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The Dependence of the Ratio of Minor Loss to Total Loss on Extent of Duct Run in Ventilation Systems

J. I. Sodiki
Department of Mechanical Engineering, Rivers State University, P.M.B. 5080, Port Harcourt, Nigeria
(jisodiki_partners@yahoo.com)

***Abstract*-** Due to the absence of statistical basis of various suggested methods for approximating the fraction of pressure loss due to fittings in ventilation index duct runs, regression analyses were done for predicting the fraction for the varying system parameters of length of duct run and number of air intake terminals. This paper evaluates the validity of the regression equations by comparing their results with those of another ventilation configuration. It is observed that the equations are not adequately representative of other ventilation systems. However, for a given ventilation network, an average fraction of loss due to duct fittings may be applied to the various duct runs in order to aid the approximation of the fitting loss. Such an average may be obtained by an initial analysis of a few duct runs of the ventilation network. All the ventilation layouts studied further show that the fitting loss constitutes the major fraction over the frictional loss.

***Keywords*-** *Ventilation Duct Fitting Loss, Validity of Regression Equations, Case Study*

I. INTRODUCTION

The calculation of the pressure losses due to friction and fittings is an important requirement in the procedure for selecting fans for ducted ventilation systems. To facilitate this effort, several approximations for the fitting loss component had been suggested. For instance, Bhatia [1] has suggested a 40% addition to be made to straight duct lengths for duct systems having a few fittings, to account for the losses in all fittings in the index duct run; while, for systems having many fittings, he had suggested a 100% addition. In the same vein, Hanby [2] had suggested that the total head loss (frictional and that due to fittings) be calculated using a loss coefficient k of 5 in the usual fitting loss equation [3, 4]. Furthermore, W. W Granger [5] suggests that a 2mm water gauge pressure be taken as the loss per duct fitting in ventilation systems. Thus, as the frictional loss component is usually easier to compute using commonly applicable methods such as the D'Arcy-Weisbach formula [4], the approximated duct fitting loss is then added to arrive at a total.

As there seems to be no clear statistical basis for the foregoing approximating methods of estimating pressure loss in ventilation duct fittings, and as the relative proportions of the frictional loss and the loss through all installed duct fittings would likely vary with system parameters (such as length of run and number of air intake terminals) in the first index run, the author has carried out some study on this variation [6, 7, 8]. Consequently, regression equations had been obtained for the variation of the fraction of the total pressure loss which is due to all installed fittings in index duct runs with system parameters. The present study aims at checking the validity and applicability of those equations by comparing the results obtained from them with those of a typical ventilation system.

II. CALCULATION OF PRESSURE LOSS

In order to study the variation of the fraction of head loss due to duct fittings in ventilation duct systems with length of index duct run and number of air intake terminals, six duct configurations for toilet rooms (2, 4, 6, 8, 10 and 12 rooms) were analyzed [6]. Only the 4 – room and 12- room layouts are shown respectively in Figs. 1 and 2 in order to maintain brevity. Results show second order variations of the fitting loss fraction with varying length of index duct run and number of air intakes. Standard system parameters (such as extract air velocity and quantity) and commonly applied methods were utilized in the computation of circular sizes and head loss components. The procedure adopted for calculating the frictional and fitting loss components in index runs of ductwork, which has been elaborated in the earlier study [6], is illustrated in the following steps:

1. Size the circular duct section using a recommended flow velocity v and air quantity q [9] as diameter

$$d = \left(\frac{4q}{\pi v}\right)^{1/2} \quad (1)$$

2. With known velocity and duct size determine flow Reynolds number Re [3, 4] as

$$\mathrm{Re} = \frac{\rho v d}{\mu} \quad (2)$$

where ρ = air density and μ = air viscosity

3. Obtain friction factor f from Blasius equation [10] as

$$f = 0.079\,\mathrm{Re}^{-0.25} \quad (3)$$

4. Obtain friction loss h_p for each duct section from D'Arcy – Weisbach formula in the form [11]

$$h_p = 0.3304\frac{flq^2}{d^5} \tag{4}$$

where l = duct section length

5. With selected loss coefficient k of duct fitting [12] calculate fitting loss h_f from the equation [11]

$$h_f = 0.08256kq^2d^{-4} \tag{5}$$

6. Obtain total frictional loss for the given composite index run. Likewise, obtain total fitting loss for the index run. Hence, obtain the fraction of total loss due to fittings for the index run
7. Carry out uni-variate second order regression of the fraction y on each of parameters length of composite duct run x_1 and number of intake terminals x_2.

