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# On the Approximation of Pressure Loss Components in Air Conditioning Ducts

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***Abstract***- Various methods proposed for approximating the total pressure loss in fittings of index duct runs of air conditioning systems are observed to be inappropriate. Regression analyses had, therefore, been done on an air distribution configuration which resulted in relationships between the fitting loss fraction, on one hand, and the variables of length of duct run and number of air outlet terminals, on the other hand. Also, other case studies had earlier been done in which the variation of total duct fitting loss fraction with changing system parameters had been investigated. The present study compares the regression analysis results with those of the other case studies; with the conclusion that the regression results are not representative enough to be applied to other air distribution configurations. However, for approximation purposes, the fitting loss fraction for an index run may be estimated by using the average values of a few duct runs in any given installation. Furthermore, it is observed that referring to the fitting loss as 'minor' is a misnomer as this loss constitutes a larger fraction than the frictional loss in all the duct configurations studied.

***Keywords***- *Regression Analysis, Air Conditioning Duct Fitting Loss, Checking the Validity, Case Studies*

## I. INTRODUCTION

The required fan pressure in a ducted air conditioning system is usually determined by addition of the duct frictional loss, the loss through duct fittings (such as elbows, tees, tap-ins and reducers), the loss through duct accessories (such as dampers, grilles, sound attenuators and diffusers), and the terminal pressure in first index duct runs. The first index duct run is that run through which the largest pressure loss is likely to occur. The terminal pressure is specified such as to satisfy the requirements of air discharge (such as the velocity and throw).

Normally, the selected fan should be capable of developing a pressure larger than this sum, on account of deteriorating performance with age and providing a design safety factor. In air duct design, there is a greater effort in the calculation of the frictional and fitting loss components than in determining the other pressure components, as the latter are usually specified by the equipment manufacturers. As the calculations of frictional and fitting loss components constitute a somewhat cumbersome exercise for elaborate duct systems, several suggestions had been made for approximating the total loss due to all installed duct fittings, taken together, in index duct runs. Some of such approximations stipulate factors or percentages to be added to the total frictional loss of the first index duct run to arrive at the total of the fitting and frictional loss components; the frictional loss component being easier to compute using commonly applicable methods such as the D'Arcy-Weisbach formula [1] on the different sections of the composite index run.

For instance, in approximating fitting losses in heating, ventilation and air conditioning duct work, Bhatia [2] suggested a 40% equivalent duct length to be added to straight duct lengths for simple duct systems (having a few fittings) and 100% for complex systems (with many fittings): a somewhat subjective stipulation in the sense of defining simple and complex. Also, a rule-of-the-thumb first approximation suggested by Hanby [3] for estimating the total head loss (i.e. frictional and through fittings) $h$ in ventilation ducts is to utilize a loss coefficient $k$ = 5 in the usual head loss equation [1, 4]

$$h = k \frac{v^2}{2g} \quad (1)$$

However, this approximation does not separate the frictional loss from that due to fittings; whereas such a separation would be more useful for estimating the fitting loss in terms of the frictional component.

Likewise, several methods abound for approximating total fitting losses in index runs of other fluid systems. In water distribution systems, for instance, Church [5], Barry [6] and Boman and Shukla [7] had suggested various percentages of the total frictional loss to account for that due to pipe fittings in index runs. Similarly, Spirax Sarco Ltd [8] had suggested percentages of total frictional loss in index runs of saturated steam piping to account for the total fitting loss. In another approximation method, adopted by W. W. Granger Inc. [9] for ventilating systems, a 2mm water gauge pressure is simply utilized as the loss per duct fitting (elbow, register, grille, damper, etc.) rather than applying a percentage to represent the fitting losses.

Useful as the foregoing approximation methods may be in facilitating the estimation of pressure losses and, hence, the selection of suitable fans for duct systems, they lack mathematical or statistical basis. As an attempt to provide this statistical basis, studies by the author had developed regression equations for predicting the fraction (or percentage) of loss due to duct fittings in conditioned air distribution systems of varying complexities [10]. Also, case studies had been done on some air conditioning duct systems for understanding the variation of the fraction (or percentage) of total fitting loss to the whole (frictional plus fitting loss). The present study attempts to check the validity of the derived regression equations by comparing results obtained from them with corresponding results calculated from the case studies.

## II. DESCRIPTION OF SYSTEM FOR OBTAINING REGRESSION EQUATIONS

The variation of the percentage of the total head loss which is due to duct fittings with the varying system parameters of length of index duct run and number of air supply outlets was studied using the air distribution system of Fig. 1 in which equal air quantities were distributed through circular ducts to 19 rooms of a hotel building using wall-mounted outlets [10]. In order to obtain variations of the system parameters, the index run ABC - - - L was analyzed in the independent successive run ABC, ABCD, ABCDE, and so on.

Thus, the head losses in the run from A through B and C to the two air outlets supplied at C were first considered (with the extension on the main distribution duct from C towards D being considered as non-existent). Next, the analysis is repeated for the duct run from A through B, C and D to the two outlets supplies at D (again considering the extension on the main duct towards E as non-existent). Subsequent steps were carried out in like manner and the progressive increase in the length of supply ductwork and number of outlets also resulted in increases of the supply fan discharge, main duct size, and losses due to friction and duct fittings. Standard system parameters and commonly applied methods were utilized in the computation of circular duct sizes and frictional and fitting losses in each step to obtain the fraction of the total loss which was due to fittings. Second order variations of this fraction with varying length of index duct run and number of supply outlets were observed within the limits of values of duct parameters utilized in the study.

