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Analysis of Pressure Losses in Conditioned Air Distribution: Case Study of an Industrial Cafeteria

John I. Sodiki

***Abstract*—**Fractions of the total head loss which constitute the loss through duct fittings are calculated for various duct runs in a conditioned air distribution system of a cafeteria building project. An 'Excel' plot shows a second order increase of the fraction from 0.70 to 0.76 for an increase in duct length from 6.2m to 22.1m. Also, an average fraction of 0.73 was obtained for an average duct length of 15.8m from the computed values. The study shows that the loss through duct fittings constitutes a major loss (being greater than 50% of the total), as corroborated by results of earlier studies. The fractions of head loss due to duct fittings obtained in this study would serve as useful approximations for similar duct layouts and lengths.

Keywords—Head Loss, Duct Fittings, Air Distribution, Cafeteria

I. INTRODUCTION

The fan static pressure required in conditioned air distribution systems is the sum of the terminal operating pressure and the loss in the ductwork [1]. The terminal pressure is specified such as to satisfy the requirements of discharge (such as velocity and throw) into the space. The loss in the ductwork comprises losses through duct fittings (such as elbows, tees, take-offs and reducers) and duct accessories (such as dampers, grilles and diffusers).

In practice, there is greater effort in determining the loss through friction and duct fittings than in determining the other components of the fan static pressure. To aid this effort, some study had been done to obtain relationships between the total frictional loss and the total loss due to fittings in composite index runs of ductwork [2, 3]. Such relationships enable quick approximations of the total head loss (frictional and through fittings) to be made. Thus, a representative fraction due to fittings may simply be added to the frictional loss and, thereby, serve in facilitating the air conditioning fan selection process. The present paper further investigates the relationship between the frictional and fitting loss components in conditioned air distribution in an industrial cafeteria.

II. AIR DISTRIBUTION SYSTEM DESCRIPTION

The distribution system for the cafeteria is shown in the floor plan of Figure. 1. The variation of the fractions of the total pressure loss due to friction and due to duct fittings with length of duct run is studied by the analysis of the following runs of duct, in the order indicated:

a. 0, 1, 2, - - -, 11
b. 0, 1, 33
c. 0, 1, 2, 31, 32
d. 0, 1, 2, 3, 29, 30
e. 0, 1, 2, 3, 26, 27, 28
f. 0, 1, 2, 3, 4, 21, - - -, 25
g. 0, 1, 2, 3, 4, 5, 17, - - , 20
h. 0, 1, 2, 3, 4, 5, 6, 12, - - - , 16

In the analysis, the following system parameters are maintained the same for all the enumerated duct runs, in order to provide a common basis for comparing the results of the different runs:

a. An air velocity of 10m/s is maintained in the initial duct section from the fan discharge on account of reducing noise levels in the circular ducts utilized in the cafeteria building [1, 4].

b. The duct fittings analysed are elbows, tees, tap-ins and reducers; whereas duct accessories such as dampers and ceiling diffusers, whose head loss values are normally provided by their respective manufacturers, are not included in the analysis. However, the head loss values of such accessories should normally be added to the other head loss components to obtain a total.

John I. Sodiki: Department of Mechanical Engineering, Rivers State University of Science and Technology, P.M.B.5080, Port Harcourt, Nigeria
Email: jisodiki_partners@yahoo.com, Cell # +2348033101488

