.124 m of air) for the design air flow and velocity.
c. A low velocity system, for which a maximum air velocity of 5.083 m /s (1000 fpm) in the main duct is recommended [4] (in order to reduce noise levels), is utilized.
d. Losses through other duct accessories, such as dampers, are not included in the analyses. Such values (which are usually provided by the equipment manufacturers) should be added to the static pressure to obtain a total.

III. STATIC HEAD EQUATIONS

The duct configuration having the index run ABCDE, which is represented as an isometric line sketch in Figure 2, is used to illustrate the analyses. In Figure 2, the duct sections in the index run are labeled by boxes which touch each section as follows: the number to the left is the section number, that to the top right is the length of the duct section and the number to the bottom right is the air quantity, in liters per second, carried by the duct section.

A. Duct Sizing

Utilizing the recommended maximum velocity of 5.083 m/s in the main duct, then if Q is the fan discharge, the main duct diameter D is obtained from the relation

$$\frac{\pi D^2}{4} = \frac{Q}{5.083} \quad (1)$$

and

$$D = \left(\frac{4Q}{5.083}\right)^{1/2} = 0.5Q^{1/2} \quad (2)$$

The equal friction method [4.5] is used to size the other duct sections. Table 1 [3] gives duct area percentages of the initial main duct in terms of percentages of the air flow rates for maintaining equal friction. In Figure 2, Q = 0.75 m^3/s and the main duct diameter from Equation 2 is

$$D = 0.5\,(0.75)^{1/2} = 0.433\,\text{m} = 433\,\text{mm}$$

The nearest stock size of 450 mm is selected.

The flow rate in duct section 2 is 0.60 m^3/s. This represents 80% of the flow in the main duct, and from Table 1, the corresponding duct area percentage is 84.5%.

$\therefore$ area of duct section 2 $= \dfrac{\pi d^2}{4} = 0.845\dfrac{\pi D^2}{4}$

and diameter d of duct section 2

$= \sqrt{0.845}\ D = \sqrt{0.845} x 433 = 398 mm$

The nearest stock size of 400 mm is selected. Other duct sections in the index run are sized in a similar manner.

B. Calculation of Frictional Head Loss

The frictional head loss in the index run is given as [6]

$$h_{friction} = 0.3304 \sum_{i=1}^{i=n} \frac{f_i 1_i q_i^2}{d_i^5} \tag{3}$$

where i denotes the ith duct section and n is the number of duct sections in the composite index run

f = friction factor of the section

l = length of the section

q = air flow rate through the section

d = diameter of the section

f depends on the flow Reynolds number Re which is given as [2]

$$\text{Re} = \frac{\rho v d}{\mu} \tag{4}$$

where ρ = air density

v = flow velocity

μ = air dynamic viscosity

Substituting common values of 1.2 kg/m^3 and 1.794 x10^{-5}kg/ms for ρ and μ, respectively, in Equation 4 yields

$$\text{Re} = 8.515 \times 10^4 \frac{q}{d} \tag{5}$$

It is observed [7] that for flow in air conditioning ductwork Re is usually lower than 3240000 and the Nikuradse equation [8]

$$f = 0.0008 + 0.055\ \text{Re}^{-0.237} \tag{6}$$

is useful in estimating f.

Thus, for duct section 1, l = 6.0 m, q = Q = 0.75 m^3/s and d = D = 450 mm (= 0.45 m)

$\therefore$ Re (Equation 5) = $8.515 \times 10^4 \times \dfrac{0.75}{0.45}$ = 141917

and f (Equation 6) = $0.0008 \times 0.055 \times 141917^{-0.237}$
= 0.0041

$\therefore h_{frictioin}$ (Equation 3)

$$= \frac{0.3304 \times 0.0041 \times 6 \times Q^2}{0.45^5} = 0.440 Q^2$$

expressed in terms of the fan discharge Q.

Similarly, for duct section 2 which has l = 4.0 m, q = 0.60 m^3/s $\left(\dfrac{0.60}{0.75}Q = 0.8Q\right)$ and d = 400 mm (= 0.4 m)

$$h_{friction} = 0.347Q^2$$

again expressed in terms of the fan discharge Q.

The total frictional head loss for the entire index run ABCDE is obtained by addition as

$$h_{friction} = 1.314Q^2 \tag{7}$$

C. Calculation of Head Loss through Fittings

The head loss through duct fittings such as elbows, tees, tap-ins and reducers is given as [6]

$$h_{friction} = 0.08256 \sum_{j=1}^{j=m} k_j q_j^2 d_j^{-4} \tag{8}$$

where j denotes the jth duct fitting, m is the number of fittings in the index run, and k is the head loss coefficient of the particular type of fitting. Values of k for the types of elbows, tees, tap-ins and reducers utilized are given as 0.16, 0.28, 0.2 and 0.06 [9].