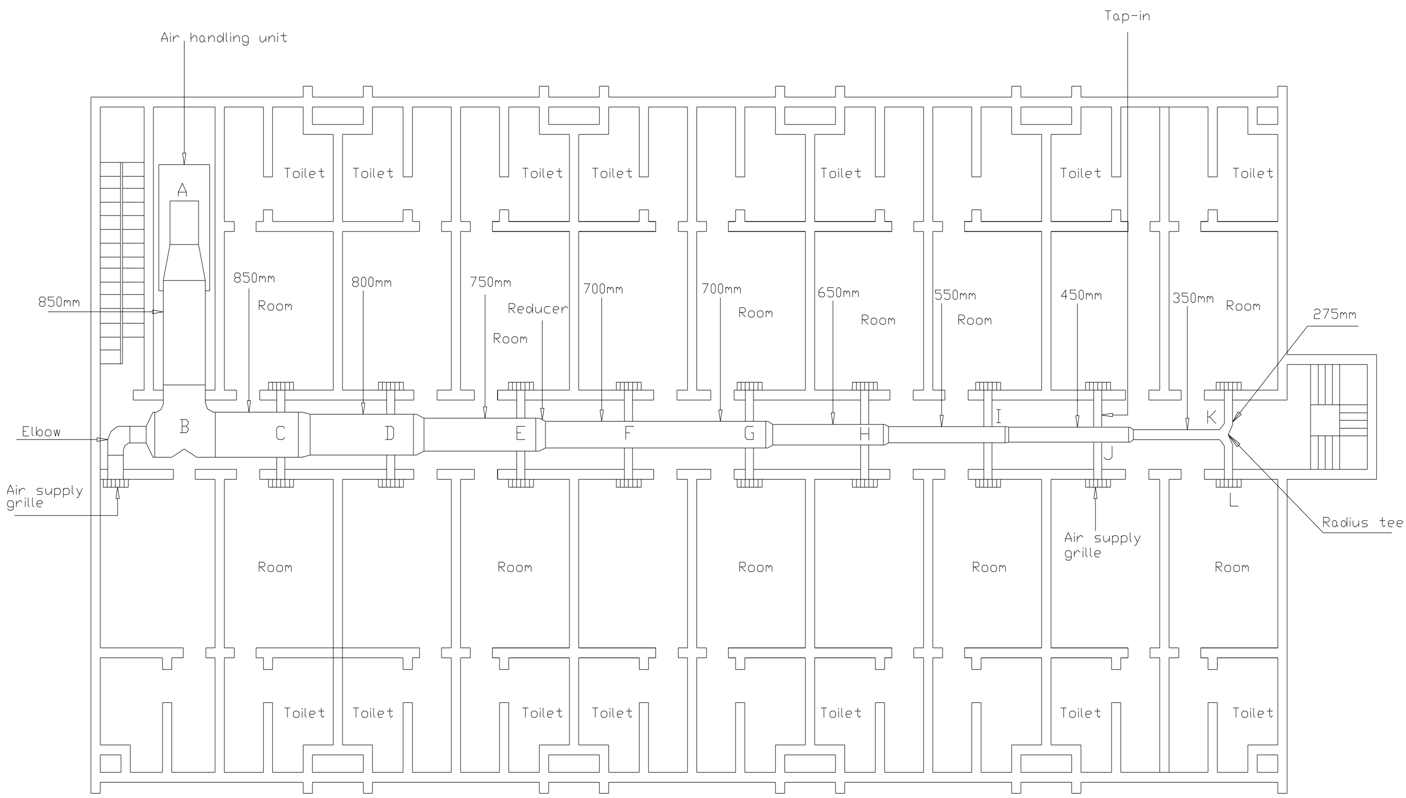


Figure 1. Plan of A Distribution Ductwork

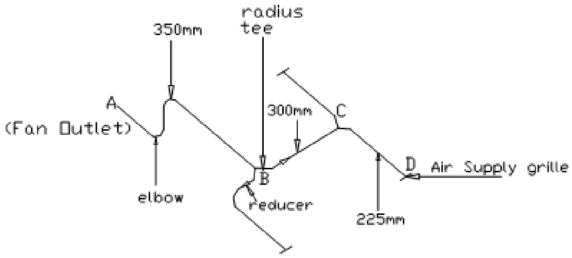


Figure 2. Isometric Sketch of Distribution Ductwork for 3 Outlets

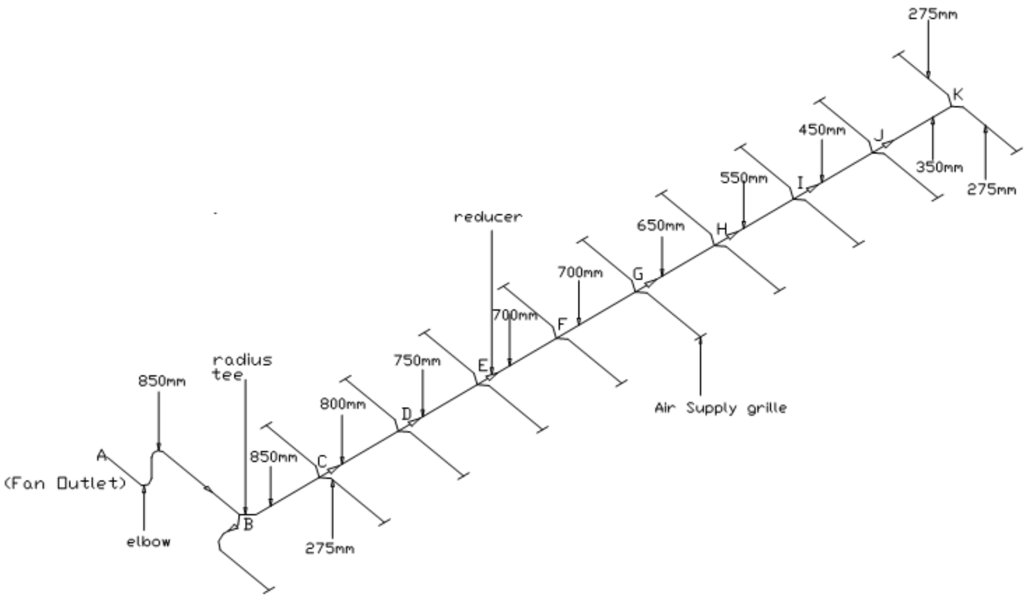


Figure 3. Isometric Sketch of Distribution Ductwork for 19 Outlets

## III. ESTIMATION OF PRESSURE LOSS COMPONENTS

The head loss due to friction was estimated using the D'Arcy – Weisbach formula expressed as [1]

$$h_p = 0.3304 \sum_{i=1}^{n} \frac{f_i \; l_i \; q_1^{\;2}}{d_1^{\;5}} \tag{2}$$

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

$f$ = friction factor

$l$ = duct section length (in m)

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

$d$ = duct section diameter (in m)

In the range of air flow rates normally encountered in air conditioning systems, the Reynolds number Re is less than 3240000 for which the Nikuradse equation [11]

$$f = 0.0008 + 0.055 \; \mathrm{Re}^{-0.237} \tag{3}$$

is useful in estimating $f$

Thus, having sized the duct sections using the 'equal friction' method [12, 13] with knowledge of $q$ from the supply air requirements, the flow velocity $v$ was determined and used to obtain Re from the expression

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

where $\rho$ = air density

$\mu$ = air dynamic viscosity

$f$ was subsequently applied in Eqn. 2 to obtain the frictional loss.

The head loss through duct fittings was obtained from the equation [1]

$$h_f = 0.08256 \sum_{j=1}^{m} k_j q_j^{\,2} d_j^{\,-4} \quad (5)$$

where $j$ denotes the $j^{th}$ duct fitting, $m$ is the number of fittings in the duct run and $k$ is the loss coefficient for the particular type of fitting [15].

The results of the head loss calculations for the shortest and longest duct runs shown respectively in isometric sketches as Figs. 2 and 3 are presented in Tables I and II, respectively. Table III gives a summary of head loss estimates for all the independent index runs of the layout of Fig. 1. The values in Table III were subsequently utilized in a regression analysis.

TABLE I. SUMMARY OF HEAD LOSS CALCULATIONS FOR DISTRIBUTION SYSTEM FOR 3 OUTLETS (FIG. 3)

| Duct Section (in Fig. 3) | Flow Rate, q ($m^3/s$) | Fractional Flow with Respect to Total Fan Discharge Q | Length, 1 (m) | Diameter, d (mm) | Reynolds Number, Re | Friction Factor, f | Frictional Head Loss (m) | Fitting | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Type | Number in Duct Section | Head loss Coefficient* | Head Loss (m) |
| 1 (A to B) | 0.45 | Q | 6.0 | 350 | 109479 | 0.0043 | $1.623Q^2$ | 350mm elbow<br>350mm tee | 2<br>1 | 0.16<br>0.28 | $0.880Q^2$ x 2<br>$1.540\ Q^2$ |
| 2 (B toC) | 0.30 | 0.667Q | 4.0 | 300 | 85150 | 0.0045 | $1.089Q^2$ | 350mm x 300mm reducer<br>300mm x 225mm reducing tee | 1<br>1 | 0.06<br>0.28 | $0.272\ Q^2$<br>$1.000\ Q^2$ |
| 3 (C to Outlet at C) | 0.15 | 0.333Q | 1.2 | 225 | 56767 | 0.0049 | $0.374Q^2$ | - | - | - | - |