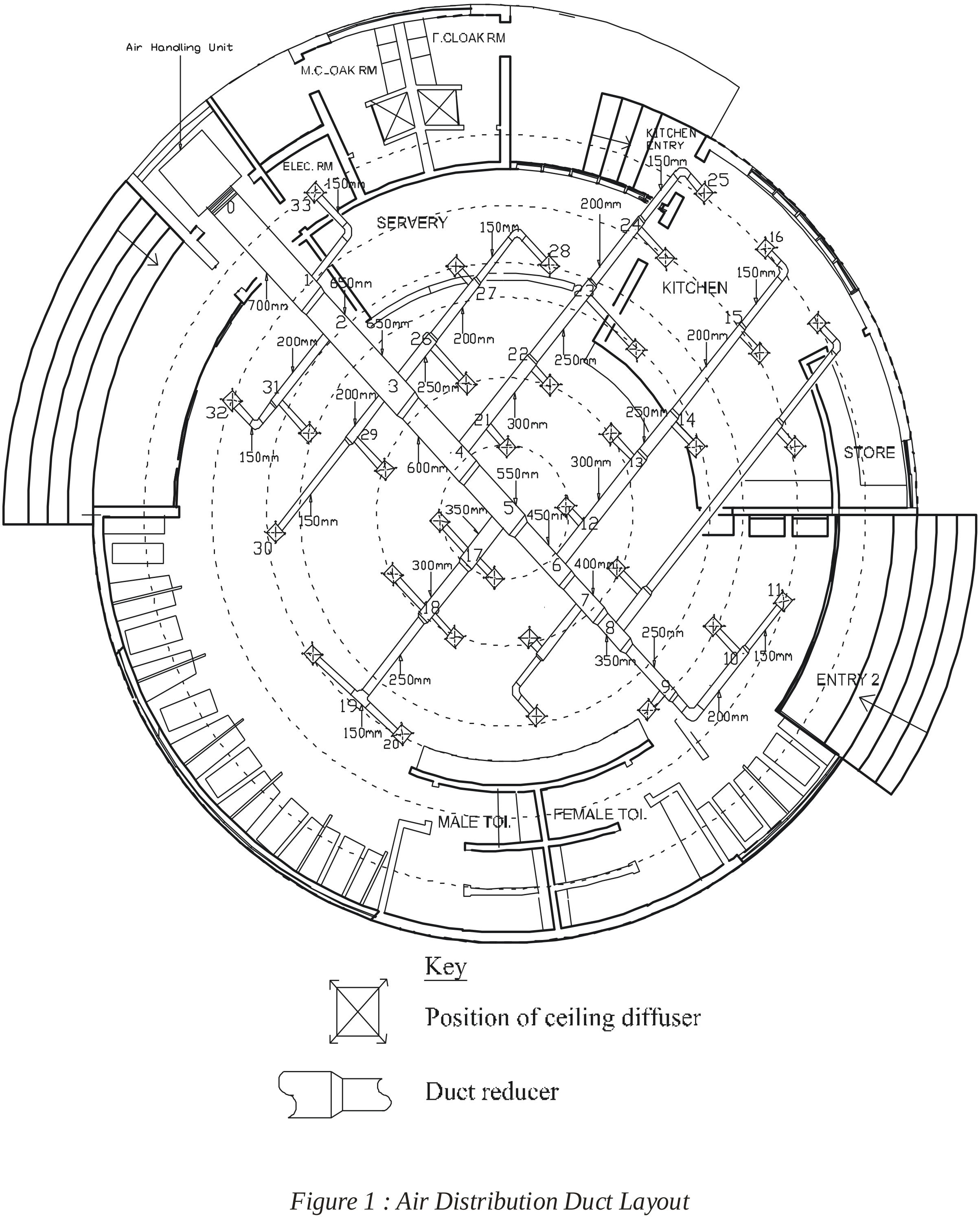

Figure 1 : Air Distribution Duct Layout

c. As the main focus of the study is to understand the variation of the frictional and fitting head loss components with length of composite duct run, other factors which do not significantly affect the differences in values of the frictional and fittings loss components, such as a velocity regain factor [1, 4] are also not included in the analysis.

III. METHODS OF ANALYSIS OF HEAD LOSS COMPONENTS

With a knowledge of the flow through each duct section and the recommended velocity, the 'equal friction' method is utilized in sizing the duct sections [1, 4]. With the duct sizes determined for each of the composite duct runs enumerated in section II above, the head loss due to friction $h_{friction}$ is obtained from the D'Arcy-Weisbach formula applied as [5]

$$h_{friction} = 0.3304 \sum_{i=1}^{n} \frac{f_i l_i q_i^2}{d_i^5} \qquad \text{- - - (1)}$$

where i denotes the i^{th} duct section, n is the number of sections in the composite run and

f = duct section friction factor

l = duct section length (in m)

q = air flow rate through the duct section (in m^3/s)

d = diameter of the duct section (in m)

f is a function of the flow Reynolds number Re given as [6, 7]

$$\mathrm{Re} = \frac{\rho v d}{\mu} \qquad \text{- - - (2)}$$

where ρ = air density (taken as 1.204kgm^{-3})

v = flow velocity

and μ = air dynamic viscosity (taken as 1.8 x 10^{-5}kgm^{-1}s^{-1})

