Pipe & Duct Design

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Agenda

Pipe design

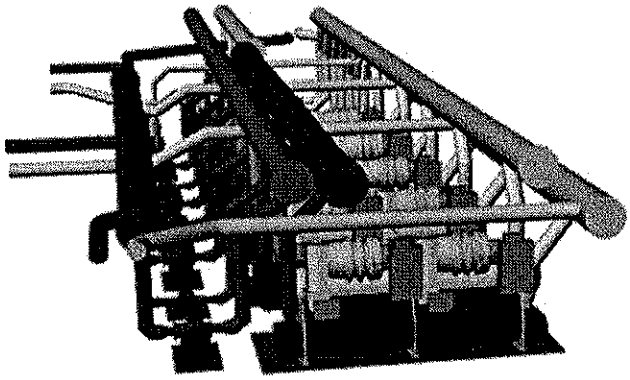
1. Introduction to Pipe Design
2. Pipe Circuit Layout
3. Pipe Design Considerations
4. Pipe Pressure Drop & Sizing
5. Pump Head Calculation
6. Case Comparison

Duct design

1. Introduction to Duct Design
2. Duct Design Considerations
3. Duct Pressure Drop & Duct Sizing

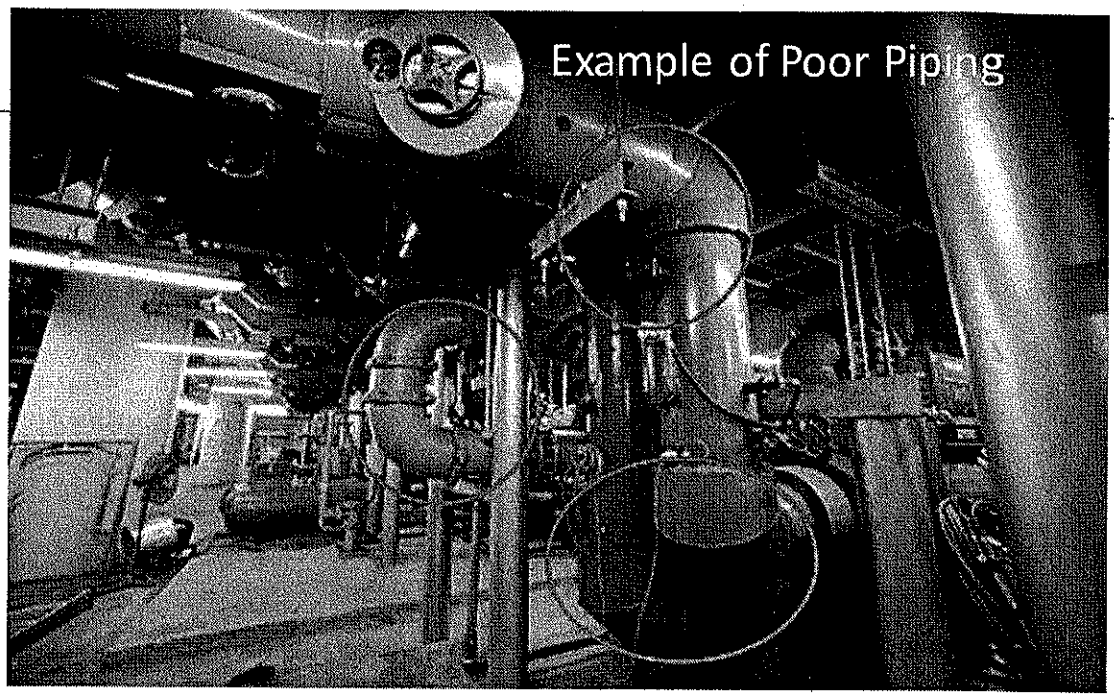
INTRODUCTION TO PIPE DESIGN

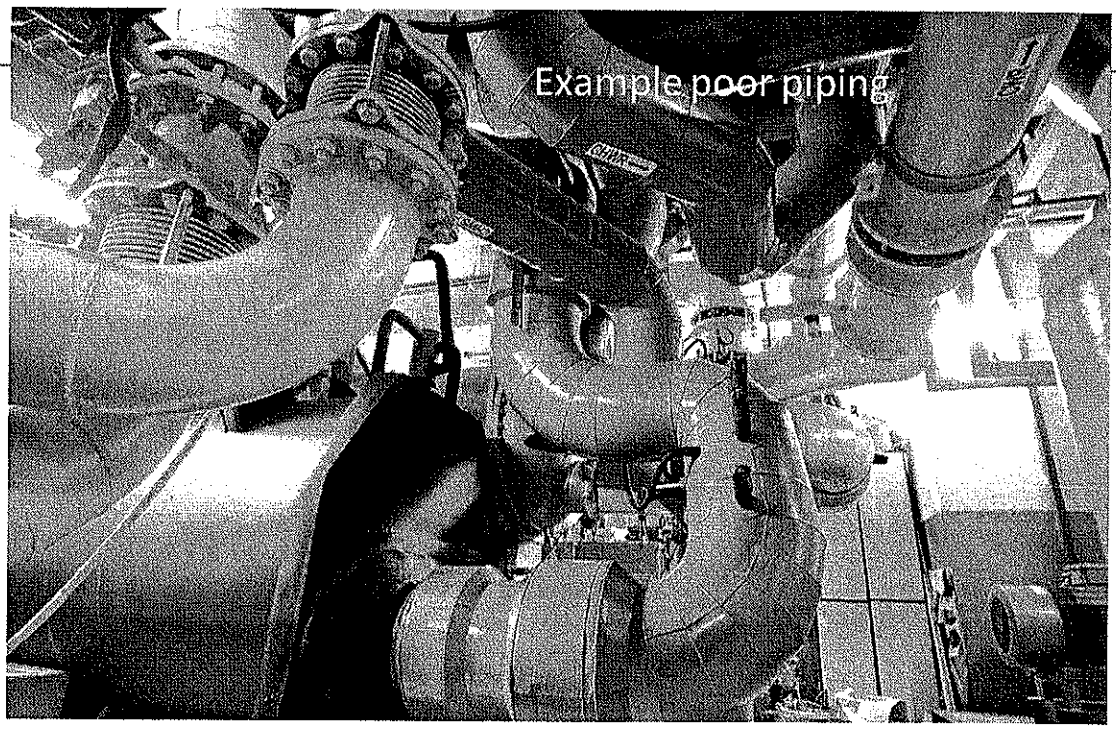
Pipe Design is an art as much as it is a science



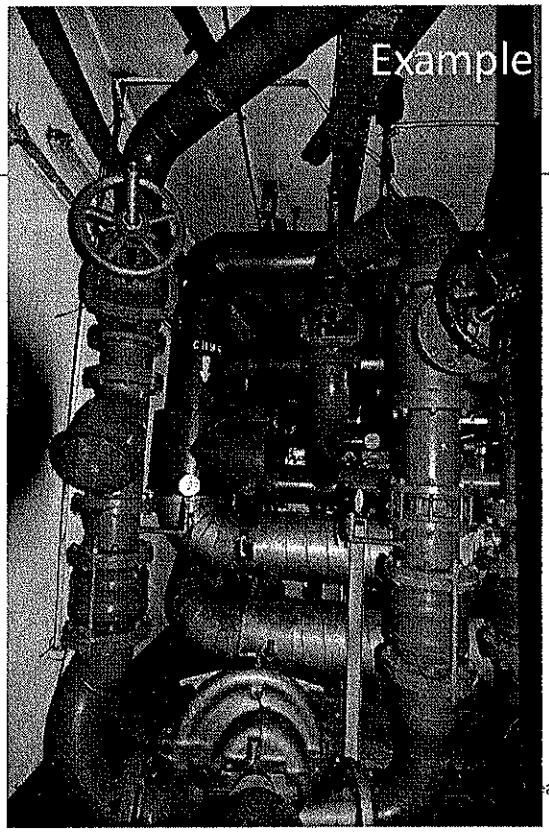
Why Good Ducting & Piping Design is Important?

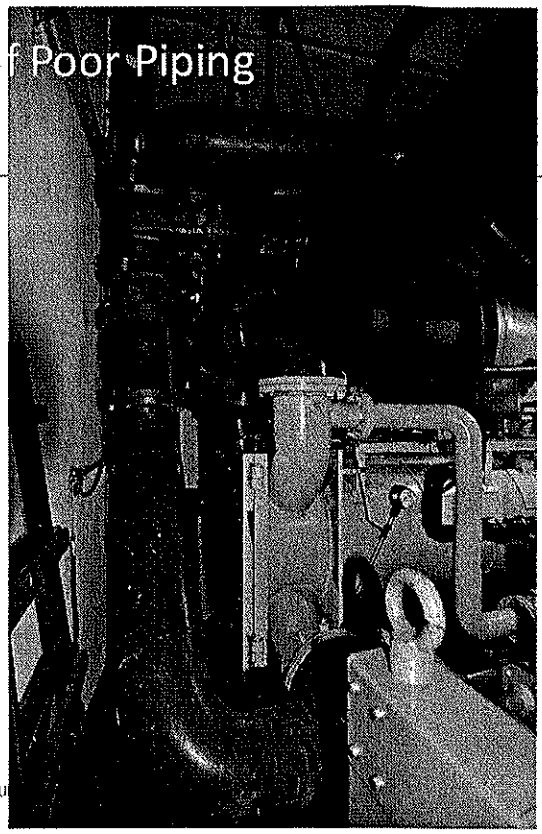
1. Design optimized system to save energy & reduce CO2 emissions
2. Allows selection of high efficiency fan & pump to save energy
3. Ensure good air & water circulation for comfort
4. Minimize space requirements
5. Minimize noise
6. Minimize 1st cost


Example of Poor Piping


Example poor piping

Example of Poor Piping







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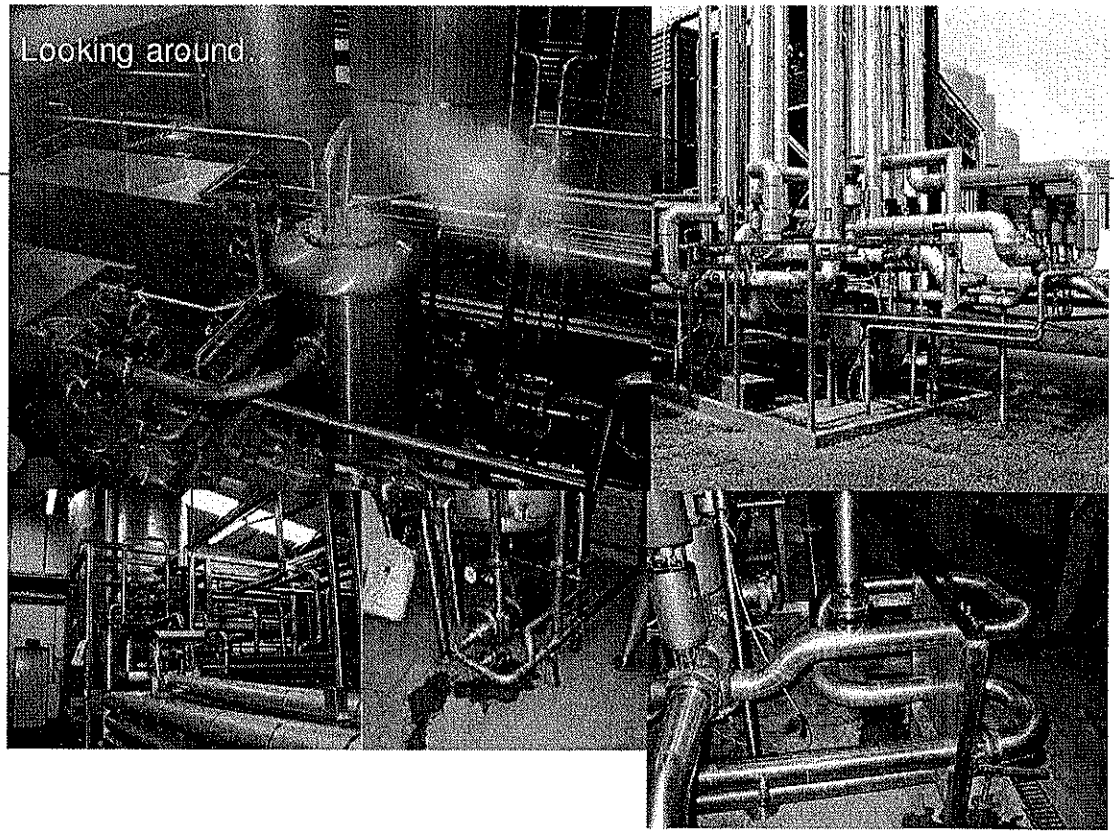
Looking around..