It is to be noted that at each node where two tap-ins are located, only one is considered in the analyses since the contributions of head loss due to the tap-ins at one location are not additive. Also, Equation 8 is applied to the smaller duct sections at tap-ins, tees and reducers.

Utilizing Equation 8 for each of the 450 mm elbow in duct section 1, for instance,

$$h_{fitting} = 0.08256 \text{ x } 0.16 \text{ x } Q^2 \text{ x } 0.45^{-4} = 0.322Q^2$$

For the 450 mm tee in this section

$$h_{fitting} = 0.08256 \text{ x } 0.28 \text{ x } Q^2 \text{ x } 0.45^{-4} = 0.564Q^2$$

For the 450 mm x 400 mm reducer in duct section 2,

$$h_{fitting} = 0.08256 \text{ x } 0.06 \text{ x } (0.8Q)^2 \text{ x } 0.4^{-4} = 0.124Q^2$$

For the 450 mm x 225 mm tap-in in this section

$$h_{fitting} = 0.08256 \text{ x } 0.2 \text{ x } (0.2Q)^2 \text{ x } 0.225^{-4} = 0.258Q^2$$

For the 450 mm x 300 mm reducer in duct section 3,

$$h_{fitting} = 0.08256 \text{ x } 0.06 \text{ x } (0.4Q)^2 \text{ x } 0.3^{-4} = 0.098Q^2$$

Finally, for the 300 mm x 225 mm reducing tee in duct section 3,

$$h_{fitting} = 0.08256 \text{ x } 0.28 \text{ x } (0.2Q)^2 \text{ x } 0.225^{-4} = 0.361Q^2$$

The total head loss due to fittings in the index run is thus

$$h_{fitting} = 2.49Q^2 + \text{loss through the supply grille at E}$$

$$= 2.049Q^2 + 2.124 \qquad (9)$$

D. Velocity Regain and Static Pressure

In calculating the total static pressure, a velocity regain [2, 4] is usually included to account for the velocity pressure difference between the duct sections at fan discharge and at the last supply terminal. This is given as [10].

$$\text{Regain} = 9.81C\left[\left(\frac{V_{in}}{4.04}\right)^2 - \left(\frac{V_{last}}{4.04}\right)^2\right] N / m^3 \qquad (10)$$

where C, which is a loss coefficient, is taken as 0.75 [4], V_{in} is the velocity in the initial duct section and V_{last} is the velocity in the last section.

Thus, the total system pressure h_s is given as

$$h_s = h_{friction} + h_{fittings} - \text{Regain} \qquad (11)$$

Equation 10 may also be written in terms of metre head of air (taking air density as 1.2 kg/m^3) as

$$\text{Regain} = 0.051C\left(V_{in}^2 - V_{last}^2\right) \qquad (12)$$

$$\text{But velocity } V = \frac{4q}{\pi d^2} \qquad (13)$$

Then, for the system being analyzed,

$$V_{in} = \frac{4Q}{\pi \times 0.45^2} = 6.28Q$$

$$V_{last} = \frac{4(0.2Q)}{\pi \times 0.225^2} = 5.029Q$$

Then, Regain = 0.051 x 0.75 $(6.287^2 - 5.029^2)Q^2 = 0.545Q^2$

$$\therefore \ h_s = 1.314Q^2 + 2.049Q^2 + 2.124 - 0.545Q^2$$

$$= 2.818Q^2 + 2.124 \qquad (14)$$

E. System Head Equations for Other Configurations

The static head equations (obtained by a similar procedure as for Equation 14) are summarized in Table 2.

IV. Static Head Curves for Air Conditioning Fan Selection

The graphs of static pressure head versus discharge are shown in Figure 3 for the different duct configurations. The graphs are shown superimposed on the characteristic curves of static pressure versus discharge of a set of dynamically similar fans; the fans being chosen to operate in the region of the discharge rate utilized in the illustrated analysis (i.e. for the 5-room supply configuration), namely 0.75m^3/s. The lower graph in Figure 3 shows the efficiency curve of the set of fans.

The fan peak efficiency of 56% occurs at a discharge of 0.95m^3/s, and as the nearest fan discharge at which a fan characteristic curve cuts the system static pressure curve is 0.96m^3/s, the corresponding fan (i.e. Fan No. 2) is selected for the duty. The static pressure head at the operating point A is 4.7m.