Putting the values of ρ and μ in Equation 2 and noting that

$$v = \frac{4q}{\pi d^2}, \text{ yields}$$

$$\mathrm{Re} = 8.515 \times 10^4 \frac{q}{d} \qquad \text{- - - (3)}$$

For Re $\leq$ 2000, which is the laminar flow regime, f is obtained from the Hagen-Poiseuille equation [8, 9]

$$f = \frac{16}{\mathrm{Re}} \qquad \text{- - - (4)}$$

For the turbulent flow regime 3000 $\leq$ Re $\leq$ 100000, the Blasius equation is commonly applied as [10]

$$f = 0.079 \ \mathrm{Re}^{-0.25} \qquad \text{- - - (5)}$$

Nikuradse [11] had further shown by experiments the dependence of f on ε, the average size of the pipe internal surface imperfections, through the relation

$$f = \phi\left(\mathrm{Re}, \frac{\varepsilon}{d}\right) \qquad \text{- - - (6)}$$

where Ø represents a function; and also proposed that for Re up to 3240000, an applicable relation is [12]

$$f = 0.0008 + 0.055 \ \mathrm{Re}^{-0.237} \qquad \text{- - - (7)}$$

Thus, to determine f, Re needs to be determined and applied in the relevant equation.

Hence, knowing f, l (from length measurements), q and d, the frictional head loss is obtained from Equation 1.

For a given composite duct run, the loss through fittings such as elbows, tees, tap-ins and reducers is given as [5]

$$h_{fittings} = 0.08256 \sum_{j=1}^{m} k_j q_j^2 d_j^{-4} \qquad \text{- - - (8)}$$

where j denotes the j^{th} duct fitting, m is the number of fittings in the duct run, and k is the head loss coefficient of the particular type of fitting. In order to reduce losses through fittings, the elbows, tees and tap-ins are taken as the 90^o radius types [13]; with a radius ratio equal to 1 for elbows and tap-ins and equal to 0.5 for tees. This results in k values of 0.16, 0.28 and 0.2, respectively, for elbows, tees and tap-ins [13]. For the reducers, a 60^o angle of contraction, for which k = 0.06 [13], is chosen.

IV. CALCULATION OF HEAD LOSS COMPONENTS FOR DUCT RUN 0, 1, 2, - - -, 11

Applying standard methods for air conditioning cooling load estimate and psychrometrics [1, 4], a supply air quantity Q of 12800m^3/h is required for the cafeteria, and a total of 32 ceiling diffusers are needed for uniform air distribution.

$$\therefore \text{ air quantity per outlet} = \frac{12800}{32} = 400 \ m^3/h$$

For the air flow velocity of 10m/s, the initial duct diameter D is obtained from the expression of the duct sectional area

$$\frac{\pi D^2}{4} = Q/10 \qquad \text{- - - - - (9)}$$

$$D = \left(\frac{4Q}{10\pi}\right)^{1/2} = \left(\frac{4 \times 12800}{5\pi \times 3600}\right)^{1/2} = 0.673 \ m \approx 700 \ mm$$

and the main duct circular cross-sectional area is

$$\frac{Q}{10} = \frac{12800}{3600} \times \frac{1}{10} = 0.356 \ m^2$$

The duct section parameters and the calculations of the frictional loss and the loss through the fittings are summarized in Table 1. By the ‘equal friction’ method adopted for duct sizing, the circular duct cross-sectional areas of Column 6 of Table 1 are obtained as fractions of the main duct area by making use of Table 2 [1, 4]. Subsequently, duct diameters d are calculated from the equation

$$\frac{\pi d^{2}}{4} = A \text{ and d} = 1.128\sqrt{A} \qquad \text{- - - - (10)}$$

where A = duct section area. The calculated duct diameters are then approximated to the nearest standard sizes.

Now, the frictional head loss is obtained from Equation 1 by first determining f from an estimate of Re from Equation 3. For the initial duct section 0 – 1

$$\text{Re} \quad = 8.515 \times 10^{4} \cdot \frac{12800}{3600} \cdot \frac{1}{0.7} = 432508$$

and for the final section 10 – 11

$$\text{Re} \quad = 8.515 \times 10^{4} \cdot \frac{400}{3600} \cdot \frac{1}{0.15} = 63074$$

The values of Re encountered in the entire duct run 0, 1, 2, - - -, 11 thus fall below 3240000 where Equation 7 is applicable.