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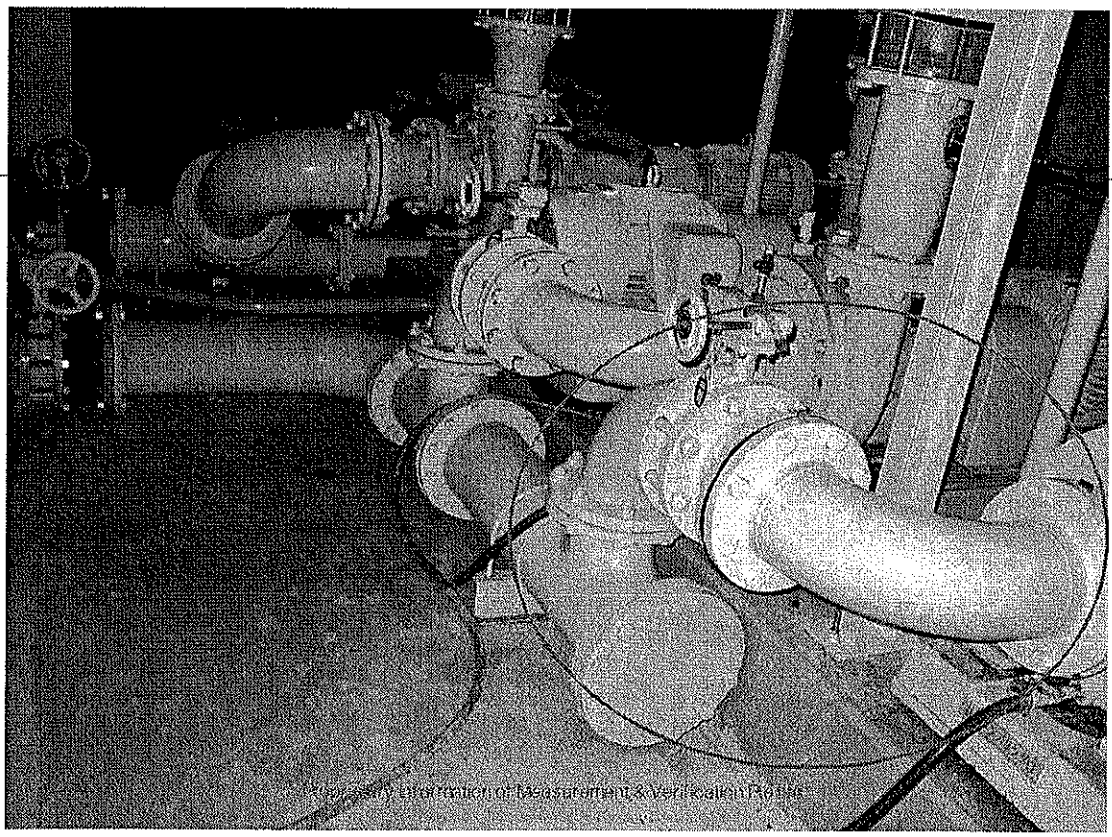

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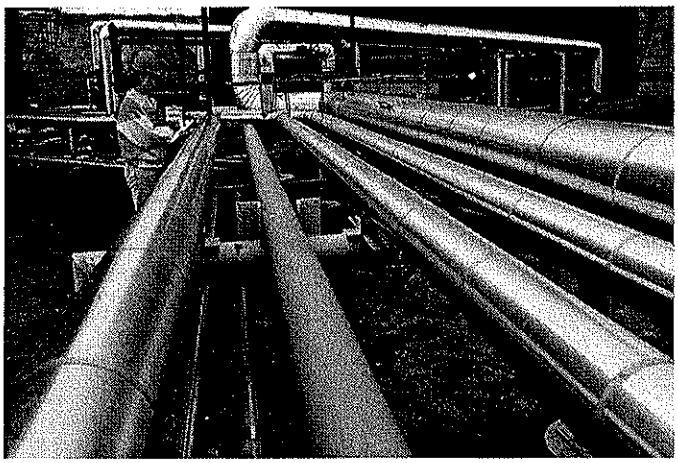
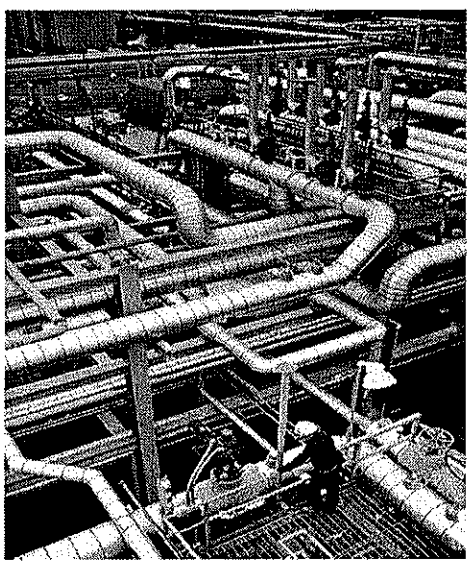
New Design Mentality



1. Big Pipes, Small Pumps

New Design Mentality

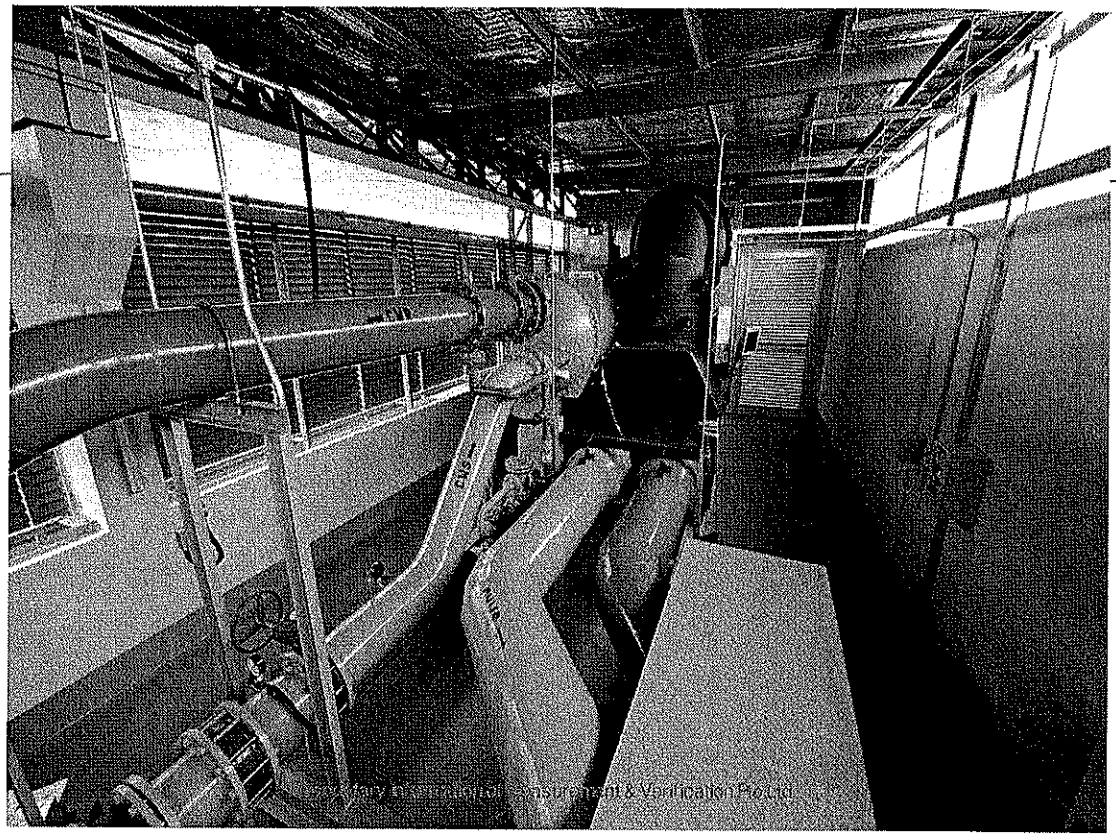


2. Lay out the pipes first, then the equipment

Fat, short, straight pipes

Not skinny, long, crooked pipes!

No new technologies, just two design changes



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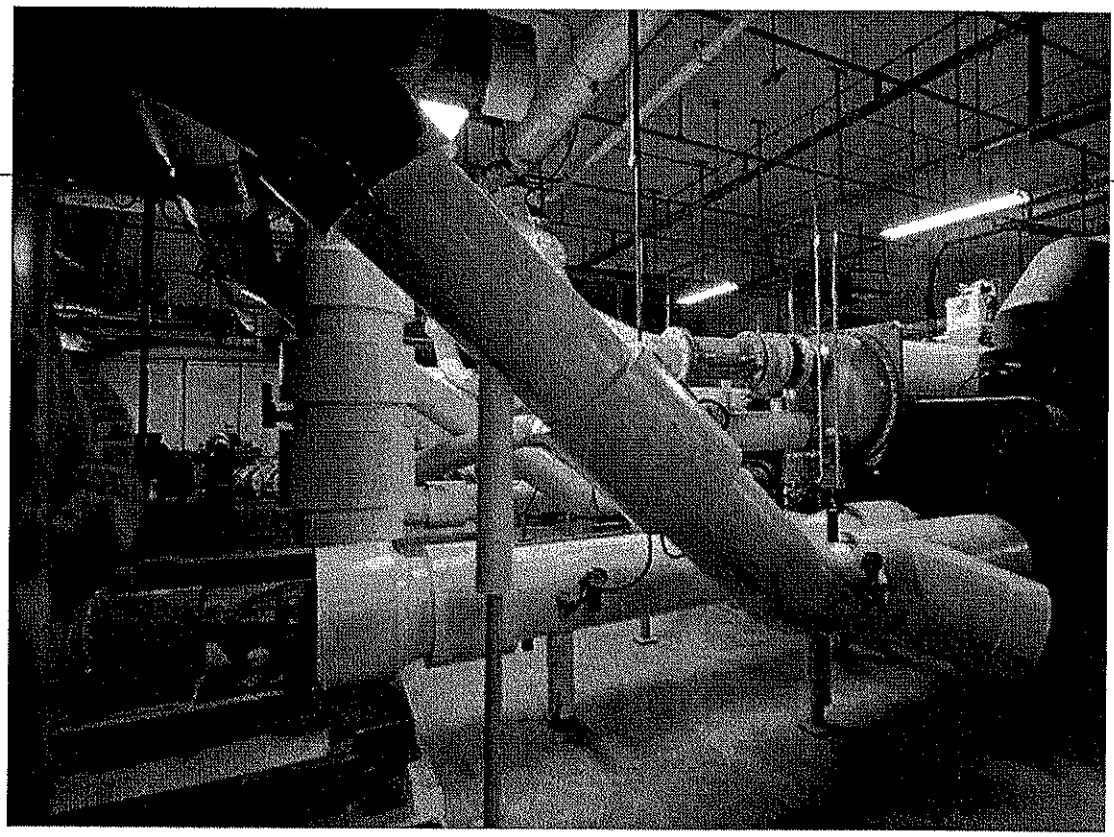

