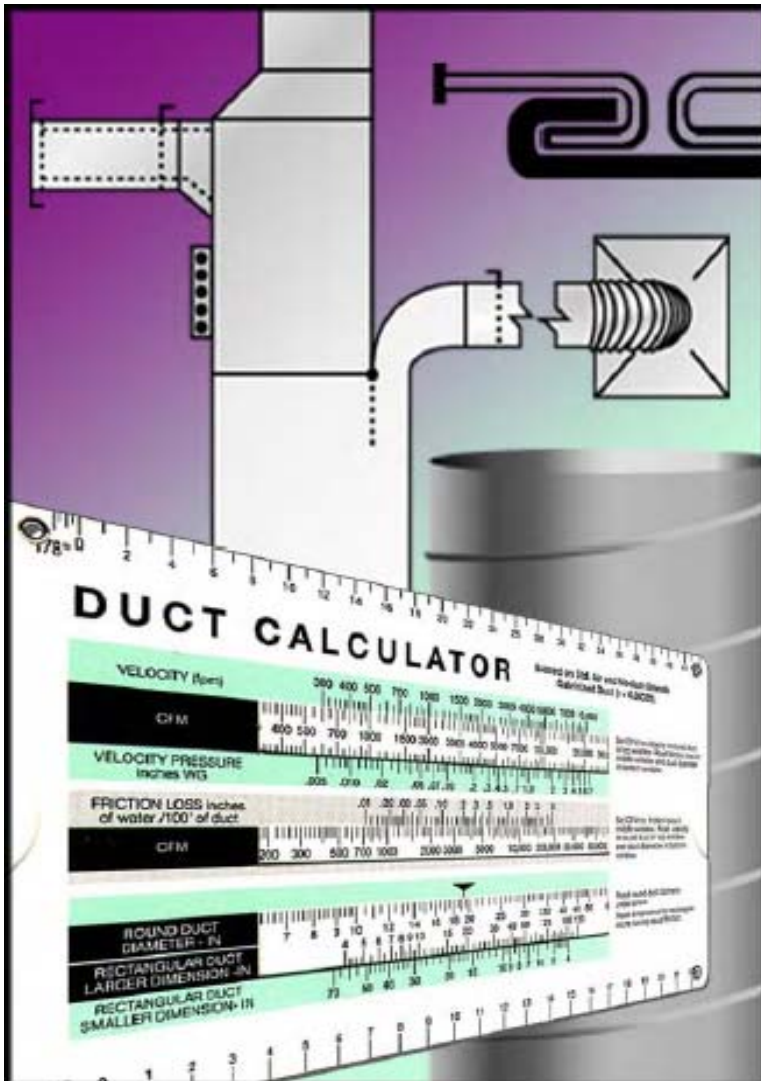


AIR CONDITIONING SYSTEM DESIGN

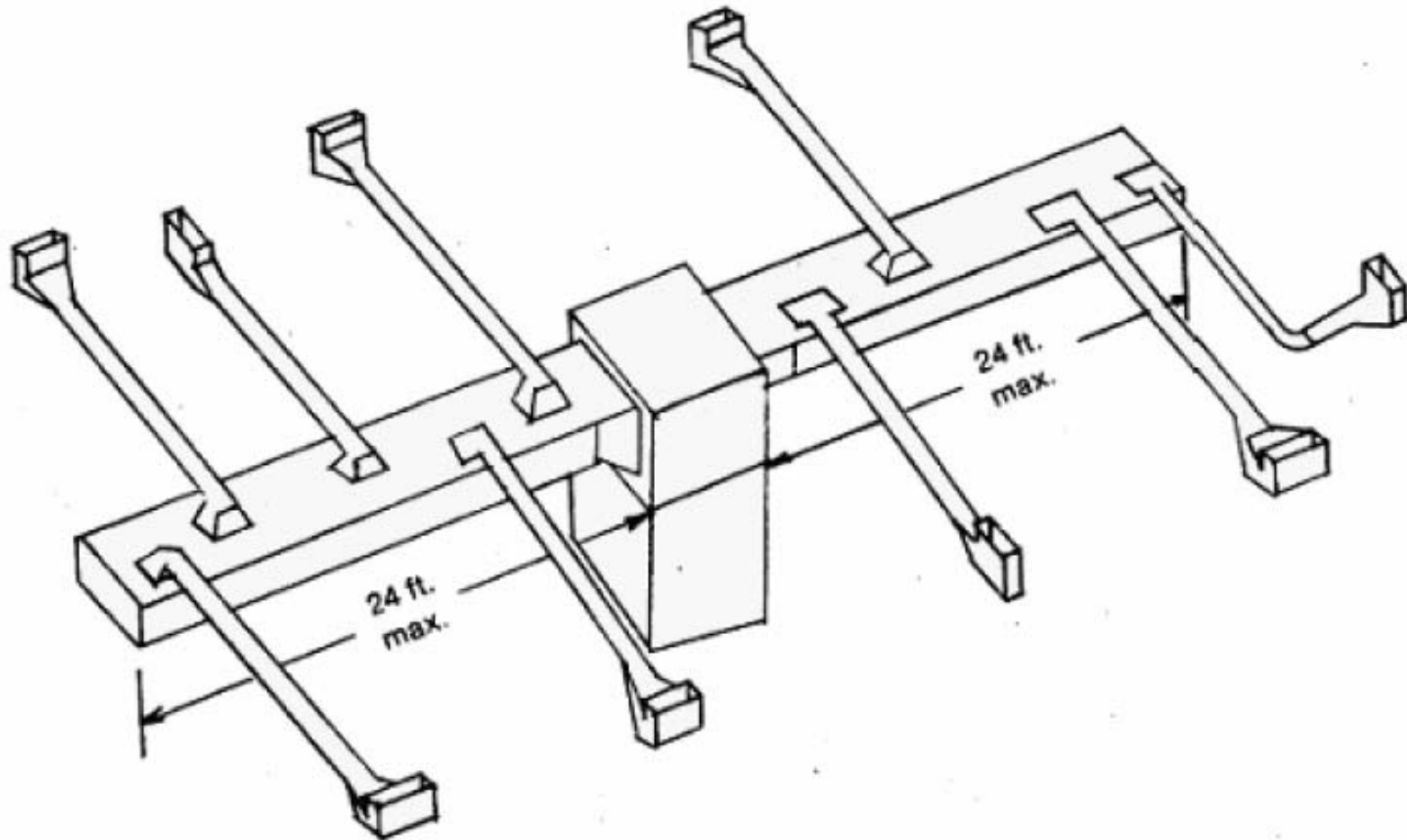
AIR DUCT DESIGN



PENGENALAN

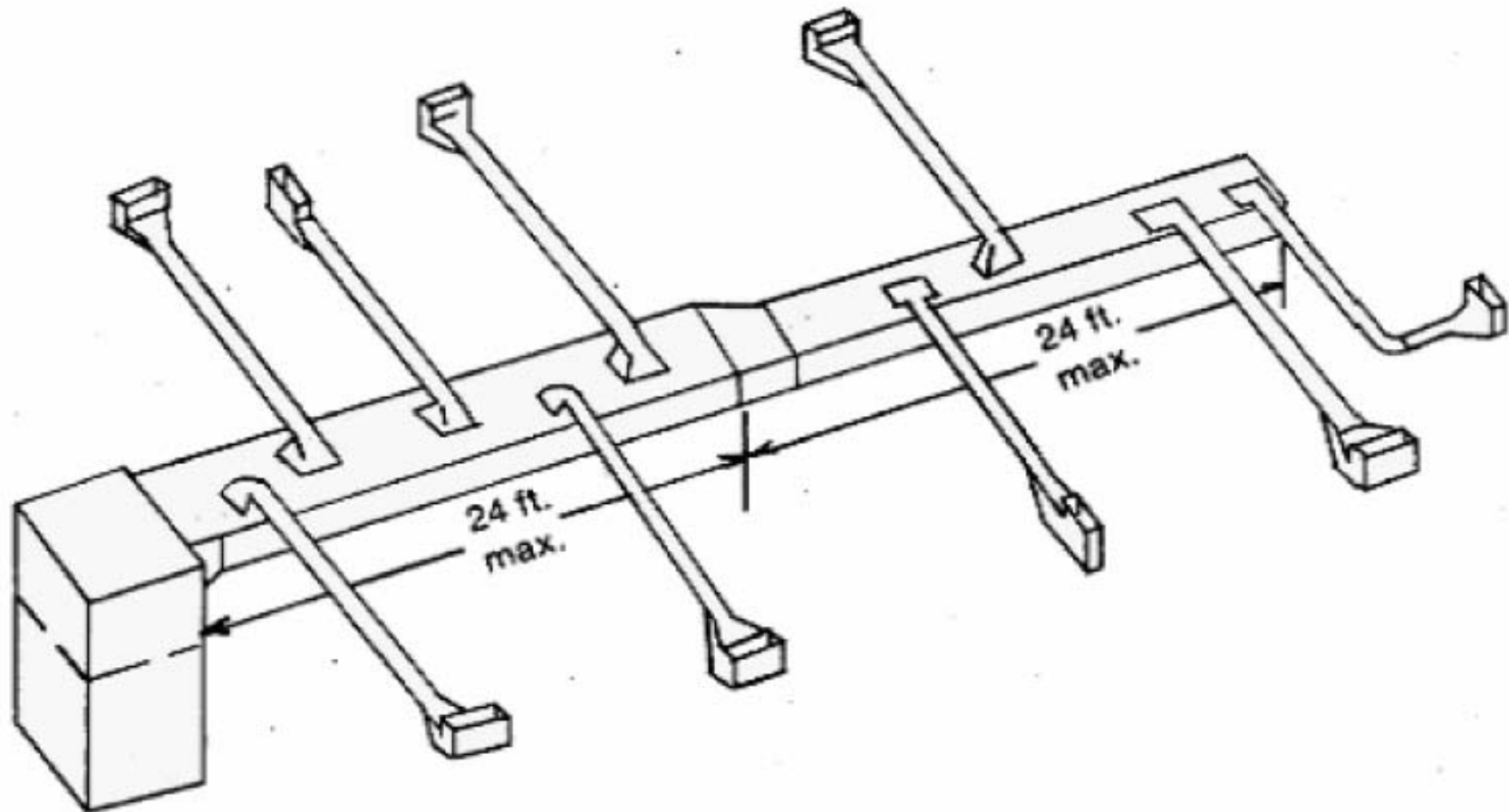
- Objektif
- Kriteria reka bentuk salur udara (*duct design*)
- Memahami teori asas
- Langkah menggunakan proses *duct design*