Table 1: Summary of Head Loss Calculations for Distribution through 0, 1, 2, - - -, 11 of Figure 1

1 Duct Section	2 Length (m)	3 Flow Rate (m^3/h)	4 Fractional Flow with Respect to Total Fan Discharge	5 % of Main Duct Area for Maintaining Equal Friction	6 Circular Cross-Section Area (m^2)	7 Duct Diameter (mm)	8 Reynolds Number Re	9 Friction Factor f	10 Frictional Head Loss (m)	Fittings: 11 Type	12 No. in Duct Section	13 Head Loss Coefficient*	14 Head Loss in Fitting (m)
0-1	3.0	12800	1.000	100.0	0.356	700	432508	0.0033	$0.0195Q^2$	700mm radius elbow 150mm tap-in	2 1	0.16 x 2 0.20	$0.179Q^2$
1-2	1.5	12400	0.969	97.5	0.347	650	451222	0.0033	$0.0132Q^2$	700mm x 650mm reducer	1	0.06	$0.026Q^2$
2-3	2.5	11600	0.906	93.0	0.331	650	422111	0.0034	$0.0199Q^2$	200mm tap-in	1	0.20	$0.076Q^2$
3-4	2.0	9600	0.750	80.5	0.286	600	378444	0.0034	$0.0163Q^2$	650mm x 600mm reducer 300mm tap-in	1 1	0.06 0.20	$0.093Q^2$
4-5	1.8	7600	0.594	66.5	0.236	550	326838	0.0035	$0.0146Q^2$	650mm x 550mm reducer 350mm tap-in	1 1	0.06 0.20	$0.083Q^2$
5-6	1.8	5200	0.406	49.0	0.174	450	273321	0.0036	$0.0191Q^2$	550mm x 450mm reducer 300mm tap-in	1 1	0.06 0.20	$0.086Q^2$
6-7	1.5	3200	0.250	32.5	0.116	400	189222	0.0039	$0.0118Q^2$	450mm x 400mm reducer 300mm tap-in	1 1	0.06 0.20	$0.052Q^2$
7-8	1.0	2400	0.188	26.0	0.094	350	162190	0.0040	$0.0089Q^2$	400mm x 350mm reducer 250mm tap-in	1 1	0.06 0.20	$0.051Q^2$
8-9	2.0	1200	0.094	14.5	0.052	250	113533	0.0043	$0.0257Q^2$	350mm x 250mm reducer 150mm tap-in	1 1	0.06 0.20	$0.049Q^2$
9-10	2.2	800	0.063	10.5	0.037	200	94611	0.0044	$0.0397Q^2$	250mm radius elbow 250mm x 200mm reducer 150mm tap-in	1 1 1	0.16 0.06 0.20	$0.086Q^2$
10-11	2.0	400	0.031	5.5	0.020	150	63074	0.0048	$0.0401Q^2$	200mm x 150mm reducer	1	0.06	$0.009Q^2$
	21.3								$0.2288Q^2$				$0.790Q^2$

**Source: J. J. Barton (1964)*

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Table 2*: Percent Section Area in Duct 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*

Re, f and $h_{friction}$ evaluated respectively from Equations 3, 7 and 1 are entered in Table 1, with $h_{friction}$ expressed in terms of the fan discharge Q.

The loss through fittings in the composite duct run is obtained by Equation 8 using the applicable k values in each section of the run. This loss is expressed in terms of the fan discharge Q in Table 1 as for the frictional loss, for convenience.

From Table 1, the total frictional loss for the composite run 0, 1, 2, - - , 11 is 0.229Q^2 while that due to fittings is 0.790^2.The sum of the two components is 1. 019Q^2 and the fraction of the total loss due to duct fittings is 0.78.

Similar to Table 1 for duct run 0, 1, 2, - - , 11, Tables 3 to 9 show the results of the analysis of the other duct runs listed as b to h in section II above.

Table 3: Summary of Head Loss Calculations for Distribution through 0, 1, - - -, 33 of Figure 1

1 Duct Section	2 Length (m)	3 Flow Rate (m^3/h)	4 Fractional Flow with Respect to Total Fan Discharge	5 % of Main Duct Area for Maintaining Equal Friction	6 Circular Cross-Section Area (m^2)	7 Duct Diameter (mm)	8 Reynolds Number Re	9 Friction Factor f	10 Frictional Head Loss (m)	Fittings			
										11 Type	12 No. in Duct Section	13 Head Loss Coefficient*	14 Head Loss in Fitting (m)
0-1	3.0	12800	1.000	100.0	0.356	700	432508	0.0033	0.0195Q^2	700mm radius elbow 150mm tap-in	2 1	0.16 x 2 0.2	0.179Q^2
1-33	3.2	400	0.031	5.5	0.020	150	63074	0.0048	0.0642Q^2	150mm tap-in	1	0.2	0.031Q^2
	6.2								0.0837Q^2				0.210Q^2

