International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

Vol.4., Issue.6., 2016
Nov-Dec.

RESEARCH ARTICLE

ISSN: 2321-7758

DESIGN AND ANALYSIS OF AN AIR DISTRIBUTION SYSTEM FOR A MULTI-STORY BUILDING

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ABSTRACT

Earlier the use of air conditioning for comfort purpose was considered to be expensive, but now-a-days, it has been a necessity for all human beings. Window air conditioners, split air conditioners are used in small buildings, offices etc. But, when the cooling load required is very high such as big buildings, multiplex, multi-story buildings, hospitals etc. centralized unit (central air conditioners) are used. The central AC's systems are installed away from building called central plant where water or air is to be cooled. This cooled air is not directly supplied to the building rooms. When the cooled air cannot be supplied directly from the air conditioning equipment to the space to be cooled, then the ducts are provided. The duct systems carry the cooled air from the air conditioning equipment for the proper distribution to rooms and also carry the return air from the room back to the air conditioning equipment for recirculation. When ducts are not properly designed, then it will lead to problem such as frictional loss, higher installation cost, increased noise and power consumption, uneven cooling in the cooling space. For minimizing this problem, a proper design of duct is needed. Equal friction method is used to design the duct, which is simple method as compared with the other design methods. These work gives the combination of theoretical and software tool to provide a comparative analysis of the duct size. It also gives the comparison between rectangular duct and circular duct.

Keywords: Friction, Ductulator, Criteria, Dehumidified

INTRODUCTION

In the present day, as the population increases the need for comfortness also increases. The human being needs more comfortness because of inferior environment (like light, sound, machine which produce heat). Sound, light and heat affect human comfort a lot. They may adversely affect the human comfort positively or negatively. Researchers suggest that, human body is used to be comfortable at a temperature of 22°C to 25°C. When the temperature of room is lower or higher than this temperature, than the human body feels uncomfortable. This is because, the human body is structured in a way that, it should receive a certain amount of light, failure to which it can cause sunburns and other skin conditions.

There are many types of air conditioning system like window air conditioners, split air conditioners etc. but these AC's system are used in small room or office where cooling load required is low. When the cooling load required is very high like multiplex building, hospital etc. central AC's system are used. In central AC's system the cooled air is directly not distributed to the rooms. The cooled air from the air conditioning equipment must be properly distributed to rooms or spaces to be cold in order to provide comfort condition. When the cooled air cannot be supplied directly from the air conditioning equipment to the spaces to be cooled, then the ducts are installed. The duct systems convey the cold air from the air conditioning equipment to the proper air distribution point and also carry the return air from the room back to the air conditioning equipment for reconditioning and recirculation.

As the duct system for the proper distribution of cold air, costs nearly 20% to 30% of the total cost of the equipment required. Thus, it is necessary to design the air duct system in such a way that the capital cost of ducts and the cost of running the fan is lower.

Classification of ducts

a) Supply air duct
b) Return air duct
c) Fresh air duct
d) Low pressure duct
e) Medium pressure duct
f) High pressure duct
g) Low velocity duct
h) High velocity duct

Duct Material

The ducts are usually made from galvanized iron sheet metal, aluminium sheet metal or black sheet. The most commonly used duct material in the air conditioning system is galvanized sheet metal, because the zinc coating of this metal prevents rusting avoids the cost of painting. The sheet thickness of galvanized iron duct varies from 0.55 mm to 1.6 mm. The aluminium is used because of its lighter weight and resistance to moisture.

The use of non-metal ducts has increased. The resin bounded glasses are used because they are quite strong and easy to manufacture according to the desired shape and size. They are used in low velocity application less than 600 m/min and for a static pressure below 5 mm.

Various shapes of duct

a) Circular/round duct:
b) Rectangular duct:
c) Flat oval duct:
d) Flexible duct:

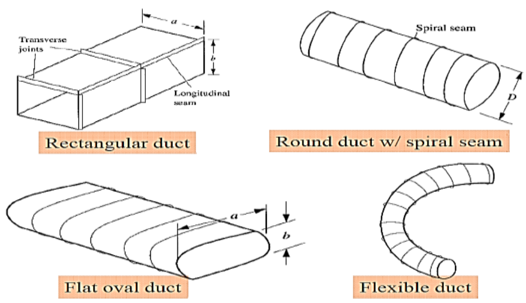

Figure 1: **Various shapes of duct**

Fan Coil Unit (FCU) A fan coil unit (FCU) is a device consisting of a cooling or heating coil and fan. It is a part of the heating ventilation and air conditioning system used to circulate the cold water into the room. In FCU no need to ductwork and it is used to govern the temperature in the region where it is fitted. It is controlled by either physically or by a regulator.

