Design of Air Conditioning Ducts

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The specific objectives are to:

١. Important requirements of an air conditioning duct

٢. General rules for duct design

٣. Classification of duct systems

٤. Commonly used duct design methods

٥. Principle of velocity method

٦. Principle of equal friction method

٧. Principle of static regains method

٨. Performance of duct systems

٩. System balancing and optimization

١٠. Introduction to fans and fan laws

١١. Interaction between fan and duct system

At the end of the study, we should be able to:

١. State the important requirements of an air conditioning duct and the general rules to be followed in the design of ducts

٢. Classify air conditioning ducts based on air velocity and static pressure

٣. Design air conditioning ducts using velocity method, equal friction Method or static regain method

٤. Explain typical performance characteristics of a duct system

٥. Explain the importance of system balancing and optimization

٦. State and explain the importance of fan laws, and use the performance Of fans under off-design conditions

٧. Describe interaction between fan and duct and the concept of balance point.

.١. Introduction:

The chief requirements of an air conditioning duct system are

١. It should convey specified rates of air flow to prescribed locations

٢. It should be economical in combined initial cost, fan operating cost and cost of building space

٣. It should not transmit or generate objectionable noise

Generally at the time of designing an air conditioning duct system, the required airflow rates are known from load calculations. The location of fans and air outlets are fixed initially. The duct layout is then made taking into account the space available and ease of construction. In principle, required amount of air can be conveyed through the air conditioning ducts by a number of combinations. However, for a given system, only one set results in the optimum design. Hence, it is essential to identify the relevant design parameters and then optimize the design.

٢.٠ General rules for duct design:

١. Air should be conveyed as directly as possible to save space, power and material

٢. Sudden changes in directions should be avoided. When not possible to avoid sudden changes, turning vanes should be used to reduce pressure loss

٣. Diverging sections should be gradual. Angle of divergence ≤ ٢٠$^{\circ}$

٤. Aspect ratio should be as close to ١.٠ as possible. Normally, it should not exceed ٤

٥. Air velocities should be within permissible limits to reduce noise and vibration

٦. Duct material should be as smooth as possible to reduce frictional losses.

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.٣. Classification of duct systems:

Ducts are classified based on the load on duct due to air pressure and turbulence. The classification varies from application to application, such as for residences, commercial systems, industrial systems etc. For example, one such classification is given below:

<u>Low pressure systems:</u> Velocity ≤ ١٠ m/s, static pressure ≤ ٥ cm H_2O (g)
<u>Medium pressure systems:</u> Velocity ≤ ١٠ m/s, static pressure ≤ ١٥ cm H_2O (g)
<u>High pressure systems:</u> Velocity > ١٠ m/s, static pressure ١٥<p_s ≤ ٢٥ cm H_2O (g)

High velocities in the ducts results in:

١. Smaller ducts and hence, lower initial cost and lower space requirement
٢. Higher pressure drop and hence larger fan power consumption

٣. Increased noise and hence a need for noise attenuation

Recommended air velocities depend mainly on the application and the noise criteria. Typical recommended velocities are:

Residences: ٣ m/s to ٥ m/s

Theatres: ٤ to ٦.٥ m/s

Restaurants: ٧.٥ m/s to ١٠ m/s

If nothing is specified, then a velocity of **٥ to ٨ m/s** is used for main ducts and a velocity of **٤ to ٦ m/s** is used for the branches. The allowable air velocities can be as high as ٣٠ m/s in ships and aircrafts to reduce the space requirement.

