THE HEAD LOSS RATIO IN CONDITIONED AIR DISTRIBUTION: CASE STUDY OF AN OFFICE BLOCK

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ABSTRACT

Total frictional losses and losses through fittings were calculated for index runs of low velocity conditioned air distribution ductwork in three floors of an office building. Within the range of lengths of index duct run utilized, it was found that the average fraction of the total head loss which constitutes that through duct fittings was 0.60. In an earlier study a regression model equation was derived for estimating the fraction of total loss due to duct fittings in terms of length of ductwork. The estimated fraction, using that model, for the average length of duct run of 28.18m utilized in the present case study was 0.64. The closeness of the two fractions gives some agreement between the results of this study and the earlier one. The determination of the fraction of head loss due to fittings is found useful for quick estimation of the total pressure loss in conditioned air distribution systems, and hence facilitating the fan selection process.

Keywords: Fittings loss fraction, air distribution, office building.

INTRODUCTION

The available pressure at the fan discharge of an air distribution system is progressively reduced away from the fan due to frictional losses and losses through duct fittings such as elbows, tees, tap-ins, reducers and dampers. Usually, long duct runs result in increased frictional loss while a multiplicity of duct fittings results in increased fitting loss; and it can reasonably be assumed that the ratio between the total frictional loss and total loss through all installed fittings in a given composite duct run may vary with varying length of run.

The estimation of the total frictional loss for a composite duct run entails adding up the calculated losses for each duct section of the composite run, and the total loss through the duct fittings is estimated by adding the losses through all the fittings in the composite run. This exercise is somewhat cumbersome for elaborate distribution systems; and so several computer software have been (and are being) developed to aid pressure loss calculations in conditioned air distribution systems (www.engineering-software.com,2014; www.coolit.co.za,2014; www.pocketengineer2:sharepoint.com,2014). These software programs usually require large inputs of system parameters.

However, in some practical situations, attempts are made at quickly obtaining representative fractions of the total head loss which would account for the loss through all installed fittings in the index composite run of the distribution duct system. With such approximating methods, it becomes unnecessary carrying out the loss calculation for every duct fitting in the index run.

In an earlier work, regression model equations had been developed for estimating representative fractions due to duct fittings in conditioned air distribution systems for varying lengths of index duct run and number of air outlets (Sodiki, 2015). This paper presents a case study of conditioned air distribution to three floors of an office building. The frictional and fitting loss components in five index runs of ductwork are calculated and, hence, the fractions of the total head loss which represent those due to duct fittings are obtained. The results are subsequently compared with those obtained in the earlier study.

AIR DISTRIBUTION SYSTEM ANALYSIS CONSIDERATIONS

The conditioned air distribution layouts for the three floors of the office block are shown in Figures 1 to 3. In the analysis of head loss components for all the selected five duct systems, the following parameters are adopted to provide a common basis for analysis as for the earlier study:

a. A low velocity system utilizing circular ducts is used, for which a maximum air velocity of 5m/s is maintained on account of reduction of noise level (Carrier Air Conditioning Company, 1972).
b. The number and type of each duct fitting shown in Figures. 1 to 3 represent those normally utilized in actual installations. However, head losses through duct accessories, such as dampers and supply grilles, whose values are usually provided by the specialist manufacturers, are not included in the analysis. Such values should be added to the frictional and fitting loss components to obtain a total head loss.
c. Other considerations which do not significantly affect the difference between the total frictional and fittings head loss values (for instance, a velocity regain effect (Desai, 2009) are excluded in the analysis.

ANALYSIS OF HEAD LOSS COMPONENTS FOR THE GROUND FLOOR

The procedures for the analysis of loss components for the ground floor distribution system are set out in this section.

Duct Sizing

Following from the air conditioning load estimate and psychrometric procedures (Desai, 2009; Jones, 1980), a 12800m ^{3}/h equipment is to be chosen. With the recommended maximum air flow velocity of 5m/s, the initial main duct diameter D would be obtained from the equation for the cross-sectional area

$$\frac{\pi D^2}{4} = Q/5 \qquad \text{- - - - - (1)}$$

where Q = fan discharge in m^3/s

Then, $D = \left(\frac{4Q}{5\pi}\right)^{1/2} = \left(\frac{4\times 12800}{5\pi\times 3600}\right)^{1/2} = 0.951m$

and the duct circular cross-sectional area = $Q/5 = 0.711m^2$

Now, for uniform distribution, there are 49 air outlets on this floor.

$\therefore$ air quantity per outlet = $\frac{12800}{49} = 261.22m^3/h$

The relevant duct parameters for calculating the frictional loss and the loss through duct fittings are tabulated in Table 1. The 'equal friction' method is utilized for duct sizing, such

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that the circular duct areas (Column 6) are obtained as fractions of the main duct area by use of Table 2 (Carrier Air Conditioning Company, 1972; Desai, 2009; Jones, 1980). Duct diameters are subsequently calculated from the equation

$$\frac{\pi D^2}{4} = A$$

$$\text{or } D = \sqrt{\frac{4}{\pi}}\sqrt{A} = 1.128\sqrt{A} \qquad \text{- - - - - (2)}$$

where A is the area of the duct section

By the method adopted, it is observed that duct sections which convey equal flows are of equal sizes. In a situation where a calculated duct diameter falls between two standard stock sizes, as is often the case, the nearer stock size is selected.

Frictional Head Loss

The D'Arcy-Weisbach equation gives the frictional loss $h_{friction}$ in a given duct section. This equation may be expressed for a composite index duct run as (Sodiki, 2014)

$$h_{friction} = 0.3304\sum_{i=1}^{n}\frac{f_i l_i q_i^2}{d_i^5} \qquad \text{- - - - - (3)}$$

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

$$Re = \frac{\rho v d}{\mu} \qquad \text{- - - - - (4)}$$

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 Eqn. 4 and noting that

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

$$Re = 8.515 \times 10^4 \frac{q}{d} \qquad \text{- - - - - (5)}$$

The values of Re need to be evaluated for the initial and final duct sections of the first index duct run, which in this duct configuration is considered to be that from 0, 1, 2, up to 15 in Figure 1, in order to determine an appropriate relationship between f and Re.