Fan coil units (FCU) are normally used in places where economic installations are desired such as storage rooms, loading docks and corridors. In high-rise buildings, fan coils may be arranged, situated one above the another from floor to floor and all interrelated by the same tubing loop. FCUs are an admirable delivery apparatus for hydraulic chiller boiler systems in large housing and light profitable applications. In these applications the FCUs are mounted in bathroom ceilings and can be used to provide infinite comfort zones - with the facility to turn off vacant areas of the building to save energy.

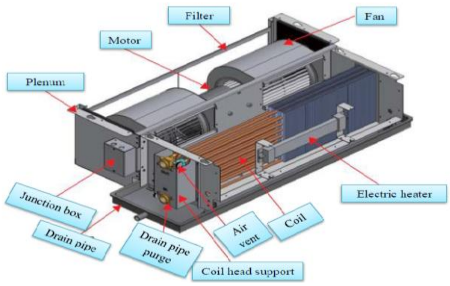

Figure 2: **Fan coil unit**

Air Handling Unit (AHU) **-** Air handling unit (AHU), is a device used to circulate the air as part of a heating, ventilating, and air-conditioning (HVAC) system. An air handling unit is usually a big metal box having a blower, chambers, heating or cooling elements, dampers and sound attenuators. AHU generally connect to a ductwork ventilation system that allocates the cooled air through the house or rooms and takings it to the AHU.

Air handling components

a) Filters
b) Heating or cooling elements
c) Humidifier
d) Blower or fan

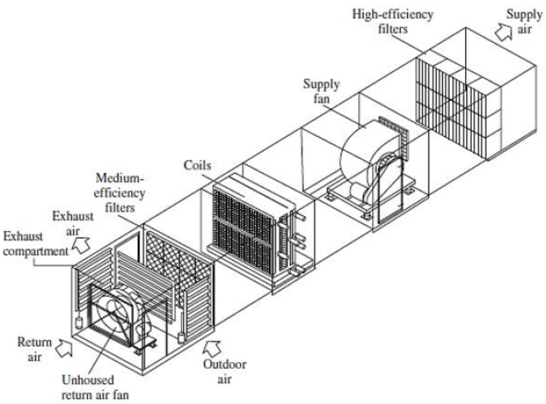

Figure 3: **Air Handling Unit**

PROCEDURE

This project gives the fundamental principles of duct or air distribution system design for a multi-story building. There are mainly three types of duct sizing method namely

(i) equal friction method,
(ii) modified friction method (static regain method) and
(iii) Velocity reduction method.

Now a days, the use of manual duct calculator is normal and computer aided duct design is becoming more popular. Also understanding the friction chart is very important to use this manual duct calculator, because these are the foundations of the other methods. This will provide the necessary knowledge to the duct design error and overcome to the errors.

For designing a proper duct system, it is necessary to estimate cooling load which is used to select the zone and air flow rate that the duct system distributes. Once the air flow rate is determined, the duct system component can be placed. This includes the supply and returns diffusers and decides to air handling unit (AHU) or fan coil unit (FCU) is good for that space.

General rules for duct design

a) Air should be conveyed as directly as possible to economize on power, material and shape.
b) Sudden change in direction should be avoided.
c) Air velocities in ducts should be within the permissible limits to minimize losses.
d) Rectangular ducts should be made as nearly square as possible. This will ensure minimum ducts surface. An aspect ratio of less than 4:1 should be maintained.
e) Damper should be provided in each branch outlet for balancing the system.

Duct Design Criteria

Many factors are considered when designing a duct system. They are as follows

a) Space availability
b) Installation cost
c) Air friction loss
d) Noise level
e) Duct heat transfer and airflow leakage

Pressure in Duct

The flow of air within a duct system is produced by the pressure difference existing between the different locations. The greater the pressure difference, the faster the air will flow. The following are the three types of pressures involved in a duct system.

