Design and Analysis of an Air Conditioning Duct Using Equal Friction Method

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Abstract- In era of continues increase in the climate temperature use of Air Conditioner for comfort is to be expensive, but it has been a necessity for all people at large. Many types of Air Conditioner like window, Split Air Conditioner are generally employed in small houses, offices, banks, etc. but when the higher TR is needed in such as shopping malls, theaters, indoor stadiums, big buildings, hotels, hospitals etc. central air conditioning systems (CACS) are used. The CACS are installed off from building called central plants where water/air is conditioned. This conditioned air supplied to the building rooms with the help of air ducts. The duct systems carry the cooled air from the CACS equipment for the desired distribution to rooms and also carry return air from the air conditioned area back to the CACS equipment for recirculation. Thus it is necessary to design the air duct system in such a way that the pressure losses, capital and operating cost can be minimized. For address the problem, a correct duct designing is very important. Equal friction method of duct designing is an easy method as compared the other methods. The most purpose of this work is to proper calculated exact TR and dehumidified CFM and to come to a decide size of duct. The work gives the mixture of theoretical calculations and "Ductulator" software tool to produce a comparative analysis of the duct size. This paper tries to formulate a methodical approach to pick the proper duct designing for a given space/situation.

Keywords- HVAC, TR, AC , CFM ,VRF, CACS, RH

I . INTRODUCTION-

In the present day more and more population needs for comfortable environment to live in. The companies and employers also learn about needs for human comfort at working space (temperature, Relative humidity, air motion air purity, Noises etc) which directly affect the productivity positively or negatively. As per biology the human body is used to be comfortable at a temperature of 22°C to 25°C with around 50% RH. When the conditions are lower or higher than this parameter, than the human body feels uncomfortable. The function of a HVAC system is to supply and maintain the quality and quantity of inside air and provide thermal comforts to the building occupants. There are a wide range of air conditioning systems available, starting from the small unitary to medium and large sizes as per demand. CACS are used to meet medium to large demands.

The field of HVAC design for CACS becomes more and more challenging ever before, due to fast changing technologies and building materials, one of a very important process is designing of ducts. The efficient duct design process enables the proper supply of air quantity and proper distribution of conditioned air at every point of conditioned space. It is to be noted that the duct system costs nearly about 20-30% of the total cost CACS. Low air flow rates and high air velocities are results of undersized, constricted, or have numerous twists and turns in duct systems. The low air flow rates promote inefficient heating and cooling of equipment and higher air velocities increase vibrations and noise.

1.1 Objectives of duct design

A. The objective of duct design is to proper size the air ducts
B. Calculate Pressure drop throughout the ducts and keeping the scale of the ductwork to a minimum at the same time.
C. A well-designed ducting system should provide optimal interior comfort at a low cost of distribution while maintaining indoor air quality.
D. Ducts that aren't handy leads to discomfort, high energy costs, bad air quality, and increased noise levels

1.2 General Duct Design Criteria

The following factors are considered when designing a duct system-

A. Space availability
B. Material and Installation cost
C. Air friction/losses
D. Noise level
E. Duct heat transfer and airflow leakages
F. System Balancing
G. System overhead

1.4 General rules used to design air duct

Before design the duct size study and knowledge of fitting is incredibly important. This is the foremost important rule of all duct goes straight in a system (also for lowering of both energy and costs, which are going to be an energy perspective) air "wants" to travel straight and can create turbulence to lose energy if the direction of the flow is changed.

i. The shape of duct shouldn't change for minimum 1.5 meter of length, it's therefore difficult for a designer and number of fitting components increases.
ii. Air should be conveyed at minimum duct lengths to save space, power and material.
iii. Obstructive changes due to fittings should be avoided to reduce frictional losses. if not possible, turning blades should be provided.
iv. Diverging sections should be gradual. Angle of divergence should be ≤ 20o
v. Aspect Ratio (height and width)should be as close to 1.0 as possible and should not exceed 4.0
vi. Air flow should be within permissible limits to scale down vibrations and noises .
vii. Duct inner surfaces should be smooth to cut back frictional losses.
viii. Circular ducts is expensive than oval and rectangular ducts, especially in long straight sections. Circular duct fittings are also relatively expensive
ix. Provision of dampers should employed in each branch outlet for system balancing .