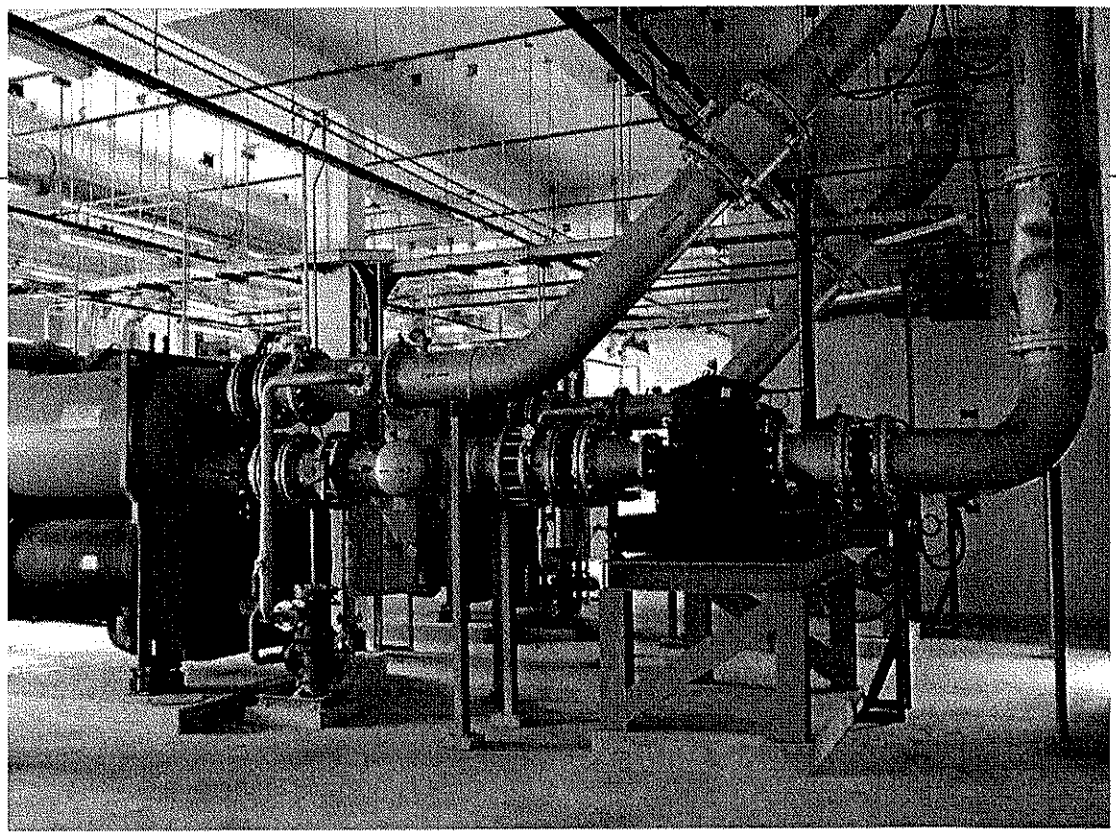

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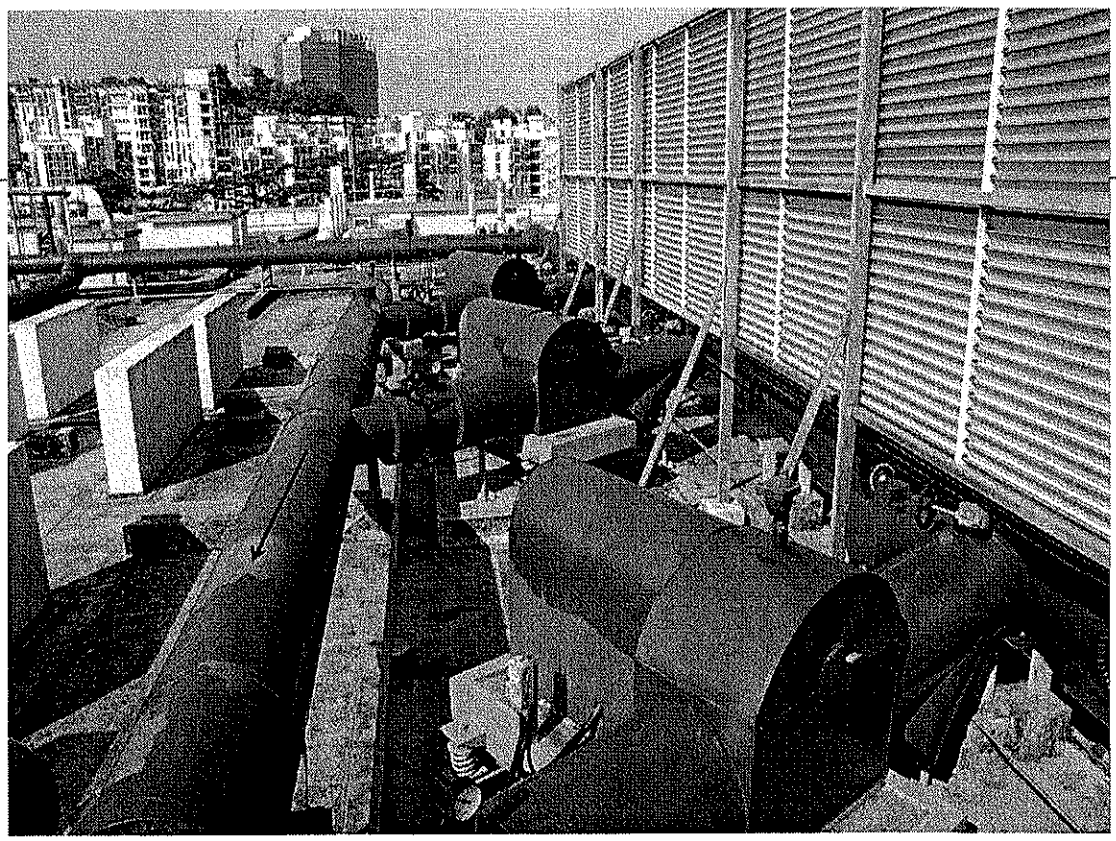

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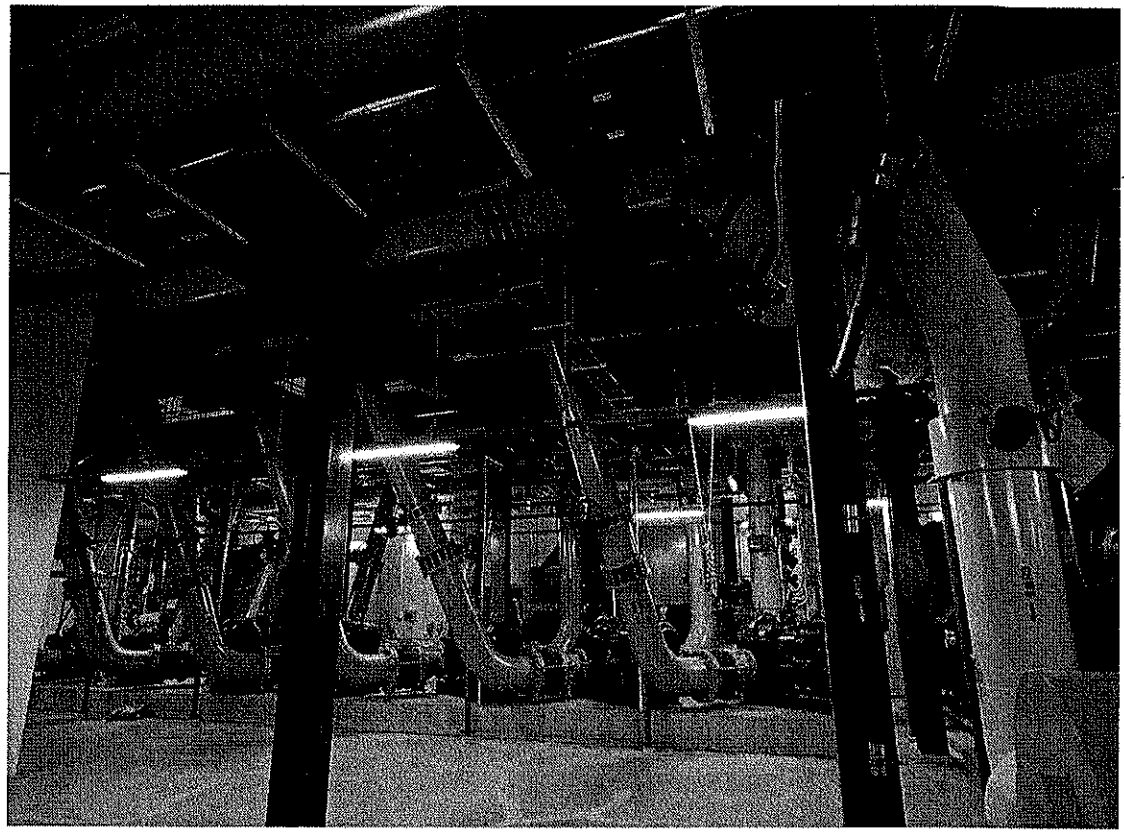

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PIPE CIRCUIT LAYOUT

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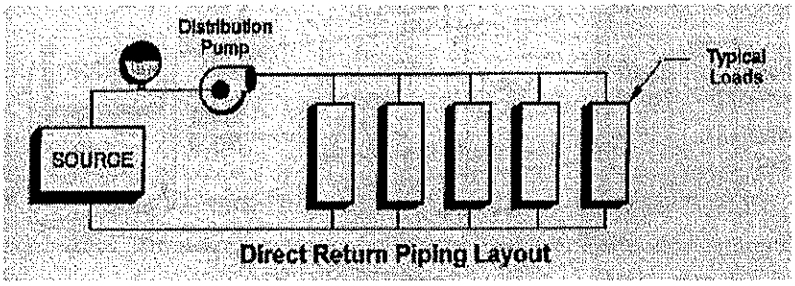
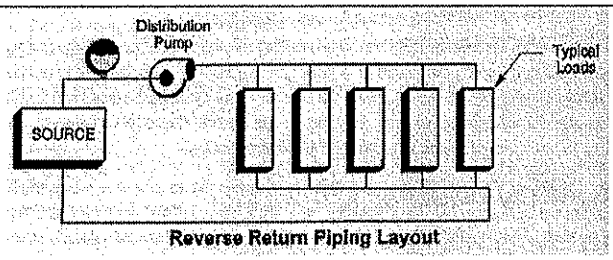
Pipe Circuit Layout



- The length of supply and return piping through the sub-circuits is unequal. It may cause unbalanced flow rates and require careful balancing to provide each sub-circuit with design flow

- Widely applied by using control valves, providing balancing devices, and minimizing distribution piping pressure drop.

Pipe Circuit Layout



- This layout provides nearly equal total lengths for all terminal circuits by using the extra piping to balance pressure drops between nearby and faraway coils. The closest coil has the shortest supply piping and the longest return piping which the farthest coils has the opposite, requires longer piping length which would drive the cost higher

- Not suitable for bigger chilled water loops having different sub-circuit head losses.

PIPE DESIGN CONSIDERATIONS

Pipe Design Considerations

Good piping design always balances first cost against future operating cost, taking the erosion, noise generation, installation into consideration.

- Location of pipe in the system: critical circuit that determines pump head
- First costs of installed piping
- Pump energy cost: pump motor efficiency, distribution system type, type of pump control, annual flow profile
- Erosion considerations: high velocities can contribute to hastening of pipe wall deterioration
- Noise considerations: control noise generation from turbulence, cavitation, release of entrained air, and water hammer
- Physical constraints
- Budget constraints

Pipe Design Considerations

Code requirements

Type	Load Condition	Min eff	Units	Remarks
CHWP	Full load	349	KW / m^3/s	
		0.053	KW / RT	=(349KW/m^3/s) x(2.4gpm/RT) x (0.0000631 m^3/s / gpm)
	Part load	Motors exceeding 15KW must modulate to 50% of design flow @ no more than 30% of design KW		
CWP	Full load	301	KW / m^3/s	
		0.057	KW / RT	=(301KW/m^3/s) x (3gpm/RT) x (0.0000631 m^3s / gpm)
	Part load	Motors exceeding 15KW must modulate to 50% of design flow @ no more than 30% of design KW		

Good practice ⇒ < less than 0.03 kW/RT

PIPE PRESSURE DROP & PIPE SIZING

Pipe Pressure Drop Equations

Darcy-Weisbach Equation

Predicts the pressure drop or " head loss" of a steady-state, incompressible fluid flowing through a length of pipe.

$$H = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

where...
H = head loss, ft wg
f = friction factor, dimensionless
L = actual pipe length **plus** equivalent length for valves and fittings, ft
V = fluid velocity, fps
D = pipe diameter, ft
g = gravitational acceleration constant, 32.1740 ft/s↑2

Pipe Pressure Drop Equations

Moody formula

Uses the Reynolds number and the roughness factor of the pipe, when known, to determine the friction factor.

$$f = 0.0055\left[1 + \left(20{,}000\,\frac{\varepsilon}{D} + \frac{1{,}000{,}000}{Re}\right)^{0.33}\right]$$

where...
f = friction factor, dimensionless
ε = pipe roughness, ft
D = pipe diameter, ft
Re = Reynolds number, dimensionless

$$Re = \frac{D \times V \times \rho}{\mu}$$

where...
D = diameter, ft
V = fluid velocity, fps
ρ = density, lb/cu ft
μ = dynamic viscosity, lb/ft-sec

Pipe Friction Calculation

1. For simplicity, a lot of pressure loss charts for different pipes are presented in pipe design handbooks.

   Ps = Length * Pressure drop per length

2. ASHRAE general design guide :

- Pipe friction loss used is between 1 and 4 ft of water per 100 ft of pipe, wider ranges may be used in specific designs if certain precautions are taken
- Pipe velocity limit is 4 fps for 2 in. pipe and smaller. Velocities in excess of 4 fps can be used in piping of larger size.

3. It is designer's responsibility to determine pipe size, maximum velocity, and the friction loss.

Open loop pipe sizing has higher losses due to corrosion compensation.

1" WG ≈ 3 kPa (1 feet)

use 1~2" per 100 ft

ASHRAE Standard 90.1-2007 Addendum

Operating hr/yr	<=2,000 hr/year		>2,000 and <4,400 hr/year		>4,400 and ≤5,760 hr/year	
Nominal Pipe Size (in.)	Other	Variable Flow/ Variable Speed	Other	Variable Flow/ Variable Speed	Other	Variable Flow/ Variable Speed
2 1/2	120	180	85	130	68	110
3	180	270	140	210	110	170
4	350	530	260	400	210	320
5	410	620	310	470	250	370
6	740	1,100	570	860	440	680
8	840	1,300	650	970	510	770
10	1,800	2,700	1,300	2,000	1,000	1,600
12	2,500	3,800	1,900	2,900	1,500	2,300
Maximum Velocity for Pipes Over 12 in. Size	8.5 fps	13.0 fps	6.5 fps	9.5 fps	5.0 fps	7.5 fps

Table 2: From Standard 90.1-2007, Table 6.5.4.5 "Piping System Design Maximum Flow Rate in Gallons Per Minute."