Static Pressure (Ps)
Velocity Pressure (Pv)
Total Pressure (Pt)

Total Pressure (Pt)

It is the algebraic sum of the static pressure and dynamic pressure.

$$P_t = P_s + P_v$$

P_t= Total pressure, Pa

P_s = static pressure, Pa (measured by any pressure measuring instrument)

P_V = velocity pressure

$= \frac{\rho V^2}{2}$, (for air ρ=1.024kg/m3)

= $0.602V^2$

V = fluid mean velocity, m/s

= $\frac{Q}{A}$

Where, Q = air flow rate, m^3/sec

A = cross sectional area, m^2

Pressure Losses in Ducts

Pressure is lost due to friction between the moving particle of the fluid and the interior surfaces of a duct. When the pressure loss occurs in a straight duct, then this loss is known as friction loss. The pressure loss is due to the changes of direction of air flow such as bends, elbows etc. and at the change of cross section of the duct, this loss is known as dynamic losses.

Pressure Loss due to Friction in Ducts

The pressure loss due to friction in ducts may be obtained by using the Darcy's formula, i.e.

$P_f = \frac{fLp_aV^2}{2D_h}$

Where

P_f = pressure loss due to friction in N/m^2

L = length of the duct in meters

f = friction factor depending upon the surface of the duct

P_a = density of air in kg/ m^3

V = mean velocity of the air flowing through the duct in m/s

D_h = hydraulic diameter in m

= $\frac{\text{cross sectional area of the fuct (A)}}{Permeter\ of\ the\ duct\ (p)}$

= $\frac{D}{4}$ for circulation cross section, D is a diameter of duct = $\frac{ab}{2(a+b)}$,

Where a and b is a side of rectangle.

The value of friction factor (*f*) for different Reynolds numbers and different roughness factor find directly from the Moody chart as shown in Figure.

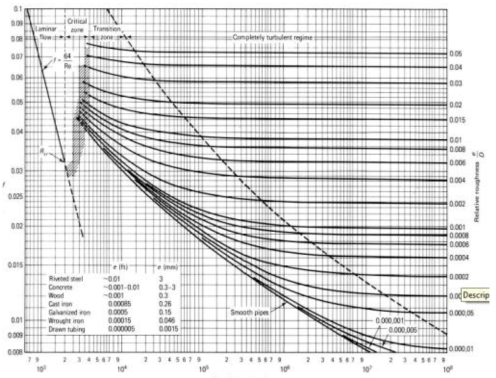

Figure 4. Moody Chart

Dynamic Losses in Ducts

The dynamic losses are caused due to the change in direction or magnitude of velocity of the fluid in the duct. The change in the direction of the velocity occurs at bends and elbow. The change in the magnitude of velocity occurs when the area of duct changes i.e. enlargement, contraction, suction etc.

The dynamic pressure loss Δpd is proportional to the velocity pressure and it is expressed as a product of the downstream velocity pressure pv and a dynamic loss coefficient (K).

$$\Delta P_d = KP_v = K\left(\frac{pC^2}{2}\right)$$

Where V=downstream velocity.

The losses in elbows, fittings etc. are also expressed in items of an equivalent length L, of the duct, so that

$$\Delta P_d = KP_v = \left(\frac{4fL_eP_v}{D}\right)$$

Friction Chart

The frictional pressure loss for circular ducts (in mm of water) for various velocities (in m/s) and duct diameters (in mm) obtained directly from the friction chart as shown In this chart, the vertical ordinate represent volume flow rate of air in m^3/s and the horizontal ordinate represents frictional pressure loss in mm of water per unit length of the circular duct. These charts are valid for 20°C and 1.013 bar and clean galvanized iron ducts with joints and seams

Duct Velocity Ranges

The velocities in the ducts must be high enough to reduce the size of the ducts but it should be low enough to reduce the noise and pressure losses to economize power requirement. The velocities recommended for various applications are

Table: 1 Recommended Velocities in (m/min)

Designation	Residences	School theatres and Public	Industrial Building
Outdoor air intake	150	150	150
Filters	75	95	105
Cooling coil	135	150	180
Air washer	150	150	150
Fan outlet	300-480	400-	480-725
Grills	40-60	60-80	80-100
Main duct	210-300	300-400	360-540
Branch duct	180	180-270	240-300
Branch riser	150	180-210	240