III. Pressure Loss Estimation

A typical estimation of duct sizes and of the head loss components is presented in Table I for the duct run for the 4 – room toilet ventilation configuration shown in Fig. 1. Table II gives the summary of the estimated loss components for all six configurations.

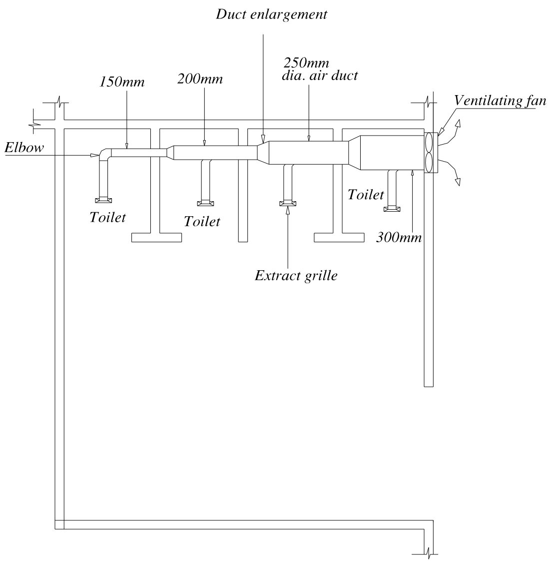

Figure 1. Plan of Ventilation Duct System for 4 Toilet Rooms

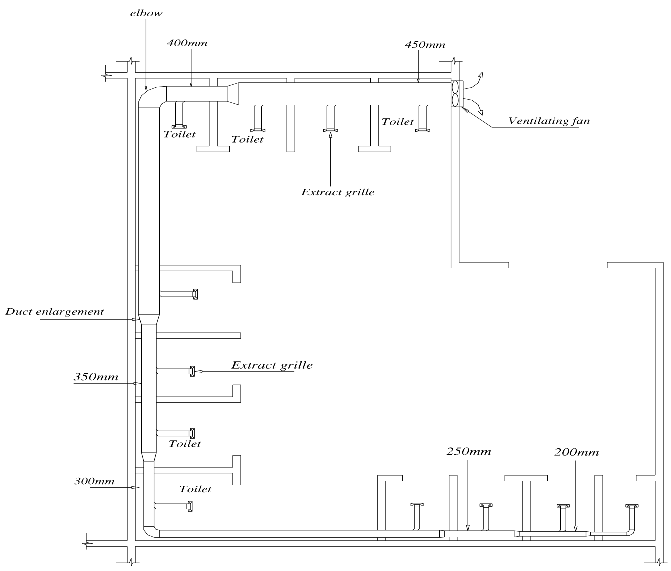

Figure 2. Plan of Ventilation Duct System for 12 Toilet Rooms

TABLE I. Parameters of Ventilation Index Duct Run for 4-Room Toilet Configuration

Duct Section	Flow Rate, q (l/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)	Type of Fitting	Number of Particular Type of Fitting in Section	Head Loss Coefficient of Fitting, k*	Head Loss Through Fitting (m)
1	0.8	0.25Q	2.0	130	45413	0.0054	$2.937Q^2$	150mm radius elbow (R/D=1.0) 150mm x 200mm enlargement (d_2/d_1 = 1.3) 200mm x 150mm radius tee	1 1 1	0.16 0.13 0.20	2 x $1.631Q^2$ $0.254\ Q^2$ $2.039\ Q^2$
2	1.6	0.50Q	1.2	200	68120	0.0049	$1.518Q^2$	250mm x 300mm enlargement (d_2/d_1 = 1.3) 250mm x 150mm radius tee	1 1	0.13 0.20	$0.217Q^2$ $2.039\ Q^2$
3	2.4	0.75Q	1.2	250	81744	0.0047	$1.073Q^2$	250mm x 300mm enlargement (d_2/d_1 = 1.3) 300mm x 150mm radius tee	1 1	0.08 0.20	$0.089\ Q^2$ $2.039\ Q^2$
4	3.2	Q	0.8	300	90827	0.0046	$0.500Q^2$	-	-	-	-

Source: [12].