*Source: [15]

TABLE II. SUMMARY OF HEAD LOSS CALCULATIONS FOR DISTRIBUTION SYSTEM FOR 19 OUTLETS (FIGS. 1 AND 3)

| Duct Section (in Figs. 1 and 3) | Flow Rate, q ($m^3/s$) | Fractional Flow with Respect to Total Fan Discharge Q | Length, l (m) | Diameter, d (mm) | Reynolds Number, Re | Friction Factor, f | Frictional Head Loss (m) | Fitting | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Type | Number in Duct Section | Head loss Coefficient* | Head Loss (m) |
| 1 (A to B) | 2.85 | Q | 6.0 | 850 | 285503 | 0.0036 | $0.016Q^2$ | 850mm radius elbow<br>850mm radius tee | 2<br>1 | 0.16<br>0.28 | $0.025Q^2$ x 2<br>$0.044Q^2$ |
| 2 (B to C) | 2.70 | 0.947Q | 4.0 | 850 | 270476 | 0.0036 | $0.010Q^2$ | 850mm tap-in | 1 | 0.20 | $0.012Q^2$ |
| 3 (C to D) | 2.40 | 0.842Q | 4.0 | 800 | 255450 | 0.0037 | $0.011Q^2$ | 850mm x 800mm reducer<br>800mm tap-in | 1<br>1 | 0.06<br>0.20 | $0.086Q^2$<br>$0.012Q^2$ |
| 4 (D to E) | 2.10 | 0.737Q | 4.0 | 750 | 238420 | 0.0037 | $0.011Q^2$ | 800mm x 750mm reducer<br>750mm tap-in | 1<br>1 | 0.06<br>0.20 | $0.009Q^2$<br>$0.012Q^2$ |
| 5 (E to F) | 1.80 | 0.632Q | 4.0 | 700 | 218957 | 0.0038 | $0.012Q^2$ | 750mm x 700mm reducer<br>700mm tap-in | 1<br>1 | 0.06<br>0.02 | $0.008Q^2$<br>$0.012Q^2$ |
| 6 (F to G) | 1.50 | 0.526Q | 4.0 | 700 | 182464 | 0.0039 | $0.008Q^2$ | 700mm tap-in | 1 | 0.20 | $0.012Q^2$ |
| 7 (G to H) | 1.20 | 0.421Q | 4.0 | 650 | 157200 | 0.0040 | $0.008Q^2$ | 700mm x 650mm reducer<br>650mm tap-in | 1<br>1 | 0.06<br>0.20 | $0.005Q^2$<br>$0.012Q^2$ |
| 8 (H to I) | 0.90 | 0.316Q | 4.0 | 550 | 139336 | 0.0041 | $0.011Q^2$ | 650mm x 550mm reducer<br>550mm tap-in | 1<br>1 | 0.06<br>0.20 | $0.005Q^2$<br>$0.012Q^2$ |
| 9 (I to J) | 0.60 | 0.211Q | 4.0 | 450 | 113533 | 0.0043 | $0.014Q^2$ | 550mm x 450mm reducer<br>450mm tap-in | 1<br>1 | 0.06<br>0.20 | $0.005Q^2$<br>$0.012Q^2$ |
| 10 (J to K) | 0.30 | 0.105Q | 4.0 | 350 | 72986 | 0.0047 | $0.013Q^2$ | 450mm x 350mm reducer<br>350mm x 275mm reducing tee | 1<br>1 | 0.06<br>0.28 | $0.004Q^2$<br>$0.017Q^2$ |
| 11 (K to L) | 0.15 | 0.053Q | 1.2 | 275 | 46445 | 0.0051 | $0.004Q^2$ | - | - | - | - |

*Source: [15]

TABLE III. SUMMARY OF HEAD LOSS ESTIMATES

| Length of Index Duct Run (m) | No. of Air Conditioned Rooms or Supply Outlets | Frictional Head Loss (m) | Head Loss Due to Fittings (m) | Total Head Loss (Static Pressure) (m) | Fraction of Loss Due to Fittings |
|---|---|---|---|---|---|
| 11.2 | 3 | $3.086Q^2$ | $4.572Q^2$ | $7.658Q^2$ | 0.60 |
| 15.2 | 5 | $1.314Q^2$ | $1.804Q^2$ | $3.118Q^2$ | 0.58 |
| 19.2 | 7 | $0.826Q^2$ | $1.379Q^2$ | $2.205Q^2$ | 0.63 |
| 23.2 | 9 | $0.369Q^2$ | $0.729Q^2$ | $1.098Q^2$ | 0.66 |
| 27.2 | 11 | $0.273Q^2$ | $0.464Q^2$ | $0.737Q^2$ | 0.63 |
| 31.2 | 13 | $0.218Q^2$ | $0.416Q^2$ | $0.634Q^2$ | 0.66 |
| 35.2 | 15 | $0.186Q^2$ | $0.361Q^2$ | $0.547Q^2$ | 0.66 |
| 39.2 | 17 | $0.151Q^2$ | $0.291Q^2$ | $0.442Q^2$ | 0.66 |
| 43.2 | 19 | $0.118Q^2$ | $0.329Q^2$ | $0.447Q^2$ | 0.74 |

## IV. REGRESSION ANALYSIS

The ratio of head loss through duct fittings to the total loss (denoted as $y$) was regressed on each measure of system complexity, namely length of index duct run (denoted as $x_1$) and the number of air supply outlets (denoted as $x_2$). The second order variations of $y$ with $x_1$ and $x_2$, the respective regression equations and the coefficients of correlation $r$ [16] as obtained from the 'Microsoft Word Excel' program are shown in Figs. 4 and 5.

From statistical tables [17] the coefficient of correlation required for 95% confidence level is 0.666. Since both of the $r$ values obtained (i.e. 0.823) in this study exceed 0.666, there is confidence that 95% of the variation in $y$ can be accounted for by the variation in the value of $x$, for the conditioned air distribution layout of Fig. 1.

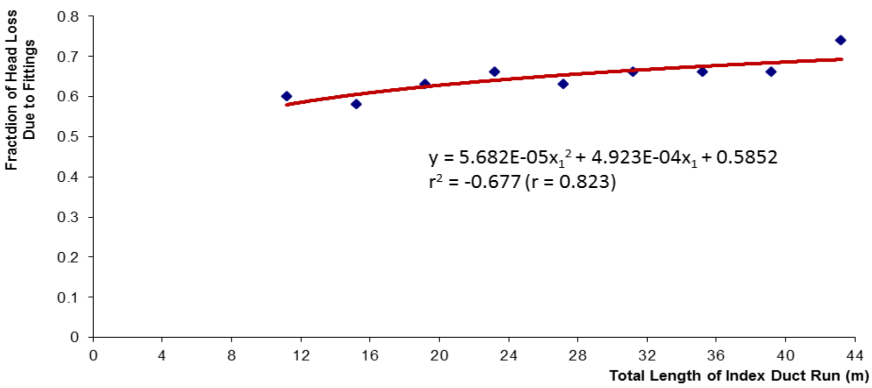


Figure 4. Graph of Fraction of Head Loss Due to Fittings Versus Length of Index Run