Now, for the initial main duct from the fan discharge (i.e. duct section 0-1)

$$Re = 8.515 \times 10^4 \cdot \frac{12800}{3600} \cdot \frac{1}{0.95} = 318690$$

and for the final section 14 - 15

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$$Re = 8.515 \text{ x } 10^4 \cdot \frac{261}{3600} \cdot \frac{1}{0.15} = 41156$$

It is, thus, observed that the values of Re encountered in all duct sections fall in the region below 3240000, where the Nikuradse equation (Douglas, 1978)

$$f = 0.0008 + 0.055 \text{ Re}^{-0.237} \qquad \text{- - - - - (6)}$$

is found useful for evaluating f.

Values of Re, f and $h_{friction}$ are, thus, evaluated from Equation 5, 6 and 3, respectively, for each duct section and entered in Columns 8, 9 and 10 of Table 1. It is noted that the frictional and fitting head loss components are expressed in terms of the total fan discharge Q, for ease of manipulation.

Head Loss through Fittings

For a given composite duct run, the head loss through fittings such as elbows, tees, tap-ins and reducers, which are illustrated in Figure 4, is given as (Sodiki, 2014)

$$h_{fittings} = 0.08256\sum_{j=1}^{m} k_j q_j^{\,2} d_j^{\,-4} \qquad \text{- - - - - (7)}$$

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. Values of k for the elbows, tees and tap-ins, obtained from the literature (Barton, 1964) are shown respectively in Table. 3 to 5.

In order to achieve reduced head losses through fittings, the elbows and tees are made of the 90^o radius type with the maximum radius ratios (R/D) listed in the respective tables, namely 1 for elbows and 0.5 for tees. For the tap-ins, a=30^o. The corresponding values of k for the elbows, tees and tap-ins are 0.16, 0.28 and 0.2, respectively (Barton, 1964).

At each node where two tap-ins are located, only one is considered in the analysis, since the contribution of head losses due to the tap-ins at one location are not additive. For the reducers, a 60^o angle of contraction, for which k = 0.06 (Douglas, 1978), is chosen. It is to be noted that this value of k is referred to the smaller duct size in the flow direction being considered at reducers.

The parameters of each duct fitting are, thus, entered in Columns 11, 12 and 13, while the fitting loss is entered in Column 14 of Table 1. It is, thus, observed from Table 1 that the total head loss due to friction is $0.355Q^2$ while that due to fittings is $0.423Q^2$, resulting in a total of $0.778Q^2$ and a fraction of loss due to duct fittings of 0.544.

A similar analysis done for another branch duct run on this ground floor, namely that from 0, 1, 16, 17, up to 28 in Figure 1 is summarized in Table 6. From Table 6, the head loss due to friction is obtained as $0.298Q^2$ while that due to fittings is $0.373Q^2$, resulting in a total of $0.671Q^2$ and a fraction of loss due to duct fittings of 0.563.

ANALYSES FOR THE OTHER FLOORS

By following similar procedures as for the ground floor distribution system the first and second floor systems are analysed.

First Floor Distribution System

For the first floor conditioned air distribution system shown in Figure 2, a fan discharge of 14000m^3/h was obtained from air handling equipment selection procedures. The number of air outlets for this floor is 62.

$\therefore$ air quantity per outlet $= \dfrac{14000}{62} = 225.8m^3/h$

Diameter of main duct from fan discharge, from Equation 1, is

$$D = \left(\frac{4Q}{5\pi}\right)^{1/2} = \left(\frac{4 \times 14000}{5\pi \times 3600}\right)^{1/2} = 0.995m \approx 1000mm$$

Following a similar procedure as for the ground floor, the two branch duct runs 0, 1, 2, up to 17, and 0, 1, 18, up to 29 are analysed to obtain the respective calculation summary tables, Tables 7 and 8, for the first floor.

The total head loss due to friction obtained from Table 7 is $0.134Q^2$ while that due to fittings is $0.223Q^2$; the total of the two components being $0.357Q^2$ and the fraction of the total loss due to fittings being 0.625. From Table 8 the total frictional loss is $0.115Q^2$, that due to fittings is $0.174Q^2$, the sum of the two components is $0.289Q^2$ and the fraction of the fittings loss is 0.602.

Second Floor Distribution System

The selected fan discharge for the second floor air distribution system shown in Figure 3 was 12800m^3/h and the number of air outlets is 46.

$\therefore$ air quantity per outlet $= \dfrac{12800}{46} = 278.26m^3/h$

Diameter of main duct from fan discharge, from Equation 1 is

$$D = \left(\frac{4Q}{5\pi}\right)^{1/2} = \left(\frac{4 \times 12800}{5\pi \times 3600}\right)^{1/2} = 0.951m \approx 950mm$$

By a similar procedure for the ground and first floor distribution systems, the calculations of the frictional and fitting loss components for the first index distribution duct run 0, 1, - - -, 15 of Figure 3 for this floor are summarized in Table 9. The table gives a total frictional loss of $0.155Q^2$ and loss due to fittings of $0.290Q^2$. Thus, the fraction of the total which is due to fittings is 0.652.

DISCUSSION OF RESULTS

The calculated fractions of total head loss through duct fittings for the different duct runs are shown in Table 10. An 'Excel' plot of the fraction for the different duct lengths is shown in Figure 5. Similar to results of an earlier study (Sodiki, 2015), this plot shows a second order variation of the fraction of the total loss due to fittings with increasing duct length. Within the range of duct lengths utilized, the fraction varies from 0.544 to 0.652 with an average value of 0.60.

In the earlier study (Sodiki, 2015), a regression model equation for estimating the fraction of total loss due to fittings (denoted as y) in terms of the length of ductwork (denoted as x) for distribution systems having index duct lengths in the range of 11.2m to 43.2m was obtained as

$$y = 0.5852 + 4.923 \times 10^{-4} x + 5.682 \times 10^{-5} x^2 \qquad \text{- - - - - (8)}$$

Applying this equation for the average length of duct run of 28.18m utilized in the present case study, a fittings loss fraction of 0.64 is obtained. This figure, being close to 0.60, gives some agreement between the results of this study and the earlier one.