1.5 Classification of ducts

i. **Supply air duct** – In CACS the duct by which conditioned air supplied from the FCU to the space to be conditioned .
ii. **Return air duct** – In CACS the duct by which used reciprocating air from the conditioned space to return
iii. **Fresh air duct** – The duct which carries the atmospheric fresh air .
iv. **Low pressure duct** – When the static pressure within the duct is lower of 50 mm of water gauge.
v. **Medium pressure duct** - When the static pressure within the duct is within 50-150 mm of water gauge.
vi. **High pressure duct -** When the static pressure within the duct is around 150-250 mm of water gauge.
vii. **Low velocity duct** – When the velocity of air within the duct is max 600 m/min.
viii. **High velocity duct** - When the velocity of air within the duct is over 600 m/min.

1.6 Duct Material

The ducts are made up with flat solid sheets of Fe, aluminum sheet, black sheet and nowadays PVC's. The most common material for CACS duct is galvanized iron (GI) sheets, due to coating of zinc this metal sheets prevents rusting and saves the cost of painting. The sheet thickness of iron duct varies between 0.55 mm to 1.6 mm. Taking Fe (GI) sheet as the reference material and properties of air as 20^{o}C at 1 atm, Absolute roughness ε (m) 0.00015

1.7 The aspect ratio

The ratio of cross sectional long side to the cross sectional short side of a duct. For initial duct design, aspect ratio is a very important factor to be considered.

1.8 Pressure in Duct

By principle, more the pressure difference, the faster the flow of air from higher to lower pressure. The air flow within a duct system is conceived by the pressure differences between the various locations. The subsequent are the three pressure varieties involved in CACS duct design .

1.8.1 Static Pressure (P_s)

The pressure independent of air flow is known as static pressure. Static pressure pushes air against the walls of the duct, which results in cross sectional expansion in a duct if it is higher than atmospheric pressure and reduction in cross section if it is lower than atmospheric pressure. These pressures are needed to overcome friction and shock losses due to air flow.

1.8.2 Velocity Pressure (P_v)

The dynamic or velocity pressure is due to the flow of air in a duct .

1.8.3. Total Pressure (P_t)

The algebraic sum of the static pressure and dynamic pressure is known as total pressure.

$$P_t = P_s + P_v$$

1 .9 Calculation of pressure losses in air ducts

When air flows in ducts, then total pressure drops in the direction of flow. The drop in pressure is due to: -
1. Frictional loss in air.
2. Change in motion due to change in direction and/or velocity.
The pressure drop due to friction is frictional pressure drop or friction loss, ΔP_f. The pressure drop because of momentum change is thought as momentum pressure drop or dynamic loss, ΔP_d. Thus the overall pressure drop Δpt is given by:

$$\Delta P_t = \Delta P_f + \Delta P_d$$

2. Equal friction method for Duct designing

In this method the duct dimensions are set so that pressure drop per meter length equals in all ducts. The velocities then adjusted automatically in the branch ducts as the flow decrease.

The main advantage is that, if the duct layout design is symmetrical with identical lengths in each duct run, then no dampers needed for balancing the system.

2.1 Procedure of Duct design using equal friction method

First measure all dimensions is finished for room and with AUTOCAD software within the equal friction method, following -

Steps for Duct Design are given below-

a. First calculate the amount of air flow. Based on this calculated air flow rate a fan unit is to be installed for desired capacity.
b. Initial velocity is taken as -6 m/s for Main duct air velocity and - 4 m/s for Branch duct air velocity
c. Area of duct = Air flow rate (Q)/ Velocity (v) m^3/s
d. From ASHRAE table for rectangular shape, equivalent duct diameter and Duct size/dimension obtained
e. Using equation on the premise of air quantity and equivalent duct diameter, The initial friction rate is determined.
f. The static and dynamic pressure drop for fittings used for determination from ASHRAE table of codes for duct fitting.