Recommended max flow rate in gpm

CHART 3—FRICTION LOSS FOR CLOSED PIPING SYSTEMS

Schedule 40 Pipe

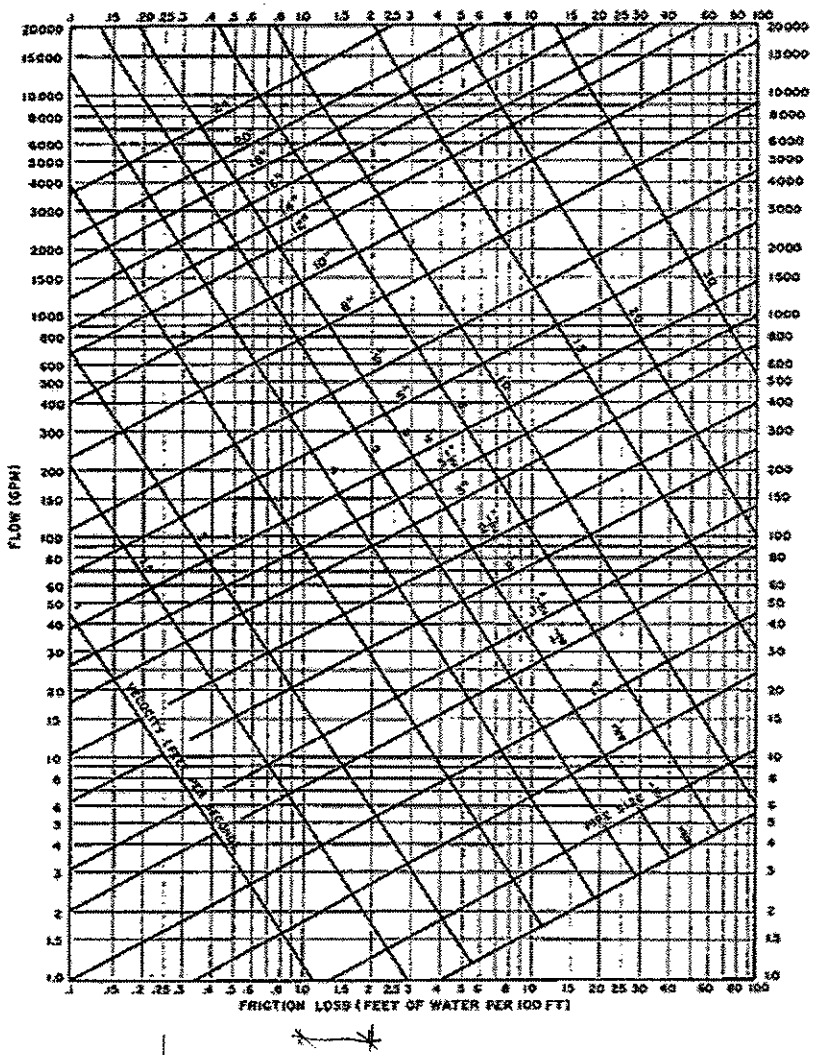
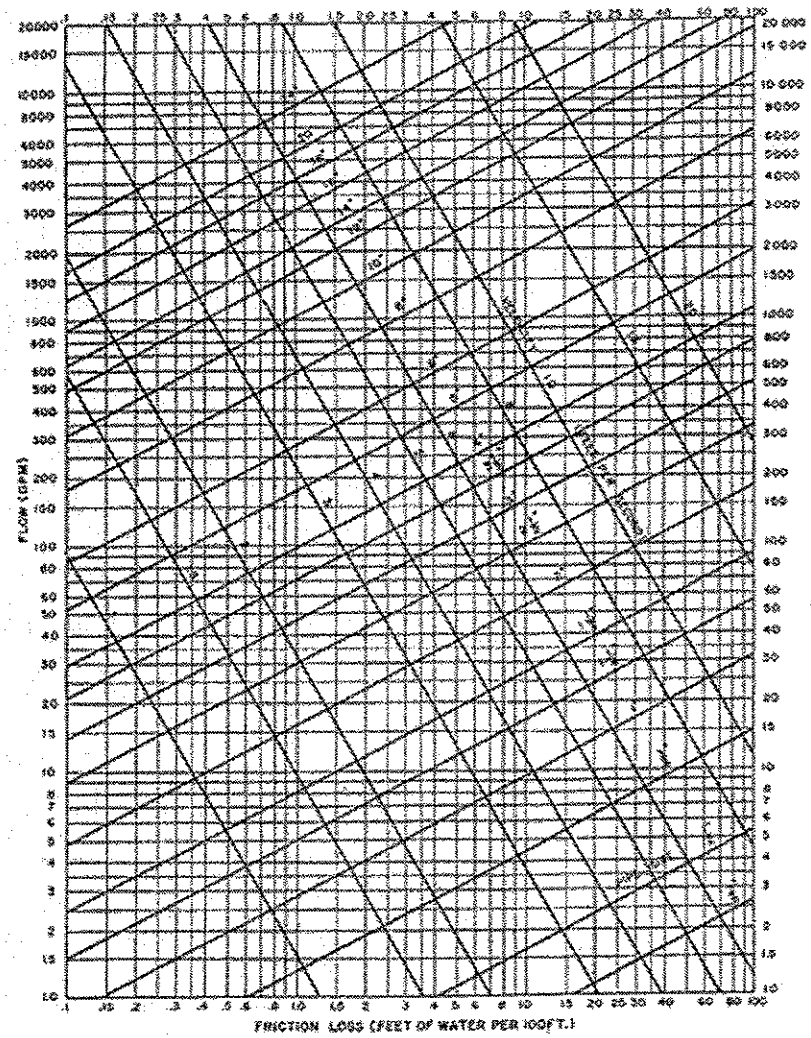


CHART 4—FRICTION LOSS FOR OPEN PIPING SYSTEMS

Schedule 40 Pipe



Pipe Fitting Pressure Drop

1. Equivalent length: determine the pressure drop for the fittings in a length of pipe, convenient to use, ASHRAE published equivalent lengths for various fittings and tabulated against diameter and velocity.

   Pf = Equivalent length * Pressure drop per length

2. Loss coefficient : dependent solely on velocity which is governed by the actual internal diameter of the particular fitting

IP Units

$$Pf = \frac{K \times Q^2}{D^4 \times 385}$$

Pf : Friction loss, FT WG
K: Friction factor
Q: Flow rate, GPM
D: Pipe diameter, in

SI Units

$$Pf = \frac{800000 \times K \times Q^2}{D^4}$$

Pf : Friction loss, KPa
K: Friction factor
Q: Flow rate, L/S
D: Pipe diameter, mm

Equivalent Length Table

Nom. Pipe Size (inches)	Angle Valve	Ball Valve	Check Valve	Gate Valve	Globe Valve	Elbow	Strainer
3/8	6.0	1.4	5.0	0.6	17.0	0.9	n/a
1/2	7.0	1.6	6.0	0.7	18.0	1.0	3.0
3/4	9.0	2.0	8.0	0.9	22.0	1.4	4.0
1	12.0	2.6	10.0	1.0	29.0	1.7	5.0
1-1/4	15.0	3.3	14.0	1.5	38.0	2.3	6.0
1-1/2	18.0	4.0	16.0	1.8	43.0	2.6	10.0
2	24.0	5.0	20.0	2.3	55.0	3.3	14.0
2-1/2	29.0	6.0	25.0	2.8	69.0	4.1	20.0
3	35.0	7.5	30.0	3.2	84.0	5.0	40.0
4	47.0	10.0	40.0	4.5	120.0	6.7	60.0
5	58.0	13.0	50.0	6.0	140.0	8.2	80.0
6	70.0	16.0	60.0	7.0	170.0	10.0	110.0
8	85.0	20.0	80.0	9.0	220.0	13.0	150.0
10	105.0	25.0	100.0	12.0	280.0	16.0	190.0
12	130.0	30.0	120.0	13.0	328.0	19.0	250.0
14	155.0	34.0	135.0	15.0	360.0	23.0	n/a
16	180.0	38.0	150.0	17.0	410.0	26.0	n/a
18	200.0	42.0	165.0	19.0	460.0	29.0	n/a
20	235.0	50.0	200.0	22.0	520.0	33.0	n/a
24	265.0	60.0	240.0	25.0	610.0	40.0	n/a

Units: FT

from 1985 *ASHRAE Handbook of Fundamentals*, Chapter 34

NOTE

- ⇒ All valves, regardless of type, are assumed to be in the full-open position.
- ⇒ Losses for check valves apply to both swing-type and ball-type designs.
- ⇒ Losses for angle valves and globe valves do not apply designs with needle-point seats.
- ⇒ Losses for elbows apply to 90-degree "long" designs with a radius-to-diameter ratio approximating 1.5.

Loss Coefficient K Charts

Table 1 *K* Factors—Threaded Pipe Fittings

Nominal Pipe Dia., in.	90° Standard Elbow	90° Long-Radius Elbow	45° Elbow	Return Bend	Tee-Line	Tee-Branch	Globe Valve	Gate Valve	Angle Valve	Swing Check Valve	Bell Mouth Inlet	Square Inlet	Projected Inlet
3/8	2.5	—	0.38	2.5	0.90	2.7	20	0.40	—	8.0	0.05	0.5	1.0
1/2	2.1	—	0.37	2.1	0.90	2.4	14	0.33	—	5.5	0.05	0.5	1.0
3/4	1.7	0.92	0.35	1.7	0.90	2.1	10	0.28	6.1	3.7	0.05	0.5	1.0
1	1.5	0.78	0.34	1.5	0.90	1.8	9	0.24	4.6	3.0	0.05	0.5	1.0
1-1/4	1.3	0.65	0.33	1.3	0.90	1.7	8.5	0.22	3.6	2.7	0.05	0.5	1.0
1-1/2	1.2	0.54	0.32	1.2	0.90	1.6	8	0.19	2.9	2.5	0.05	0.5	1.0
2	1.0	0.42	0.31	1.0	0.90	1.4	7	0.17	2.1	2.3	0.05	0.5	1.0
2-1/2	0.85	0.35	0.30	0.85	0.90	1.3	6.5	0.16	1.6	2.2	0.05	0.5	1.0
3	0.80	0.31	0.29	0.80	0.90	1.2	6	0.14	1.3	2.1	0.05	0.5	1.0
4	0.70	0.24	0.28	0.70	0.90	1.1	5.7	0.12	1.0	2.0	0.05	0.5	1.0

Source: Engineering Data Book (Hydraulic Institute 1979).

Table 2 *K* Factors—Flanged Welded Pipe Fittings

Nominal Pipe Dia., in.	90° Standard Elbow	90° Long-Radius Elbow	45° Long-Radius Elbow	Return Bend Standard	Return Bend Long-Radius	Tee-Line	Tee-Branch	Globe Valve	Gate Valve	Angle Valve	Swing Check Valve
1	0.43	0.41	0.22	0.43	0.43	0.26	1.0	13	—	4.8	2.0
1-1/4	0.41	0.37	0.22	0.41	0.38	0.25	0.95	12	—	3.7	2.0
1-1/2	0.40	0.35	0.21	0.40	0.35	0.23	0.90	10	—	3.0	2.0
2	0.38	0.30	0.20	0.38	0.30	0.20	0.84	9	0.34	2.5	2.0
2-1/2	0.35	0.28	0.19	0.35	0.27	0.18	0.79	8	0.27	2.3	2.0
3	0.34	0.25	0.18	0.34	0.25	0.17	0.76	7	0.22	2.2	2.0
4	0.31	0.22	0.18	0.31	0.22	0.15	0.70	6.5	0.16	2.1	2.0
6	0.29	0.18	0.17	0.29	0.18	0.12	0.62	6	0.10	2.1	2.0
8	0.27	0.16	0.17	0.27	0.15	0.10	0.58	5.7	0.08	2.1	2.0
10	0.25	0.14	0.16	0.25	0.14	0.09	0.53	5.7	0.06	2.1	2.0
12	0.24	0.13	0.16	0.24	0.13	0.08	0.50	5.7	0.05	2.1	2.0

Source: Engineering Data Book (Hydraulic Institute 1979).