TABLE II. SUMMARY OF HEAD LOSS ESTIMATES

Length of Index Duct Run (m)	No. of Air Inlet Terminals (or Rooms)	Frictional Head Loss (m)	Head Loss Due to Fittings (m)	Total Head Loss (m)	Fraction of Total Loss Due of Fittings
2.8	2	$15.795Q^2$	$22.215Q^2$	$38.010Q^2$	0.584
5.2	4	$6.028Q^2$	$9.939Q^2$	$15.967Q^2$	0.622
11.4	6	$5.630Q_2$	$7.767Q^2$	$13.397Q^2$	0.580
13.8	8	$2.963Q^2$	$4.962Q^2$	$7.925Q^2$	0.626
20.0	10	$2.872Q^2$	$5.535Q^2$	$8.407Q^2$	0.658
22.4	12	$1.931Q^2$	$3.744Q^2$	$5.675Q^2$	0.660
					Average = 0.622

IV. REGRESSION ANALYSIS

The 'Excel' plots of Figs. 3 and 4 depict the respective variations of the fraction of loss due to fittings (denoted as y) with length of duct run (denoted as x_1) and number of ventilation air intake terminals (denoted as x_2). The respective regression equations and coefficients of correlation r as obtained from the 'Excel' program are shown in Figs. 3 and 4. The coefficients of correlation for x_1 and x_2 (0.713 and 0.707, respectively), thus, fall within the 90% confidence interval of $0.629 \leq r \leq 0.785$, as obtained from statistical data [13].

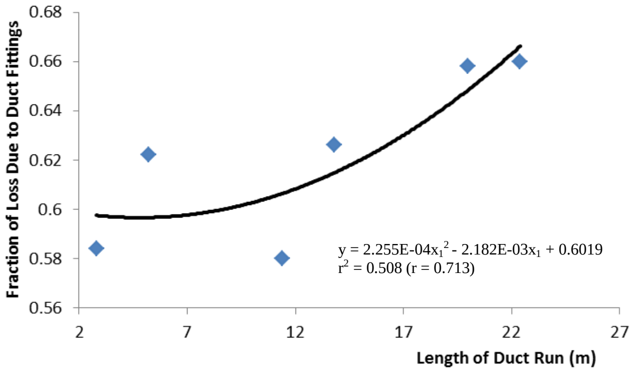

Figure 3. Variation of Fitting Loss Fraction with Length of Ventilation Duct Run (m)

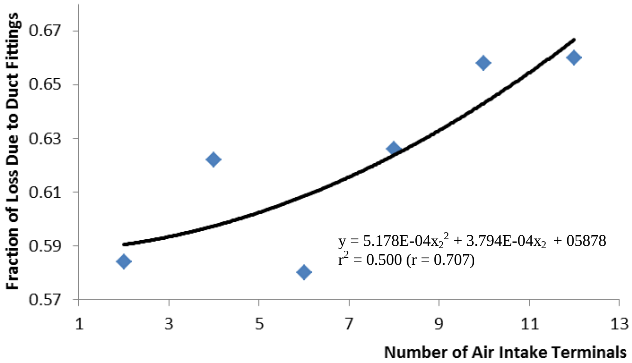

Figure 4. Variation of Fitting Loss Fraction with Number of Ventilation Air Intake Terminals

V. CASE STUDY FOR CHECKING THE VALIDITY OF THE REGRESSION RESULTS [8]

An industrial extract duct system which serves a canteen, kitchen and ablution spaces was utilized in checking the validity of the regression results. The system is shown in the line diagram of Fig. 5. The following duct runs are utilized to study the variation of the fraction of loss due to duct fittings with length of duct run and number of air intakes:

a. 0, 1, 2, - - -, 12

b. 0, 1, 2, - - , 10, 13, 14

c. 0, 1, 2, - -, 9, 15, 16

d. 0, 1, 2, - - , 7, 17, 18

e. 0, 1, 2, - -, 5, 19

f. 0, 1, 2, 3, 20, - - -, 24

g. 0, 1, 2, 3, 20, 25

h. 0, 1, 26, - - -, 31

i. 0, 1, 26, 27, 32

The calculation results for index run 'd' (0, 1, 2, - - - , 7, 17, 18) are given in Table III, as an example of a typical set of calculations. From this table, the total fitting loss is 2.762m while the total loss (frictional and that due to fittings) is 5.001m, resulting in a fraction due to fittings of 0.552. The index run 'd' is taken for this illustration as its system parameters (17.1m length and 12 number of air intake terminals) fall within the range of parameters utilized in the regression analysis, thus providing a common basis for comparison of results.

The summary of the calculations for the other duct runs are shown in Table IV. The plots of Figs. 6 and 7 show the variation of the fitting loss fraction with length of duct run and number of air intakes, respectively.