**Source: J. J. Barton (1964)*

Table 4: Summary of Head Loss Calculations for Distribution through 0, 1, 2, 31, 32 of Figure 1

1 Duct Section	2 Length (m)	3 Flow Rate (m^3/h)	4 Fractional Flow with Respect to Total Fan Discharge	5 % of Main Duct Area for Maintaining Equal Friction	6 Circular Cross-Section Area (m^2)	7 Duct Diameter (mm)	8 Reynolds Number Re	9 Friction Factor f	10 Frictional Head Loss (m)	Fittings			
										11 Type	12 No. in Duct Section	13 Head Loss Coefficient*	14 Head Loss in Fitting (m)
0-1	3.0	12800	1.000	100	0.356	700	432508	0.0033	$0.0195Q^2$	700mm radius elbow 150mm tap-in	2 1	0.16 x 2 0.20	$0.179Q^2$
1-2	1.5	12400	0.969	97.5	0.347	650	451222	0.0033	$0.0132Q^2$	700mm x 650mm reducer	1	0.06	$0.026Q^2$
2-31	2.3	800	0.063	10.5	0.037	200	94611	0.0044	$0.0415Q^2$	150mm tap-in	1	0.20	$0.041Q^2$
31-32	2.0	400	0.031	5.5	0.020	150	63074	0.0048	$0.0401Q^2$	200mm x 150mm reducer 150mm radius elbow	1 1	0.06 0.16	$0.034Q^2$
	8.8								$0.1143Q^2$				$0.280Q^2$

Source: J. J. Barton (1964)

Table 5: Summary of Head Loss Calculations for Distribution through 0, 1, 2, 3, 29, 30 of Figure 1

1 Duct Section	2 Length (m)	3 Flow Rate (m^3/h)	4 Fractional Flow with Respect to Total Fan Discharge	5 % of Main Duct Area for Maintaining Equal Friction	6 Circular Cross-Section Area (m^2)	7 Duct Diameter (mm)	8 Reynolds Number Re	9 Friction Factor f	10 Frictional Head Loss (m)	Fittings			
										11 Type	12 No. in Duct Section	13 Head Loss Coefficient*	14 Head Loss in Fitting (m)
0-1	3.0	12800	1.000	100.0	0.356	700	432508	0.0033	$0.0195Q^2$	700mm radius elbow 150mm tap-in	2 1	0.16 x 2 0.20	$0.179Q^2$
1-2	1.5	12400	0.969	97.5	0.347	650	451222	0.0033	$0.0132Q^2$	700mm x 650mm reducer	1	0.06	$0.026Q^2$
2-3	2.5	11600	0.906	93.0	0.331	650	422111	0.0034	$0.0199Q^2$	200mm tap-in	1	0.20	$0.076Q^2$
3-29	1.5	800	0.063	10.5	0.037	200	94611	0.0044	$0.0270Q^2$	150mm tap-in	1	0.20	$0.041Q^2$
29-30	3.8	400	0.031	5.5	0.020	150	63074	0.0048	$0.0763Q^2$	200mm x 150mm reducer 150mm radius elbow	1 1	0.06 0.16	$0.034Q^2$
	12.3								$0.1559Q^2$				$0.356Q^2$

Source: J. J. Barton (1964)

Table 6: Summary of Head Loss Calculations for Distribution through 0, 1, 2, 3, 26, 27, 28 of Figure 1