V. Conclusions

Fluid mechanics analyses have been carried out to obtain a set of static pressure head curves for air conditioning duct systems. Such sets of ready-made curves can be used to select fans for approximately equivalent duct configurations.

Other sets of curves can be derived by the same method for duct arrangements which differ widely from those analyzed in this paper.

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TABLE I. PERCENT SECTION AREA IN BRANCHES FOR MAINTAINING EQUAL FRICTION

Flow Capacity	Duct Area	Flow Capacity	Duct Area	Flow Capacity	Duct Area	Flow Capacity	Duct Area
%	%	%	%	%	%	%	%
1	2.0	26	33.5	51	59.0	76	81.0
2	3.5	27	34.5	52	60.0	77	82.0
3	5.5	28	35.5	53	61.0	78	83.0
4	7.0	29	36.5	54	62.0	79	84.0
5	9.0	30	37.5	55	63.0	80	84.5
6	10.5	31	39.0	56	64.0	81	85.5
7	11.5	32	40.0	57	65.0	82	86.0
8	13.0	33	41.0	58	65.5	83	87.0
9	14.5	34	42.0	59	66.5	84	87.5
10	16.5	35	43.0	60	67.5	85	88.5
11	17.5	36	44.0	61	68.0	86	89.5
12	18.5	37	45.0	62	69.0	87	90.0
13	19.5	38	46.0	63	70.0	88	90.5
14	20.5	39	47.0	64	71.0	89	91.5
15	21.5	40	48.0	65	71.5	90	92.0
16	23.0	41	49.0	66	72.5	91	93.0
17	24.0	42	50.0	67	73.5	92	94.0
18	25.0	43	51.0	68	74.5	93	94.5
19	26.0	44	52.0	69	75.5	94	95.0
20	27.0	45	53.0	70	76.5	95	96.0
21	28.0	46	54.0	71	77.0	96	96.5
22	29.5	47	55.0	72	78.0	97	97.5
23	30.5	48	56.0	73	79.0	98	98.0
24	31.5	49	57.0	74	80.0	99	99.0
25	32.5	50	58.0	75	80.5	100	100.0

(Source: Carrier Air Conditioning Company, 1972)

TABLE II. SUMMARY OF STATIC PRESSURE HEAD EQUATIONS

No. of Air Conditioned Rooms	Frictional Head Loss (m)	Head Loss through Fittings (m)	Static Regain (m)	Static Pressure Head (m)
3	$3.086Q^2$	$4.572Q^2 + 2.124$	$1.449Q^2$	$6.209Q^2 + 2.124$
5	$1.314Q^2$	$2.049Q^2 + 2.124$	$0.545Q^2$	$2.818Q^2 + 2.124$
7	$0.826\ Q^2$	$1.379Q^2 + 2.124$	$0.497Q^2$	$1.708Q^2 + 2.124$
9	$0.369Q^2$	$0.729Q^2 + 2.124$	$0.283Q^2$	$0.815Q^2 + 2.124$
11	$0.273Q^2$	$0.464Q^2 + 2.124$	$0.216Q^2$	$0.521Q^2 + 2.124$
13	$0.218Q^2$	$0.416Q^2 + 2.124$	$0.164Q^2$	$0.470Q^2 + 2.124$
15	$0.186Q^2$	$0.361Q^2 + 2.124$	$0.125Q^2$	$0.422Q^2 + 2.124$
17	$0.151Q^2$	$0.291Q^2 + 2.124$	$0.096Q^2$	$0.346Q^2 + 2.124$
19	$0.120Q^2$	$0.329Q^2 + 2.124$	$0.074Q^2$	$0.375Q^2 + 2.124$

