Duct Design using equal friction method & CFD
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ABSTRACT:
Earlier the use of air-conditioning for comfort purpose was considered a luxurious but now-a-day, it has been a necessity in extreme climatic conditions, such as extreme cold and hot in western countries. Window air conditioners are preferred for office rooms while large centralized units are installed for conditioning the auditorium, hospitals etc. The correct estimation of cooling load of an auditorium is very complicated due to many factors such as outdoor temperature, humidity, air leakage into the conditioned space, occupants, quantity of fresh air taken in and solar load etc. The authors have calculated cooling load, quantity of supply air (in cmm) of an auditorium using CLTD method which is more accurate. Equal friction method is adopted to design the duct which is simple as compared with the other duct design methods. Using CFD software, analysis of air flow considering velocity and pressure is done in main duct and in elbow. The authors concluded that the combine effect of proper duct design method & CFD could be used to achieve proper air distribution inside the auditorium with minimum pressure loss, running cost & energy consumption have calculated cooling load, quantity of supply air (in cmm) of an auditorium using CLTD method which is more accurate. Equal friction method is adopted to design the duct which is simple as compared with the other duct design methods. Using CFD software, analysis of air flow considering velocity and pressure is done in main duct and in elbow. The authors concluded that the combine effect of proper duct design method & CFD could be used to achieve proper air distribution inside the auditorium with minimum pressure loss, running cost & energy consumption

Keywords- duct, equal friction, CLTD, Cooling Load, CFD

INTRODUCTION

Without A/C system, person working in industry is feeling unhealthy, uncomfortable and inefficient. In order to achieve required cooling load, proper method is required. Proper air distribution is achieved with proper duct design which leads minimum losses in the system, suitable selection of fan with high efficiency, optimum air velocity in duct, inlet and outlet of fan. Today some software’s are available to estimate cooling load, to design the duct, to select the fan etc. Life has become easier due to AUTOCAD software to draw plant layout. CFD as a analysis tool has the ability to establish firm quantitative data regarding air motion and can predict fluid characteristics and pressure differentials to a very low level that are experimentally impossible during experimentation. Analysis of air flow in duct with static pressure and velocity pressure is made easier and faster in Fluent software. The requirement of air conditioner is that it must provide adequate cooling to the occupants in the conditioned space under a wide variety of ambient conditions. A normal healthy person feels comfortable at 25°C DBT, 50% RH with 9 to 12m/min air velocity. Human comfort is influenced with the physiological conditions determined by the internal heat generation.

Large number of researchers have worked on duct design with various methods. The contribution of various researchers on the topics is briefed as follows.

1. design for high velocity duct system is done by determining the pressure losses, calculating the noise level, determining the out of balance pressures & optimizing this against the total cost of the system.
2. VAV optimization procedure was applied to the three VAV duct systems to investigate the impact of varying airflow rates on the sizing of duct systems. For comparison purposes, other duct design methods, such as, equal friction, static regain, and the T-Meth, were also applied to the duct systems.
3. Design optimization of industrial ducts is achieved with CFD. The CFD analysis has offered a comprehensive range of output including velocity distribution, pressure profiles and turbulence levels

The main purpose of this paper is make proper calculation of cooling load, supply air quantity using proper method, decide size of main duct & elbow using proper duct design method so person seating in the auditorium can feel comfortable.

THEORY

Cooling Load Temperature Differential (CLTD) / Cooling Load Factors (CLF) / Solar Cooling Load (SCL) is used to calculate the cooling load of an auditorium. It was an attempt to simplify two steps TFM & TETD /TA methods into a single step technique that allowed proceeding directly from raw data to cooling load. A series of factors were
taken from cooling load calculation results as ‘Equivalent Temperature Difference’ for use in traditional condition (\( q = UA \Delta T \)) equation. The conditioned air (cooled or heated) from the air conditioning equipment must be properly distributed to rooms or spaces to be conditioned in order to provide comfort conditions. When the conditioned air cannot be supplied directly from the air conditioning equipment to the spaces to be conditioned, then the ducts are installed. The duct systems convey the conditioned air from air conditioning equipment to proper air distribution points or air supply outlets in the room and carry the return air from the room back to the air conditioning equipment for reconditioning and recirculation. The conditioned air (cooled or heated) from the air conditioning equipment must be properly distributed to rooms or spaces to be conditioned in order to provide comfort conditions. It may be noted that duct system for proper distribution of conditioned air cost nearly 20 to 30 % of total cost of equipments required.

ii) Velocity Reduction Method

iii) Static Regain Method

In Equal Friction Method the frictional pressure drop per unit length of the duct is maintained constant throughout the duct system. Due to its simplicity, this method is used in the thesis to design the duct.