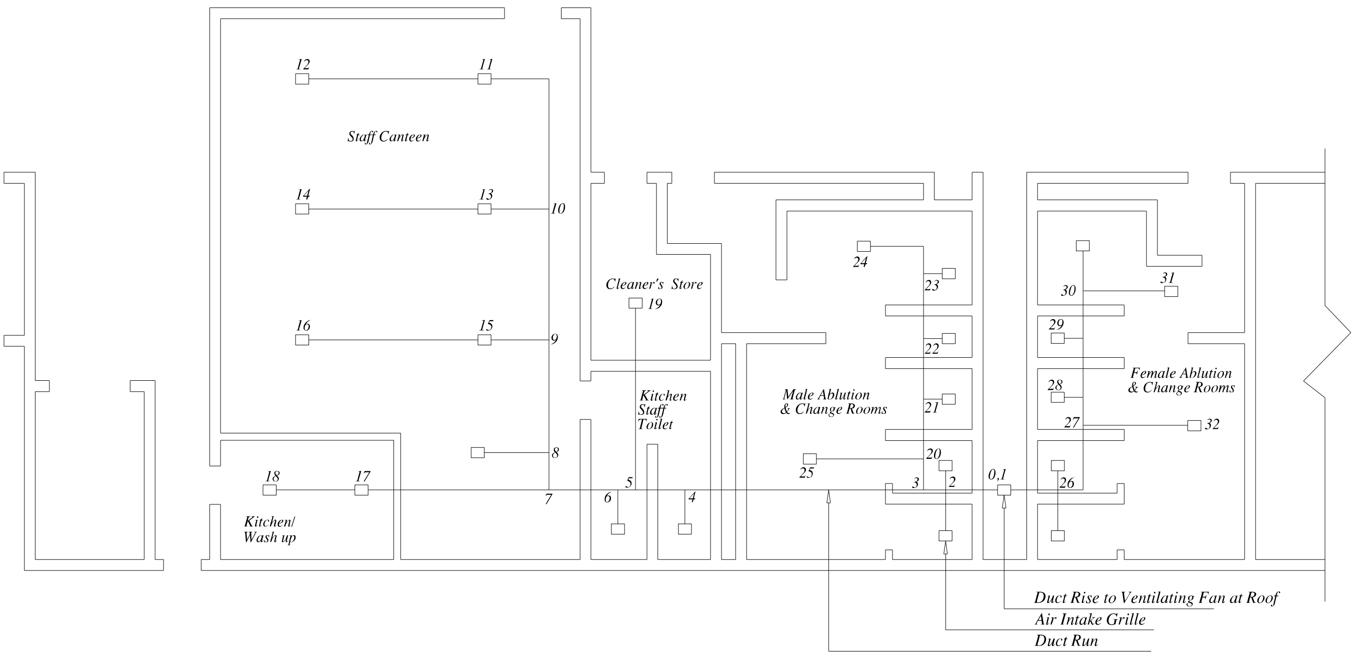

Figure 5. Line Diagram of the Industrial Ventilation Ductwork

TABLE III. HEAD LOSS COMPUTATIONS FOR INDEX RUN 'D' (0, 1, 2, - - - , 7, 17, 18) FOR 12 INTAKE TERMINALS

Duct Section	Flow Rate q		Length (m)	Diameter d (mm)	Reynolds Number Re	Friction Factor f	Frictional Head Loss (m)	Type of Fitting	Number of Particular Type of Fitting in Duct Section	Head Loss Coefficient of Fitting*	Head Loss thru Fitting (m)
	m^3/min	m^3/s									
0-1	71.73	1.200	2.0	500	204360	0.0037	0.113	-	-	-	-
1-2	54.04	0.901	1.0	450	170300	0.0039	0.057	450 x 500 enlargement, d_2/d_1 = 1.11 500mm tee	1 1	0.04 0.20	0.002 0.214
2-3	48.98	0.816	0.6	400	173706	0.0039	0.050	400 x 450 enlargement, d_2/d_1 = 1.13 450mm tee	1 1	0.05 0.20	0.005 0.268
3-4	36.33	0.606	5.1	350	147431	0.0040	0.471	350 x 400 enlargement, d_2/d_1 = 1.14 400mm tee	1 1	0.05 0.20	0.006 0.237
4-5	34.83	0.581	1.0	350	141349	0.0041	0.087	350mm tee	1	0.20	0.371
5-6	32.43	0.541	0.4	350	131618	0.0041	0.030	350mm tee	1	0.20	0.322
6-7	30.93	0.516	1.5	300	146456	0.0040	0.217	300 x 350 enlargement, d_2/d_1 = 1.17 350mm tee	1 1	0.06 0.20	0.013 0.293
7-17	17.33	0.289	3.8	250	98433	0.0045	0.483	250 x 300 enlargement, d_2/d_1 = 1.2 300mm tee	1 1	0.08 0.20	0.113 0.170
17-18	8.67	0.145	1.7	150	82312	0.0047	0.731	150 x 250 enlargement, d_2/d_1 = 1.67 250mm tee 150mm elbow	1 1 1	0.30 0.20 0.16	0.210 0.089 0.549
			17.1				2.239				2.762