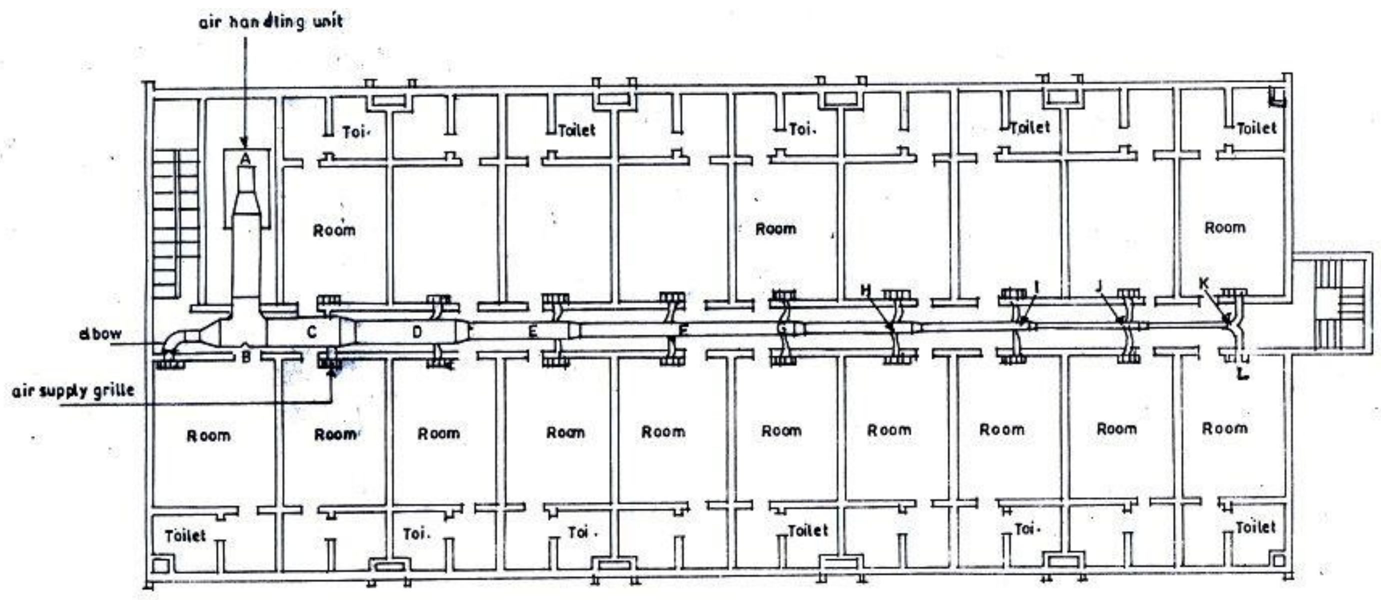

Figure 1. Plan of Air Distribution Ductwork

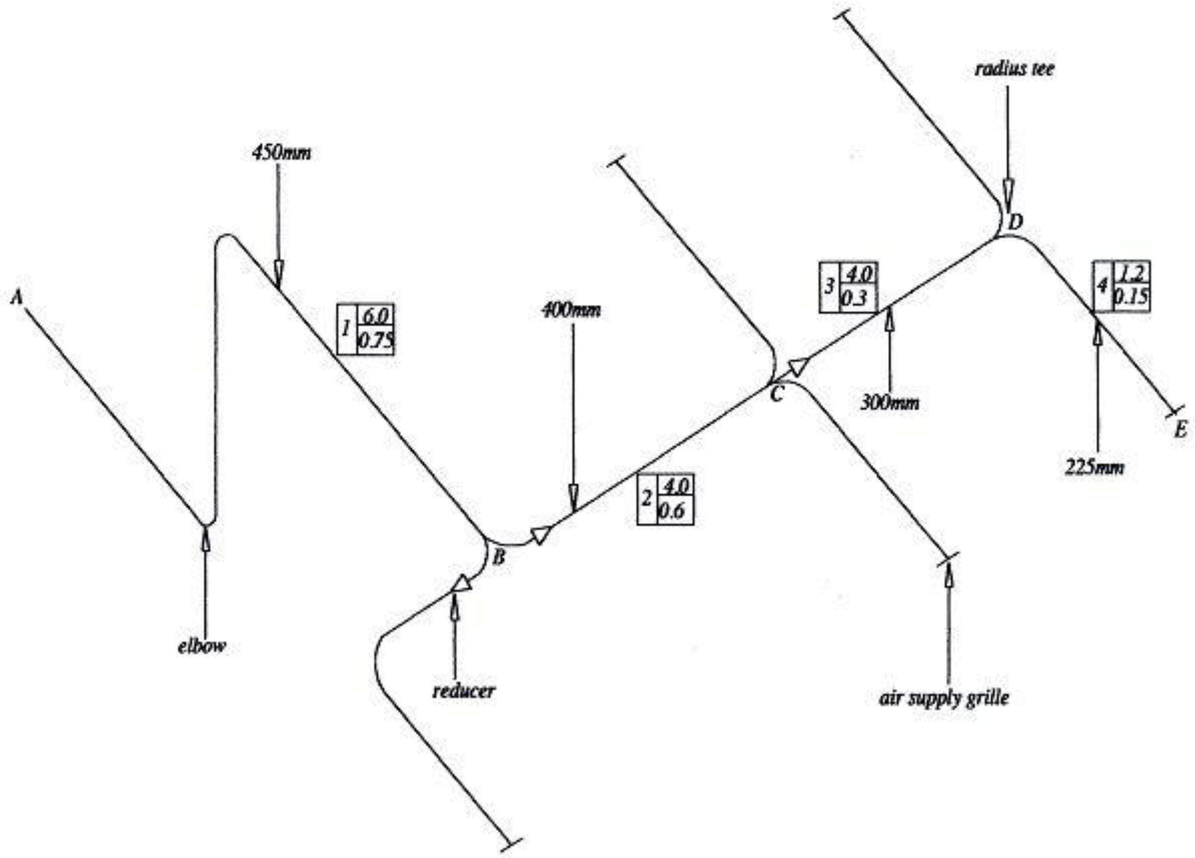