.٤. Commonly used duct design methods:

Figure no.١ shows the schematic of a typical supply air duct layout. As shown in the figure, supply air from the fan is distributed to five outlets (١ to ٥), which are located in five different conditioned zones. The letters A to I denote the portions of the duct to different outlets. Thus A-B is the duct running from the supply air fan to zone ١; A-B-C is the duct running
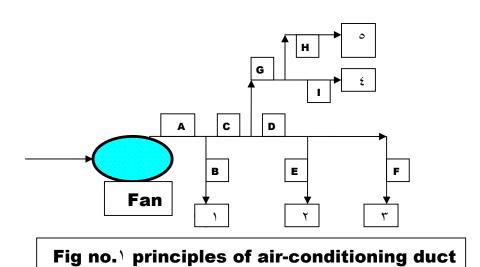
from supply fan to conditioned zone and so on. These are known as duct runs. The run with the highest pressure drop is called as the **index run**. From load and psychometric calculations the required supply airflow rates to each conditioned space are known. From the building layout and the location of the supply fan, the length of each duct run is known. The purpose of the duct design is to select suitable dimensions of duct for each run and then to select a fan, which can provide the required supply airflow rate to each conditioned zone.

Due to the several issues involved, the design of an air conditioning duct system in large buildings could be a sophisticated operation requiring the use of Computer Aided Design (CAD) software. However, the following methods are most commonly used for simpler lay-outs such as the one shown in fig no.١

١. Velocity method

٢. Equal Friction Method

٣. Static Regain method

Fig no.١ principles of air-conditioning duct

.٤.١ Velocity method

The various steps involved in this method are:

١- Select suitable velocities in the main and branch ducts

٢- Find the diameters of main and branch ducts from airflow rates and velocities for circular ducts. For rectangular ducts, find the cross-sectional area from flow rate and velocity, and then by fixing the aspect ratio, find the two sides of the rectangular duct

٣- From the velocities and duct dimensions obtained in the previous step, find the frictional pressure drop for main and branch ducts using friction chart or equation

٤- From the duct layout, dimensions and airflow rates, find the dynamic pressure losses for all the bends and fittings

٥- Select a fan that can provide sufficient FTP for the index run

٦- Balancing dampers have to be installed in each run. The damper in the index run is left completely open, while the other dampers are throttled to reduce the flow rate to the required design values.

The velocity method is one of the simplest ways of designing the duct system for both supply and return air. However, the application of this method requires selection of suitable velocities in different duct runs, which requires experience. Wrong selection of velocities can lead to very large ducts, which, occupy large building space and increases the cost, or very small ducts which lead to large pressure drop and hence necessitates the selection of a large fan leading to higher fan cost and running cost. In addition, the method is not very efficient as it requires partial closing of all the dampers except the one in the index run, so that the total pressure drop in each run will be same

For example, let the duct run A-C-G-H be the index run and the total pressure drop in the index run is ١٠٠ Pa. If the pressure drop in the shortest duct run (says A-B) is ١٠ Pa, then the damper in this run has to be closed to provide an additional pressure drop of ٩٠ Pa, so that the required airflow rate to the conditioned zone ١ can be maintained. Similarly the dampers in the other duct runs also have to be closed partially, so that the total pressure drop with damper partially closed in each run will be equal to the pressure drop in the index run with its damper left open fully.

.٤.٢. Equal friction method:

In this method the frictional pressure drop per unit length in the main and branch ducts ($\Delta p_f/L$) are kept same, i.e.

$$(dP/L)A = (dP/L)\ B = (dP/L\}\ C= \ ....\quad ...$$

Then the stepwise procedure for designing the duct system is as follows:

١-   Select a suitable frictional pressure drop per unit length ($\Delta p_f/L$) so that the combined initial and running costs are minimized

٢-   Then the equivalent diameter of the main duct (A) is obtained from the selected value of (Δp$_f$/L) and the airflow rate. As shown in Fig.١, airflow rate in The main duct is equal to the sum total of airflow rates to all the conditioned zones, i.e.,

QA=Q١+Q٢+Q٣+Q٤+Q٥= Sigma Q١٢٣٤٥...n

From the airflow rate and (Δp$_f$/L) the equivalent diameter of the main duct (**D**$_{eq, A}$) can be obtained either from the friction chart or using the frictional pressure drop equation, i.e.