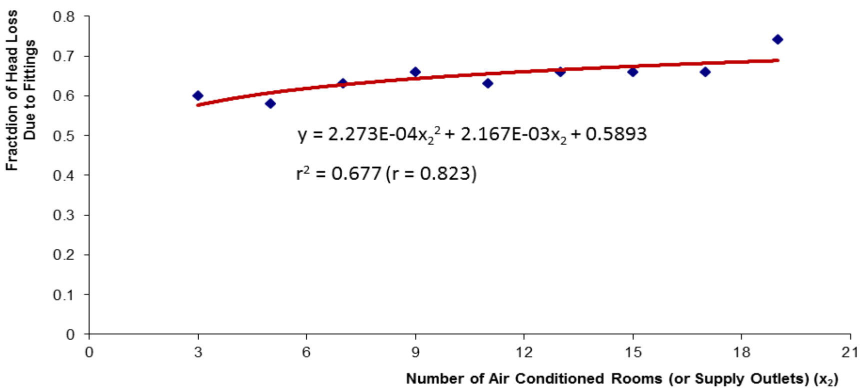


Figure 5. Graph of Fraction of Head Loss Due to Fittings Versus Number of Conditioned Rooms (or Supply Outlets)

## V. Case Studies for Checking the Validity of the Regression Results

The following three cases of conditioned air distribution duct system were studied: an auditorium building, an industrial cafeteria and an office block. The same design equations and procedures applied in arriving at the regression equations were adopted in the case studies, in order to have a common basis for the comparisons that may be made.

### *A. The Auditorium Building Duct System [17]*

The duct layout in the building is shown in Fig. 6. In order to study the variation of the fraction of head loss due to fittings with varying system parameters, seven runs of branch duct were studied, in the indicated sequence.

a. 0, 1, 2, 3, - - -, 11
b. 0, 1, 2, 3, 4, 5, 6, 7, 12 ,13, 14
c. 0, 1, 2, 3, 4, 5, 15, - - -, 22
d. 0, 1, 2, 3, 4, 23, - - -, 31
e. 0, 1, 2, 32, - - -, 36
f. 0, 1, 2, 3, 37, - - -, 40
g. 0, 1, 41, 42, 43

An example of the computed results is shown in Table IV for the run ‘f’: 0, 1, 2, 3, 37,- - -, 40. For this run whose length is 13.0m and which supplies 13 outlets, for instance, the frictional loss is $0.0112Q^2$ while the loss through duct fittings is $0.112Q^2$; resulting in a fraction of the total due to fittings of 0.91. The index run ‘f’ is taken for this illustration as its system parameters (13.0m length and 13 number of diffusers) fall within the range of parameters utilized in the regression analysis, thus providing a common basis for comparison of results. Table V summarizes the calculation of the head loss components as well as the fraction due to fittings for all the branch ducts listed as ‘a’ to ‘g’ above.

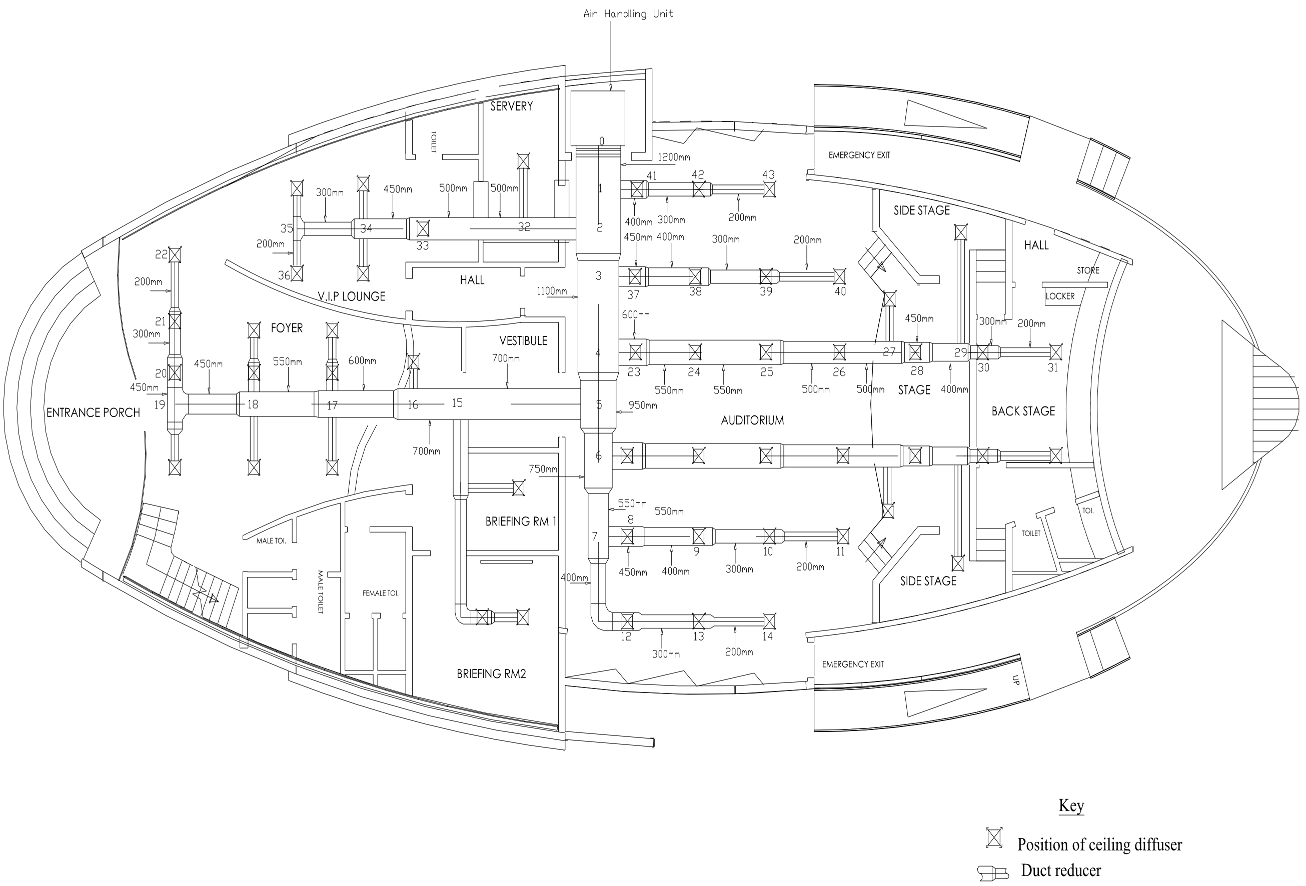


Figure 6. Auditorium Distribution Ductwork

TABLE IV. SUMMARY OF HEAD LOSS CALCULATIONS FOR DISTRIBUTION ALONG DUCT RUN 0, 1, 2, 3, 37 - - -, 40 SUPPLYING 13 DIFFUSERS IN AUDITORIUM BUILDING