http://chemicalengineeringnow.com/Equivalentlengths.aspx

http://www.tlv.com/global/TI/calculator/math-pressure-loss-through-

PUMP HEAD CALCULATION

Pump head Calculation

$$H_p = H_L + H_E + H_F$$

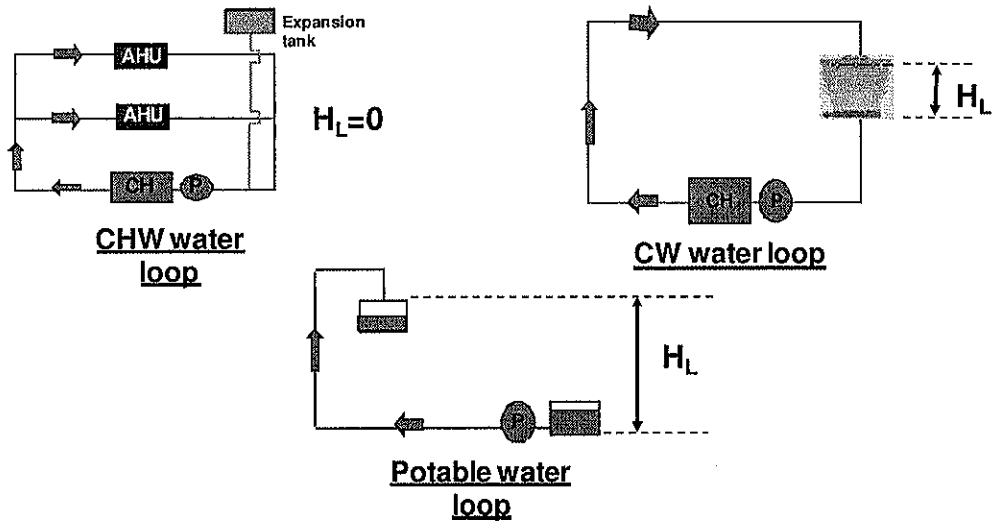
H_p: Pump head

H_L: Static lift

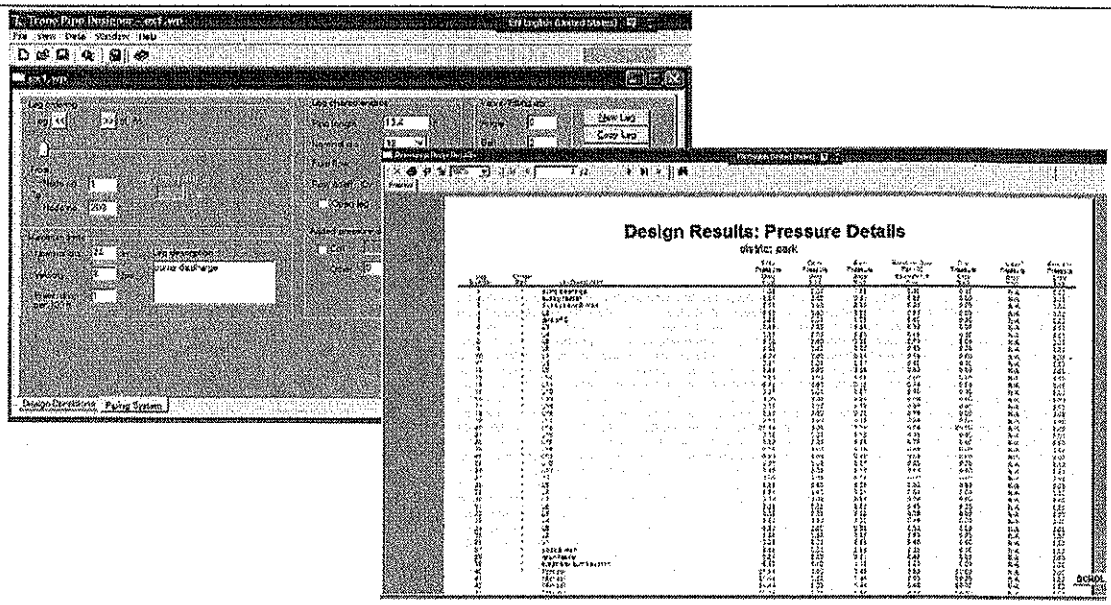
H_E: Equipment friction loss at design flow

H_F: Pipe and fitting friction loss at design flow

Pump head calculation



Computer Software Pipe Designer



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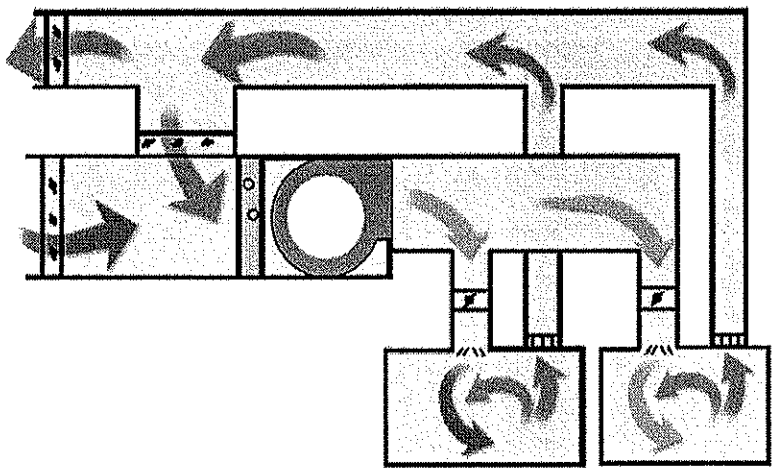
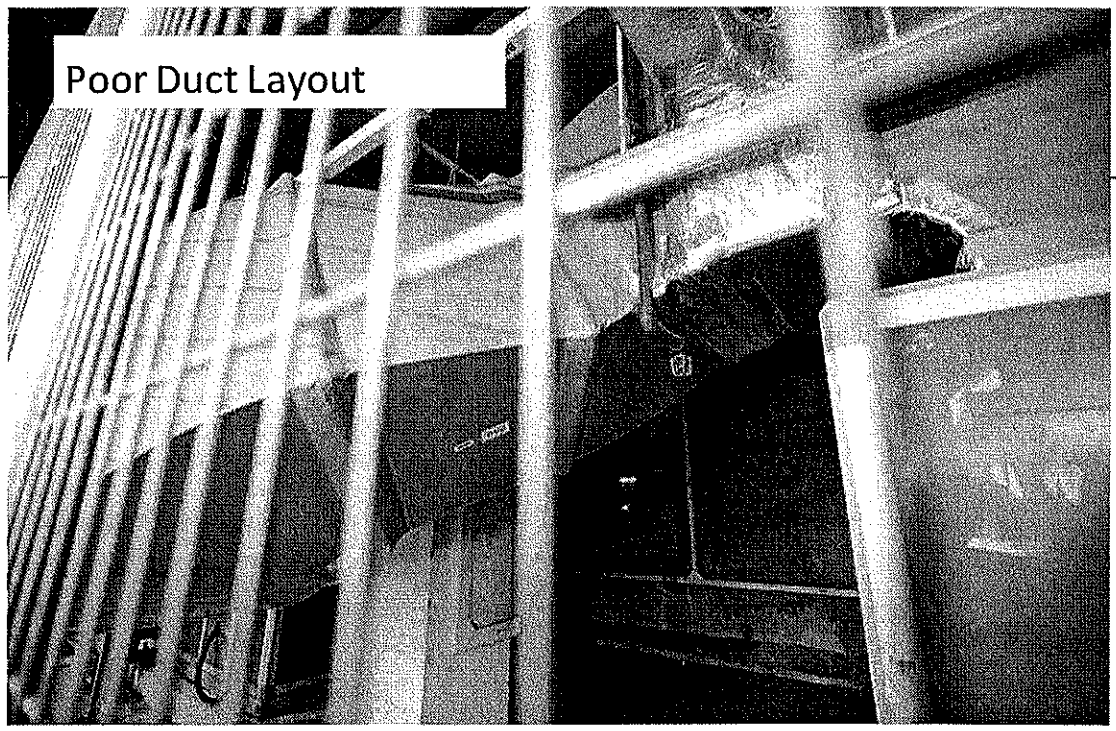
INTRODUCTION TO DUCT DESIGN

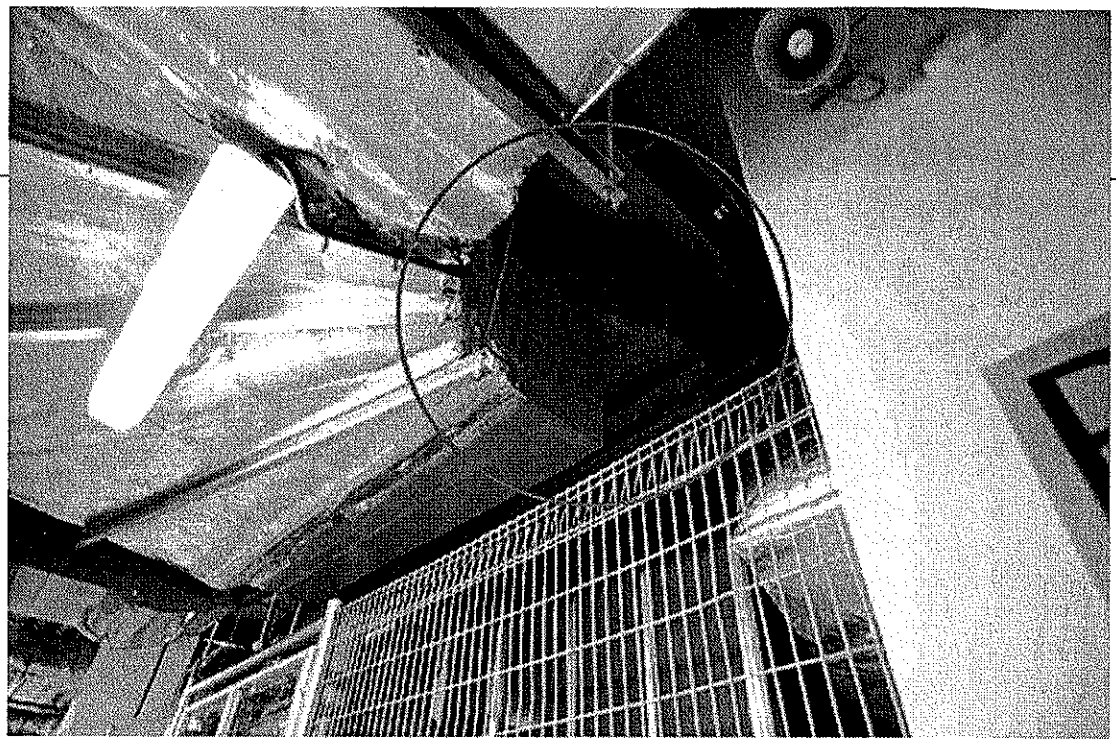
Introduction to Duct Design

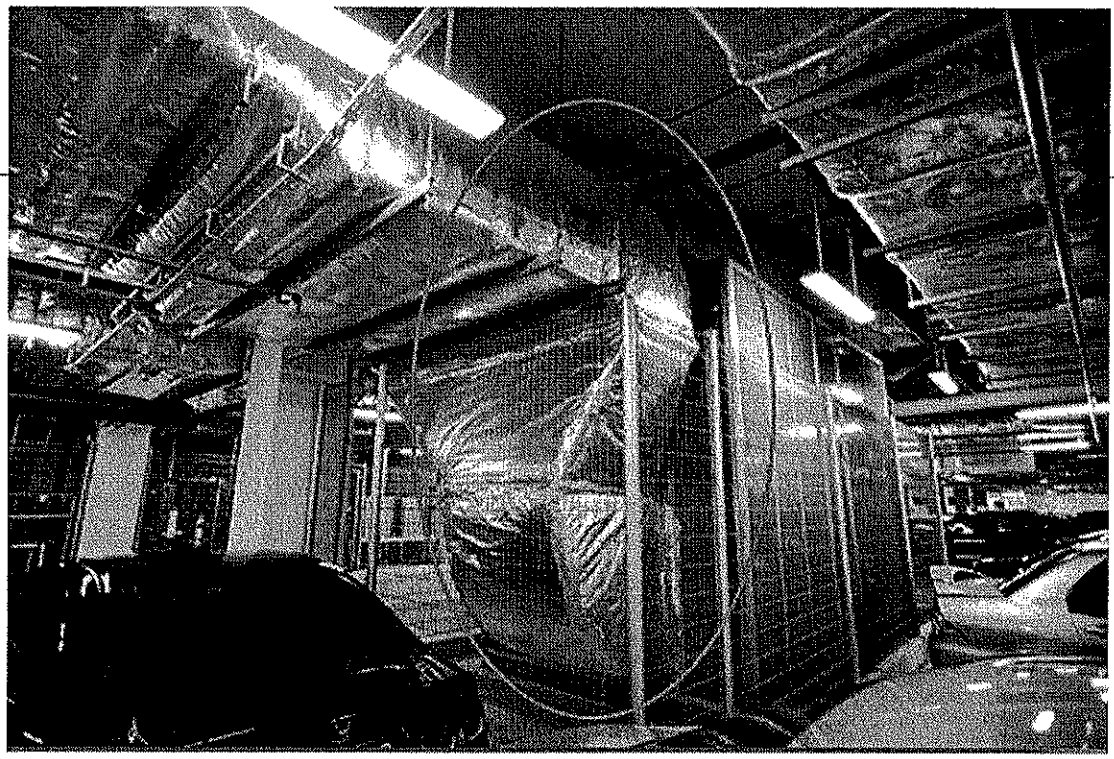
Duct Design is an art as much as it is a science