- *Saiz Duct dengan friction chart/ calculator*
- *Kaedah mensaiz duct*

Konfigurasi Salur Udara Bekalan



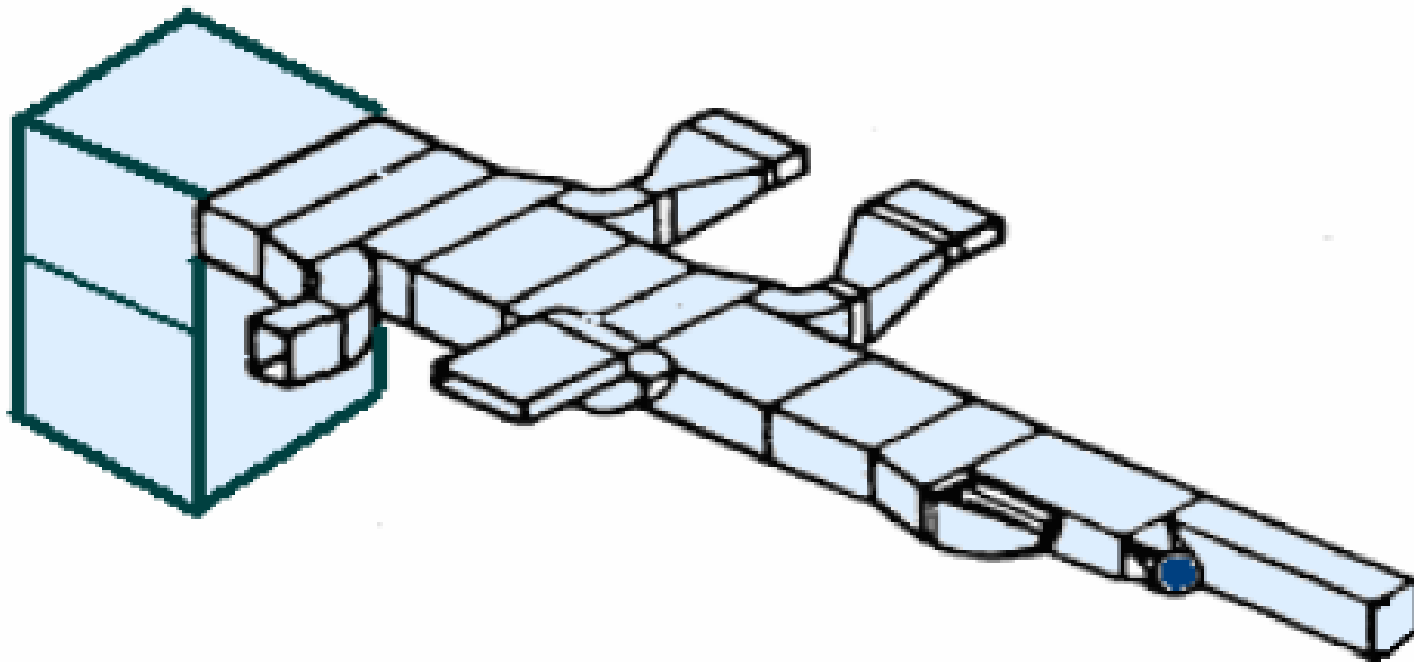
Extended Plenum System (Equipment Centrally Located)

Extended Plenum System



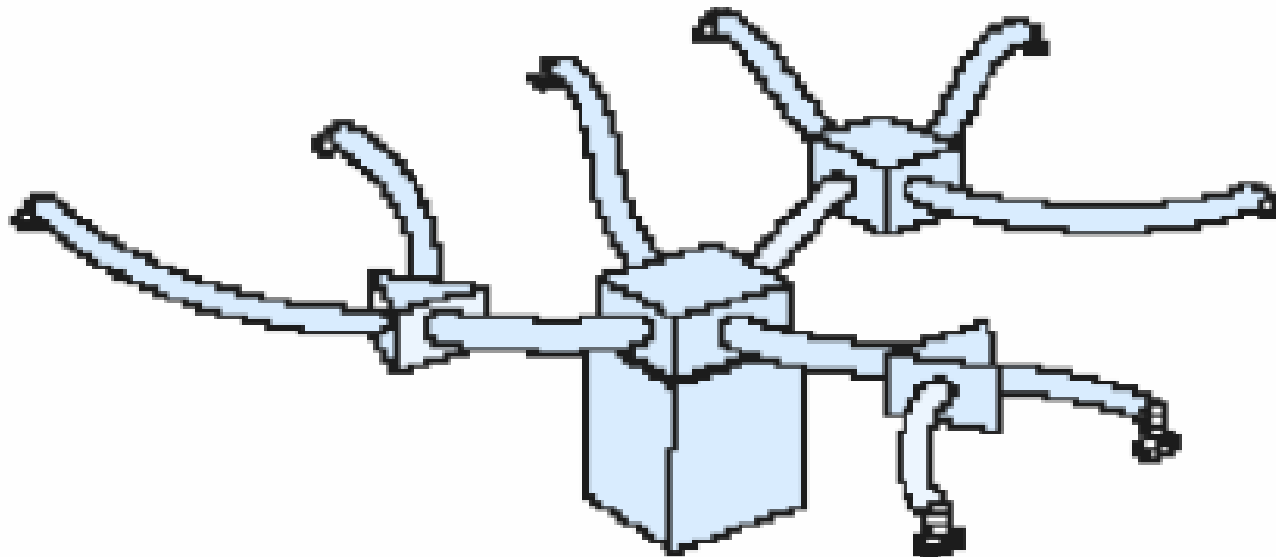
Extended Plenum System (Equipment Located at One End)