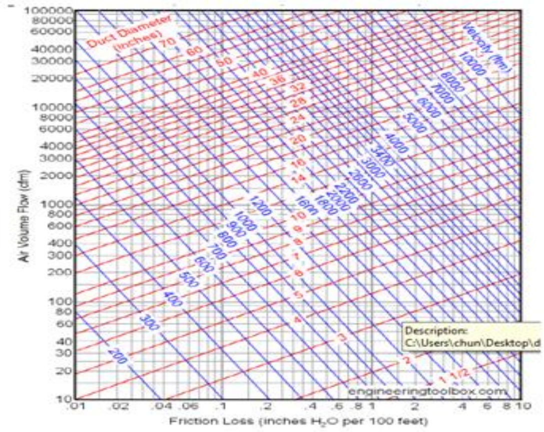

Figure: 5 Duct Friction Chart

Duct Material Roughness

Duct material roughness refers to the inside surface of the duct material the rougher the surface, higher the friction loss. The recommended roughness for different material pipes or ducts are

Table: 2 The recommended roughness for different material pipes or ducts material

Types of duct or pipes material	Roughness Category	Absolute roughness
PVC Plastic pipe	Smooth	0.01-0.05
Galvanized steel longitudinal seam	Medium Smooth	0.05-0.1
Galvanized steel continuous roll	Medium Smooth	0.06-0.12
Fibrous flass duct,rigid	Medium Smooth	0.9
Flexible duct metallic	Rough	1.2-2.1
Aluminum	Smooth	0.04-0.06
Concrete	Medium	1.2
Concrete	Smooth	0.3
Commercial steel pipe	Smooth	0.045

Equivalent Duct Diameter

In order to find the equivalent diameter of a circular duct for a rectangular duct for the same pressure loss per unit length, Huebscher developed a relationship between rectangular and round duct. According to this,

$$D_e = \frac{1.30(ab)^{0.625}}{(a+b)^{0.250}}$$

Where, De = equivalent circular diameter of rectangular duct for equal length, mm

a = length one side of duct, mm

b = length adjacent side of duct, mm

Equivalent round duct diameter can also be determined by using which is based on the above equation.

Lgth Adj.[b]	Length of One Side of Rectangular Duct (a), mm																			
	100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	650	700	750	800	900
	Circular Duct Diameter, mm																			
100	109																			
125	122	137																		
150	133	150	164																	
175	143	161	177	191																
200	152	172	189	204	219															
225	161	181	200	216	232	246														
250	169	190	210	228	244	259	273													
275	176	199	220	238	256	272	287	301												
300	183	207	229	248	266	283	299	314	328											
350	195	222	245	267	286	305	322	339	354	383										
400	207	235	260	283	305	325	343	361	378	409	437									
450	217	247	274	299	321	343	363	382	400	433	464	492								
500	227	258	287	313	337	360	381	401	420	455	488	518	547							
550	236	269	299	326	352	375	398	419	439	477	511	543	573	601						
600	245	279	310	339	365	390	414	436	457	496	533	567	598	628	656					
650	253	289	321	351	378	404	429	452	474	515	553	589	622	653	683	711				
700	261	298	331	362	391	418	443	467	490	533	573	610	644	677	708	737	765			
750	268	306	341	373	402	430	457	482	506	550	592	630	666	700	732	763	792	820		
800	275	314	350	383	414	442	470	496	520	567	609	649	687	722	755	787	818	847	875	
900	289	330	367	402	435	465	494	522	548	597	643	686	726	763	799	833	866	897	927	984
1000	301	344	384	420	454	486	517	546	574	626	674	719	762	802	840	876	911	944	976	1037
1100	313	358	399	437	473	506	538	569	598	652	703	751	795	838	878	916	953	988	1022	1086
1200	324	370	413	453	490	525	558	590	620	677	731	780	827	872	914	954	993	1030	1066	1133
1300	334	382	426	468	506	543	577	610	642	701	757	808	857	904	948	990	1031	1069	1107	1177
1400	344	394	439	482	522	559	595	629	662	724	781	835	886	934	980	1024	1066	1107	1146	1220
1500	353	404	452	495	536	575	612	648	681	745	805	860	913	963	1011	1057	1100	1143	1183	1260
1600	362	415	463	508	551	591	629	665	700	766	827	885	939	991	1041	1088	1133	1177	1219	1298
1700	371	425	475	521	564	605	644	682	718	785	849	908	964	1018	1069	1118	1164	1209	1253	1335
1800	379	434	485	533	577	619	660	698	735	804	869	930	988	1043	1096	1146	1195	1241	1286	1371
1900	387	444	496	544	590	663	674	713	751	823	889	952	1012	1068	1122	1174	1224	1271	1318	1405
2000	395	453	506	555	602	646	688	728	767	840	908	973	1034	1092	1147	1200	1252	1301	1348	1438
2100	402	461	516	566	614	659	702	743	782	857	927	993	1055	1115	1172	1226	1279	1329	1378	1470
2200	410	470	525	577	625	671	715	757	797	874	945	1013	1076	1137	1195	1251	1305	1356	1406	1501
2300	417	478	534	587	636	683	728	771	812	890	963	1031	1097	1159	1218	1275	1330	1383	1434	1532
2400	424	486	543	597	647	695	740	784	826	905	980	1050	1116	1180	1241	1299	1355	1409	1461	1561
2500	430	494	552	606	658	706	753	797	840	920	996	1068	1136	1200	1262	1322	1379	1434	1488	1589
2600	437	501	560	616	668	717	764	810	853	935	1012	1085	1154	1220	1283	1344	1402	1459	1513	1617
2700	443	509	569	625	678	728	776	822	866	950	1028	1102	1173	1240	1304	1366	1425	1483	1538	1644
2800	450	516	577	634	688	738	787	834	879	964	1043	1119	1190	1259	1324	1387	1447	1506	1562	1670
2900	456	523	585	643	697	749	798	845	891	977	1058	1135	1208	1277	1344	1408	1469	1529	1586	1696