CONCLUSIONS

The present case study has further shown the dependence of the ratio of total frictional loss and the total loss due to duct fittings with length of index duct run in conditioned air distribution systems.

It is also observed that for all the index duct runs utilized, the fraction of the loss due to duct fittings is greater than that due to friction. It would, therefore, be a misnomer to refer to the head loss through duct fittings as 'minor loss'.

The present case study and the earlier study (Sodiki, 2015) are useful as they enable approximations of the total head loss (frictional and through fittings) to be made quickly, since a representative fraction due to fittings, obtained in this manner, may simply be added to the frictional loss to obtain the total and, thereby, serving to facilitate the air conditioning fan selection process.

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Table 1: Summary of Head Loss Calculations for Distribution along Duct Run 0, 1, 2, - - 15 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	2.5	12800	1.000	100.0	0.711	950	318690	0.00353	$0.011Q^2$	950mm radius elbow 950mm radius tee	2 1	0.16 x 2 0.28	$0.061Q^2$
1-2	1.4	5747	0.449	53.0	0.377	650	209127	0.00382	$0.009Q^2$	950mm x 650mm reducer 150mm tap-in	1 1	0.06 0.20	$0.024Q^2$
2-3	1.3	5486	0.429	51.0	0.363	600	216265	0.00379	$0.012Q^2$	150mm tap-in 650mm x 600mm reducer	1 1	0.06 0.20	$0.030Q^2$
3-4	3.6	5224	0.408	49.0	0.348	600	205937	0.00383	$0.030Q^2$	600mm radius elbow 200mm tap-in	1 1	0.16 0.20	$0.038Q^2$
4-5	1.5	4702	0.367	45.0	0.320	600	185359	0.00390	$0.010Q^2$	200mm tap-in	1	0.20	$0.017Q^2$
5-6	1.5	4180	0.327	41.0	0.292	550	179761	0.00393	$0.013Q^2$	600mm x 550mm reducer 200mm tap-in	1 1	0.06 0.20	$0.025Q^2$
6-7	1.6	3657	0.286	34.5	0.245	500	172996	0.00395	$0.017Q^2$	250mm tap-in 550mm x 500mm reducer	1 1	0.20 0.06	$0.028Q^2$
7-8	1.4	2873	0.224	29.5	0.209	450	151009	0.00406	$0.015Q^2$	200mm tap-in 500mm x 450mm reducer	1 1	0.20 0.06	$0.026Q^2$
8-9	2.0	2351	0.184	25.5	0.178	400	139019	0.00412	$0.027Q^2$	200mm tap-in 450mm x 100mm reducer	1 1	0.20 0.06	$0.028Q^2$
9-10	2.1	1829	0.143	20.5	0.146	350	123607	0.00422	$0.035Q^2$	150mm tap-in 400mm x 350mm reducer	1 1	0.20 0.06	$0.029Q^2$
10-11	2.3	1567	0.122	18.5	0.132	350	105897	0.00434	$0.028Q^2$	350mm radius tee	1	0.28	$0.027Q^2$
11-12	1.1	1306	0.102	16.5	0.117	300	102968	0.00437	$0.021Q^2$	200mm tap-in 350mm x 300mm reducer	1 1	0.20 0.06	$0.036Q^2$
12-13	1.6	784	0.061	10.5	0.075	250	74175	0.00466	$0.028Q^2$	150mm tap-in 300mm x 250mm reducer	1 1	0.20 0.06	$0.020Q^2$
13-14	2.6	522	0.041	7.0	0.050	200	61734	0.00483	$0.066Q^2$	150mm tap-in 200mm elbow 250mm x 200mm reducer	1 1 1	0.20 0.16 0.06	$0.036Q^2$
14-15	1.2	261	0.020	3.5	0.025	150	41156	0.00523	$0.033Q^2$	200mm x 150mm reducer	1	0.06	$0.004Q^2$
	27.7								$0.355Q^2$				$0.429Q^2$

*Source: J. J. Barton (1964)

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*

Table 3*: Head Loss Coefficients K for Radius Elbows (See Figure 4)

R/D	K
0	0.8
0.25	0.4
0.5	0.25
1.0	0.16

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

Table 4*: Head Loss Coefficient K Across Radius Tees (See Figure 4)

R/D	$a = 90^o$	$a = 135^o$
0.25	0.43	0.3
0.5	0.28	0.18

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

Table 5*: Head Loss Coefficients K Across Radius Tap-ins (See Figure 4)

a	K
90^o	1.0
60^o	0.5
45^o	0.3
30^o	0.2

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

Table 6: Summary of Head Loss Calculations for Distribution along Duct Run 0, 1, 16, - - -, 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	2.5	12800	1.000	100.0	0.711	950	318690	0.00353	$0.011Q^2$	950mm radius elbow 950mm radius tee	2 1	0.16 x 2 0.28	$0.061Q^2$
1-16	1.6	7053	0.551	63.0	0.462	700	238317	0.00372	$0.011Q^2$	150mm tap-in 950mm x 700mm reducer	1 1	0.20 0.06	$0.027Q^2$
16-17	2.2	6530	0.510	59.0	0.420	700	220647	0.00378	$0.013Q^2$	150mm tap-in 700mm radius elbow	1 1	0.20 0.16	$0.023Q^2$
17-18	2.0	6008	0.469	55.0	0.391	650	218624	0.00378	$0.014Q^2$	150mm tap-in 700mm x 650mm reducer	1 1	0.20 0.06	$0.026Q^2$
18-19	2.0	5486	0.429	51.0	0.363	600	216265	0.00379	$0.018Q^2$	150mm tap-in 650mm x 600mm reducer	1 1	0.20 0.06	$0.030Q^2$
19-20	2.0	4963	0.388	47.0	0.334	600	195648	0.00387	$0.015Q^2$	150mm tap-in	1	0.20	$0.019Q^2$
20-21	1.8	4441	0.347	43.0	0.306	550	190985	0.00388	$0.017Q^2$	200mm tap-in 600mm x 550mm reducer	1 1	0.20 0.06	$0.028Q^2$
21-22	2.0	3657	0.286	36.5	0.260	500	172996	0.00397	$0.021Q^2$	200mm tap-in 550mm x 500mm reducer	1 1	0.20 0.06	$0.028Q^2$
22-23	2.0	2873	0.224	29.5	0.210	450	151009	0.00406	$0.022Q^2$	150mm tap-in 500mm x 450mm reducer	1 1	0.20 0.06	$0.026Q^2$
23-24	2.4	2351	0.184	25.0	0.178	400	139019	0.00412	$0.033Q^2$	250mm tap-in 400mm x 250mm reducer	1 1	0.20 0.06	$0.028Q^2$
24-25	1.4	1045	0.082	13.0	0.092	250	98869	0.00440	$0.042Q^2$	150mm tap-in	1	0.20	$0.028Q^2$
25-26	0.5	784	0.061	10.5	0.075	250	74175	0.00466	$0.009Q^2$	150mm tap-in	1	0.20	$0.016Q^2$
26-27	1.1	522	0.041	7.0	0.050	200	61734	0.00483	$0.028Q^2$	150mm tap-in 250mm x 200mm reducer	1 1	0.20 0.06	$0.023Q^2$
27-28	1.6	261	0.020	3.5	0.025	150	41156	0.00523	$0.044Q^2$	200mm x 150mm reducer	1	0.16	$0.010Q^2$
	25.1								$0.298Q^2$				$0.373Q^2$