Reducing Trunk System



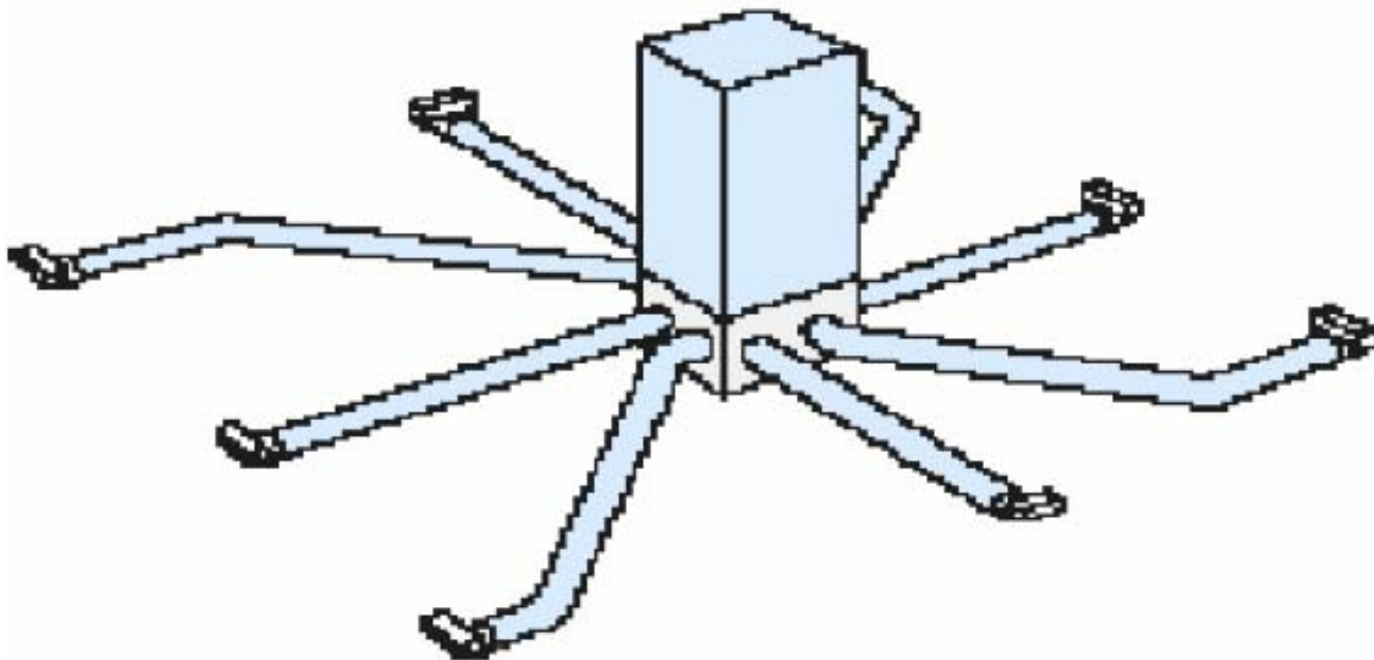
Reducing Trunk Duct System

Spider System



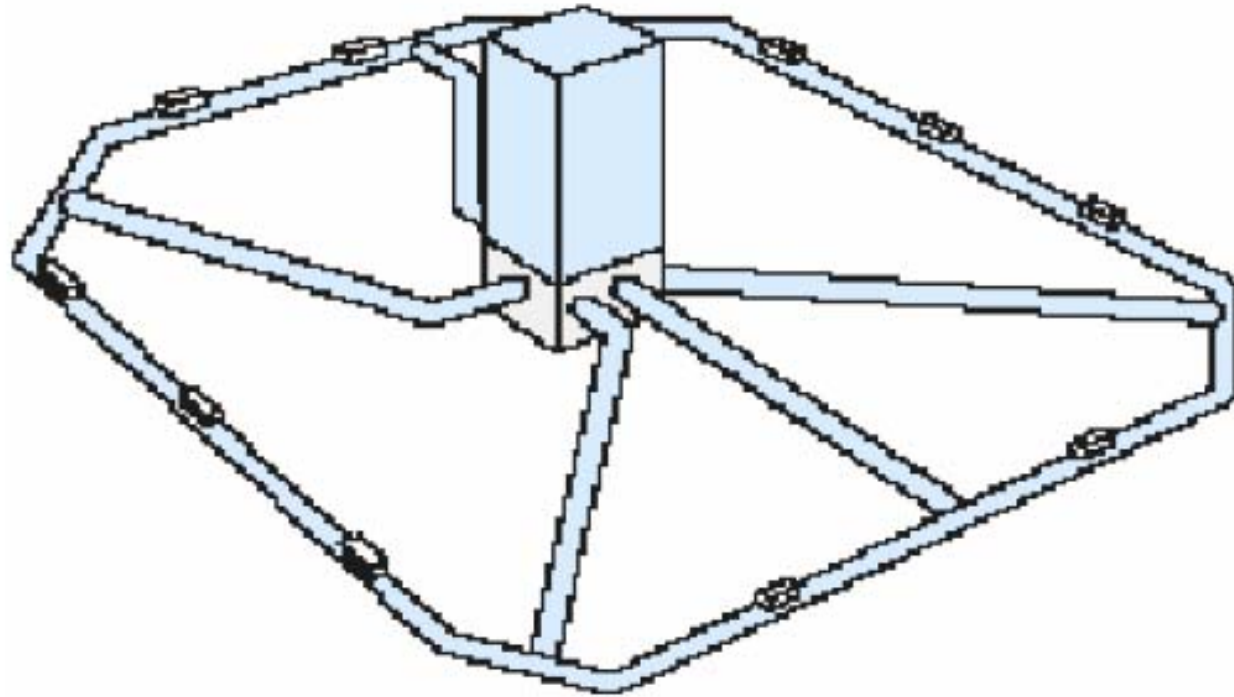
Spider Duct System

Radial Duct System



Radial Duct System

Perimeter Loop System

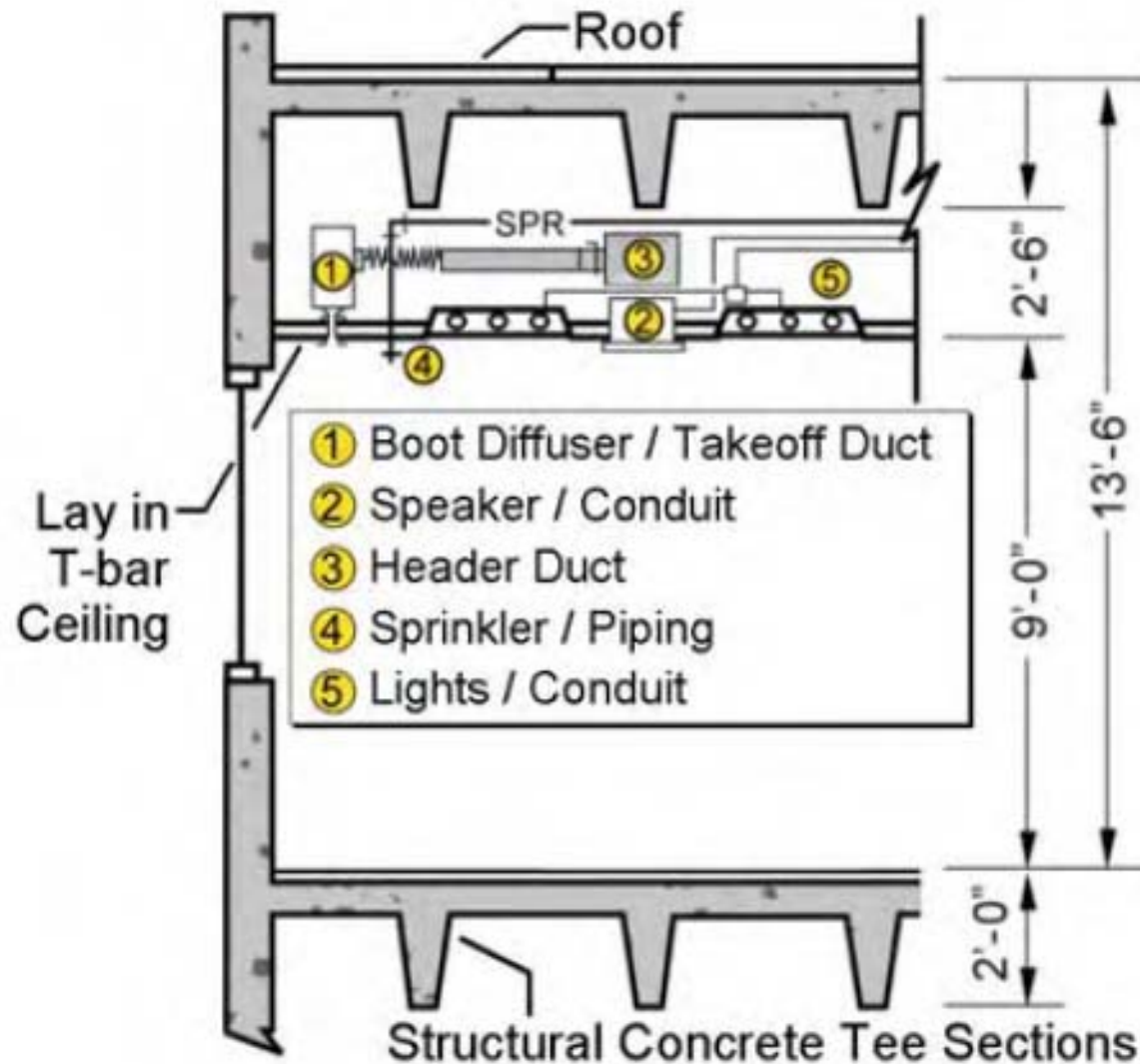