Figure: 6 Equivalent round duct diameters

Duct Design Method

There are mainly three methods of duct design. These are:

Velocity Reduction Method

The duct are designed in such a way that the velocity decreases as flow proceeds. The pressure drops are calculated for these velocities for respective branches and main duct. The pressure at the outlet is adjusted by damper in the respective ducts. The advantages of this system are:

a) This method is the easiest among all methods in sizing the duct diameters.
b) The velocities can be adjusted to avoid noise.
c) This is adopted only for simple system.

Equal Friction Drop (friction loss) Method

In this method, the size of the duct is decided to give equal pressure drop per meter length an all ducts. The velocities are automatically reduced in the branch duct as the flow is decreased.

The main advantage of this method is that, if the duct layout is symmetrical giving the same length in each run, then no dampers are required to balance the system as this method gives equal pressure loss in various branches.

The Static Regain Method

For the perfect balancing of the air duct layout system, the pressure at all outlets must be made same. This can be done by equalizing the pressure losses in the various branches. This is possible if the friction loss in each run is made equal to pressure gain due to reduction in velocity. The gain in pressure due to change in velocity is given by

SPR = R ($\frac{V_1^2 - V_2^2}{2g}$)

Where,

SPR = Static Pressure regain

R = Static regain factor

DESIGN CALCULATION

In the building there are total 18 rums, where cooling is required. The list of few rooms floor wise in the Building where cooling load is required is given below:

Table:3 List of rooms

S.No	Room	Width(m)	Length(m)	Area(m2)	Celling HT(m)	AC Requirement
1	120Seat lecture room 1	14.17	8.67	122.85	3.4	122.85
2	Seminar Room	12.53	6.97	87.33	3.35	87.33
3	Central Design Office	14.17	20.09	284.68	3.32	284.68
4	Auditorium	20	25	500	7.55	500
5	Library Facility	9.07	6.87	62.31	3.35	62.31

On the basis of cooling load required in a room, fan coil unit (FCU) or air handling unit (AHU) is used. In this work it is decided to use FCU where cooling load required up to 5 tons and to use AHU above 5 tons. As we know that, for FCU there is no duct is required. So, we calculate the duct size only for those rooms where cooling load is required more than 5 tons or where AHU is used. For that purpose firstly calculate the air flow rate/dehumidified air. After that the calculation for duct dimension has to be done.