| 1<br>Duct Section | 2<br>Length (m) | 3<br>Flow Rate ($m^3$/h) | 4<br>Fractional Flow with Respect to Total Fan Discharge | 5<br>% of Main Duct Area for Maintaining Equal Friction | 6<br>Circular Cross-Section Area ($m^2$) | 7<br>Duct Diameter (mm) | 8<br>Reynolds Number Re | 9<br>Friction Factor f | 10<br>Frictional Head Loss (m) | Fittings | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 11<br>Type | 12<br>No. in Duct Section | 13<br>Head Loss Coefficient* | 14<br>Head Loss in Fitting (m) |
| 0-1 | 2.5 | 20000 | 1.000 | 100.0 | 1.111 | 1200 | 394213 | 0.0034 | $0.0011Q^2$ | 1200mm radius elbow<br>400mm tap-in | 2<br>1 | 0.16 x 2<br>0.20 | $0.021Q^2$ |
| 1-2 | 1.5 | 18846 | 0.942 | 95.0 | 1.055 | 1200 | 371467 | 0.0034 | $0.0006Q^2$ | 500mm tap-in | 1 | 0.02 | $0.071Q^2$ |
| 2-3 | 1.5 | 16538 | 0.827 | 87.0 | 0.967 | 1100 | 355609 | 0.0035 | $0.0007Q^2$ | 1200mm x 1100mm reducer<br>450mm tap-in | 1<br>1 | 0.06<br>0.20 | $0.010Q^2$ |
| 3-37 | 1.5 | 1538 | 0.077 | 13.0 | 0.144 | 450 | 80840 | 0.0046 | $0.0007Q^2$ | 200mm tap-in | 1 | 0.20 | $0.002Q^2$ |
| 37-38 | 2.0 | 1154 | 0.058 | 10.5 | 0.117 | 400 | 68238 | 0.0047 | $0.0010Q^2$ | 200mm tap-in<br>450mm x 400mm reducer | 1<br>1 | 0.20<br>0.06 | $0.003Q^2$ |
| 38-39 | 2.0 | 769 | 0.038 | 7.0 | 0.078 | 300 | 60630 | 0.0048 | $0.0019Q^2$ | 200mm tap-in<br>400mm x 300mm reducer | 1<br>1 | 0.20<br>0.06 | $0.004Q^2$ |
| 39-40 | 2.0 | 385 | 0.019 | 3.5 | 0.039 | 200 | 45532 | 0.0051 | $0.0038Q^2$ | 300mm x 200mm reducer | 1 | 0.06 | $0.001Q^2$ |
| | 13.0 | | | | | | | | $0.0112Q^2$ | | | | $0.112Q^2$ |

*Source: [15]*

TABLE V. RATIOS OF LOSS THROUGH DUCT FITTINGS FOR DIFFERENT BRANCH DUCTS OF AUDITORIUM BUILDING

| Duct Run | Duct Length (m) | No. of Diffusers | Total Frictional Loss (m) | Total Loss through Fittings (m) | Ratio of Loss through Fittings to Total Loss |
|---|---|---|---|---|---|
| 0, 1, 2, 3, - - -, 11 | 19.5 | 49 | $0.0129Q^2$ | $0.129Q^2$ | 0.91 |
| 0, 1, 2, 3, 4, 5, 6 , 7 , 12, - - -, 14 | 19.0 | 52 | $0.0110Q^2$ | $0.127Q^2$ | 0.92 |
| 0, 1, 2, 3, 4, 5, 15, - - -, 22 | 24.0 | 39 | $0.0117Q^2$ | $0.138Q^2$ | 0.92 |
| 0, 1, 2, 3, 4, 23, - - -, 31 | 21.8 | 21 | $0.0146Q^2$ | $0.143Q^2$ | 0.91 |
| 0, 1, 2, 32, - - -, 36 | 14.0 | 9 | $0.0105Q^2$ | $0.106Q^2$ | 0.91 |
| 0, 1, 2, 3, 37, - - -, 40 | 13.0 | 13 | $0.0112Q^2$ | $0.112Q^2$ | 0.91 |
| 0, 1, 41, 42, 43 | 8.0 | 3 | $0.0039Q^2$ | $0.028Q^2$ | 0.88 |
| | | | | | Average = 0.91 |

The ‘Excel’ plots of Figs. 7 and 8 show an increasing fraction for the loss through duct fittings with increasing length of branch duct and number of diffusers; and within the range of duct lengths and number of diffusers utilized, the fraction varies from 0.88 to 0.92 with an average value of 0.91. It is observed that the fraction due to fittings, being greater than 0.5, is larger than that due to friction, for all duct runs.

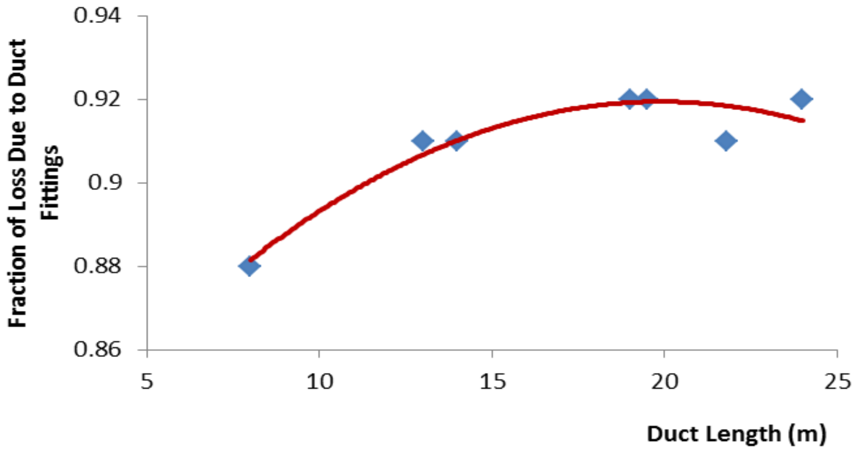


Figure 7. Variation of Fitting Loss Fraction with Duct Length for Auditorium Building

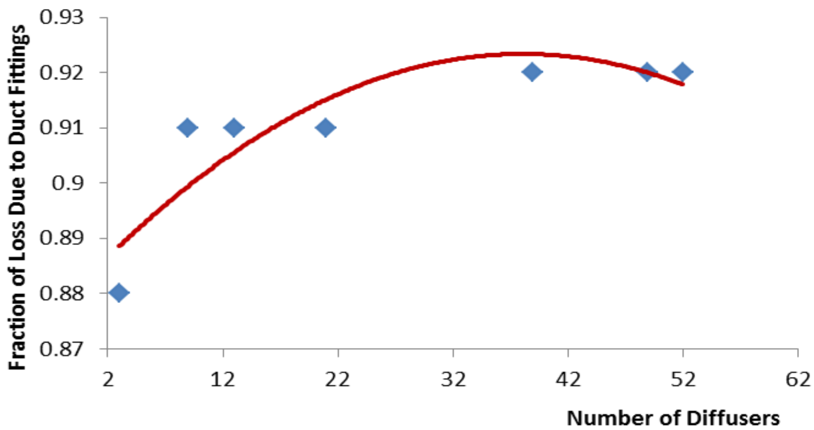


Figure 8. Variation of Fitting Loss Fraction with Number of Diffusers for Auditorium Building

*B. The Industrial Cafeteria Duct System [18]*

The distribution system for the cafeteria is shown in the floor plan of Fig. 9. The variation of the fractions of the total pressure loss due to friction and that due to duct fittings with length of duct run and number of diffusers 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

The summary calculations presented in Table VI for the run 0, 1, 2, 3, 4, 5, 17, - - , 20 is an example of the corresponding tables for the other listed duct runs. For this duct run, the length is 18.4m while the number of air supply outlets is 19. The total frictional loss is $0.178Q^2$ while that due to fittings is $0.609Q^2$, resulting in a total loss of $0.787Q^2$ and a fraction due to fittings of 0.77. The summary of the results for all the listed duct runs is given in Table VII, from which it is observed that, for all duct runs, the fitting loss fraction (being greater than 50%) exceeds the frictional loss; the average fraction due to fittings being 0.73. The plots of Fig. 10 and 11 show the variation of the fitting loss fraction with length of duct run and number of outlets. The plots show an increase from 0.71 to 0.77 of the fraction for an increase in duct length from 6.2m to 22.1m and an increase in number of outlets from 1 to 32.