Perimetric Loop System

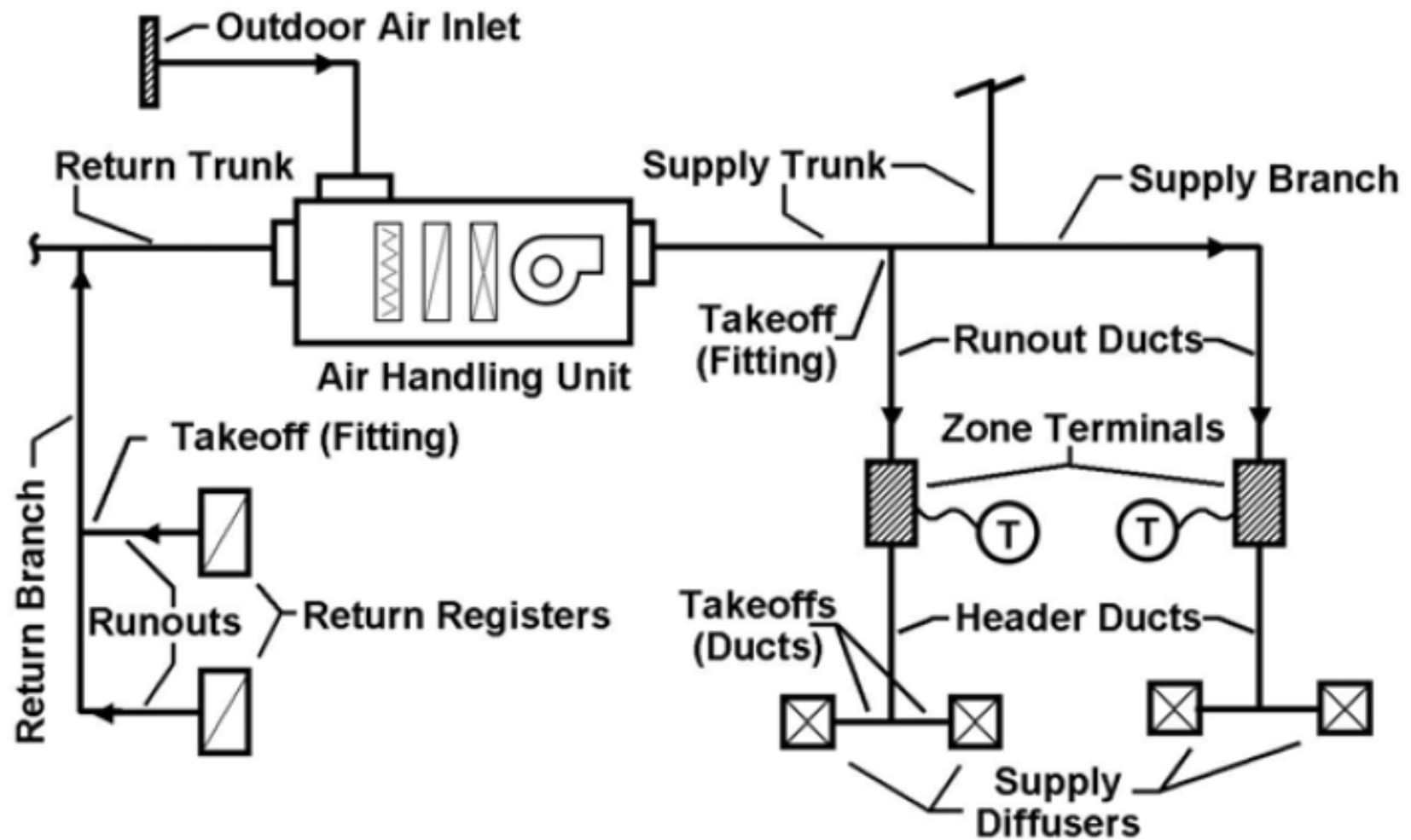
Duct design criteria

- Ruang yang bersesuaian
- Kos pemasangan
- Kejatuhan geseran udara (air friction loss)
- Tahap kebisingan (noise level)
- Kebocoran aliran udara dan pemindahan haba
- Kod dan standard yang diperlukan