**Cooling Load Calculation for an Auditorium:**

<table>
<thead>
<tr>
<th>Data collected for an existing auditorium, Pune</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No. of doors : 9 Entry and exit.</td>
</tr>
<tr>
<td>1. Back stage.</td>
</tr>
<tr>
<td>2. No. of windows : 8</td>
</tr>
<tr>
<td>3. No. of Chairs:</td>
</tr>
<tr>
<td>Dress circle</td>
</tr>
<tr>
<td>Balcony</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

4. Equipments : Total item having 11.78 KW

**DESIGN CONDITIONS**

1. Latitude of Pune : 18°6´ North.
2. Design Day : 25th May. (Max. temperature during last week of may, from last 5 years data.)
3. Outside conditions : DBT = 38° C
   *RH* = 50%
4. Indoor conditions : DBT = 22°
   *RH* = 55%
5. Daily range (DR) : 10°
6. Time : 4:00 pm
7. Average outside temperature on design day;
   \( T_e = T_o - (DR/2) = 38 - (10/2) = 91.6° F \)

**TOTAL COOLING LOAD**

\[
\text{Total} = Q_s + Q_t = 2.55 + 4.54 = 7.09 \text{ kW}
\]

Total sensible load on cooling coil = 248132.64 W

Total latent load on cooling coil = 276989.83 W

Therefore, Total cooling coil load = 525122.47 W

Therefore, Refrigeration load = 525122.47/3.516 = 150TR

Safety factor of 5% due to duct heat gain

Therefore,

\[
\text{Cooling load} = 157.5 \text{ TR} \approx 160 \text{ TR}
\]
Assuming by-pass factor (BPF) 0.15, mass flow rate is calculated. Mass flow rate of air, \( m = 19.28 \, \text{kg/s} \) (cmm) = 1288.88 \approx 1290

**CALCULATION OF FRICTION LOSS IN DUCT & DUCT DIAMETER**

Rearranging fanning equation, Colebrook-White relation & Fritzsche relation

\[
\Delta P_f = \left(0.0142 C^{1.852} L\right) / D^{1.269}
\]

\[
\Delta P_f = \left(0.002268 Q_v^{1.852} L\right) / D^{4.973} \, \text{mm of H}_2\text{O}
\]

\[
\Delta P_f = \left(0.012199 C^{2.4865} L\right) / Q_v^{0.6343} \, \text{N/m}^2
\]

Recommended velocity in duct for auditorium, \( C = 6.5 \, \text{m/s} \) or 390 mpm

So, \( \Delta P_f / L = 0.36629 \, \text{N/m}^2 / \text{m} \)

\( = 0.03669 \, \text{mmH}_2\text{O/m} \approx 0.04 \, \text{mmH}_2\text{O/m} \)

\( = 0.04 \, \text{in. w./100 ft} \) (in industry standard value for pressure loss = 0.1 in.w./100 ft. = 0.846 N/m²/m)

**Circular Duct Diameter = 1.187 m**

For rectangular duct dimension, minimum aspect ratio 1.3 is taken. \( a/b = 1.3 \) (a= width, b= height)

(it should be kept as low as possible to keep friction losses reasonably low and thereby avoid excess energy consumption.)

\( D = 1.265 \left(a + b\right)^{0.6} / \left(a + b\right)^{0.2} \)

Large dimension(a)=1.24 m & small dimension(b) = 0.9543 m

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**DUCT DESIGN USING EQUAL FRICTION METHOD**

First measurement of all dimensions are done for auditorium and with AUTOCAD software, drawings are made (front view and top view). It is shown below

In the equal friction method, the frictional pressure drop per unit length of the duct is maintained constant throughout the duct system. The procedure is to select a suitable velocity in the main duct from sound level considerations. Knowing the air flow rate and the velocity in the main duct, the size and friction loss are determined from the friction chart. The remaining ducts are then sized maintaining the friction loss per unit length at this value for their respective air-flow rates.