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

Table 7: Summary of Head Loss Calculations for Distribution along Duct Run 0, 1, 2, - - 17 of Figure 2

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	2.9	14000	1.000	100.0	0.778	1000	331139	0.00350	$0.011Q^2$	1000mm radius elbow 1000mm radius tee	2 1	0.16 x 2 0.28	$0.050Q^2$
1-2	1.1	7903	0.565	65.0	0.506	800	233660	0.00374	$0.004Q^2$	200mm tap-in 1000mm x 800mm reducer	1 1	0.20 0.06	$0.017Q^2$
2-3	1.6	7677	0.548	63.0	0.490	800	226978	0.00376	$0.012Q^2$	200mm tap-in	1	0.20	$0.012Q^2$
3-4	3.4	7452	0.532	61.0	0.474	800	220326	0.00378	$0.011Q^2$	250mm tap-in 800mm radius elbow	1 1	0.20 0.16	$0.021Q^2$
4-5	1.7	7000	0.500	58.0	0.451	750	220759	0.00378	$0.007Q^2$	250mm tap-in 800mm x 750mm reducer	1 1	0.20 0.06	$0.017Q^2$
5-6	0.7	6548	0.468	55.0	0.428	750	206505	0.00382	$0.002Q^2$	350mm tap-in	1	0.20	$0.011Q^2$
6-7	2.4	5645	0.403	48.0	0.373	700	190743	0.00388	$0.009Q^2$	250mm tap-in	1	0.20	$0.011Q^2$
7-8	1.6	4516	0.306	39.0	0.303	600	178027	0.00393	$0.008Q^2$	250mm tap-in 700mm x 600mm reducer	1 1	0.20 0.06	$0.016Q^2$
8-9	1.8	3839	0.270	34.5	0.268	600	151338	0.00406	$0.007Q^2$	250mm tap-in	1	0.20	$0.010Q^2$
9-10	1.9	2935	0.210	28.0	0.218	550	126220	0.00420	$0.007Q^2$	250mm tap-in 600mm x 550mm reducer	1 1	0.20 0.06	$0.010Q^2$
10-11	2.1	2258	0.161	23.0	0.179	500	106816	0.00434	$0.007Q^2$	250mm tap-in 550mm x 500mm reducer	1 1	0.20 0.06	$0.009Q^2$
11-12	2.7	1581	0.113	17.5	0.136	400	93488	0.00445	$0.016Q^2$	400mm radius tee 500mm x 400mm reducer	1 1	0.28 0.06	$0.014Q^2$
12-13	0.6	1355	0.097	16.5	0.128	400	80124	0.00459	$0.002Q^2$	250mm tap-in	1	0.20	$0.006Q^2$
13-14	1.5	903	0.065	11.5	0.089	350	61024	0.00484	$0.006Q^2$	200mm tap-in 400mm x 350mm reducer	1 1	0.20 0.06	$0.006Q^2$
14-15	0.7	677	0.048	9.0	0.070	300	53376	0.00497	$0.003Q^2$	250mm tap-in 350mm x 300mm reducer	1 1	0.20 0.06	$0.006Q^2$
15-16	2.9	452	0.032	5.5	0.043	250	42762	0.00519	$0.016Q^2$	200mm tap-in 300mm x 250mm reducer	1 1	0.20 0.06	$0.006Q^2$
16-17	1.4	226	0.016	3.5	0.027	200	26728	0.00571	$0.006Q^2$	250mm x 200mm reducer	1	0.06	$0.001Q^2$
	31.0								$0.134Q^2$				$0.223Q^2$

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

Table 8: Summary of Head Loss Calculations for Distribution along Duct Run 0, 1, 18, - - -, 29 of Figure 2