2.2 Rectangular ducts:

Rectangular ducts are commonly used in practice because they fit well into building structures and are simple to create. Comparing to a circular duct, square ducts with aspect ratio of 1.0 will have similar performance. To get best performance, an aspect ratio near about 1.0 is needed. A rectangular duct is similar to a circular duct for equal volumetric flow rate and frictional pressure drop per unit length (ΔP air. Q^f/L). Equating these two parameters for a rectangular duct

$$D^{eq}=1.3\ (ab)^{0.625}d/(a+b)^{0.25}d$$

D^{eq} as the equivalent diameter and air flow rate can be used to calculate the frictional pressure drop per unit length by using the friction chart.

2.3 Psychrometric Conditions of Location -

Psychrometric conditions are calculated from ASHRAE /ISHRAE/carrier guidelines. Occupancy load =50 persons Location –Indore M.P. Latitude =22.72N , Alt=567m

2.3.1 Inside Conditions-

Dry bulb temperature Tdb = 24°C, Wet bulb temperature T w =17 °C , Relative Humidity =50% ,and Specific humidity=0.0095 kg/kg of dry air

2.3.2 Outside Conditions

Dry bulb temperatureTdb-40.5°C, Wet bulb temperature Twb–25°C, Relative Humidity -28% , and specific humidity-0.0135 kg/kg of d.a, Average temperature -29.45 °C, Daily range -11.21 °C

3. Calculation for duct size/dimension using Equal Friction Method

Based on the cooling load calculation, AHU is selected. After selection of AHU is done then dimensions of the duct determined for the CACS .

Length- 9.5 (m), Width -7.6(m), Area -72.2 (m2) Height- 4.2/2.65(m), required cooling load -7.76 TR

Dehumidified quantity of air –75.16 m^3/min (2654 CFM)

Quantity of outside air -11.5 m^3/min (406 CFM)

Quantity of Recalculated air -63.66 m3/min (2228 CFM)

Supply air temperature -12.38 °C

ADP-10.8, BPF -0.12

Suitable Indoor unit air quantity –2542 CFM for an area

In this method the frictional pressure drop per unit length for whole the main and branch ducts (Δpf/L) are constant

(Δpf/L)A =1.1 (Δpf/L)B = (Δpf/L)C = (Δpf/L)D = Figure

(Δpf/L)E=1.1

Then the step by step process for designing the duct system is as below -

An acceptable frictional pressure drop per unit length (Δpf/L) is assumed, so that combined initial and running costs are minimized. (Δpf/L) =1.1

Then, using the chosen value of (pf/L) and airflow rates, equivalent diameter of the main duct (Deq,A) is obtained either from the friction chart or using the frictional pressure drop equation,

DeqA= 0.022243Q1.852 ¼.973

Since the (Δpf/L) is constant for entire the duct lengths, the equivalent diameters (Deq) of the other duct runs, B to I are calculated from the below equation:

(Q 1.852/D 4.973)A= (Q 1.852/D 4.973)B= (Q 1.852/D 4.973)C so,from this equation

DeqA =0.4898m

similarly ,

D eq B = DeqA(QB/QA)1.852/4.973= 0.25

D eq C = DeqA(QC/QA)1.852/4.973= 0.25

D eq D = DeqA(QD/QA)1.852/4.973=0.42

D eq E = DeqA(QE/QA)1.852/4.973= 0.25

D eq F = DeqA(QF/QA)1.852/4.973= 0.25

D eq G = DeqA(QD/QA)1.852/4.973= 0.324

D eq H=0.25 and D eq I= 0.25

And air flow rate, velocity, length, friction loss, duct loss are measured in table 1 and AUTOCAD Drawing of duct shown in fig- 1