Figure 2. Isometric sketch of supply air ductwork for 5 rooms

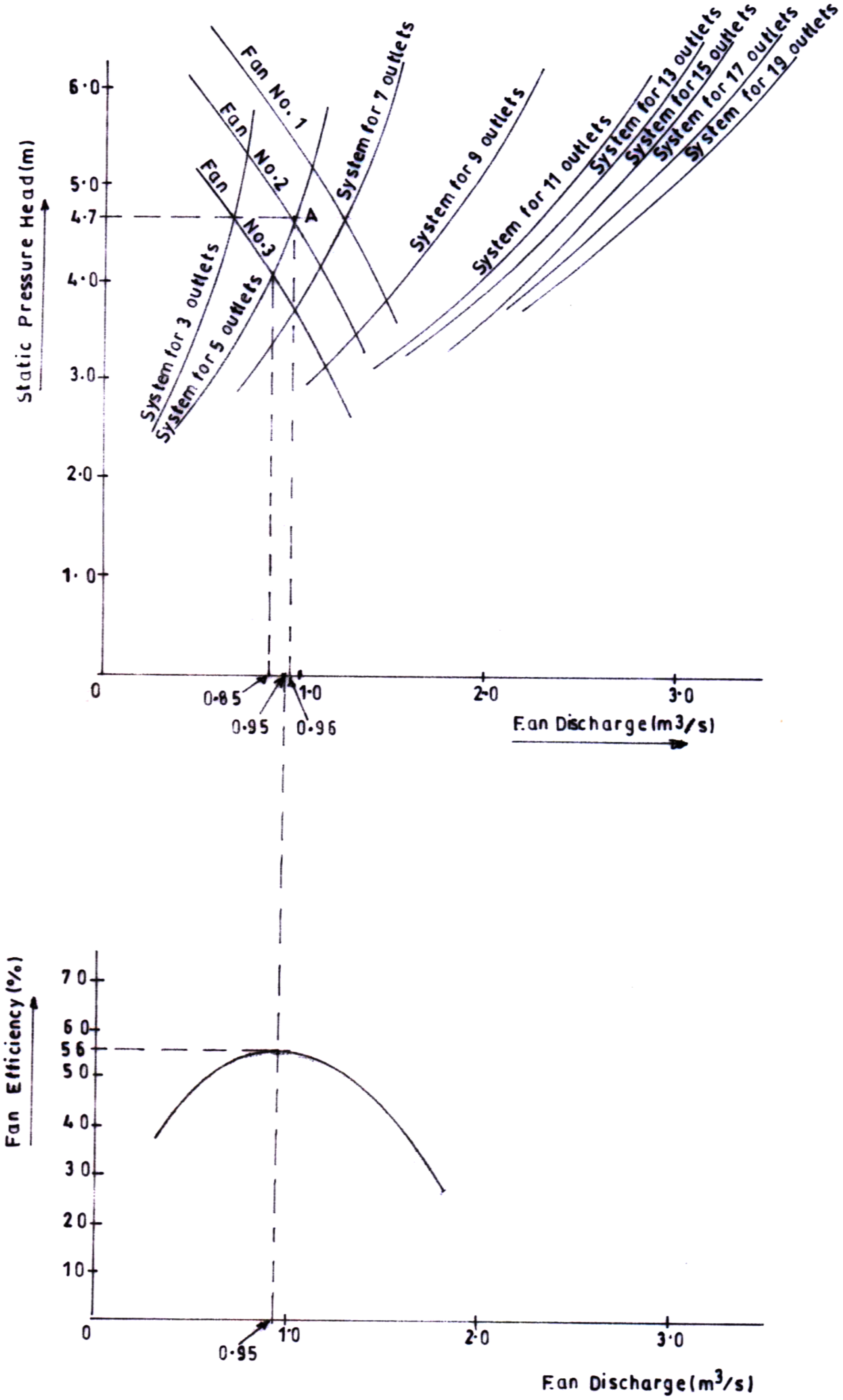

Figure 3. Graphs of system static pressure and fan characteristics