Fitting in the ductwork



Duct terms



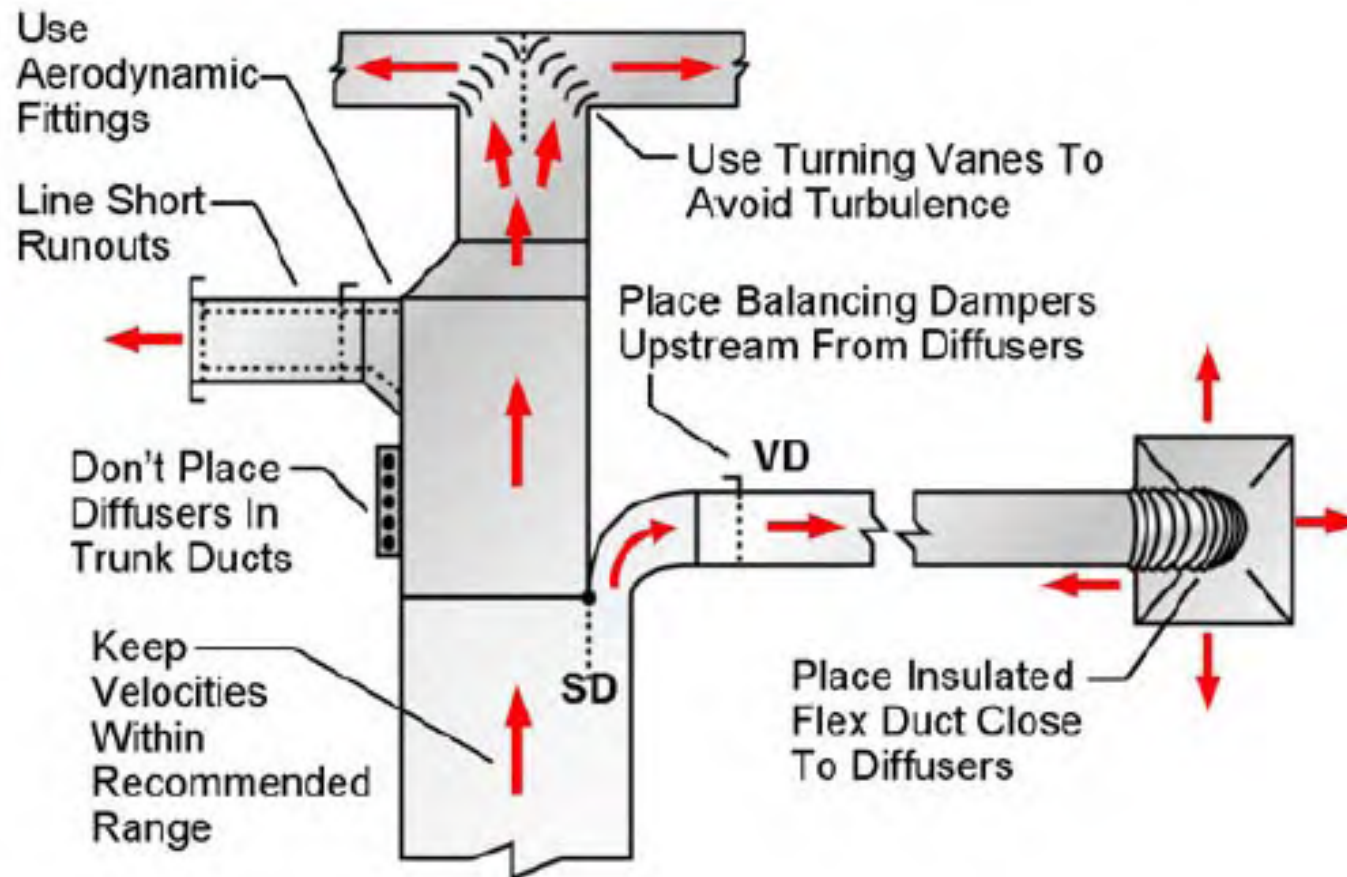
Air friction loss

- Kejatuhan geseran udara berlaku akibat drp bentuk, saiz dan bahan yang digunakan pada salur udara
- Penggunaan salur udara bulat galvanized (GI) mengurangkan kejatuhan geseran yag paling manimum
- Penggunaan salur udara flexible akan memberikan kesan kejatuhan geseran yang tinggi
- Penjodoh (Fitting) memberikan kesan kejatuhan geseran secara langsung dalam sistem salur udara

Noise level

- Bunyi bising dalam salur udara disebabkan sistem sesalur udara direkabentuk *undersized* ini disebabkan berlakunya *high velocities*
- Kegagalan memilih atau memasang *fitting* yang betul akan mencipta *turbulence* ini juga menyebabkan bunyi bising dan berlakunya kejatuhan tekanan.

Limit noise creation



Heat transfer and leakage

- Salur udara akan menyalurkan udara yang sangat sejuk, kehilangan *heat gain* mengakibatkan kapasiti sistem berkurangan, pembaziran tenaga/kos dan tidak selesa.

Sealing ductwork from ASHRAE

ASHRAE 90.1

duct insulation requirements range from R-1.9 to R-10 for extremely cold climates.

ASHRAE 90.1 Energy Code dictates appropriate levels of insulation and joint seal levels for all ductwork in order to minimize these energy-wasting conditions. Figure 5 shows the extent of sealing required. Two extensive duct insulation tables in ASHRAE 90.1 cover all usages and climate areas.

Minimum Duct Seal Level

ASHRAE 90.1
Table
6.2.4.3A

Duct Location	Duct Type			
	Supply		Exhaust	Return
	≤ 2 in. w.c.	> 2 in. w.c.		
Outdoors	A	A	C	A
Unconditioned Spaces	B	A	C	B
Conditioned Spaces **	C	B	B	C

Duct Seal Levels

ASHRAE 90.1
Table 6.2.4.3B

Seal Level	Sealing Requirements *
A	All transverse joints and longitudinal seams, and duct wall penetrations. Pressure-sensitive tape shall not be used as the primary sealant.
B	All transverse joints and longitudinal seams. Pressure-sensitive tape shall not be used as the primary sealant.
C	Transverse joints only

Figure 5

Sealing Ductwork Reprinted by permission from ASHRAE Standard 90.1 Copyright (2001) American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (www.ASHRAE.org)

Reka Bentuk Salur Udara

Duct Design

- Tujuan salur udara air cond. dipasang adalah untuk membawa udara dari kipas dan di - agihkan kedalam bilik/ruang melalui diffuser.
- Perbezaan tekanan yang terhasil dari kipas membolehkan udara bergerak.
- Perbezaan tekanan yang terhasil adalah untuk membolehkan salur udara berfungsi dan kita perlu menentukan rekabentuk (lay-out) dan saiznya.

Duct design

- Objektif utama rekabentuk saiz salur udara dibuat adalah untuk mengurangkan kejatuhan tekanan seterusnya dapat juga meminimalkan kos dan saiz yang sepatutnya.
- Reka bentuk yang betul memerlukan pengetahuan mengenai faktor kesan kejatuhan tekanan dan halaju (velocity) dalam salur udara.