Calculation for dehumidified air quantity

Room Rise = (1 – by pass factor)*(Room temp - ADP)

Dehumidified Air = RSH / (20.44 * dehumidified rise)

Where,

ADP = apparatus due point

RSH = room sensible heat

Calculation for duct size/dimension:

a) First find out the air flow rate i.e. dehumidified air and cooling load.
b) Based on cooling load select AHU or FCU which is to be installed. For FCU there is no need to duct system. If AHU then calculate the duct dimension.
c) Select initial velocity from table 1

$$Duct\ Area = \frac{Air\ flow\ rate}{Velocity}$$

d) Select duct size/dimension from figure 6 also Equivalent duct diameter.
e) Then initial friction rate is determined by using friction chart, on the basis of air quantity and equivalent duct diameter or velocity of air from figure 5.

Calculations for the list of rooms:

1. 120 seat lecture room

By pass factor = 0.12

Room temperature = 23°C

ADP = 9°C

RSH = 27078.65 W

Room Rise = (1 – 0.12)*(296 - 282)

= 12.32
Dehumidified Air = 27078.65 / (20.44 * 12.34)
= 107.53 m3/min
Safety factor (5%) = 5.37 m^3/min
Total dehumidified air = 112.90 m^3/min ≈ 113 m^3/min
Cooling load = 12.39 tons
Initial Velocity=300m/min
Duct area=$\frac{air\ flow\ rate}{velocity}$
=$\frac{113}{300}$=0.38m^2=4.09ft^2
Duct size = 26 * 24 inch = 650 * 600 mm
Equivalent duct diameter = 27.2 inch = 680 mm
Friction rate = 0.0514

2. Seminar room

By pass factor = 0.12
Room temperature = 23°C
ADP = 9°C
RSH = 16495.36 W
Room Rise = (1 – 0.12)*(296 - 282)
= 12.32
Dehumidified Air = 16495.36 / (20.44 * 12.32)
= 65.50 m^3/min
Safety factor (5%) = 3.27 m^3/min
Total dehumidified air = 68.77 m^3/min ≈ 69 m^3/min
Cooling load = 7.16 tons
Initial velocity = 300 m/min
Duct area = = 0.23 m^2= 2.47 ft^2 300 69
Duct size = 24 * 16 inch = 600 * 400 mm
Equivalent duct diameter = 21.3 inch = 532.5 mm ≈ 530 mm
Friction drop = 0.0601

3 Central design office

By pass factor = 0.12
Room temperature = 23°C
ADP = 10°C
RSH = 55041.21 W
Room Rise = (1 – 0.12)*(296 - 283)
= 11.44
Dehumidified Air = 55041.21 / (20.44 * 11.44)
= 235.38 m^3/min
Safety factor (5%) = 11.76 m^3/min
Total dehumidified air = 247.14 m^3/min ≈ 247 m^3/min
Cooling load = 24.69 tons
Initial velocity = 300 m/min
Duct area = $\frac{247}{300}$= 0.82 m^2 = 8.82 ft^2
Duct size = 38 * 36 inch = 950 * 900 mm
Equivalent duct diameter = 40.4 inch = 1010 mm ≈ 1000 mm
Friction drop = 0.0236

4 Auditorium.

By pass factor = 0.12
Room temperature = 23°C
ADP = 9°C
RSH = 101211.71 W
Room Rise = (1 – 0.12)*(296 – 282)
= 12.32
Dehumidified Air = 101211.71 / (20.44 * 12.32)
= 401.91 m3/min
Safety factor (5%) = 20.09 m^3/min
Total dehumidified air = 422 m^3/min
Cooling load = 50.14 tons
Initial velocity = 300 m/min
Duct area = $\frac{422}{300}$= 1.40 m^2 = 15.06 mft^2
Duct size = 48 * 48 inch = 1200 * 1200 mm
Equivalent duct diameter = 52.6 inch = 1315 mm ≈ 1300 mm
Friction drop = 0.0318

5. Library Facility

By pass factor = 0.12
Room temperature = 23°C
ADP = 9°C
RSH = 11554.81 W
Room Rise = (1 – 0.12)*(296 – 282)
= 12.32
Dehumidified Air = 11554.81 / (20.44 * 12.32)
= 45.88 m^3/min
Safety factor (5%) = 2.29 m^3/min
Total dehumidified air = 48.17 m^3/min ≈ 48 m^3/min
Cooling load = 5.57 tons
Initial velocity = 300 m/min
Duct area = = 0.16 m^2= 1.72 ft^2
Duct size = 18 * 16 inch = 450 * 400 mm
Equivalent duct diameter = 18.5 inch = 462.5 mm ≈ 460 mm
Friction drop = 0.0318

RESULT ANALYSIS

The result analysis is based on the duct design of the building with hand calculation and duct design software like ductulator.