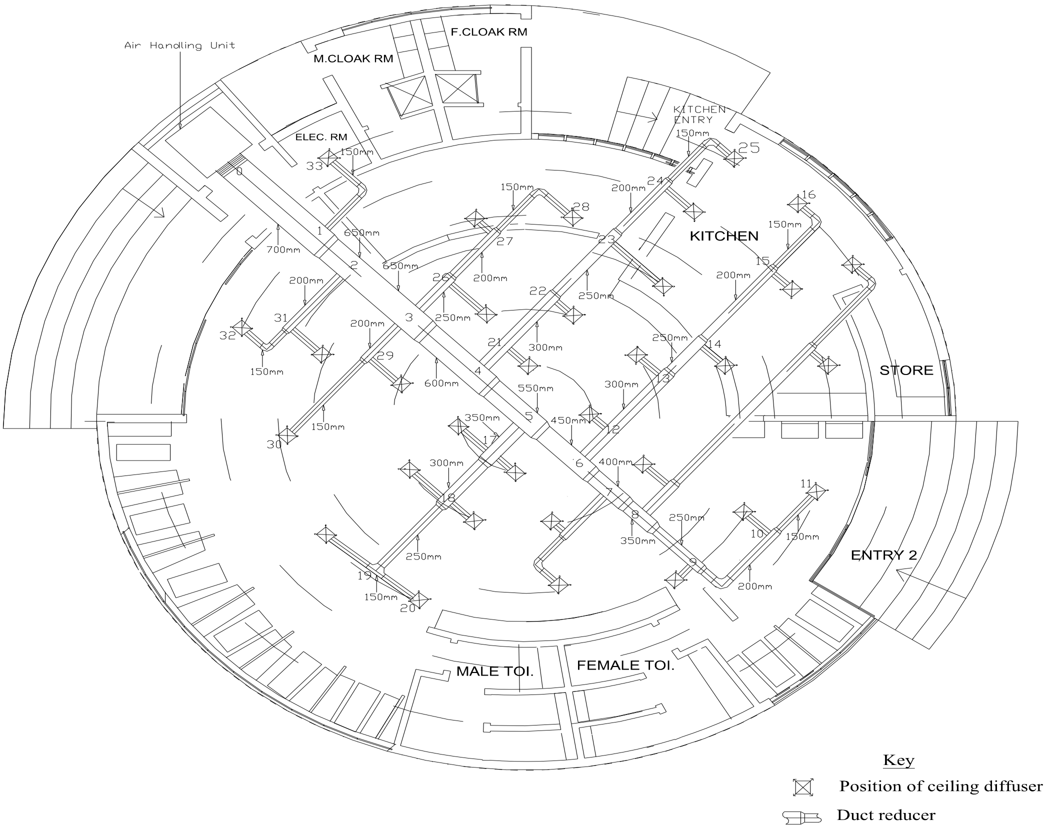


Figure 9. Cafeteria Distribution Ductwork

TABLE VI. SUMMARY OF HEAD LOSS CALCULATIONS FOR DISTRIBUTION THROUGH 0, 1, 2, 3, 4, 5, 17, - - -, 20 SUPPLYING 19 DIFFUSERS IN CAFETERIA BUILDING

| 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<br>150mm tap-in | 2<br>1 | 0.16 x 2<br>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<br>300mm tap-in | 1<br>1 | 0.06<br>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<br>350mm tap-in | 1<br>1 | 0.06<br>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<br>350mm x 300mm reducer | 1<br>1 | 0.20<br>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<br>300mm x 350mm reducer | 1<br>1 | 0.28<br>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: [15]*

TABLE VII. RATIOS OF LOSS THROUGH DUCT FITTINGS FOR DIFFERENT BRANCH DUCTS IN CAFETERIA BUILDING

| Duct Run | Duct Length (m) | No. of Diffusers | Total Frictional Loss (m) | Total Loss through Fittings (m) | Ratio of Loss through Fittings to Total Loss |
|---|---|---|---|---|---|
| 0, 1, 2, - - -, 11 | 21.3 | 32 | $0.236Q^2$ | $0.790Q^2$ | 0.77 |
| 0, 33 | 6.2 | 1 | $0.084Q^2$ | $0.210Q^2$ | 0.71 |
| 0, 1, 2, 31, 32 | 8.8 | 3 | $0.114Q^2$ | $0.280Q^2$ | 0.71 |
| 0, 1, 2, 3, 29, 30 | 12.3 | 8 | $0.145Q^2$ | $0.356Q^2$ | 0.71 |
| 0, 1, 2, 3, 26, - - -, 28 | 18.5 | 8 | $0.164Q^2$ | $0.443Q^2$ | 0.73 |
| 0, 1, 2, 3, 4, 21, - - -, 25 | 18.8 | 13 | $0.219Q^2$ | $0.592Q^2$ | 0.73 |
| 0, 1, 2, 3, 4, 5, 17, - - -, 20 | 18.4 | 19 | $0.192Q^2$ | $0.609Q^2$ | 0.76 |
| 0, 1, 2, 3, 4, 5, 6, 12, ---, 16 | 22.1 | 24 | $0.247Q^2$ | $0.736Q^2$ | 0.75 |
| | | | | | Average = 0.73 |

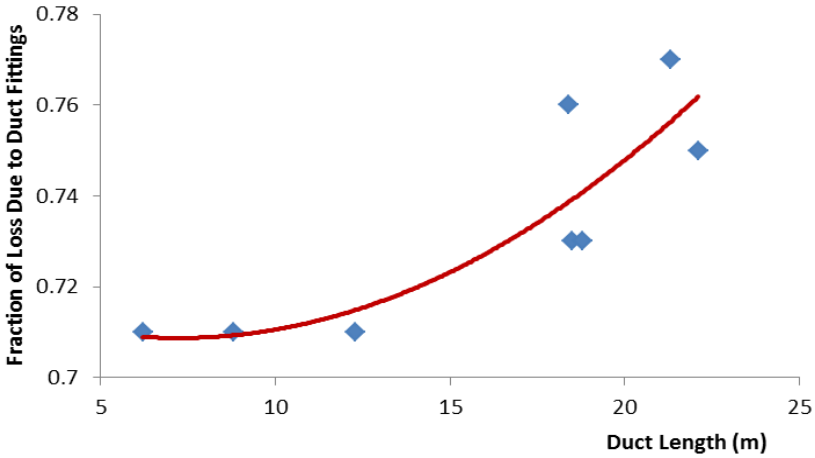


Figure 10. Variation of Fitting Loss Fraction with Duct Length for Cafeteria Building