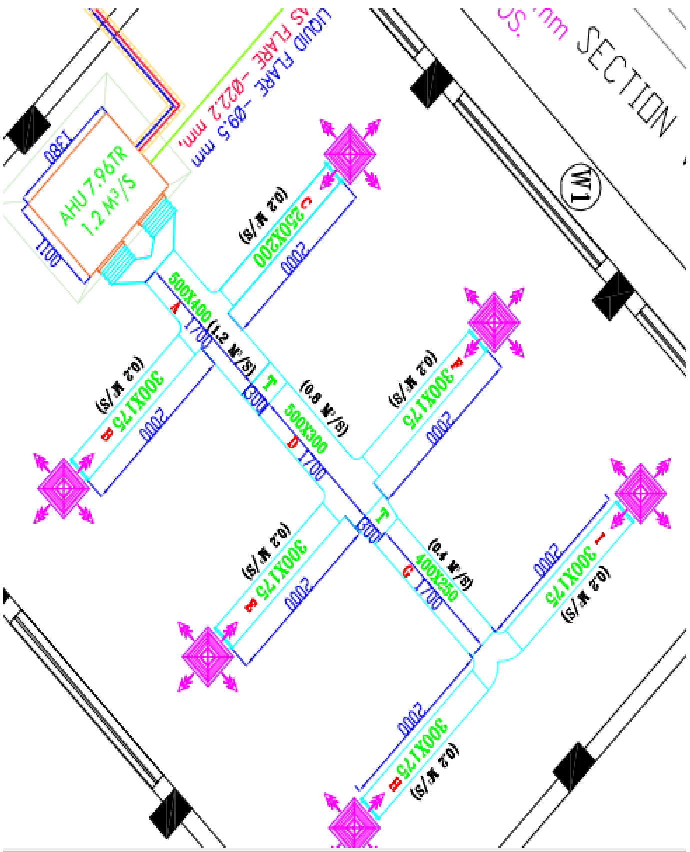

Fig -1 Duct Network For Room

All value shown in table

a) For the rectangular ducts, both cross sectional sides of the rectangular duct of each length are obtained from the equivalent diameter of that length.

b) the rate of air flow through every duct is calculated from the volumetric air flow rate and therefore the cross sectional area.

c) The next process from the cross sectional dimensions of the ducts in each length, the total frictional pressure(Δpf) drop of that length is obtained by multiplying the(Δpf/L) i.e.

(Pf)A=PfLB

d) Then dynamic pressure losses in each duct lengths are obtained on the basis of types of bends fitted in that length

e) Then the total pressure added in each duct length is calculated by adding the frictional and dynamic (fitting) losses of that lengths.

Table -1 Duct sizing

Sec.	Q (m^3/s)	Deq (mm)	H (mm)	W (mm)	Asp. ratio	L (m)
A	1.2	488	500	400	1.25	2
B	0.2	250	300	175	1.71	2
C	0.2	250	250	200	1.25	2
D	0.8	420	500	300	1.67	2
E	0.2	250	300	175	1.71	2
F	0.2	250	300	175	1.71	2
G	0.4	324	400	225	1.78	1.5
H	0.2	250	300	175	1.71	2
I	0.2	250	300	175	1.71	2

To design the duct for the room, cooling load and air flow rate is calculated. Duct size is then calculated using equal friction method. Equivalent duct diameters, widths, heights and velocities are also calculated. Based on these duct cross sectional areas, the duct sizes, frictional losses for the rectangular duct is calculated as shown in *table -2*

Table- 2 Friction losses and Fitting losses according to section for Rectangular Duct