$$D_{eq, A} = \left(\frac{0.022245 \; Q^{1.852}}{(\Delta p_f/L) \, a} \right)^{(1/4.973)}$$

٣- Since the frictional pressure drop per unit length is same for all the duct runs, the equivalent diameters of the other duct runs, B to I are obtained from the equation:

$$\left(\frac{Q^{1.852}}{D_{eq, A}^{4.973}} \right)_A = \left(\frac{Q^{1.852}}{D_{eq, A}^{4.973}} \right)_B = \left(\frac{Q^{1.852}}{D_{eq, A}^{4.973}} \right)_C = \ldots\ldots$$

٤- If the ducts are rectangular, then the two sides of the rectangular duct of each run are obtained from the equivalent diameter of that run and by fixing aspect ratio as explained earlier. Thus the dimensions of the all the duct runs can be obtained. The velocity of air through each duct is obtained from the volumetric flow rate and the cross-sectional area.

٥- Next from the dimensions of the ducts in each run, the total frictional pressure drop of that run is obtained by multiplying the frictional pressure drop per unit length and the length, i.e.,

(Δp$_{f,A}$/L) = (Δp$_{f.}$/L)$_A$ * L$_A$ = (Δp$_f$/L)$_B$ * L$_A$ = ...

٦- Next the dynamic pressure losses in each duct run are obtained based on the type of bends or fittings used in that run.

٧- Next the total pressure drop in each duct run is obtained by summing up the frictional and dynamic losses of that run,

i.e.   **ΔPA= ΔPfA+ΔPd,A   ΔPB=ΔPFB+ ΔPdB**

٨- Next the fan is selected to suit the index run with the highest pressure loss. Dampers are installed in all the duct runs to balance the total pressure loss.

Equal friction method is simple and is most widely used conventional method. This method usually yields a better design than the velocity method as most of the available pressure drop is dissipated as friction in the duct runs, rather than in the balancing dampers. This method is generally suitable when the ducts are not too long, and it can be used for both supply and return ducts. However, similar to velocity method, the equal friction method also requires partial closure of dampers in all but the index run, which may generate noise. If the ducts are too long then the octal pressure drop will be high and due to diapering, ducts near the fan get over-pressurized.
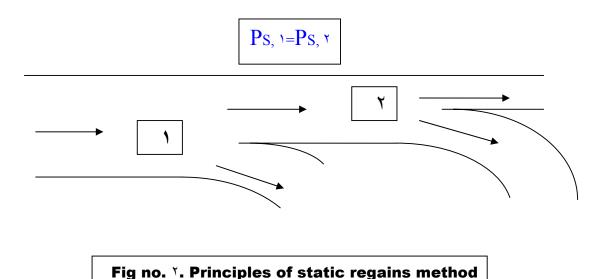
.٤.٣. Static Regain Method:

This method is commonly used for high velocity systems with long duct runs, especially in large systems. In this method the static pressure is maintained same before each terminal or branch. The procedure followed is as given below:
١- Velocity in the main duct leaving the fan is selected first.

٢- Velocities in each successive runs are reduced such that the gain in static pressure due to reduction in velocity pressure equals the frictional pressure drop in the next duct section. Thus the static pressure before each terminal or branch is maintained constant. For example, Fig.٢ shows a part of the duct run with two sections ١ and ٢ before two branch take-offs. The velocity at ١ is greater than that at ٢, such that the static pressure is same at ١ and ٢. Then using the static regain factor, one can write:

$$\Delta p_{f,٢} + \Delta p_{d,٢} = R(p_{v,١} - p_{v,٢})$$

where $\Delta p_{f,٢}$ and $\Delta p_{d,٢}$ are the frictional and dynamic losses between ١ and ٢, and $p_{v,١}$ and $p_{v,٢}$ are the velocity pressures at ١ and ٢ respectively.