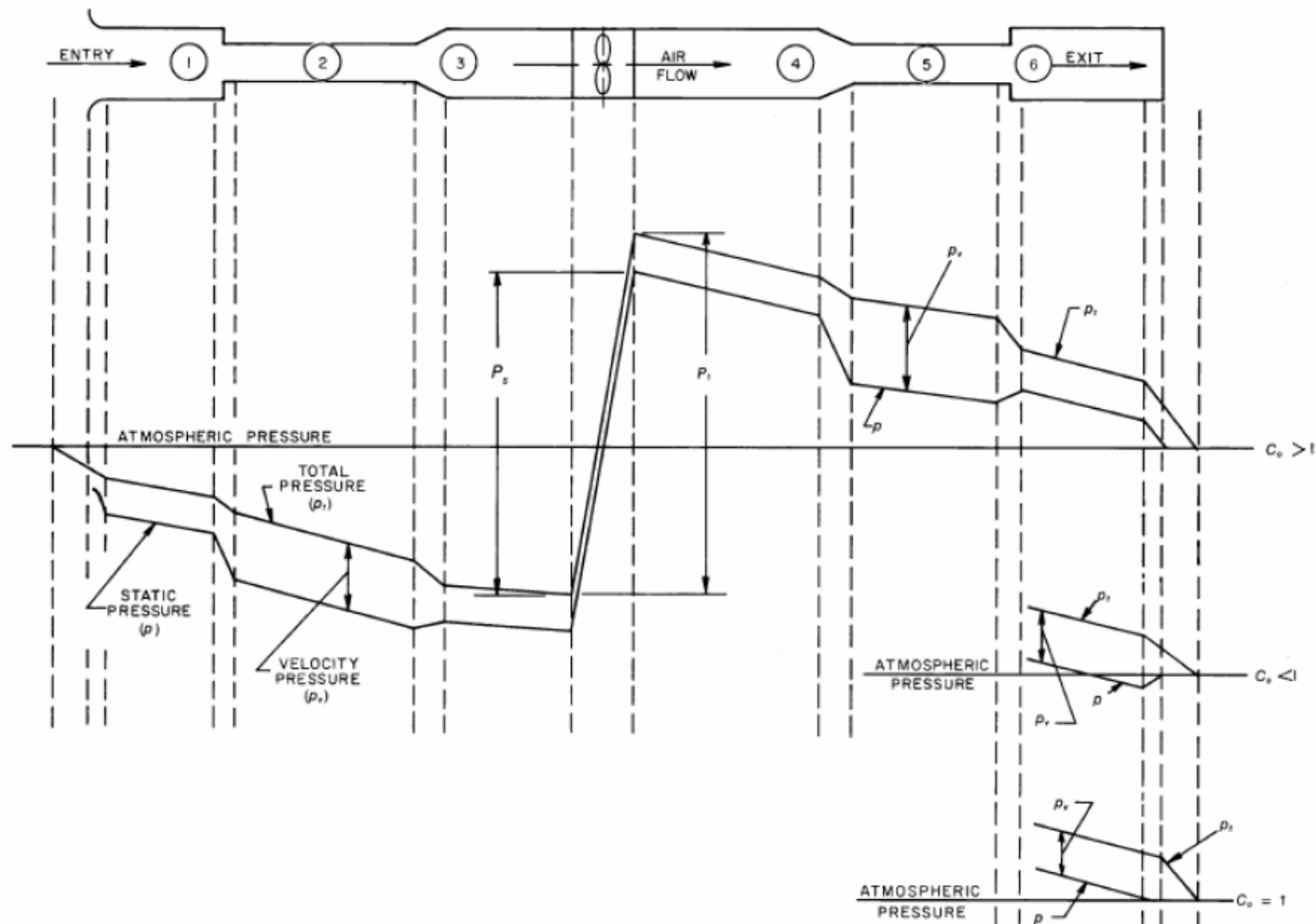
Sistem Tekanan Salur udara

- Jumlah tekanan (*total pressure (TP)*), adalah hubungkait dengan tenaga dalam salur udara (*Air Stream*), seperti dinyatakan pada persamaan berikut:
- $TP = \text{Static Pressure} + \text{Velocity Pressure}$

Sistem Tekanan Salur udara

- Tekanan static dan tekanan halaju (static pressure and velocity pressure) meningkat dan menurun apabila ia dialirkan melalui salur udara, bergantung kepada keluasan permukaan salur tersebut (cross-sectional area of the flow).
- Jumlah tekanan (TP) dalam salur berkurang bila udara dibekalkan dalam salur udara sebaik saja berpindah kepada tenaga haba mekanikal disebabkan oleh geseran (friction).

Duct system pressure



Tekanan Halaju (Velocity Pressure)

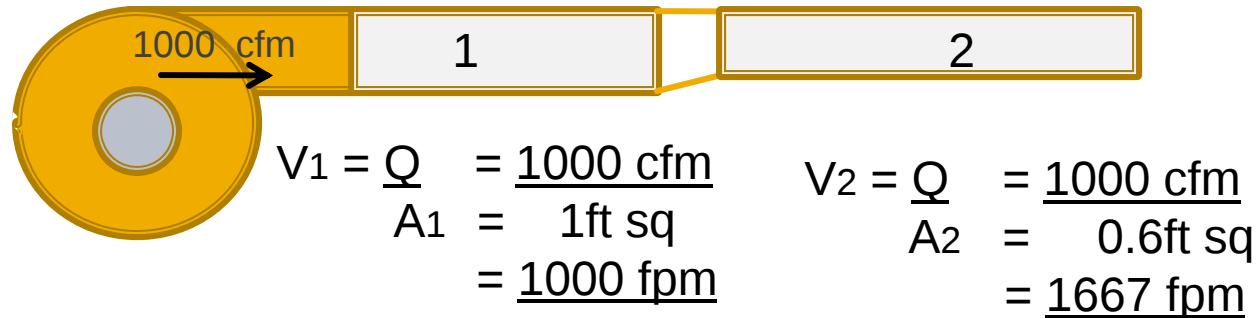
$$VP = \left(\frac{V}{4005} \right)^2$$

Where:

VP = Velocity Pressure, inches H_2O

V = Velocity, feet per minute

Velocity pressure conversion



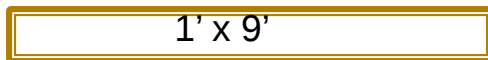
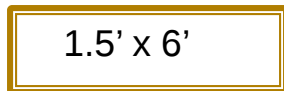
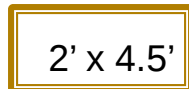
$$\text{Velocity Pressure } V_p = \left(\frac{V}{4005} \right)^2$$

$$V_p = \left(\frac{1000}{4005} \right)^2 = 0.062 \text{ in. wg}$$

$$V_p = \left(\frac{1667}{4005} \right)^2 = 0.173 \text{ in. wg}$$

Effect of shape duct of equal area

All duct = 9 sq.ft



Aspect Ratio	Perimeter (ft)	Ratio of perimeter to area	Equivalent round duct (in)	Friction 15,000 cfm (in.wg/100 ft EL)
1:1	10.7	1.18:1	40.7	0.070
1:1	12	1.33:1	39.4	0.086
2.3:1	13	1.45:1	38.7	0.095
4:1	15	1.67:1	37.2	0.113
9:1	20	2.22:1	34.5	0.156

Surface Roughness of Duct

Duct Material Roughness Multipliers		
For internal ductwork surfaces other than smooth sheet metal multiply length by		
Ductwork Description	MULTIPLIER	
	SUPPLY	RETURN
Rigid fiberglass-preformed round duct-smooth inside	1.0	1.0
Rigid fiberglass duct board	1.32	1.30
Duct liner-airside has smooth facing material	1.32	1.30

Surface Roughness of Duct

Duct Material Roughness Multipliers		
For internal ductwork surfaces other than smooth sheet metal multiply length by		
Ductwork Description	MULTIPLIER	
	SUPPLY	RETURN
*Flexible metal duct (straight installation)	1.6	1.6
Duct liner-airside spray coated	1.9	1.9
Flexible vinyl coated duct with helical wire core (straight installation)	3.2	3.4

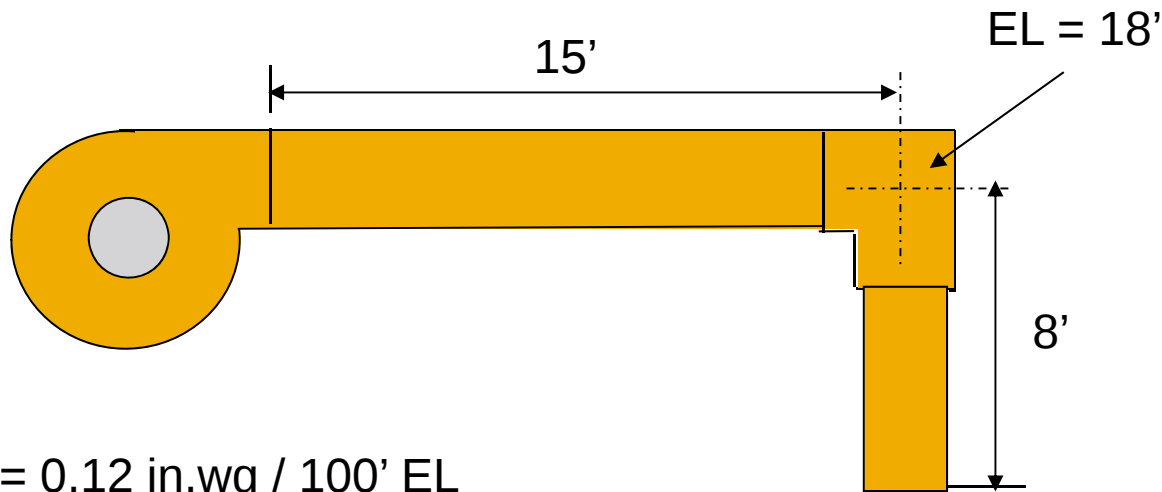
Recommended Friction Rates (f)