	Friction losses								Fitting losses				
Sec.	**Q (m^3/s)**	**Deq (m)**	**Area (m2)**	**Velo. (m/s)**	**length (m)**	**Frict. Pa/m)**	**Duct loss (pa)**	**Fitting comp.**	**ASHRAE fitting code**	**Loss Coeff.**	**Fitting loss coeff.**	**dynamic loss ($k\rho V^2/2$)**	**Total section loss**
A	1.2	0.488	0.187	6.42	2	1.1	2.2	Cross main	SD5-24	0.2	0.2	5.94	8.14
B	0.2	0.25	0.049	4.06	2	1.1	2.2	Cross branch	SD5-24	2.07	3.09	30.56	32.76
	-	-	-	-	-	-		Pyramidal Diffuser	SR2-5	1.02			
C	0.2	0.25	0.049	4.06	2	1.1	2.2	Cross branch	SD5-24	2.07		30.56	32.76
								Pyramidal Diffuser	SR2-5	1.02			
D	0.8	0.42	0.138	5.79	2	1.1	2.2	Damper	CD9-1	0.19	0.33	6.64	8.84
								Cross, main	SD5-24	0.14			
E	0.2	0.25	0.049	4.06	2	1.1	2.2	Cross branch	SD5-24	2.2	3.22	31.85	34.05
								Pyramidal Diffuser	SR2-5	1.02			
F	0.2	0.25	0.049	4.06	2	1.1	2.2	1.Cross branch	SD5-24	2.2	3.22	31.85	34.05
								2.Exit	SR2-5	1.02			
G	0.4	0.324	0.082	4.85	1.5	1.1	1.65	Damper	CD9-1	0.19		2.68	4.33
H	0.2	0.25	0.049	4.06	2	1.1	2.2	Wye,Dovetail,	SR5 -14	0.23	1.25	12.36	16.83
								Pyramidal Diffuser	SR2-5	1.02			
I	0.2	0.25	0.049	4.06	2	1.1	2.2	Wye,Dovetail,	SR5 -14	0.23	1.25	12.36	4.47
Total friction 193 (PA)								Pyramidal Diffuser	SR5-14	1.02			16.83

4. Result Analysis ---

4.1 Results of Duct Size Velocity and Friction Losses Calculated By Hand Calculation(HC) and Using Ductulator Software (DL) for Rectangular Duct shown in Table -3

section	Q(m3/s)	Pf/L		Dia.		h	Width w		Velocity m/s		Length (mm)	Pa	
		HC	DL	HC	DL		HC	DL	HC	DL		HC	DL
A	1.2	1.1	1.093	488	473	500	400	375	6.42	6.83	2	2.2	2.186
B	0.2	1.1	1.095	250	241	300	175	175	4.06	4.4	2	2.75	2.19
C	0.2	1.1	1.095	250	241	250	200	175	4.06	4.4	2	2.2	2.19
D	0.8	1.1	2.58	420	406	500	300	275	5.79	6.191	2	2.75	3.16
E	0.2	1.1	1.095	250	241	300	175	175	4.06	4.4	2	2.2	2.19
F	0.2	1.1	1.095	250	241	300	175	175	4.06	4.4	2	2.75	2.19
G	0.4	1.1	1.68	324	312	400	225	200	4.85	5.223	1.5	2.75	2.52
H	0.2	1.1	1.095	250	241	300	175	175	4.06	4.4	2	2.75	2.19
I	0.2	1.1	1.095	250	241	300	175	175	4.06	4.4	2	2.2	2.19

Where –HC –Hand calculated ,DL-ductulator ,It is shows that is diameter deq ,width and velocity is found using hand calculated and using Mc Quay software can shown in table at different section . The duct losses is found by equal friction method is 22.55 pa and if using software it is found 21pa

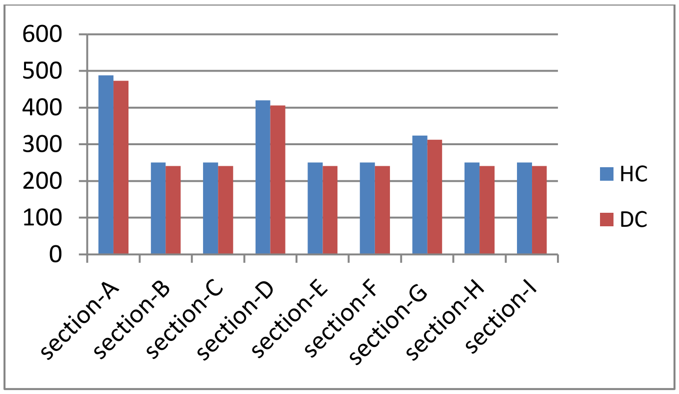

Fig-2 Comparative analysis of duct sizing between manual calculations and "Ductulator" software

Also clearly shown The variation of duct size and velocity using equal friction method and McQuay software system as shown are shown in Fig-2. It shows that there are little different between calculated duct diameter ,width velocity and duct friction losses using equal friction method and McQuay software.