1 Duct Section	2 Length (m)	3 Flow Rate (m^3/h)	4 Fractional Flow with Respect to Total Fan Discharge	5 % of Main Duct Area for Maintaining Equal Friction	6 Circular Cross-Section Area (m^2)	7 Duct Diameter (mm)	8 Reynolds Number Re	9 Friction Factor f	10 Frictional Head Loss (m)	Fittings			
										11 Type	12 No. in Duct Section	13 Head Loss Coefficient*	14 Head Loss in Fitting (m)
0-1	3.0	12800	1.000	100.0	0.356	700	432508	0.0033	$0.0195Q^2$	700mm radius elbow 150mm tap-in	2 1	0.16 x 2 0.20	$0.179Q^2$
1-2	1.5	12400	0.969	97.5	0.347	650	451222	0.0033	$0.0132Q^2$	700mm x 650mm reducer	1	0.06	$0.026Q^2$
2-3	2.5	11600	0.906	93.0	0.331	650	422111	0.0034	$0.0199Q^2$	200mm tap-in	1	0.20	$0.076Q^2$
3-26	1.5	1200	0.094	14.5	0.052	250	113533	0.0043	$0.0193Q^2$	150mm tap-in	1	0.20	$0.037Q^2$
26-27	1.8	800	0.063	10.5	0.037	200	94611	0.0044	$0.0325Q^2$	250mm x 200mm reducer 150mm tap-in	1 1	0.06 0.20	$0.091Q^2$
27-28	3.2	400	0.031	5.5	0.020	150	63074	0.0048	$0.0642Q^2$	200mm x 150mm reducer 150mm radius elbow	1 1	0.06 0.16	$0.034Q^2$
	18.5								$0.1686Q^2$				$0.443Q^2$

Source: J. J. Barton (1964)

Table 7: Summary of Head Loss Calculations for Distribution through 0, 1, 2, 3, 4, 21, - - -, 25 of Figure 1

1 Duct Section	2 Length (m)	3 Flow Rate (m^3/h)	4 Fractional Flow with Respect to Total Fan Discharge	5 % of Main Duct Area for Maintaining Equal Friction	6 Circular Cross-Section Area (m^2)	7 Duct Diameter (mm)	8 Reynolds Number Re	9 Friction Factor f	10 Frictional Head Loss (m)	Fittings			
										11 Type	12 No. in Duct Section	13 Head Loss Coefficient*	14 Head Loss in Fitting (m)
0-1	3.0	12800	1.000	100.0	0.356	700	432508	0.0033	$0.0195Q^2$	700mm radius elbow 150mm tap-in	2 1	0.16 x 2 0.20	$0.179Q^2$
1-2	1.5	12400	0.969	97.5	0.347	650	451222	0.0033	$0.0132Q^2$	700mm x 650mm reducer	1	0.06	$0.026Q^2$
2-3	2.5	11600	0.906	93.0	0.331	650	422111	0.0034	$0.0199Q^2$	200mm tap-in	1	0.20	$0.076Q^2$
3-4	2.0	9600	0.750	80.5	0.286	600	378444	0.0034	$0.0163Q^2$	650mm x 600mm reducer 300mm tap-in	1 1	0.06 0.20	$0.093Q^2$
4-27	1.5	2000	0.156	23.0	0.082	300	157685	0.0040	$0.0199Q^2$	150mm tap-in	1	0.20	$0.050Q^2$
21-22	1.8	1600	0.125	19.5	0.069	300	126148	0.0042	$0.0205Q^2$	150mm tap-in	1	0.20	$0.032Q^2$
22-23	2.3	1200	0.094	14.5	0.052	250	113533	0.0043	$0.0296Q^2$	300mm x 250mm reducer 150mm tap-in	1 1	0.06 0.20	$0.049Q^2$
23-24	2.0	800	0.063	10.5	0.037	200	94611	0.0044	$0.0361Q^2$	250mm x 200mm reducer 150mm tap-in	1 1	0.06 0.20	$0.053Q^2$
24-25	2.2	400	0.031	5.5	0.020	150	63074	0.0048	$0.0442Q^2$	200mm x 150mm reducer 150mm radius elbow	1 1	0.06 0.16	$0.034Q^2$
	18.8								$0.2192Q^2$				$0.592Q^2$

**Source: J. J. Barton (1964)*

Table 8: Summary of Head Loss Calculations for Distribution through 0, 1, 2, 3, 4, 5, 17, - - -, 20 of Figure 1