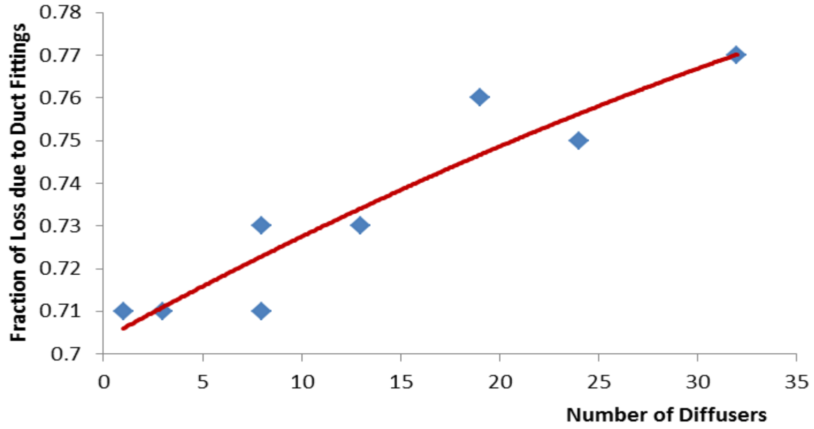


Figure 11. Variation of Fitting Loss Fraction with Number of Diffusers for Cafeteria Building

## C. The Office Block Duct System [19]

This case study is one of conditioned air distribution to three floors of an office building. Only the ground floor distribution layout is shown in Fig. 12 in order to maintain brevity. A typical summary of analysis of head loss components is shown in Table VIII (for the duct run 0, 1, 2, - - -, 15 of Fig. 12), while Table IX gives a summary of the results for all the duct runs utilized in the case study. Utilizing the analysis results of the various duct runs, as was done for the earlier case studies, an average fraction of loss through fittings to total loss of 0.60 was obtained for the office block air distribution duct system; this fraction, again, being larger than 0.50. The fitting head loss fraction is, thus, larger than the friction loss fraction. The 'Excel' plots of Figs. 13 and 14 show the trends of the variation of the fraction with length of duct run and number of air outlets, respectively.

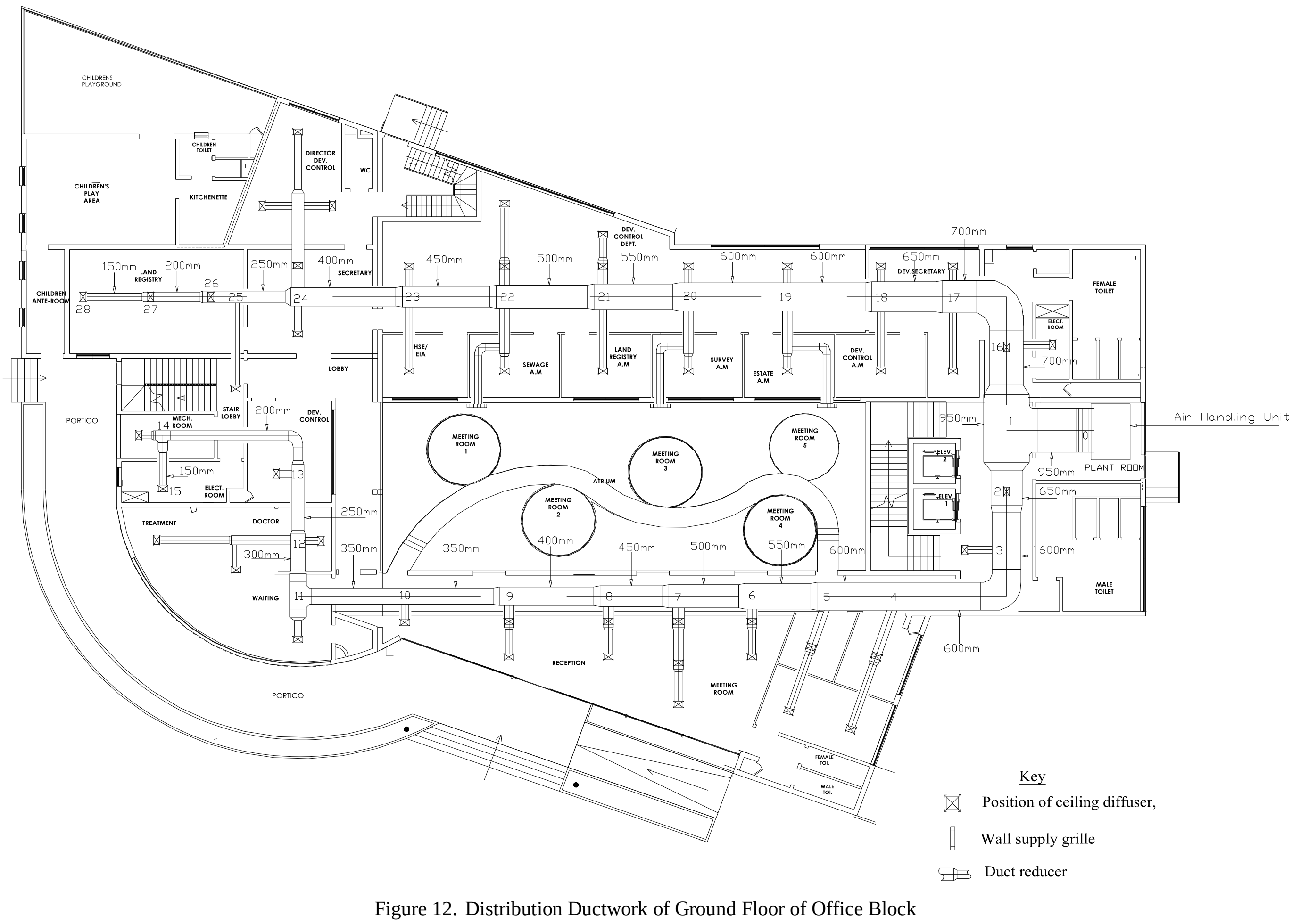


Figure 12. Distribution Ductwork of Ground Floor of Office Block

TABLE VIII. SUMMARY OF HEAD LOSS CALCULATIONS FOR DISTRIBUTION ALONG DUCT RUN 0, 1, 2, - - 15 SUPPLYING 20 OUTLETS IN OFFICE BLOCK

| 1<br>Duct Section | 2<br>Length (m) | 3<br>Flow Rate ($m^3$/h) | 4<br>Fractional Flow with Respect to Total Fan Discharge | 5<br>% of Main Duct Area for Maintaining Equal Friction | 6<br>Circular Cross-Section Area ($m^2$) | 7<br>Duct Diameter (mm) | 8<br>Reynolds Number Re | 9<br>Friction Factor f | 10<br>Frictional Head Loss (m) | Fittings | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 11<br>Type | 12<br>No. in Duct Section | 13<br>Head Loss Coefficient* | 14<br>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<br>950mm radius tee | 2<br>1 | 0.16 x 2<br>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<br>150mm tap-in | 1<br>1 | 0.06<br>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<br>650mm x 600mm reducer | 1<br>1 | 0.06<br>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<br>200mm tap-in | 1<br>1 | 0.16<br>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<br>200mm tap-in | 1<br>1 | 0.06<br>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<br>550mm x 500mm reducer | 1<br>1 | 0.20<br>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<br>500mm x 450mm reducer | 1<br>1 | 0.20<br>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<br>450mm x 100mm reducer | 1<br>1 | 0.20<br>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<br>400mm x 350mm reducer | 1<br>1 | 0.20<br>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<br>350mm x 300mm reducer | 1<br>1 | 0.20<br>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<br>300mm x 250mm reducer | 1<br>1 | 0.20<br>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<br>200mm elbow<br>250mm x 200mm reducer | 1<br>1<br>1 | 0.20<br>0.16<br>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 | | | | | | | | $0.337Q^2$ | | | | $0.429Q^2$ |

*Source: [15]