Duct size: To design the duct for building calculation of cooling load and air flow rate is done. By taking some suitable velocity considering noise factor main duct area is calculated. Based on these duct area, the duct size is find out for the rectangular duct as well as round duct. The cooling load, dehumidified air flow, duct size for all room is given in below:

Table: 4 Cooling Load and dehumidified air for respective room

S.No	Room NAME	Cooling Load (tons)	Dehumidified Air Flow (m/min)	Type of unit used (FCU/AHU)
1	120Seat lecture room 1	12.39	113	AHU
2	Seminar Room	7.16	69	AHU
3	Central Design Office	24.69	247	AHU
4	Auditorium	50.14	422	AHU
5	Library Facility	5.57	48	AHU

Table: 5 duct size comparison between hand calculation and ductulator software

S.No	Room	Hand calculation			Using software (ductulator)		
1	120Seat lecture room 1	650*600	680	0.0445	700*550	675	0.0487
2	Seminar Room	600*400	530	0.0623	550*450	530	0.0655
3	Central Design Office	950*900	1000	0.0295	1000*850	1000	0.0303
4	Auditorium	1200*1200	1300	0.0195	1250*1150	1300	0.022
5	Library Facility	450*400	460	0.0792	450*400	460	0.0822

1. For calculating duct size equal friction method is used. Frictional pressure drop are different for all rooms (given in above table) as velocity kept constant.

2. Ansys is used to observe the friction loss in rectangular duct as well as circular duct. For analysis we select only small portion of duct (3 m), also it can be applied for all ducting in a building.

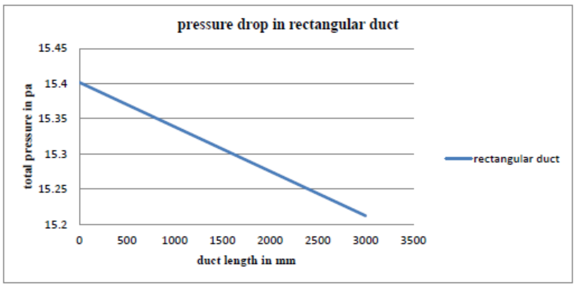

Figure: 7 Pressure drop in rectangular duct

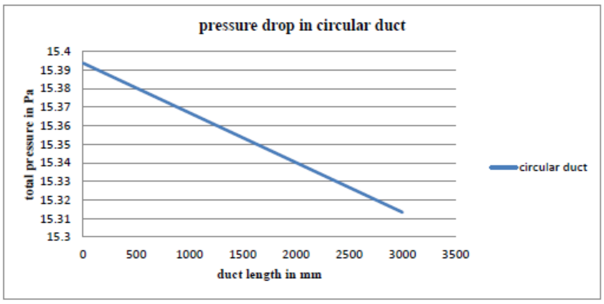

Figure:8 Pressure drop in rectangular duct

After studying the result (from Figure7 & 8) comes that circular duct has minimum friction loss as compared to the rectangular duct.

CONCLUSION

- The following conclusion summarizes the design work presented in this thesis:-
- The duct design for building is done, by using equal friction method. All values are comparable with duct software called ductulator.
- The calculated value of frictional is less or near as calculated by software. Due to less value of friction drop, duct diameter is increased but loss in total pressure (i.e. static pressure, velocity pressure) can be avoided.
- Due to increased duct diameter the use of damper may be decreased.
- Also the circular duct can carry more air in less space, because of that, less duct material, less duct surface friction and less insulation is required.
- Pressure loss in duct fitting can be minimized by proper design the elbow shape.
- Ansys 13.0 software is used to analyse the pressure loss in circular and rectangular duct. After analysis we conclude that the circular duct has minimum friction loss, so it is better shape for ducting.

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