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$$P_{S,\ 1} = P_{S,\ 2}$$

Fig no. ٢. Principles of static regains method

٣- If section ١ is the outlet of the fan, then its dimensions are known from the flow rate and velocity (initially selected), however, since both the dimensions and velocity at section ٢ are not known, a trial-and-error method has to be followed to solve the above equation, which gives required dimensions of the section at ٢.

٤- The procedure is followed in the direction of airflow, and the dimensions of the downstream ducts are obtained.

٥- As before, the total pressure drop is obtained from the pressure drop in the longest run and a fan is accordingly selected.

Static Regain method yields a more balanced system and does not call for unnecessary dampering. However, as velocity reduces in the direction of airflow, the duct size may increase in the airflow direction. Also the velocity at the exit of the longer duct runs may become too small for proper air distribution in the conditioned space.

.٥. Performance of duct systems:

For the duct system with air in turbulent flow, the total pressure loss (Δp_t) is proportional to the square of flow rate; i.e.

Total pressure drop ΔPt   (Q)²

Total pressure drop ΔPt = C (Q)²

Where C is the resistance offered by the duct system. Once the duct system is designed and installed, the value of C is supposed to remain constant. However, if the air filters installed in the duct become dirty and/or if the damper position is altered, then the value of C changes. Thus variation of total pressure drop with airflow rate is parabolic in nature as shown in Fig ٣. In this figure, the curve A refers to the performance of the duct at design conditions, while curve B refers to the performance under the conditions of a dirty filter and/or a higher damper closure and curve C refers to the performance when the damper is opened more.
From the duct characteristic curve for constant resistance, one can write

$$\frac{\Delta P_{t,1}}{\Delta P_{t,2}} = \frac{(Q_1)^2}{(Q_2)^2}$$

Thus knowing the total pressure drop and airflow rate at design condition one can obtain the total pressure drop at an off-design condition using the above equation.
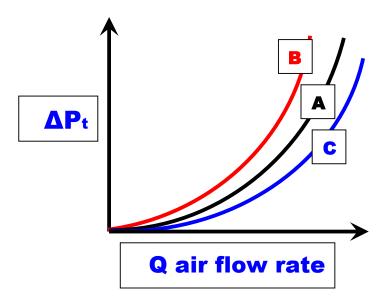
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ΔP$_t$

Q air flow rate

Fig no ٣.   Variation of total pressure with flow rate for a given duct system

The curve A refers to the performance of the duct at design conditions, while curve B refers to the performance under the conditions of a dirty filter and/or a higher damper closure and curve C refers to the performance when the damper is opened more.
        From the duct characteristic curve for constant resistance

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.٦. System balancing and optimization:

In large buildings, after the Air Handling Unit is installed, it has to be balanced for satisfactory performance. System balancing requires as a first step, measurements of actual airflow rates at all supply air outlets and return air inlets. Then the dampers are adjusted so that the actual measured flow rate corresponds to the specified flow rates. System balancing may also require adjusting the fan speed to get required temperature drop across the cooling or heating coils and required airflow rates in the conditioned zone. Balancing a large air conditioning system can be a very expensive and time consuming method and may require very accurate instruments for measuring air flow rates and temperatures. However, system balancing is always recommended to get the full benefit from the total cost incurred on air conditioning system.

Large air conditioning systems require optimization of the duct design so as to minimize the total cost, which includes the initial cost of the system and the lifetime operating cost. At present very sophisticated commercial computer software are available for optimizing the duct design. One such method is called as T-Method. The reader should refer to advanced textbooks or ASHRAE handbooks for details on duct optimization methods. ***Fig. ٣:*** *Variation of total pressure drop with flow rate for a given*
Duct system

.٧. Fans:

The fan is an essential and one of the most important components of almost all air conditioning systems. Thus a basic understanding of fan performance characteristics is essential in the design of air conditioning systems. The centrifugal fan is most commonly used in air conditioning systems as it can efficiently move large quantities of air over a large range of pressures. The operating principle of a centrifugal fan is similar to that of a centrifugal compressor. The centrifugal fan with forward-curved blades is widely used in low-pressure air conditioning systems. The more efficient backward-curved and airfoil type fans are used in large capacity, high-pressure systems.