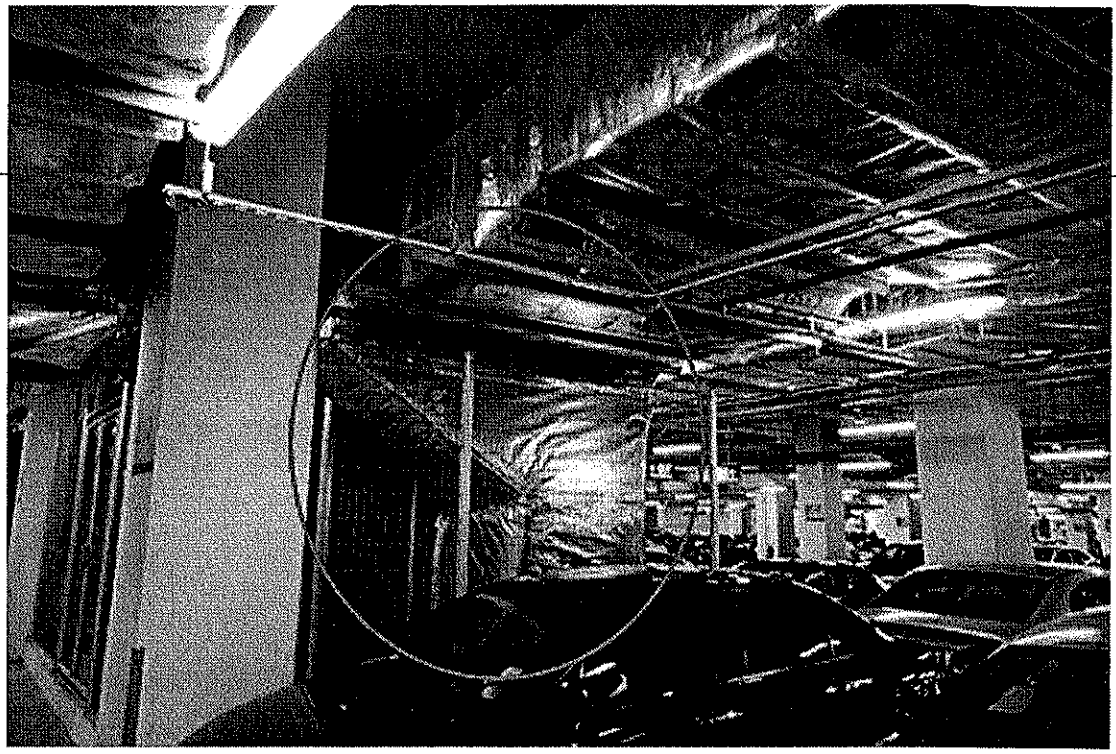


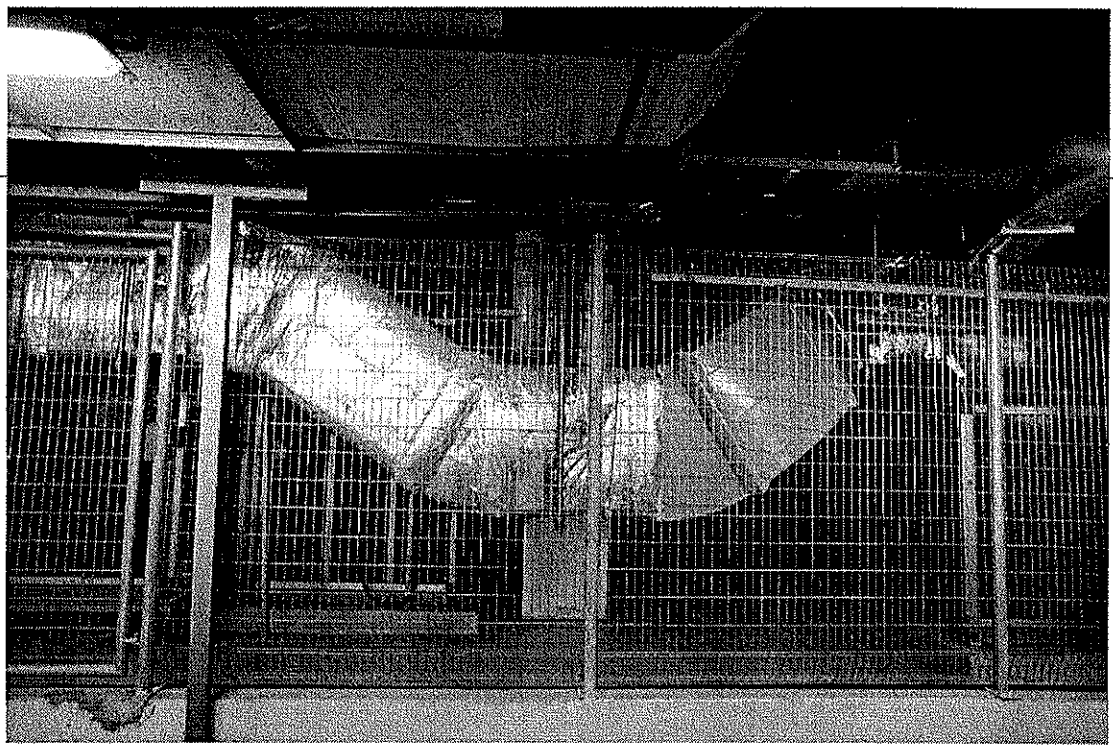
Poor Duct Layout

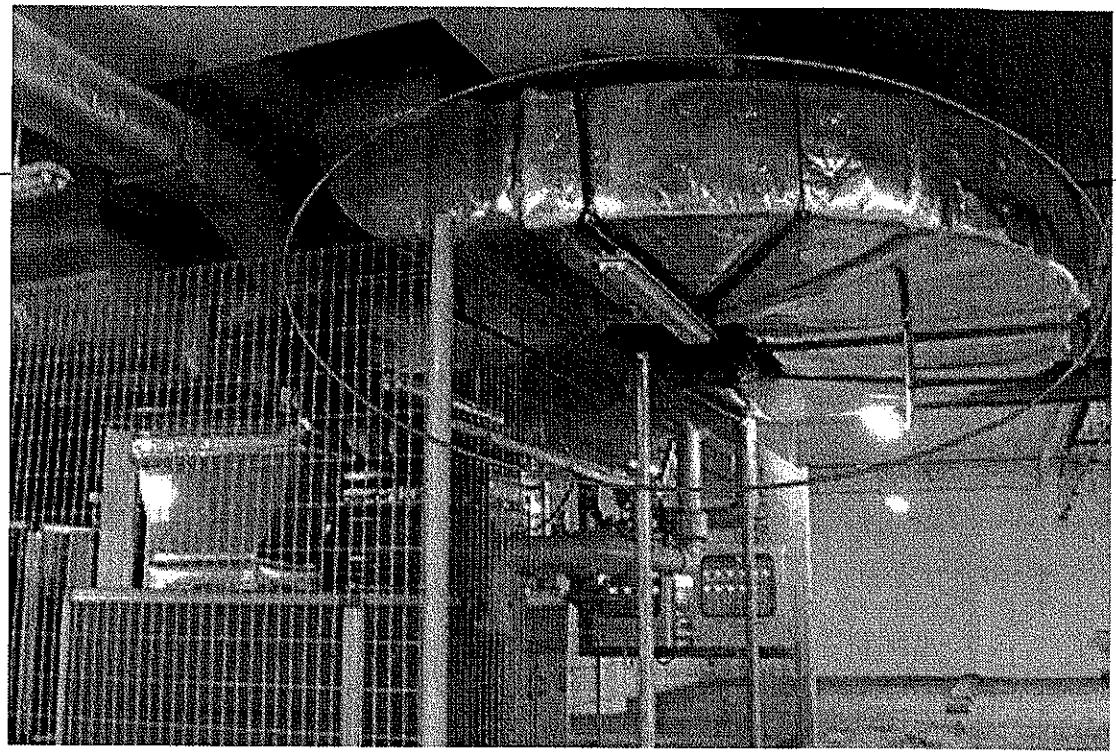


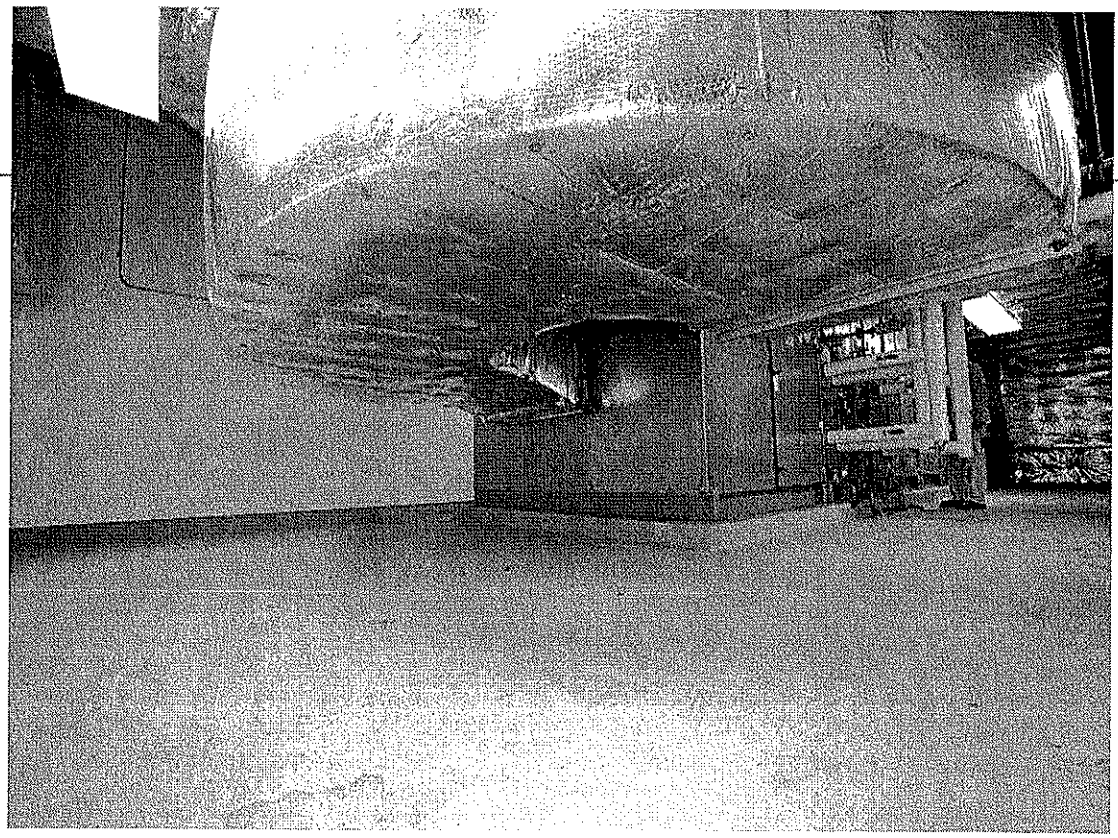


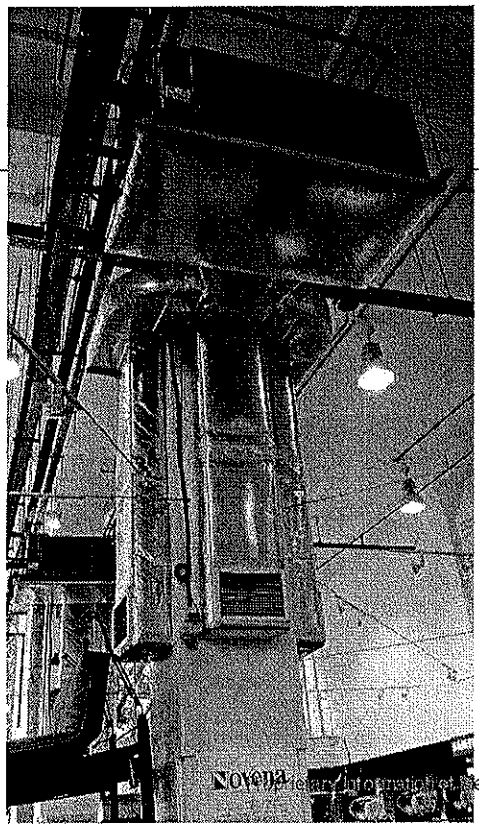


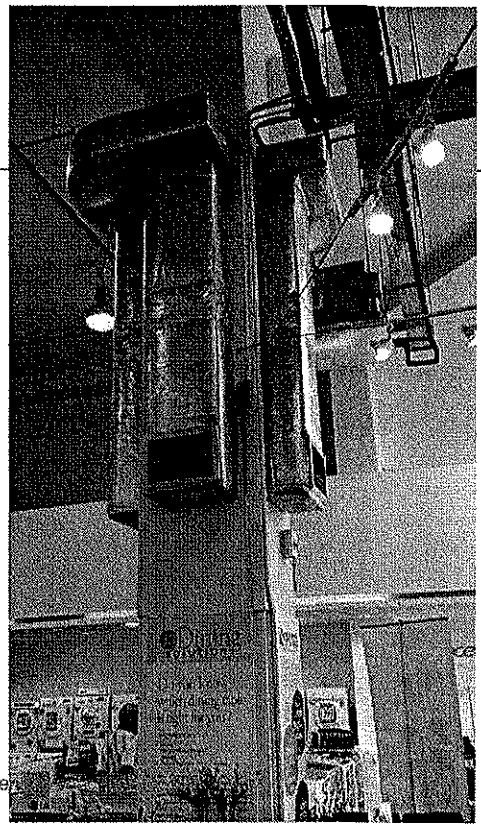












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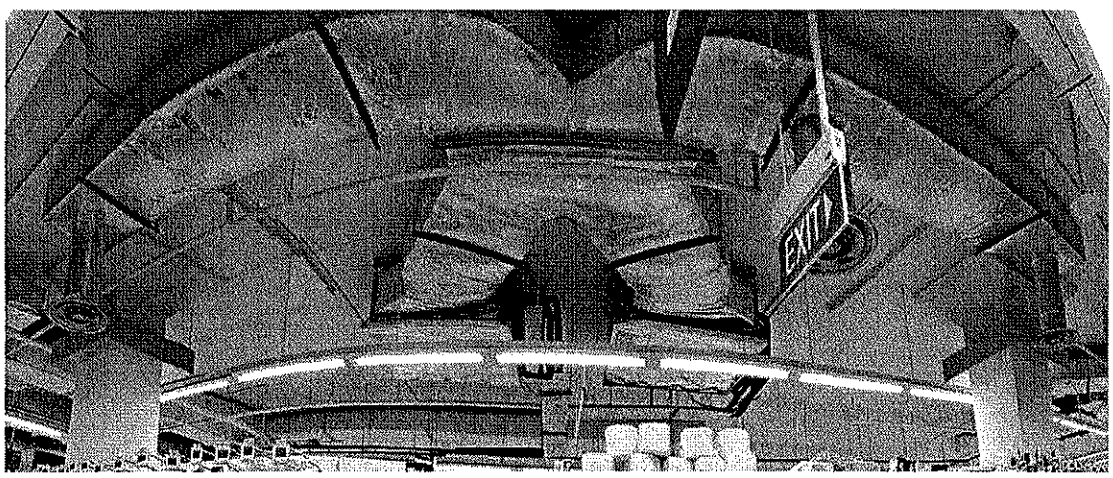

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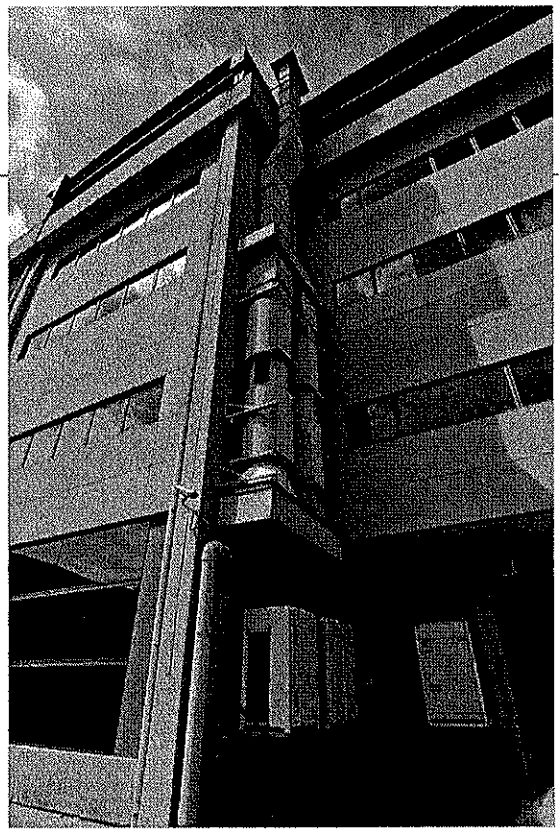

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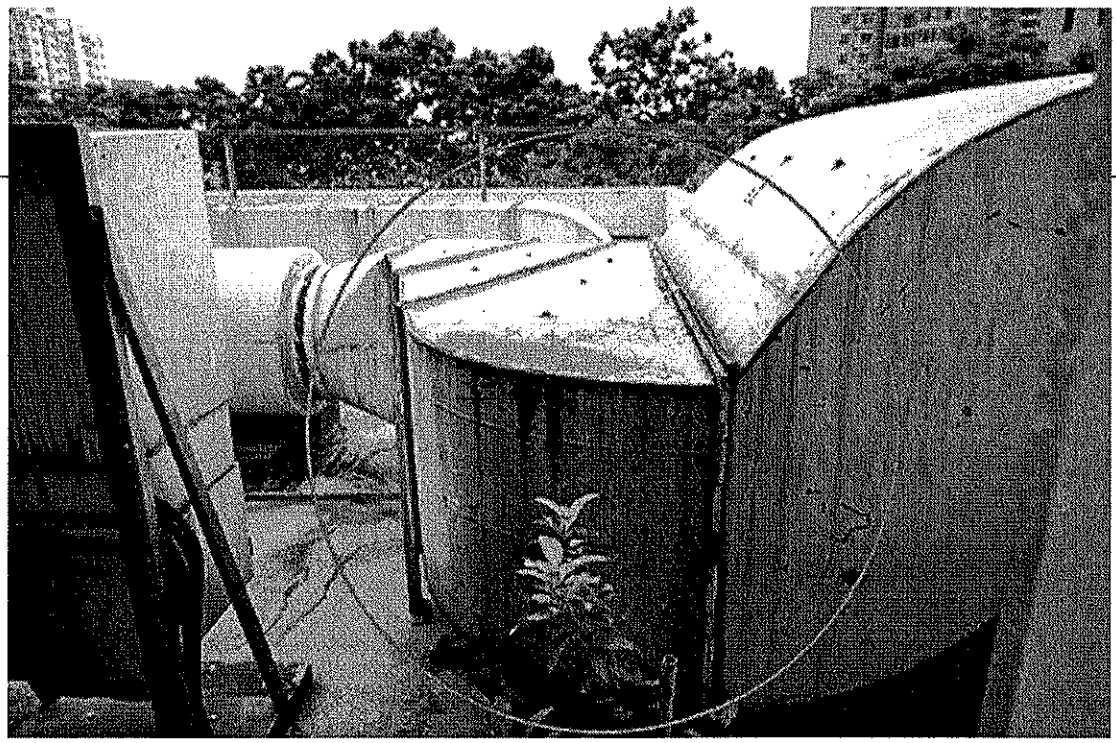

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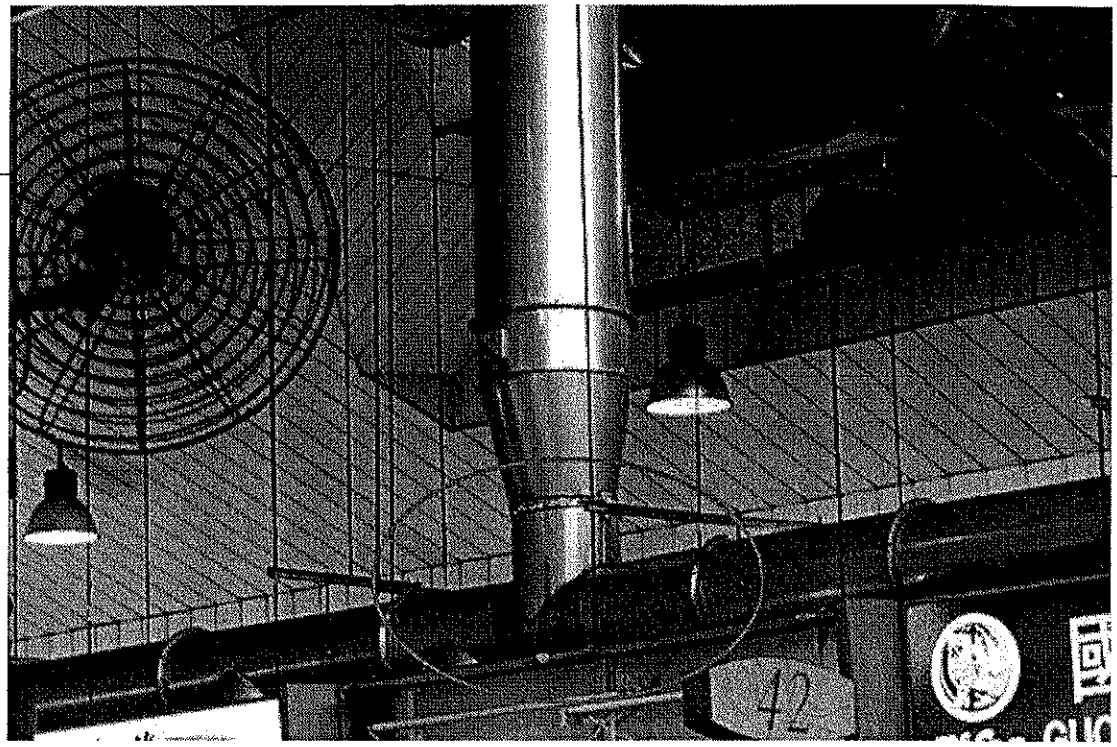

DUCT DESIGN CONSIDERATIONS

Duct Design Considerations

1. Go straight

The most important rule of all. The straighter the duct system, the lower both energy and first costs will be.



2. Reduce pressure losses

Avoid duct fittings that have high pressure losses and consequently high noise generation especially in high velocity systems.

Avoid consecutive fittings because they can dramatically increase pressure drop.

3. Plan your layout

2-1/2 duct diameters straight duct after fan connection to reduce fan system effect losses

Avoid duct locations where access for installation is restricted. This normally results in poor installation and consequently excess leakage from poorly installed joints, inadequate support etc

Recognize that in many cases a smooth elbow with internal insulation will give effective and cheap noise control.

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Duct Design Considerations : Code requirements

SS553-2009				
Type	Load Condition	Min Eff	Units	Remarks