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	2.9	14000	1.000	100.0	0.778	1000	331139	0.00350	$0.011Q^2$	1000mm radius elbow 1000mm radius tee	2 1	0.16 x 2 0.28	$0.050Q^2$
1-18	3.0	6097	0.435	52.0	0.404	700	204326	0.00383	$0.013Q^2$	450mm tap-in 700mm radius elbow 1000mm x 700mm reducer	1 1 1	0.20 0.16 0.06	$0.027Q^2$
18-19	2.6	4290	0.306	39.0	0.303	600	169117	0.00397	$0.012Q^2$	250mm tap-in 700mm x 600mm reducer	1 1	0.20 0.06	$0.016Q^2$
19-20	1.8	3839	0.274	34.5	0.268	600	151338	0.00406	$0.007Q^2$	250mm tap-in	1	0.20	$0.010Q^2$
20-21	1.9	3387	0.242	31.5	0.245	600	133520	0.00415	$0.006Q^2$	250mm tap-in	1	0.20	$0.010Q^2$
21-22	1.7	2935	0.210	28.0	0.218	550	126220	0.00420	$0.006Q^2$	250mm tap-in 600mm x 550mm reducer	1 1	0.20 0.06	$0.010Q^2$
22-23	1.7	2484	0.177	25.0	0.194	500	117507	0.00426	$0.007Q^2$	300mm tap-in 550mm x 500mm reducer	1 1	0.20 0.06	$0.011Q^2$
23-24	1.9	1806	0.129	19.5	0.152	450	94926	0.00444	$0.008Q^2$	200mm tap-in 500mm x 450mm reducer	1 1	0.20 0.06	$0.009Q^2$
24-25	3.0	1581	0.113	17.5	0.136	400	93488	0.00445	$0.017Q^2$	400mm radius tee 450mm x 400mm reducer	1 1	0.28 0.06	$0.011Q^2$
25-26	2.0	1355	0.097	16.5	0.128	400	80124	0.00459	$0.008Q^2$	250mm tap-in	1	0.20	$0.006Q^2$
26-27	0.5	903	0.065	11.5	0.089	350	61024	0.00484	$0.002Q^2$	200mm tap-in 400mm x 350mm reducer	1 1	0.20 0.06	$0.006Q^2$
27-28	2.0	677	0.048	9.0	0.070	300	53376	0.00497	$0.009Q^2$	200mm tap-in 350mm x 300mm reducer	1 1	0.20 0.06	$0.005Q^2$
28-29	2.0	226	0.016	3.5	0.027	200	26728	0.00571	$0.009Q^2$	200mm radius elbow 300mm x 200mm reducer	1 1	0.16 0.06	$0.003Q^2$
	27.1								$0.115Q^2$				$0.174Q^2$

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

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Table 9: Summary of Head Loss Calculations for Distribution along Duct Run 0, 1, 2, - - -, 14 of Figure 3

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	2.5	12800	1.000	100.0	0.711	950	318690	0.00353	$0.011Q^2$	950mm radius elbow 200mm tap-in	3 1	0.16 x 3 0.2	$0.069Q^2$
1-2	6.0	12522	0.978	98.0	0.697	950	311769	0.00354	$0.026Q^2$	350mm tap-in	1	0.2	$0.019Q^2$
2-3	2.3	11407	0.891	91.5	0.651	900	299786	0.00367	$0.011Q^2$	300mm tap-in 950mm x 900mm reducer	1 1	0.2 0.06	$0.026Q^2$
3-4	2.0	10574	0.826	87.0	0.619	900	277894	0.00362	$0.008Q^2$	350mm tap-in	1	0.2	$0.017Q^2$
4-5	2.0	9461	0.739	80.0	0.569	850	263269	0.00366	$0.009Q^2$	400mm tap-in 900mm x 850mm reducer	1 1	0.2 0.06	$0.022Q^2$
5-6	2.4	7791	0.609	68.0	0.484	800	230348	0.00375	$0.010Q^2$	400mm tap-in 850mm x 800mm reducer	1 1	0.2 0.06	$0.019Q^2$
6-7	1.5	6400	0.500	58.0	0.412	700	216254	0.00379	$0.008Q^2$	400mm tap-in 800mm x 700mm reducer	1 1	0.2 0.06	$0.022Q^2$
7-8	1.6	5009	0.391	47.0	0.334	650	182272	0.00392	$0.008Q^2$	200mm tap-in 700mm x 650mm reducer	1 1	0.2 0.06	$0.018Q^2$
8-9	1.3	4730	0.370	45.0	0.320	650	172119	0.00396	$0.006Q^2$	200mm tap-in	1	0.2	$0.013Q^2$
9-10	1.5	4452	0.348	42.0	0.299	600	175504	0.00494	$0.009Q^2$	600mm radius tee 650mm x 600mm reducer	1 1	0.28 0.06	$0.026Q^2$
10-11	1.9	2504	0.196	27.0	0.192	500	118453	0.00425	$0.010Q^2$	300mm tap-in 600mm x 500mm reducer	1 1	0.2 0.06	$0.013Q^2$
11-12	2.2	1670	0.130	19.5	0.139	400	98750	0.00440	$0.016Q^2$	250mm tap-in 500mm x 400mm reducer	1 1	0.2 0.06	$0.014Q^2$
12-13	1.4	835	0.065	11.5	0.082	300	73718	0.00466	$0.011Q^2$	200mm tap-in 400mm x 300mm reducer	1 1	0.2 0.06	$0.011Q^2$
13-14	1.4	278	0.022	3.5	0.025	200	32877	0.00548	$0.012Q^2$	300mm x 200mm reducer	1	0.06	$0.001Q^2$
	30.0								$0.155Q^2$				$0.290Q^2$

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

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Table 10: Ratios of Loss through Duct Fittings for Different Duct Runs

Floor of Building	Duct Run	Duct Length (m)	Total Frictional Loss (m)	Total Loss through Fittings (m)	Ratio of Loss through Fittings to Total Loss
Ground Floor	0,1,2, - - -, 15 0,1,16, - - -, 28	27.7 25.1	$0.355Q^2$ $0.298Q^2$	$0.429Q^2$ $0.373Q^2$	0.547 0.563
First Floor	0,1,2, - - -, 17 0,1,18, - - -, 29	31.0 27.1	$0.134Q^2$ $0.115Q^2$	$0.223Q^2$ $0.171Q^2$	0.625 0.602
Second Floor	0,1,3, - - -, 14	30.0	$0.155Q^2$	$0.290Q^2$	0.652
		Average = 28.18			Average = 0.60