1 Duct Section	2 Length (m)	3 Flow Rate (m^3/h)	4 Fractional Flow with Respect to Total Fan Discharge	5 % of Main Duct Area for Maintaining Equal Friction	6 Circular Cross-Section Area (m^2)	7 Duct Diameter (mm)	8 Reynolds Number Re	9 Friction Factor f	10 Frictional Head Loss (m)	Fittings			
										11 Type	12 No. in Duct Section	13 Head Loss Coefficient*	14 Head Loss in Fitting (m)
0-1	3.0	12800	1.000	100	0.356	700	432508	0.0033	$0.0195Q^2$	700mm radius elbow 150mm tap-in	2 1	0.16 x 2 0.20	$0.179Q^2$
1-2	1.5	12400	0.969	97.5	0.347	650	451222	0.0033	$0.0132Q^2$	700mm x 650mm reducer	1	0.06	$0.026Q^2$
2-3	2.5	11600	0.906	93	0.331	650	422111	0.0034	$0.0199Q^2$	200mm tap-in	1	0.20	$0.076Q^2$
3-4	2.0	9600	0.750	80.5	0.286	600	378444	0.0034	$0.0163Q^2$	650mm x 600mm reducer 300mm tap-in	1 1	0.06 0.20	$0.093Q^2$
4-5	1.8	7600	0.594	66.5	0.236	550	326838	0.0035	$0.0146Q^2$	650mm x 550mm reducer 350mm tap-in	1 1	0.06 0.20	$0.083Q^2$
5-17	1.5	2400	0.188	2.6	0.094	350	162190	0.0040	$0.0133Q^2$	150mm tap-in	1	0.20	$0.039Q^2$
17-18	2.0	1600	0.125	19.5	0.069	300	126148	0.0042	$0.0178Q^2$	150mm tap-in 350mm x 300mm reducer	1 1	0.20 0.06	$0.041Q^2$
18-19	2.6	1200	0.094	14.5	0.052	250	113533	0.0043	$0.0193Q^2$	200mm radius tee 300mm x 350mm reducer	1 1	0.28 0.06	$0.063Q^2$
19-20	1.5	400	0.031	5.5	0.020	150	63074	0.0048	$0.0442Q^2$	250mm x 150mm reducer	1	0.06	$0.009Q^2$
	18.4								$0.1781Q^2$				$0.609Q^2$

**Source: J. J. Barton (1964)*

Table 9: Summary of Head Loss Calculations for Distribution through 0, 1, 2, 3, 4, 5, 6, 12, - - -, 16 of Figure 1

1 Duct Section	2 Length (m)	3 Flow Rate (m^3/h)	4 Fractional Flow with Respect to Total Fan Discharge	5 % of Main Duct Area for Maintaining Equal Friction	6 Circular Cross-Section Area (m^2)	7 Duct Diameter (mm)	8 Reynolds Number Re	9 Friction Factor f	10 Frictional Head Loss (m)	Fittings 11 Type	Fittings 12 No. in Duct Section	Fittings 13 Head Loss Coefficient*	Fittings 14 Head Loss in Fitting (m)
0-1	3.0	12800	1.000	100.0	0.356	700	432508	0.0033	$0.0195Q^2$	700mm radius elbow 150mm tap-in	2 1	0.16 x 2 0.20	$0.179Q^2$
1-2	1.5	12400	0.969	97.5	0.347	650	451222	0.0033	$0.0132Q^2$	700mm x 650mm reducer	1	0.06	$0.026Q^2$
2-3	2.5	11600	0.906	93.0	0.331	650	422111	0.0034	$0.0199Q^2$	200mm tap-in	1	0.20	$0.076Q^2$
3-4	2.0	9600	0.750	80.5	0.286	600	378444	0.0034	$0.0163Q^2$	650mm x 600mm reducer 300mm tap-in	1 1	0.06 0.20	$0.093Q^2$
4-5	1.8	7600	0.594	66.5	0.236	550	326838	0.0035	$0.0146Q^2$	650mm x 550mm reducer 350mm tap-in	1 1	0.06 0.20	$0.083Q^2$
5-6	1.8	5200	0.406	49.0	0.174	450	273321	0.0036	$0.0191Q^2$	550mm x 450mm reducer 300mm tap-in	1 1	0.06 0.20	$0.086Q^2$
6-12	1.2	2000	0.156	23.0	0.082	300	157685	0.0040	$0.0159Q^2$	150mm tap-in	1	0.20	$0.050Q^2$
12-13	2.0	1600	0.125	19.5	0.069	300	126148	0.0042	$0.0178Q^2$	150mm tap-in	1	0.20	$0.032Q^2$
13-14	1.5	1200	0.094	14.5	0.052	250	113533	0.0043	$0.0193Q^2$	150mm tap-in 300mm x 200mm reducer	1 1	0.20 0.06	$0.049Q^2$
14-15	2.6	800	0.063	10.5	0.037	200	94611	0.0044	$0.0469Q^2$	150mm tap-in 250mm x 200mm reducer	1 1	0.20 0.06	$0.053Q^2$
15-16	2.2	400	0.031	5.5	0.020	150	63074	0.0048	$0.0442Q^2$	200mm x 150mm reducer	1	0.06	$0.009Q^2$
	22.1								$0.2467Q^2$				$0.736Q^2$