Ductwork	Friction rate range (in.wg / 100 ft EL)
Pressure classes 1/2, 1.2	0.10 to 0.15
Pressure classes 3	0.20 to 0.25
Pressure classes 4.6,10	0.40 to 0.45
Transfer air ducts	0.03 to 0.05
Outdoor air ducts	0.05 to 0.10
Return air ducts	80% of above supply duct values

Fitting Losses

- Kaedah persamaan setara (equivalent length) (EL) method) – convert fitting to straight duct
- Kaedah kejatuhan Dinamik (Dynamic loss (C_v) method) – uses coefficients for number of velocity heads lost

Kaedah Panjang Setara (Using equivalent length)

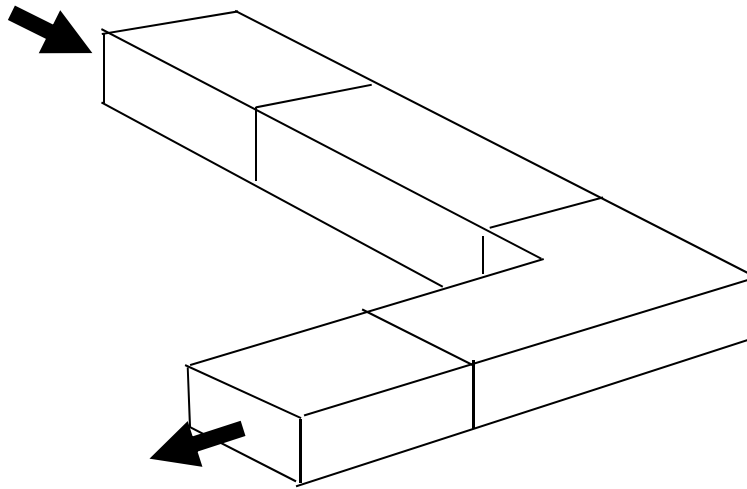


$$F = 0.12 \text{ in.wg} / 100' \text{ EL}$$

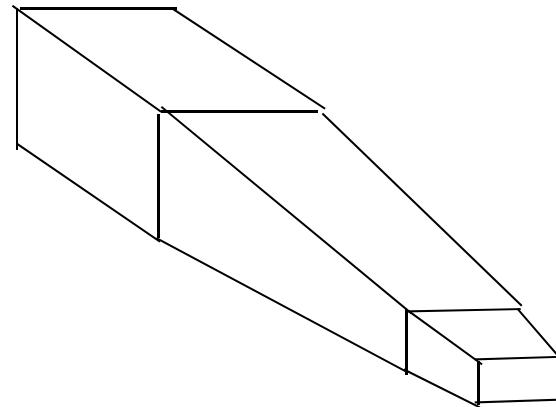
$$\text{Total length} = 15' + 8' + 18' = 41' \text{ EL}$$

$$\begin{aligned} \text{Duct pressure loss} &= f \cdot \text{EL} / 100' \\ &= 0.12 \text{ in.wg} \times 41/100 \\ &= \underline{\underline{0.049 \text{ in. wg}}} \end{aligned}$$

Dynamic fitting losses



Change of
direction



Change of area

Static Pressure Losses

- Frictional Losses

Due to fluid viscosity and turbulence in the flow through the ductwork, and occur along the entire length of the ductwork

- Dynamic Losses

Result from flow disturbances caused by fittings that change the airflow direction or area.

Kaedah mensaiz salur udara (Duct sizing method)

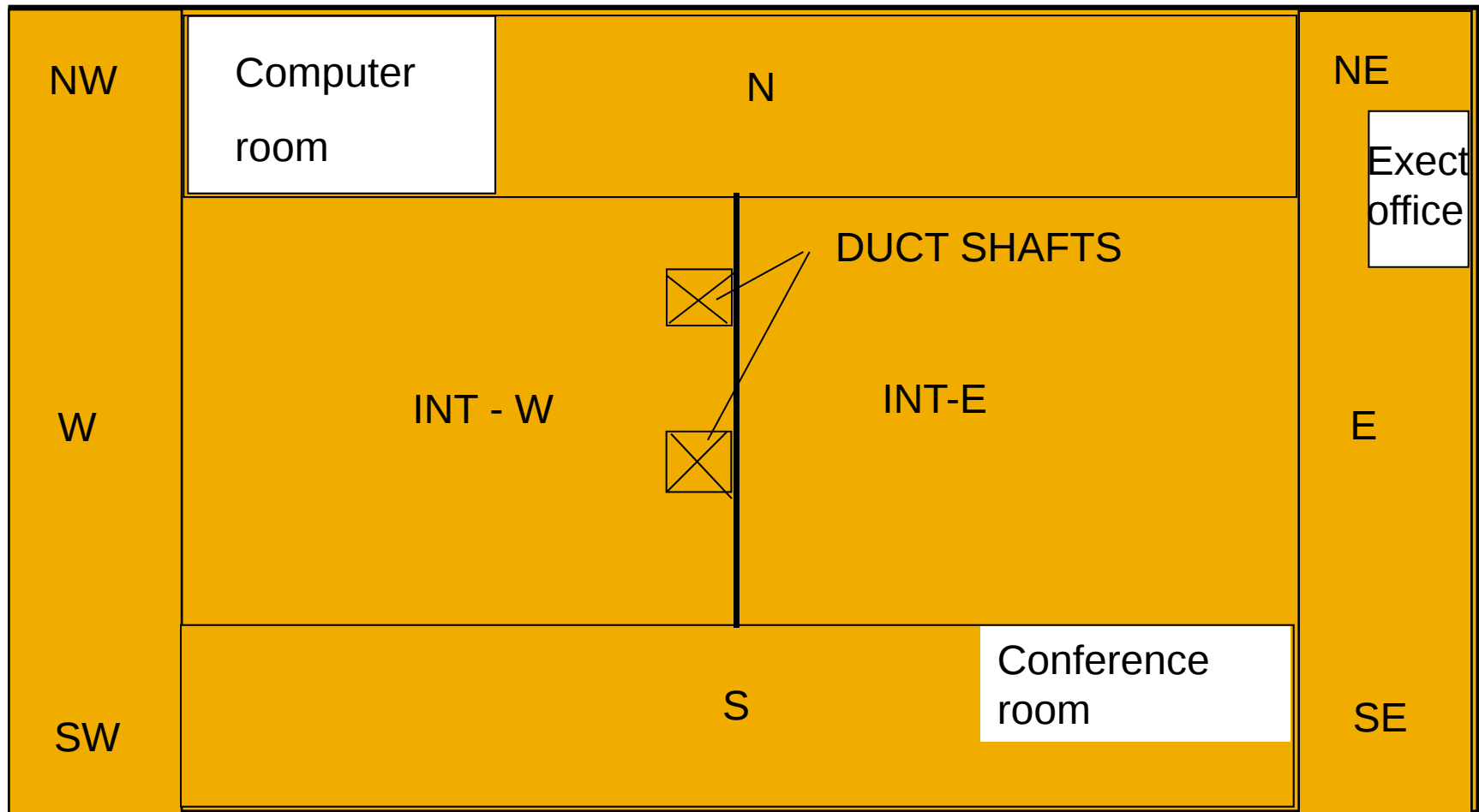
- Geseran sama (equal friction)
- Modified equal friction
- Static regain – sizing with software
- Other method – many variation self balancing

Duct design process

- Determine number of zone
- Perform heating & cooling estimate
- Determine room/zone airflow quantities
- Select duct material, shape and insulation
- Layout ductwork from AHU to diffusers
- Summarize airflows and label duct
- Size duct from fan outlet to diffusers
- Calculated air system pressure losses
- Select fan and adjust system pressures