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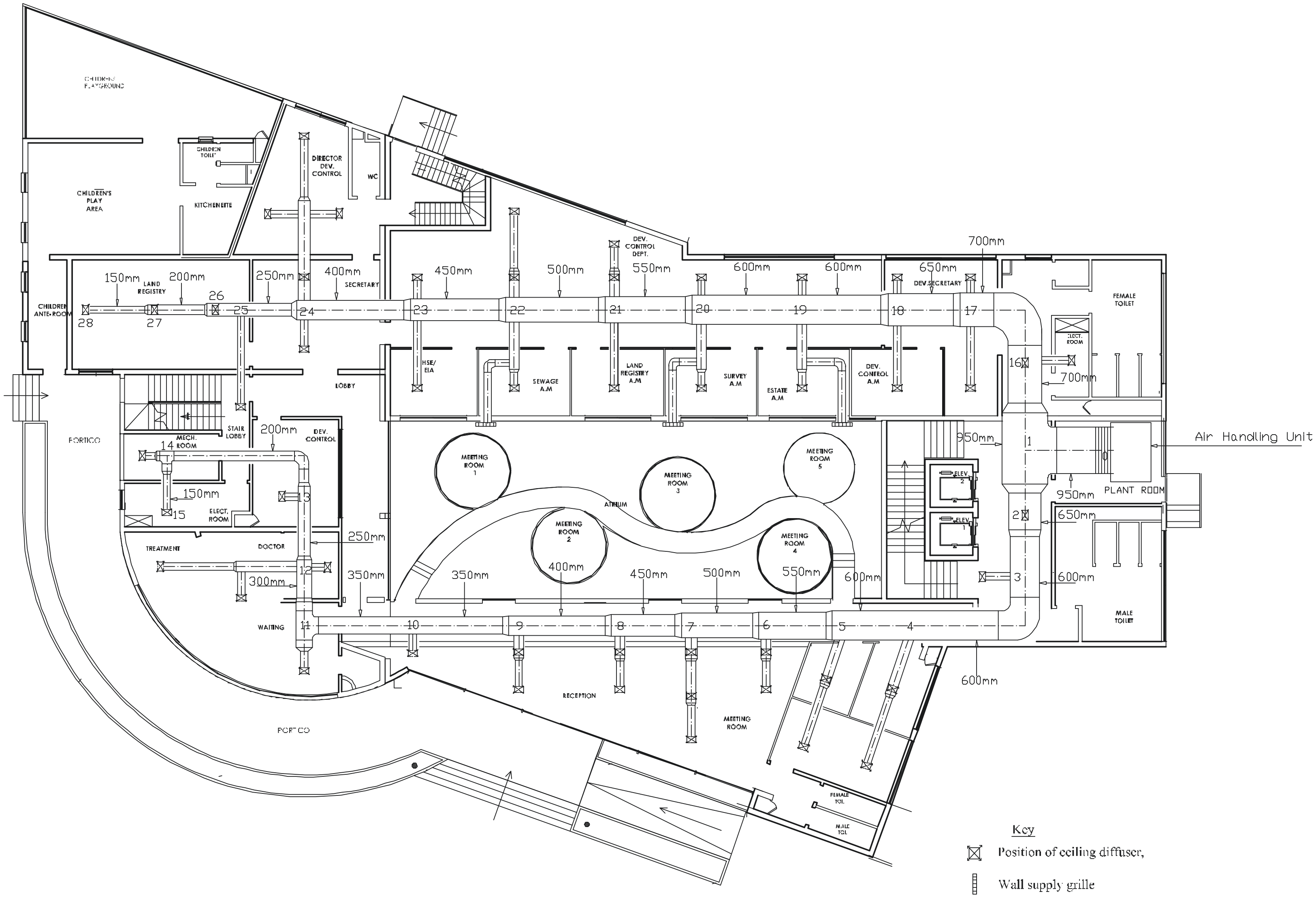