**Source: J. J. Barton (1964)*

Table 10**:** Ratios of Loss through Duct Fittings for Different Branches Duct

Duct Run	Duct Length (m)	Total Frictional Loss (m)	Total Loss through Fittings (m)	Ratio of Loss through Fittings to Total Loss
0, 1, 2, - - -, 14	21.3	$0.229Q^2$	$0.790Q^2$	0.78
0, 13	6.2	$0.084Q^2$	$0.210Q^2$	0.71
0, 1, 2, 31, 32	8.8	$0.114Q^2$	$0.280Q^2$	0.71
0, 1, 2, 3, 29, 30	12.3	$0.156Q^2$	$0.356Q^2$	0.70
0, 1, 2, 3, 26, - - -, 28	18.5	$0.169Q^2$	$0.443Q^2$	0.72
0, 1, 2, 3, 4, 21, - - -, 25	18.8	$0.219Q^2$	$0.592Q^2$	0.73
0, 1, 2, 3, 4, 5, 17, - - -, 20	18.4	$0.178Q^2$	$0.609Q^2$	0.77
0, 1, 2, 3, 4, 5, 6, 12, ---, 16	22.1	$0.247Q^2$	$0.736Q^2$	0.75
	Average = 15.8			Average = 0.73

V. DISCUSSION OF RESULTS

Table 10 gives a summary of the head loss components and the fractions of loss due to fittings for the different duct runs. It is observed from Table 10 that, for all duct runs, the fitting loss fraction (being greater than 50%) exceeds the frictional loss. The average fraction is 0.73 for an average duct length of 15.8m. The 'Excel' plot of Figure 2 shows the variation of the fitting loss fraction with length of duct run. The plot shows an increase from 0.70 to 0.76 of the fraction for an increase in duct length from 6.2m to 22.1m.

The fractions of loss due to fittings obtained in this plot would aid the approximation of the total head loss through air distribution systems of similar duct layouts to those analysed, since they can simply be added to the frictional loss to obtain the total.

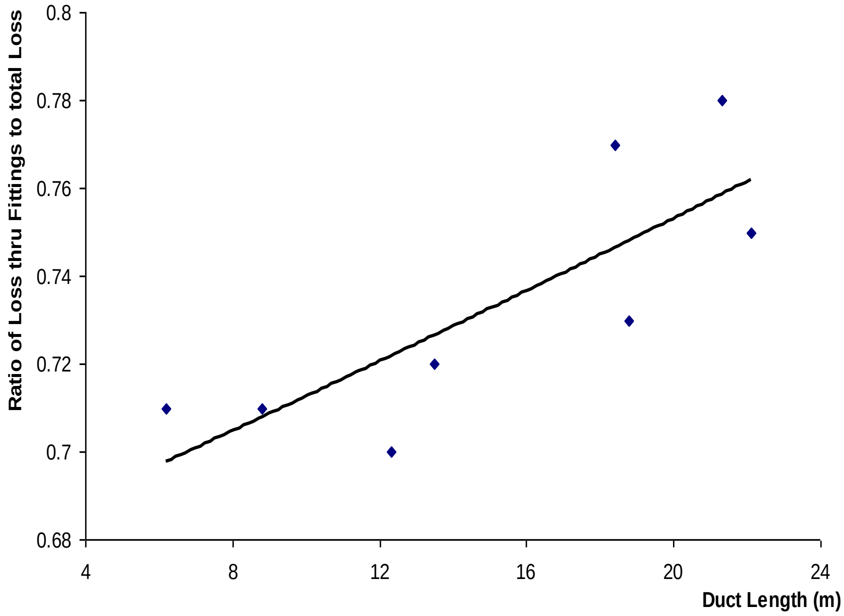

Figure 2: Variation of Fitting Loss Fraction with Duct Length

VI. CONCLUSION

Within the limits of system parameters utilized in the study, the fraction of total pressure loss which constitutes the head loss through fittings increases with duct length. This result agrees with the results of similar studies [2, 3]. Furthermore, the loss through duct fittings is the major loss component (compared with the frictional loss) in many conditioned air distribution system; as corroborated by results of earlier studies [2, 3].

The fractions of head loss due to fittings obtained in this study would be useful approximations for similar duct layouts and lengths to those analysed. Other analyses can be done by the procedure applied in this study for different duct configurations. The results would aid pressure loss estimates and facilitate air distribution fan selection.

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