TABLE IX. RATIOS OF LOSS THROUGH DUCT FITTINGS FOR DIFFERENT DUCT RUNS OF OFFICE BLOCK

| Floor of Building | Duct Run | Duct Length (m) | No. of Air Outlets | Total Frictional Loss (m) | Total Loss through Fittings (m) | Ratio of Loss through Fittings to Total Loss |
|---|---|---|---|---|---|---|
| Ground Floor | 0,1,2, - - -, 15<br>0,1,16, - - -, 28 | 27.7<br>25.1 | 20<br>29 | $0.337Q^2$<br>$0.298Q^2$ | $0.429Q^2$<br>$0.373Q^2$ | 0.560<br>0.563 |
| First Floor | 0,1,2, - - -, 17<br>0,1,18, - - -, 29 | 31.0<br>27.1 | 34<br>28 | $0.134Q^2$<br>$0.115Q^2$ | $0.223Q^2$<br>$0.171Q^2$ | 0.625<br>0.602 |
| Second Floor | 0,1,3, - - -, 14 | 30.0 | 46 | $0.163Q^2$ | $0.290Q^2$ | 0.640 |
| | | | | | | Average = 0.60 |

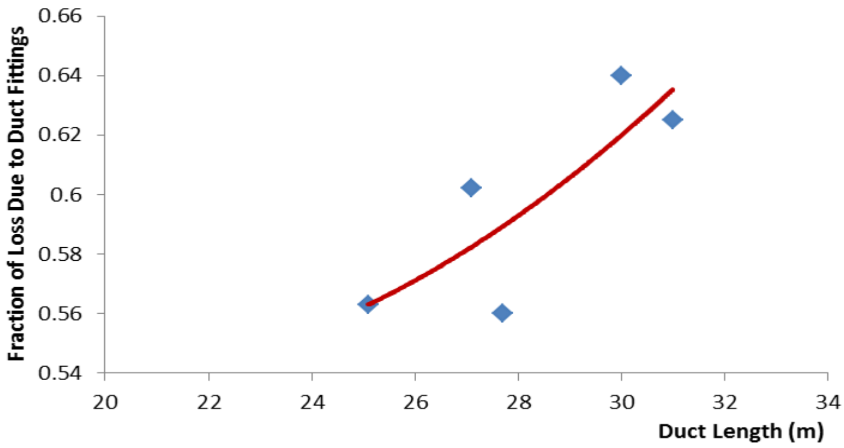


Figure 13. Variation of Fitting Loss Fraction with Duct Length for Office Building

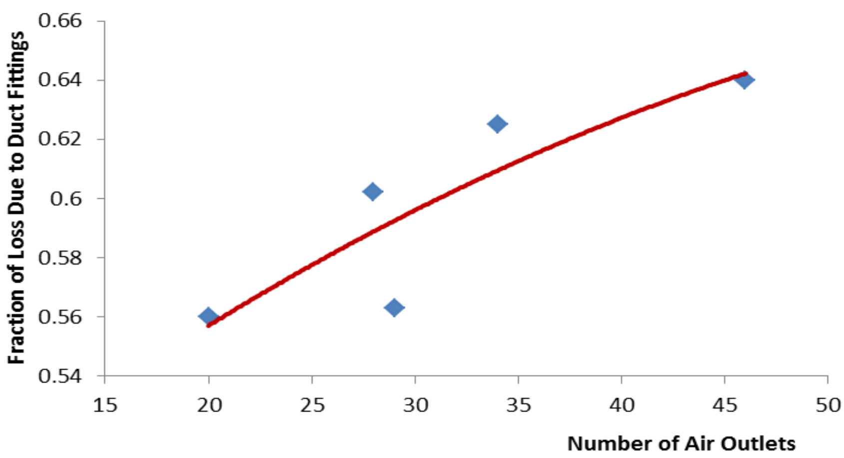


Figure 14. Variation of Fitting Loss Fraction with Number of Air Outlets for Office Building

## VI. DISCUSSIONS

Within the range of duct lengths and numbers of air outlet terminals utilized in the case studies, all variations of the duct fitting loss fraction depict second order increases with increasing duct length and number of outlets. Also, the fraction of the total loss which is due to fittings is greater than that due to friction (being greater than 0.5) for all duct runs. This indicates a misnomer in referring to pressure losses in air conditioning duct fittings as 'minor' losses.

It is further observed that the regression equations obtained for one distribution configuration were not valid for the other systems as corresponding results between the regression equations and case studies (and between case studies) showed wide variances. The wide variances in results are due to the varying spacing of conditioned rooms and air outlets in the different installations. This comparison is summarized in Table X. In the table, only deviations of the regression equation results (from those obtained by the usual procedure) which are less than 20% are acceptable for validating the corresponding regression equations. This follows from a similar reasoning for validating regression models for the fraction of fitting loss in water distribution systems of earlier studies [14, 20].

TABLE X. COMPUTATIONS FOR CHECKING THE VALIDITY OF REGRESSION EQUATIONS

| S/No. | Case Study | Regression Equation | Independent Variable, $x$ | | Dependent Variable y: Ratio of Fitting Loss to Total Loss (i.e. Fraction of Loss due to Fittings) | | | Remarks* |
|---|---|---|---|---|---|---|---|---|
| | | | Definition | Value | Calculated from Regression Equation | Calculated by Usual Procedure | % Deviation of Regression Equation from Usual Procedure | |
| 1 | Auditorium Building Duct System | $Y = 5.682E\text{-}05x_1^2 + 4.932E\text{-}04x_1 + 0.5852$ | Length of Index Duct Run | 13.0m | 0.60 | 0.91 | 34.1 | Equation not Validated |
| | | $Y = 2.273E\text{-}04x_2^2 + 2.167E\text{-}03x_2 + 0.5893$ | Number of Supply Air Outlets | 13 | 0.66 | 0.91 | 27.8 | Equation not Validated |
| 2 | Industrial Cafeteria Duct System | $Y = 5.682E\text{-}05x_1^2 + 4.932E\text{-}04x_1 + 0.5852$ | Length of Index Duct Run | 18.4m | 0.61 | 0.78 | 21.8 | Equation not Validated |
| | | $Y = 2.273E\text{-}04x_2^2 + 2.167E\text{-}03x_2 + 0.5893$ | Number of Supply Air Outlets | 19 | 0.71 | 0.78 | 9.0 | Equation Validated |
| 3 | Office Building Duct System | $Y = 5.682E\text{-}05x_1^2 + 4.932E\text{-}04x_1 + 0.5852$ | Length of Index Duct Run | 27.7m | 0.64 | 0.56 | 14.3 | Equation Validated |
| | | $Y = 2.273E\text{-}04x_2^2 + 2.167E\text{-}03x_2 + 0.5893$ | Number of Supply Air Outlets | 20 | 0.72 | 0.56 | 28.6 | Equation not Validated |

*Deviations less than 20% from the usual procedure are considered acceptable for approximation purposes and, hence, validate the relevant regression equation.

## VII. CONCLUSION

In many air conditioning duct systems, the duct fitting loss component constitutes the major loss, rather than the minor; and this loss component fraction generally increases with increasing duct length and number of air outlet terminals of index duct runs.

However, the regression analysis and case studies indicate no representative relationship for the variation of the fitting loss fraction with system parameters. This necessitates the suggestion that different sets of calculations of frictional and fitting loss be done for different duct systems. Approximate estimates of the fraction of fitting loss for an index duct run, may, however, be made by using randomly made averages of the fraction for a few runs in any given installation, as there is a good representative average for the fraction of loss due to duct fittings for the different index duct runs in each case study.

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