.٧.١. Fan laws:

The fan laws are a group of relations that are used to predict the effect of change of operating parameters of the fan on its performance. **The fan laws are valid for fans, which are geometrically and dynamically similar**.

The fan laws have great practical use, as it is not economically feasible to test fans of all sizes under all possible conditions.
The important operating parameters of a fan of **fixed diameter** are:

١. Density of air (ρ) which depends on its temperature and pressure

٢. Operating speed of the fan (ω in r p s), and

٣. Size of the fan.

Here the fan laws related to the density of air and the relative speed of the fan are considered. The effect of the size of the fan is important at the time of designing the fan. For a given air conditioning system with fixed dimensions, fittings etc. it can be easily shown that:

Airflow rate, Q∝ω

Static pressure rise, ΔPs $\propto \dfrac{\rho V^٢}{٢}$

Fan power input W $\propto Q\,(\Delta Ps) + Q\left(\dfrac{\rho V^٢}{٢}\right)$ **Eqn. ١**

From the expression for fan power input (Eqn .١), it can be seen that the ١[st] term on the RHS accounts for power input required for increasing the static pressure of air and the ٢[nd] term on RHS accounts for the power input required to impart kinetic energy to air as it flows through the fan. Using the above relations, the following fan laws can be obtained.

 Law ١: Density of air ρ **remains constant** and the speed ω **varies**:

$Q \propto \omega$, $\Delta Ps \propto \omega^٢$, $W \propto \omega^٣$

Law ٢: Airflow rate **remains constant** and the density ρ **varies**:

$Q = constant$, $\Delta Ps \propto \rho$, $W \propto \rho$

Law ٣: Static pressure rise **Δp$_s$ remains constant** and density ρ **varies**:

Q ∝ ١/ (ρ)$^{١/٢}$, ΔPs∝ constant, ω∝١/ (ρ)$^{١/٢}$, W∝ ١/ (ρ)$^{١/٢}$

.٨. Interaction between fan and duct system:

Figure no .٤ shows the variation of FTP of a centrifugal fan (fan performance curve) and variation of total pressure loss of a duct system (duct performance curve) as functions of the airflow rate. As shown in the figure, the point of intersection of the fan performance curve and the duct performance curve yield the **balance point** for the combined performance of fan and duct system. Point ١ gives a balance point between the fan and duct system when the relative speed of fan is ω$_١$. At this condition the airflow rate is Q$_١$ and the total. Pressure loss which is equal to the FTP is Δp$_{t,١}$. Now if the flow rate is reduced to Q$_٢$, then the total pressure loss reduces to Δp$_{t,٢}$. To match the reduced flow rate and the reduced pressure loss, the speed of the fan has to be reduced to ω$_٢$ or the position of the inlet guide vanes of the centrifugal fan have to be adjusted to reduce the flow rate. This will give rise to a new balance point at ٢. Thus the fan and duct system have to be matched when there is a change in the operating conditions.
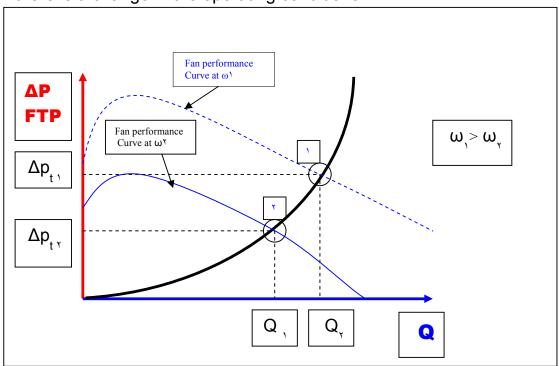

Fig no ٤. Fan and Duct performance curve and balance point