*Source: [12]

TABLE IV. SUMMARY OF HEAD LOSSES

Index Run Designation	Length of Run (m)	Frictional Loss (m)	Head Loss through Fittings (m)	Total Loss (m)	Fraction of Loss Due to Fittings
a	25.5	6.275	3.896	10.171	0.38
b	22.5	4.254	3.623	7.877	0.46
c	19.8	3.316	3.544	6.860	0.52
d	17.1	2.239	2.762	5.001	0.55
e	13.5	1.948	1.722	3.670	0.47
f	9.9	1.769	2.361	4.130	0.57
g	6.6	1.132	1.708	2.840	0.60
h	11.0	1.969	2.703	4.672	0.58
i	7.1	1.376	1.640	3.016	0.54
					Average = 0.519

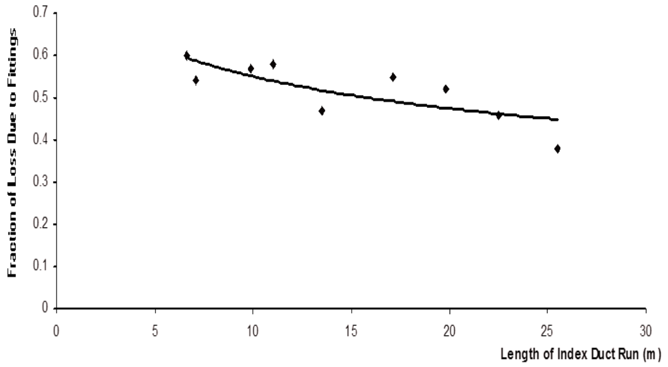

Figure 6. Variation of Fraction of Loss due to Fittings with Length of Index Run for Industrial Ventilation System

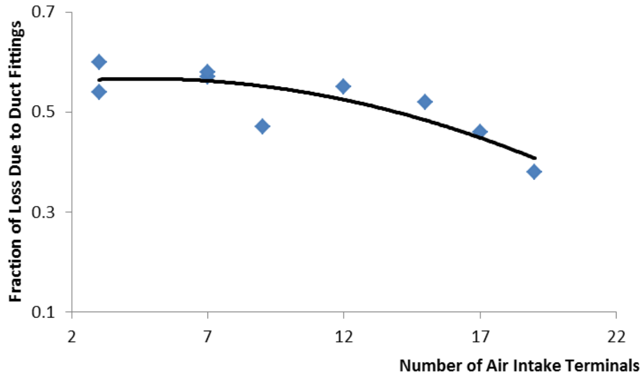

Figure 7. Variation of Fitting Loss Fraction with Number of Air Intake Terminals for Industrial Ventilation System

VI. DISCUSSIONS

Table V shows the comparison of the regression results with those obtained using the usual calculation procedure. It is observed that the parameter length of index run gives an acceptable validation of the corresponding regression equation, whereas the parameter number of intake terminals does not. Thus, the regression equations, though providing acceptable correlation coefficients for the ventilation system from which they were derived, are not adequately representative for other systems.

It is further observed that the fitting loss fractions for different index runs in a given ventilation system do not vary widely, thus providing a representative average fraction which can be applied for the entire system. Similar to earlier results obtained from a study on air conditioning duct system [15] the fraction of pressure loss due to fittings is generally greater than that due to friction, indicating a misnomer in referring to the fitting loss as ‘minor’.

TABLE V. COMPUTATIONS FOR CHECKING THE VALIDITY OF REGRESSION EQUATIONS

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	
Industrial Extract Duct System	$Y = 2.255E\text{-}04x_1^2 - 2.182E\text{-}03x_1 + 0.6019$	Length of Index Duct Run	17.1m	0.63	0.55	14.5	Equation Validated
	$Y = 5.178E\text{-}04x_2^2 + 3.794E\text{-}04x_1 + 0.5876$	Number of Air Intake Terminals	12	0.67	0.55	21.8	Equation not Validated

*Deviations less than 20% from the usual procedure are considered acceptable for approximation purposes and, hence, validate the relevant regression equation. [14, 15]

VII. CONCLUSION

As the obtained regression equations are not adequately validated by the case study, individual analyses of losses due to friction and fittings in index duct runs need to be done for different ventilation layouts. However, for each case, a representative average fraction of loss due to all installed fittings in an index run can be utilized to estimate this loss component.

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