Constant volume system	Full load	1.7	KW / m^3/s	
		0.47	W / CMH	
Variable volume system	Full load	2.4	KW / m^3/s	
		0.67	W / CMH	
	Part load	Motor >= 11kw must able to modulate to 50% design flow at less than 30% of design KW		

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Duct Design Considerations
Green Mark for New Building v4.1

1-2C Airside energy efficiency (Max 6pts)

Fan System Motor Nameplate Power OR **Fan System Input Power**

Baseline Air Distribution System Type	Allowable Motor Nameplate Power	
	($kW/m^3/s$)	(W/CMH)
AHUs/FCUs ≥ 4kW (Constant Volume)	1.7	0.47
AHUs ≥ 4kW (Variable Volume)	2.4	0.67
Fan systems with nameplate motor power < 4 kW	No baseline	

Baseline Air Distribution System Type	Allowable Fan System Input Power*	
	($kW/m^3/s$)	(W/CMH)
AHUs/FCUs ≥ 4kW (Constant Volume)	1.5	0.42
AHUs ≥ 4kW (Variable Volume)	2.1	0.58
Fan systems with nameplate motor power < 4 kW	0.6	0.17

Duct Design Considerations
Green Mark for Existing Building v3.0

(c) Air Distribution system:
- Air Handling Units (AHUs)
- Fan Coil Units (FCUs)

Baseline – Fan power limitation in air conditioning system

Allowable nameplate motor power	
Constant volume	Variable volume
0.47 W/CMH	0.74 W/CMH

DUCT PRESSURE DROP & DUCT SIZING

Terminology and Equations:

Static Pressure (SP) - The amount of energy (static) required to overcome the frictional compression of air in a duct system.

Velocity Pressure (VP) - The amount of kinetic energy (dynamic) required to move the airflow through a duct system.

Total Pressure (TP) - The total amount of energy required to overcome both the frictional losses (SP) and dynamic losses (VP) imposed by the resistance of airflow in a duct system.