Due to 3 fans in the system, there will be 3 main supply ducts. The air supply from three main ducts goes to three different areas

i) First main duct – balcony and remaining area (excluding stage) of one side

ii) Second main duct - balcony and remaining area (excluding stage) of other side

iii) Third main duct - stage
Layout of First Main Duct (Supply Duct)
Flow rate = 15524 CFM = 7.2 m³/s,
\[ \Delta P_f = 0.04 \text{ mm } H_2O/m = 0.4 \text{ N/m}^2/m \]

Fig. 3: Layout of First Main Duct (Supply Duct)

Branch A
From main duct to first supply outlet, Flow rate = 2.5 m³/s = 5390 CFM
\[ \Delta P_f = 0.04 \text{ mm } H_2O/m = 0.4 \text{ N/m}^2/m \]
Recommended branch duct Velocity = 4.5 m/s
So from friction chart of duct
Diameter of duct = \( D = 32'' = 0.8128 \text{ m} \)
For rectangular duct, \( a/b = 1.3 \)
\[ D = 1.3(a+b)^{0.625}/(a+b)^{0.25} \]
From this equation, we get \( a = 0.85 \text{ m} \) \( b = 0.65 \text{ m} \)

CFD Analysis:
Duct design is done using equal friction method. For CFD analysis, Fluent 6.1 software is used. Gambit 2.0 is used for modeling the main duct and elbow. Geometry and meshing is carefully done in Gambit. Pressure and velocity variations are observed in this analysis. Eddies observed in elbow are due to improper shape and velocity. All figures from geometry, boundary condition to eddy are given here. This CFD tool can be used for a whole building to analyze air pressure and velocity fluctuation in all ducts

Fig. 6: Analysis of Elbow considering inlet Velocity

RESULT ANALYSIS
The result analysis is based on duct design of auditorium and existing plant. Comparison among these plants can be made with some points.
1) Duct size: To design the duct in an auditorium calculation of cooling load and air flow rate is done. By assuming suitable air velocity (from 1967 systems and equipment ASHRAE Handbook) considering noise factor, calculation of main duct is done. Then size of rectangular duct is calculated considering minimum aspect ratio.
So maximum care is taken to apply standard rules to design the system. Variation occurred in some points are given below

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Points</th>
<th>Plant 1</th>
<th>Plant 2</th>
<th>Auditorium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Capacity of plant</td>
<td>100 TR</td>
<td>100 TR</td>
<td>160 TR</td>
</tr>
<tr>
<td>2</td>
<td>Ducts</td>
<td>Three main ducts</td>
<td>One main ducts</td>
<td>Three main ducts</td>
</tr>
<tr>
<td>3</td>
<td>Main Duct size</td>
<td>1.2 m* 0.9 m</td>
<td>1.62 m* 1.21m</td>
<td>1.24m* 0.95m</td>
</tr>
</tbody>
</table>

II) Branch ducting:
Branch connection with low pressure are used.

III) Equal friction method is used in industry or in existing design or in an auditorium. But equal frictional pressure drop used in industry is 0.1 in.w./100ft. or 0.846 N/m²/m, while designing of an auditorium, 0.04 in. w / 100 ft. or 0.4 N/m²/m is used. Practical knowledge is very important to study and make some conclusion about this point.

IV) Aspect Ratio: It is kept minimum in each design
V) CFD Analysis: It is a new tool which is applied to observe air motion through straight duct and elbow. Also it can be applied for all ducting in a building. Due to improper shape and velocity, eddies are observed in elbow with CFD analysis. so by proper shape, eddies are minimized. Analysis of all ducting...
and fan will reduce pressure loss, noise and obviously it saves time and cost. So CFD is best tool for HVAC system.

**CONCLUSION:**

The following conclusions summarize the experimental results presented in this paper.

1) The cooling load calculation of an auditorium is done, applying CLTD method and duct design is carried out by equal friction method. All results are comparable with existing plant.

2) The calculated value of frictional pressure drop is less as compared to existing plant or value used in industry. Due to less value, duct diameter is increased but loss in static pressure, velocity pressure can be avoided. Smaller diameter of duct would increase noise level. So requirement of sound attenuating devices may need. Also probability of dampers is decreased with increasing diameter. But first cost is increased with increasing duct diameter.

3) Due to proper branching (with elbow) of ducts, loss is minimized in this design. But in existing plant, there is straight branching in so many locations, which may increase the pressure loss.

4) Aspect ratio is kept minimum in this design. So friction loss and excess energy consumption is decreased.

5) Pressure loss in duct fitting is kept minimum by using elbow with proper shape considering very less pressure loss coefficient.

6) CFD software is used to analyze the air flow in straight duct and in elbow. Eddies are observed due to incorrect shape of elbow. So proper shape of elbow and correct velocity are estimated to minimize the eddies as well as pressure loss.

7) CFD can be used to study pressure and velocity fluctuation for a whole building. So it is a better tool which can be used in HVAC system to save time and cost.

**ACKNOWLEDGEMENT**

Valuable information & layout of plant 1 & 2 is taken from existing central air-conditioning plant in Pune.

**REFERENCES**