Fig. 1 : Air Distribution Duct Layout for Ground Floor

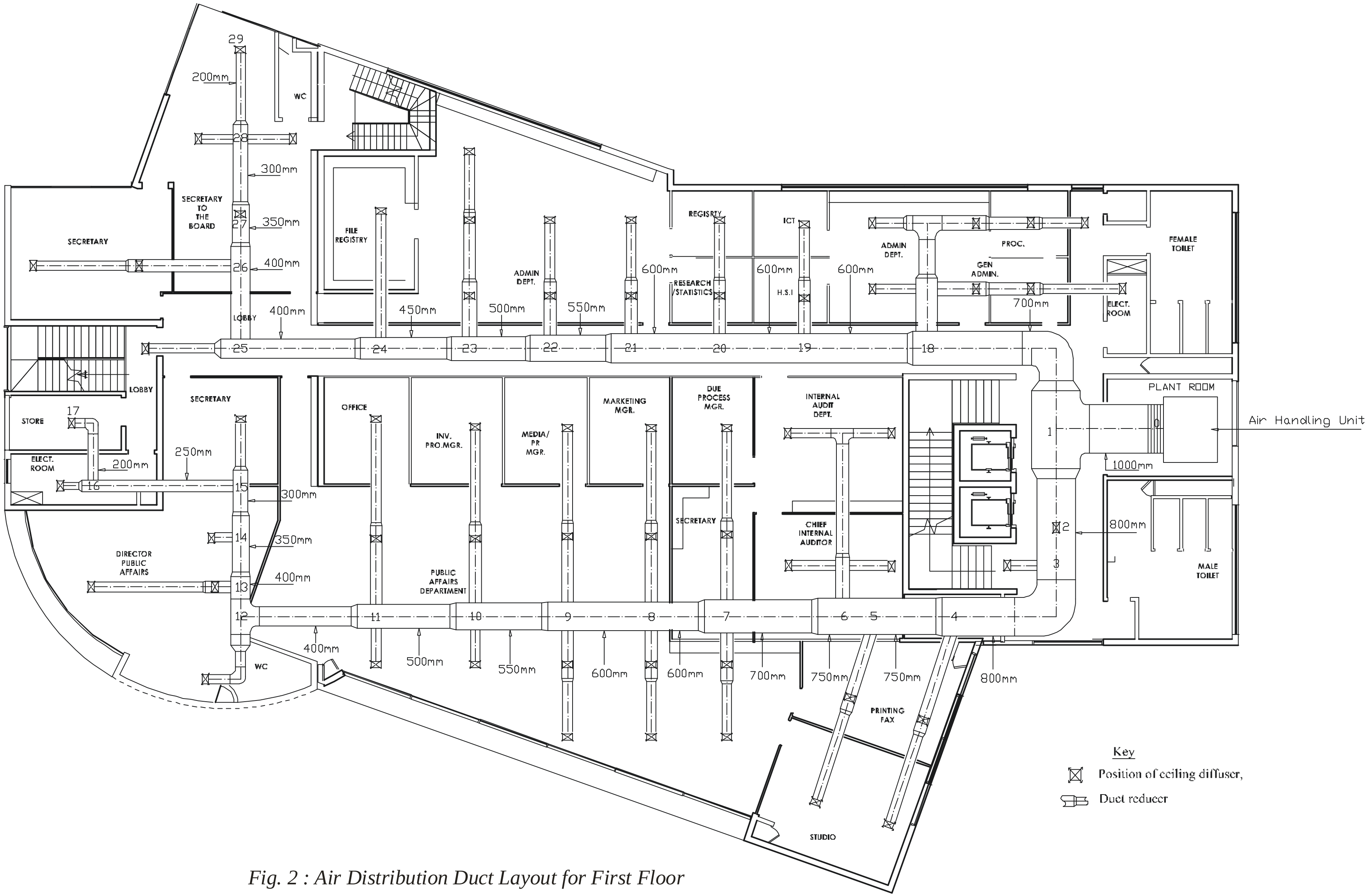

Fig. 2 : Air Distribution Duct Layout for First Floor

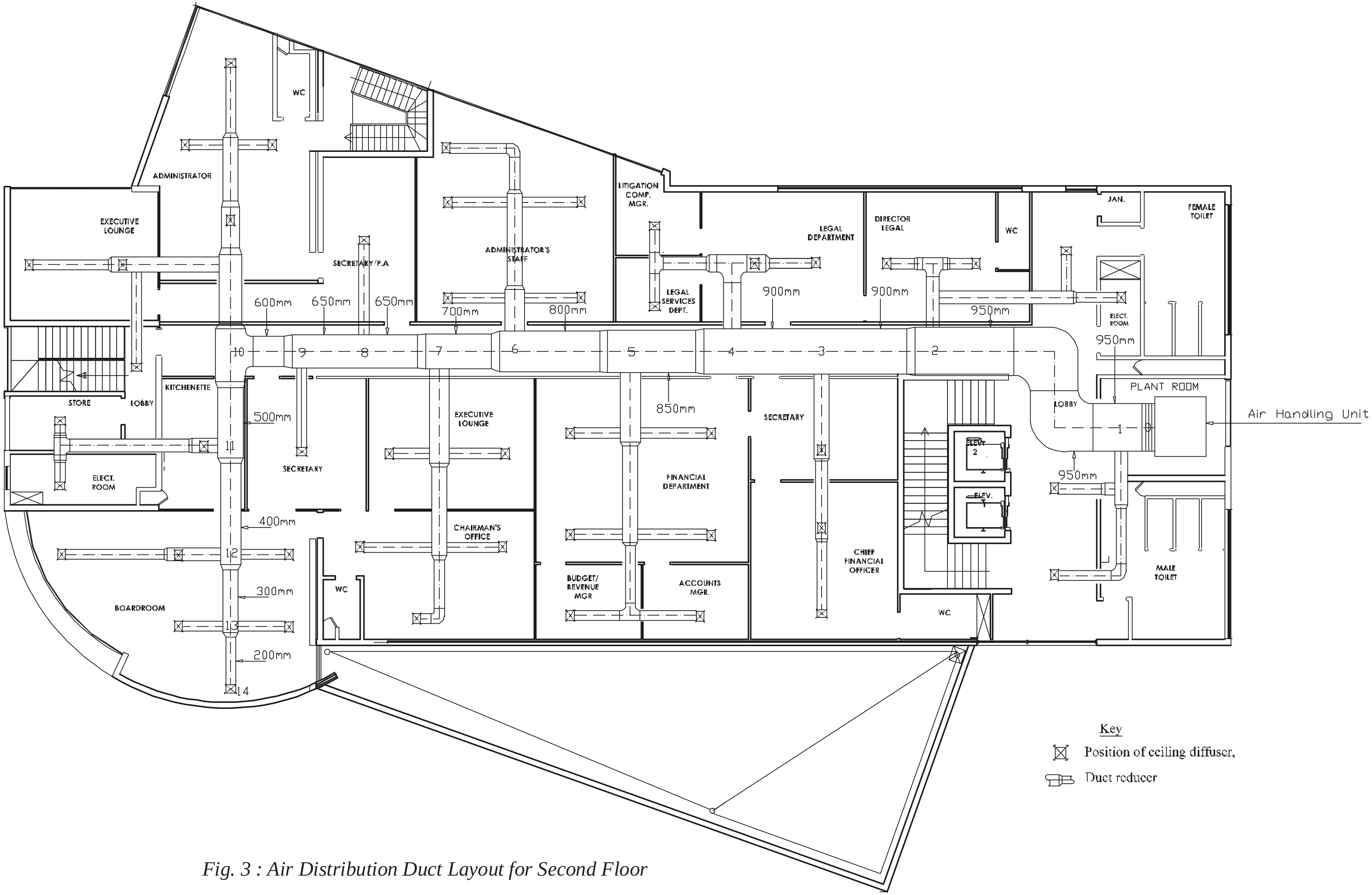

Fig. 3 : Air Distribution Duct Layout for Second Floor