Equations:

$$VP := \rho \cdot \left(\frac{\text{Velocity}}{1097}\right)^2 \quad \text{(in w.g.)}$$

ρ = The density of the air

$$\text{Velocity} := \frac{\text{Airflow}}{\text{Area}} \quad \begin{matrix}\text{(cfm)} \\ \text{(cross-sectional)}\end{matrix}$$

$$TP = SP + VP$$

Δ = Change

$$\Delta TP = \Delta SP + \Delta VP$$

Pressure drop along ductwork

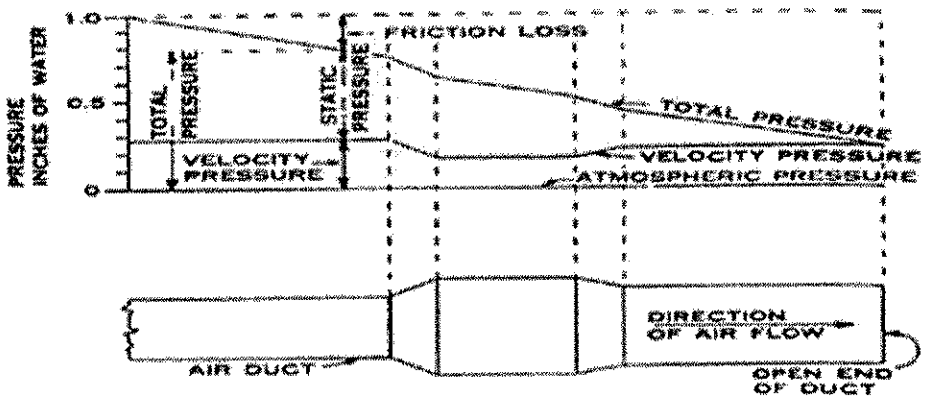
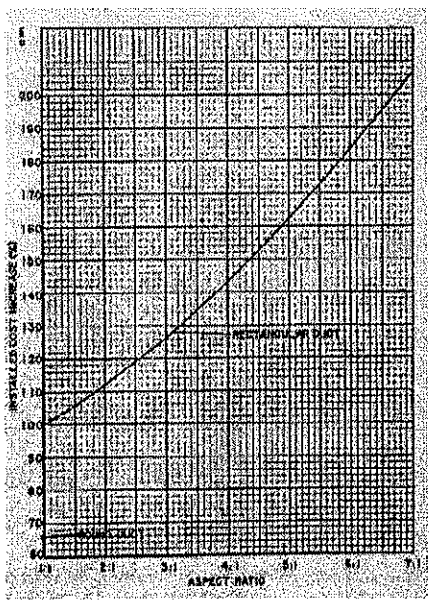


FIGURE 9-J

ACTUAL CHANGES IN PRESSURE WITH CHANGES IN DUCT AREA

Aspect Ratio

- Duct should have aspect ratio (W/H) as close to 1 as possible
- Duct with low aspect ratio have
- Lower friction rate (Lower operating cost)
- Lower perimeter to area ratio (Lower material cost)



Friction loss

Due to fluid viscosity, momentum exchanges between
boundary layer and the main flow, occur along the entire duct length

Pf = f * L

Pf: friction losses Pa

f: friction loss per meter Pa/m (from friction chart)

L: duct length m

Friction chart: based on standard air flowing through round galvanized ducts with an absolute roughness of 0.0003 ft.

For rectangular ducts: Circular equivalent diameter De

$De = 1.30(ab)^{0.625}/(a+b)^{0.250}$

a: length one side of duct

b; length adjacent side of duct

Fitting losses

Due to the change of air flow direction or area when flowing through equipment or fittings

Calculation methods:

1. Exact losses from catalogs
2. Equivalent length estimate
3. Fitting loss coefficients
   $Pc = C * \rho v^2/2g$
   Pc: fitting losses Pa
   C: fitting loss coefficients (from fitting database)
   $\rho v^2/2g$: Velocity pressure Pa

Difference for different elbows

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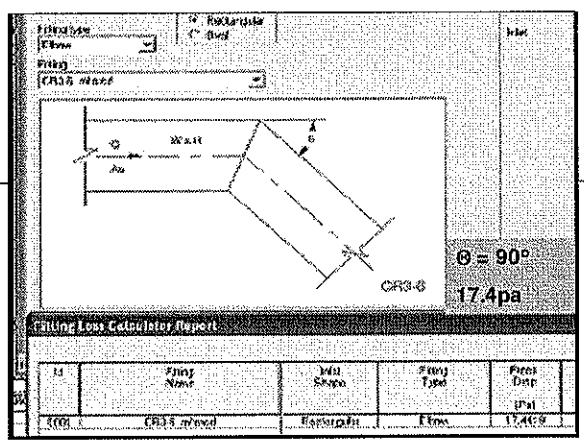
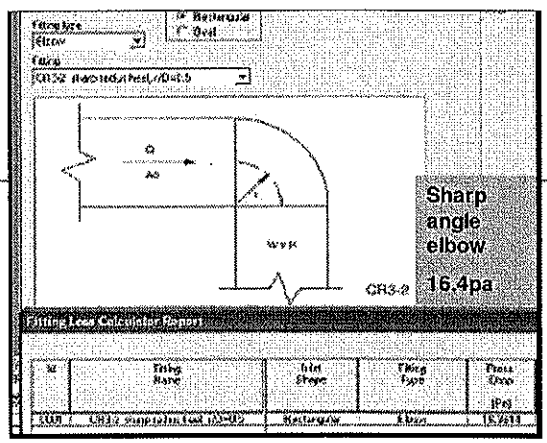
Comparison of Loss Coefficients of Abrupt Turn Fittings.

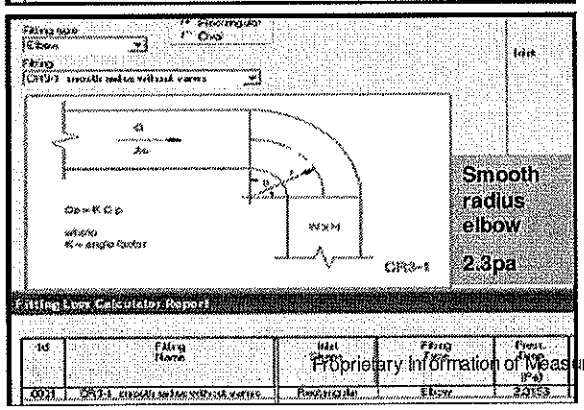
FITTING	90° ELBOWS 8" Dia.	LOSS COEFFICIENT[1]
Die Stamped		0.10
5-Piece		0.22
Mitered with Turning Vanes		0.52
Mitered with Throat Gore		0.65
Mitered with Heel Gore		1.04
Mitered		1.24

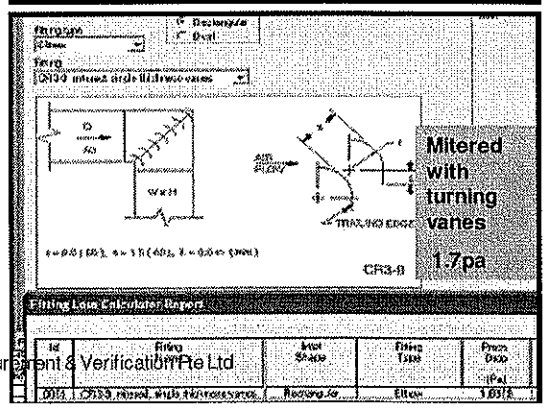
[1]For Elbows: $\Delta p = K \times VP$

* Extracted from ASHRAE 2002 Duct Fitting Database









Duct Sizing Method

1. Velocity Method

Assign velocities to each duct based on recommended velocity tables and then choose the proper duct size, typically apply to small systems, such as homes and small offices

2. Equal Friction

Each segment of the duct work system is sized on using the same friction rate or loss per unit length for the entire system. This method is far superior to the velocity reduction since it require less balancing for symmetrical duct layout.

3. Static Regain

The static regain method is to size the duct network so that the decrease in velocity pressure of each branch just offset the friction loss in the succeeding section of the duct. The static pressure will then be in theory be the same at each terminal and at each branch throughout. This method is applicable for supply duct only and is most suitable for VAV system.

Velocity Method

1. LOW VELOCITY SYSTEM

NC of area being served	Main supply duct (m/s)	Branch supply duct (m/s)	Return air duct (m/s)
50	10.0	8.0	6.0
45	9.0	7.0	6.0
40	8.0	6.0	5.0
35	6.5	5.0	4.0
30	5.0	4.0	3.0

2. HIGH VELOCITY SYSTEM

Air quantity carried by duct l/s (CMH)	Max. Velocity m/s
Above 5000 (18,000)	20.0
5000 to 3000 (18,000 to 10,800)	17.5
3000 to 1500 (10,800 to 5,400)	15.0
1500 to 500 (5,400 to 1,800)	12.5

Equal Friction

Attempts to keep the pressure drop per unit length (generally 100 ft.) of duct relatively constant throughout the system.

- Calculation revolves around the design friction rate.
- Typical friction rates range from 0.05 in. w.g. per 100 ft. to 0.15 in w.g. per 100 ft. (0.4pa/m to 1.2pa/m)

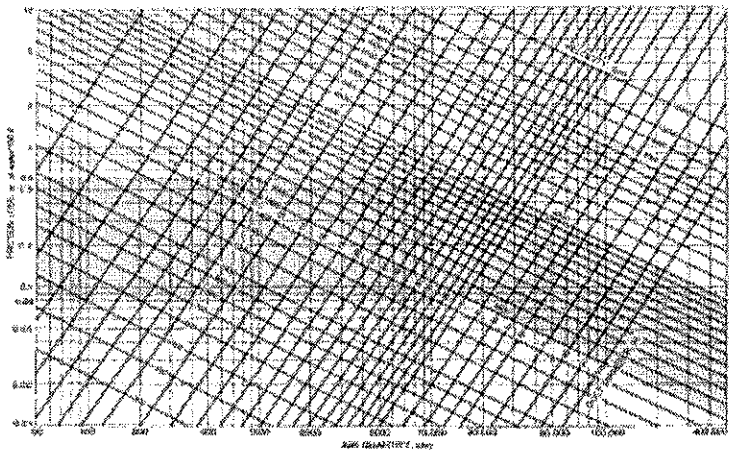
Design Friction Rate = 0.047

Determined by first trunk section... unless overridden

Section	Length	Actual Friction Rate	Airflow	Velocity	Diameter	Actual SP Loss	Height	Width
0001	20	0.047	3740	991		0.0093	24	24
001A	1	0.034	3740	875	28	0.0003		
0005	27	0.031	2929	794	26	0.0085		
0009	27	0.036	2035	771	22	0.0098		
0013	37	0.029	1059	672	18	0.0108		
0015	45	0.030	550	597	14	0.0137		
0023	1	0.472	550	1576	8	0.0047		

Equal Friction

The shade area of the friction chart is the suggested ranged of friction rate and air velocity. Friction rate is designed by balancing between energy cost and duct cost.



Static Regain

- Complicated design requiring computer software design programes, used for large, complex, high velocity systems
- Static regain factor : 75%(considering the splitting of mass at junctions and the dynamic loss between junctions, ranging from 0.5-0.95)
- Calculation equation:

$$\Delta P = R(\frac{\rho V_1^2}{2g} - \frac{\rho V_2^2}{2g})$$

- R : Static regain factor
- ΔP: static pressure regain between junctions

Static Regain

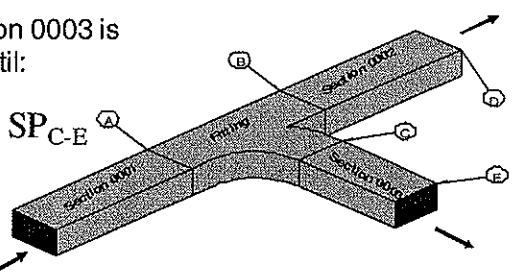
- Attempts to maintain a constant static pressure throughout the duct system (a balanced system).
- Calculation is limited by parameters such as minimum velocity, fan size, and sometimes fitting selections (rectangular).
- Fan outlet size is critical
- Typical minimum velocity = 500 fpm.. when decreased the method can actually be limited in it's effectiveness

Size of section 0002 is increased (converting velocity pressure to static pressure) until:

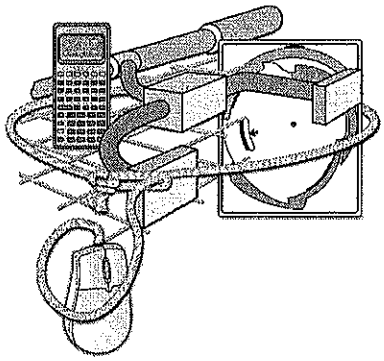
$$\Delta SP_{A-B} = \Delta SP_{B-D}$$

Size of section 0003 is increased until:

$$\Delta SP_{A-C} = \Delta SP_{C-E}$$



Softwares are Available for Duct Design



VariTrane™ Duct Designer

- Models supply duct systems from fan to diffuser or VAV box
- Uses the ASHRAE fitting database
- Models round, rectangular, and flat-oval duct

Noise Control Considerations

- Fan Selection: to reduce the sound power at the fan source.
- Pressure drop: lowering the system pressure drop allows for lower fan speed which lowers sound power levels.
- Duct Velocities: Keep to limits.
- Avoid take-offs near fan: Take-offs near to the fan normally needs dampers that are near full throttle position resulting in noise.
- Duct insulation and attenuator: attenuate sound generated by the noise sources during transportation. A smooth elbow with internal insulation will often give effective and cheap noise control

THANK YOU

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