4.2 Comparative analysis of velocity(m) in duct using manual calculations and duct calculator

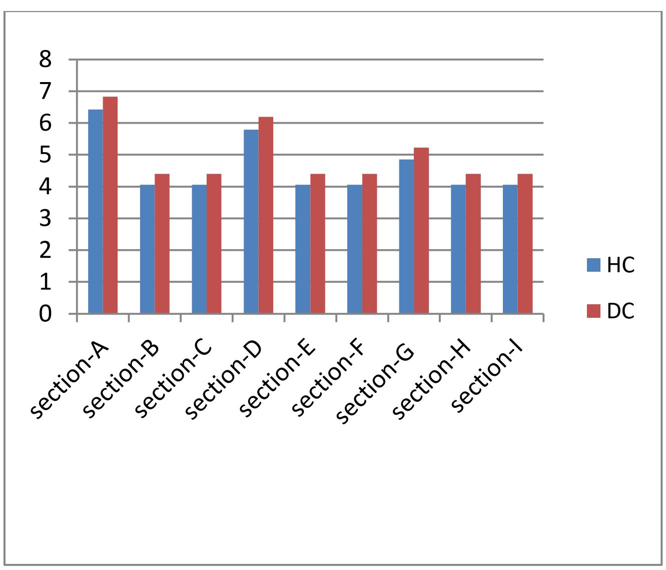

Figure -3. Variation of velocity(m) by manual calculations vs. Duct calculator

4.3 **Comparative analysis of duct losses using manual calculations and duct calculator**

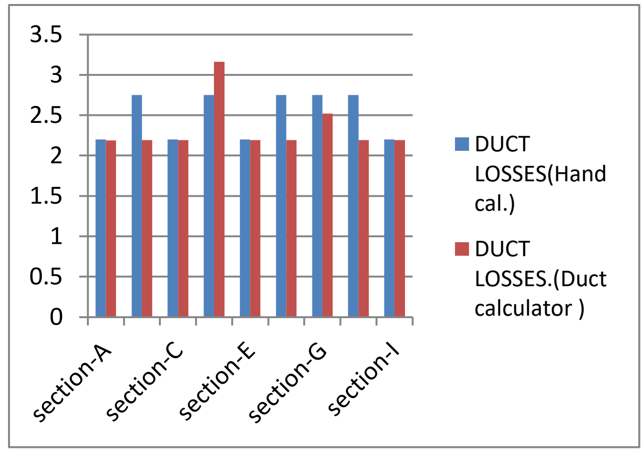

Figure 1 Variation of duct losses by hand calculations vs. Duct calculator

4.4 Comparison between calculated value and addendum *n* to ANSI/ASHRAE thumb rule standard 62-2001 Table 6.1 and It shows that there are little different between calculate value and as per standard such as TR/ft2 ,CFM/person and CFM/TR are satisfactory as standards.

4.5 Available ductable indoor unit as per survey of f VRF System ceiling mounted duct type CFM -2542 7.96TR, Ductable Unit Dimensions (H×W×D)- 470X1,380X1,100 Outdoor Unit HP-10.2 Piping Connections liquid line piping 9.5 gas line piping 22.2 drain PS1B is suitable

5.CONCLUSION

The subsequent conclusion summarizes the planning work presented during this work -

A. The duct design for building is completed, by using equal friction method. All values are validated with duct design software called "Ductulator (McQuay)"

B. The duct design is done for rectangular ducts for a space of a building using equal friction method.

C. The calculated values of frictional losses are near about as calculated by the software. if less value of friction drop, duct diameter is increased but loss in total pressure (i.e. static pressure, velocity pressure) will be avoided. Because of increased duct diameter the employment of dampers could also be decreased

D. Pressure losses in duct fittings are minimized by proper design the elbow/bend shape.

E. Dynamic and fitting losses also calculated as per taking fitting coefficient properly

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BIOGRAPHY –

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