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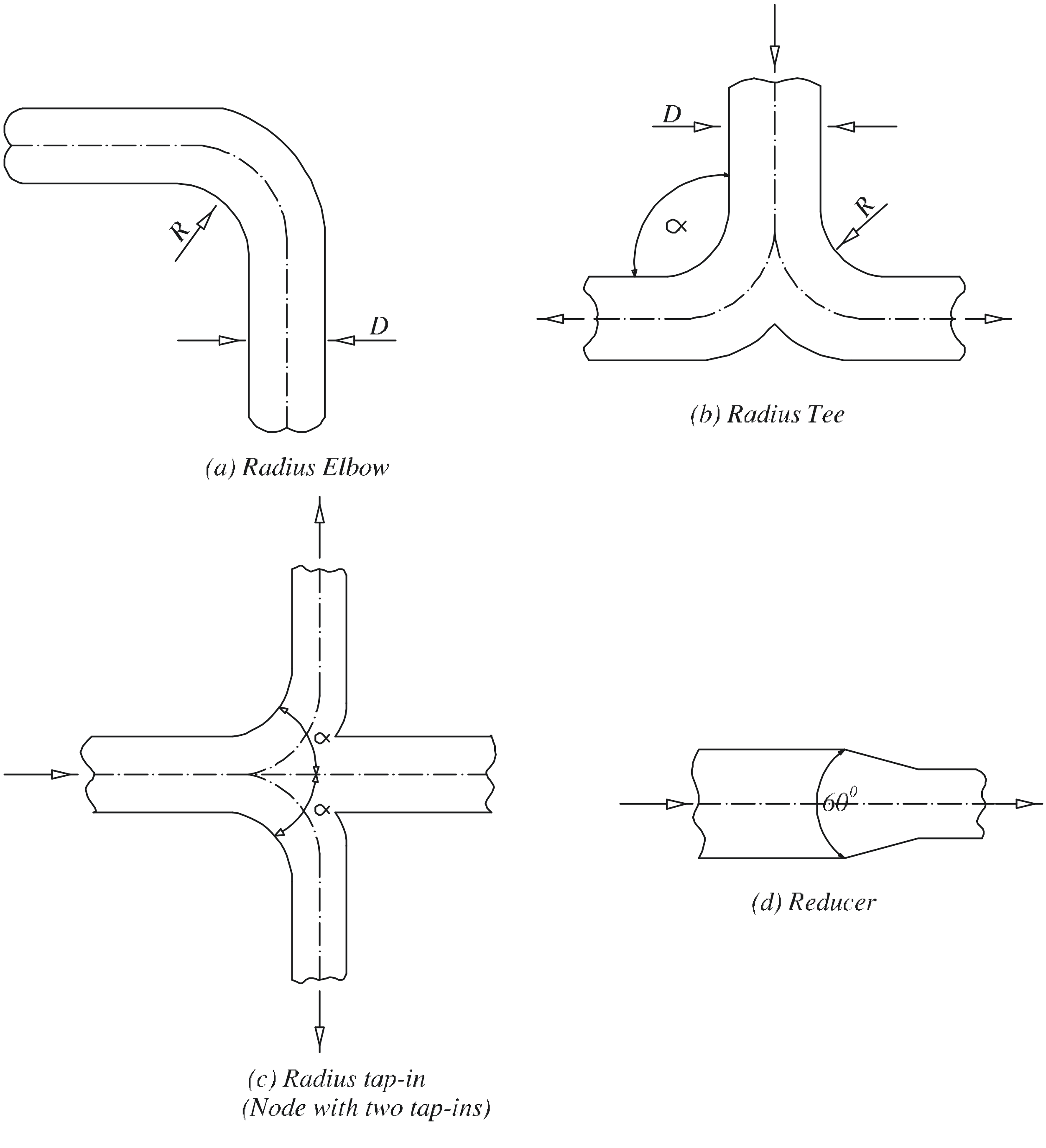

Fig.4: Illustration of Duct Fittings

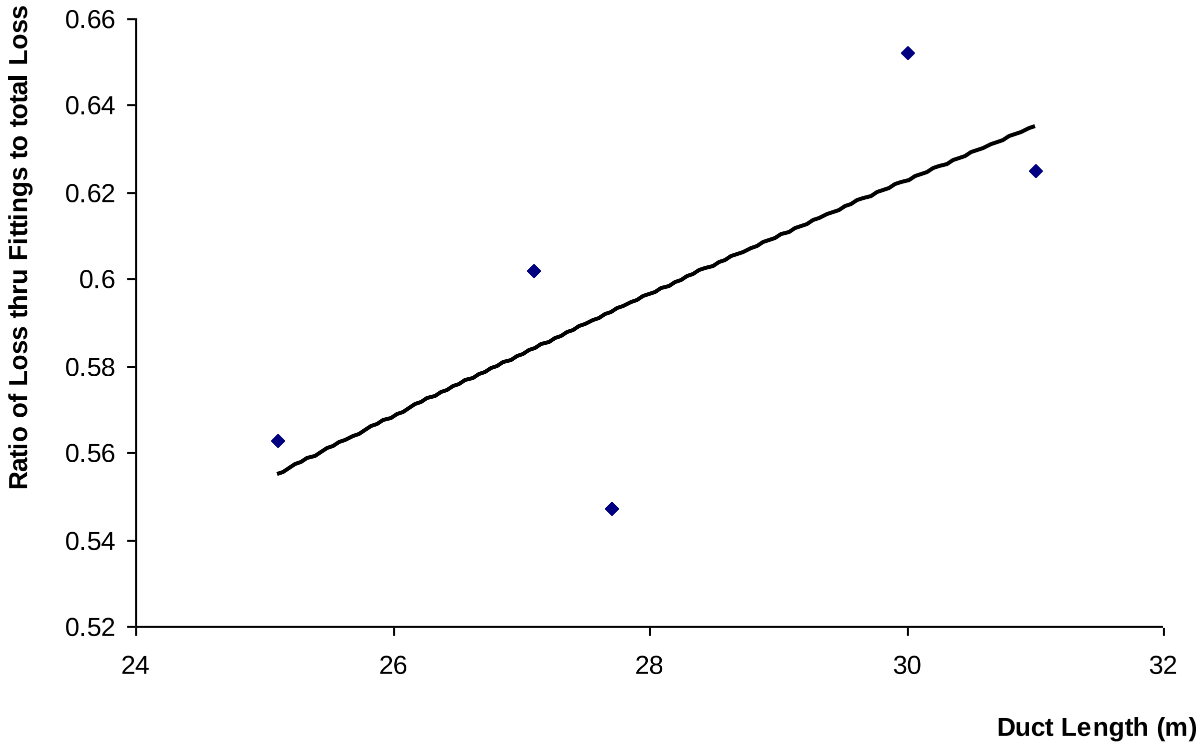

Fig. 5: Variation of Fitting Loss Fraction with Duct Length