Design step 1

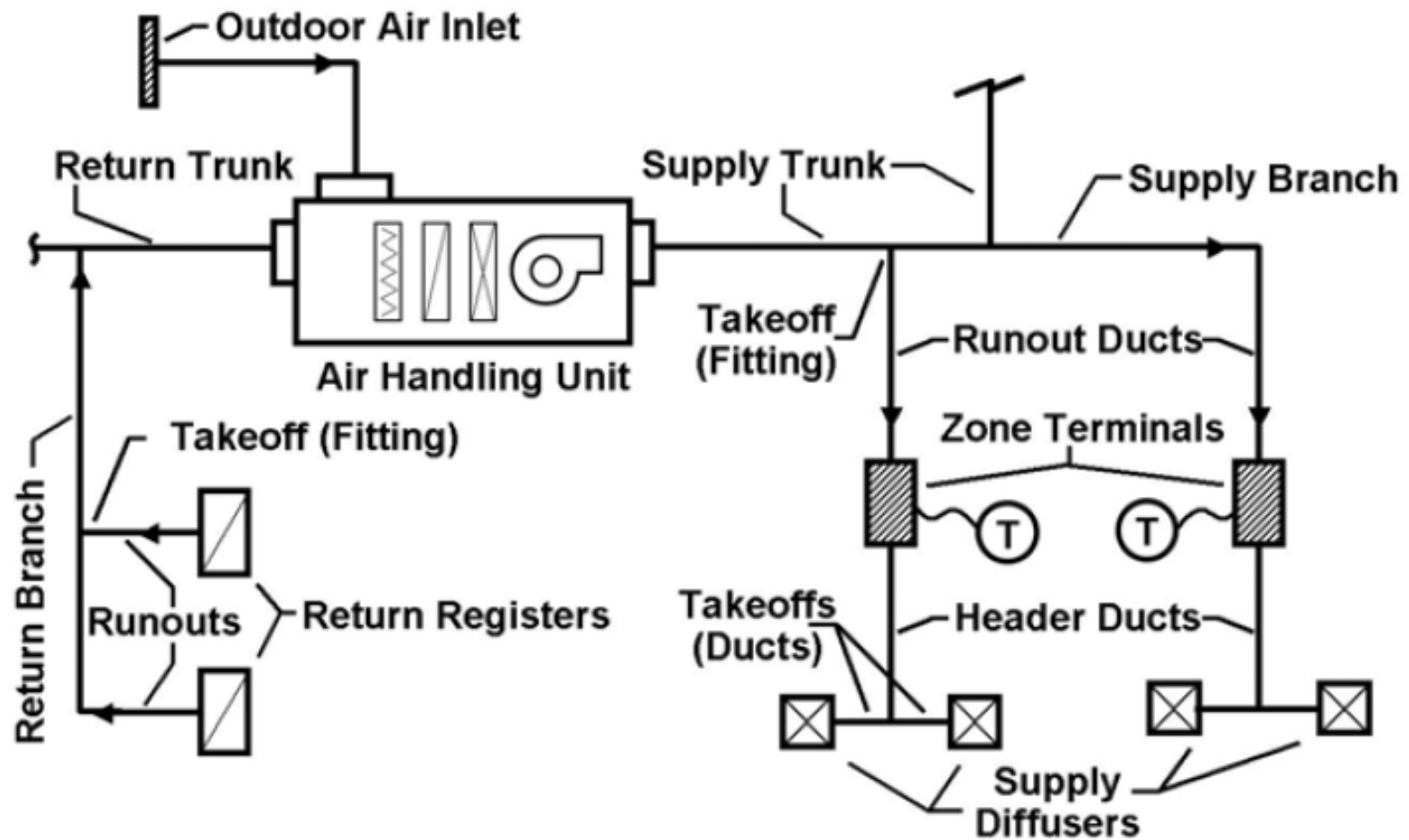
DETERMINE NUMBER OF ZONES



Design step 2

- Perform cooling and heating load estimates.
 - accurately enter the building takeoff
 - set system parameters for block, zone and space load
 - run loads

Design step 3



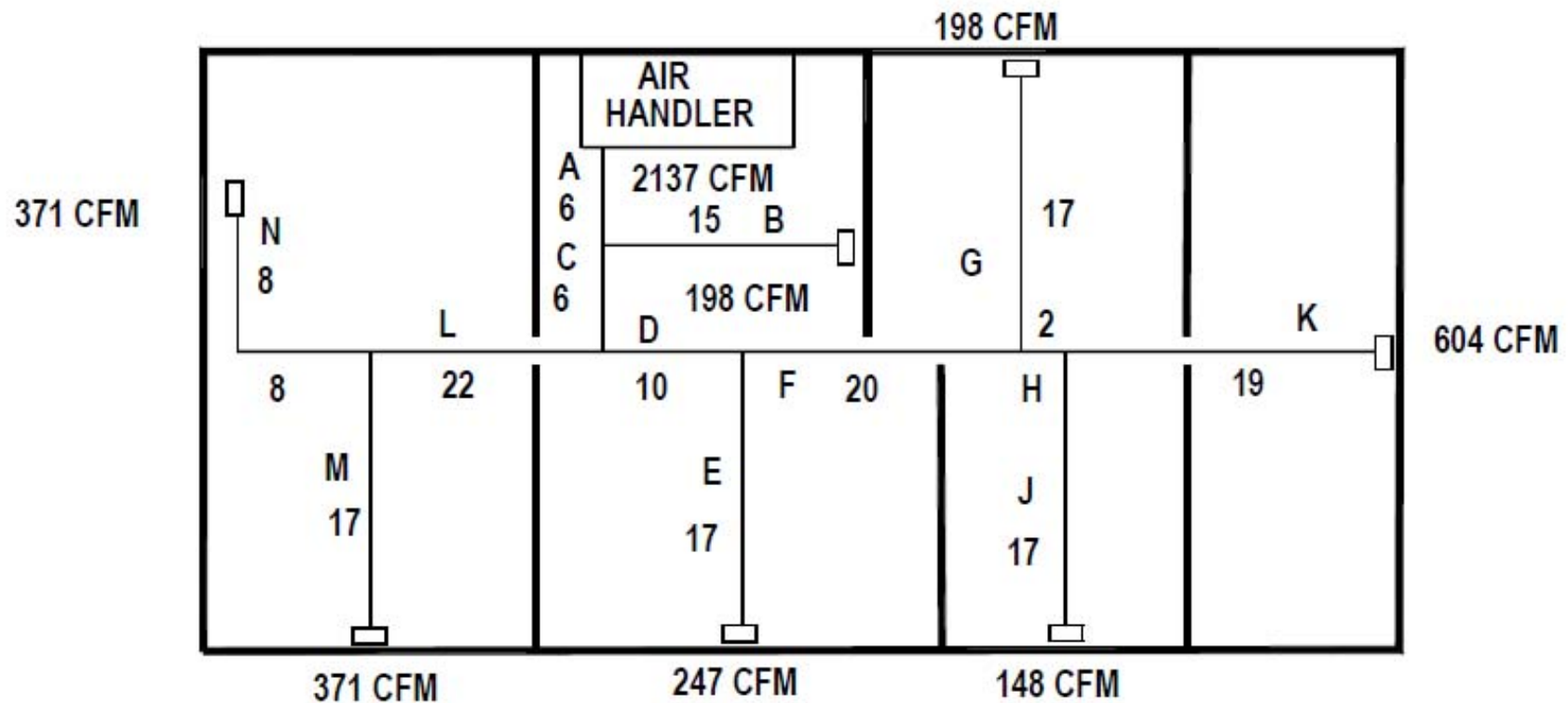
Design step 4

- Select duct material, shape and insulation
 - cost-effective material to fit the conditions
 - round, rectangular, or flat oval to fit the space and for efficient installation
 - adequate insulation to conserve energy and avoid condensation

Pressure velocity duct classifications

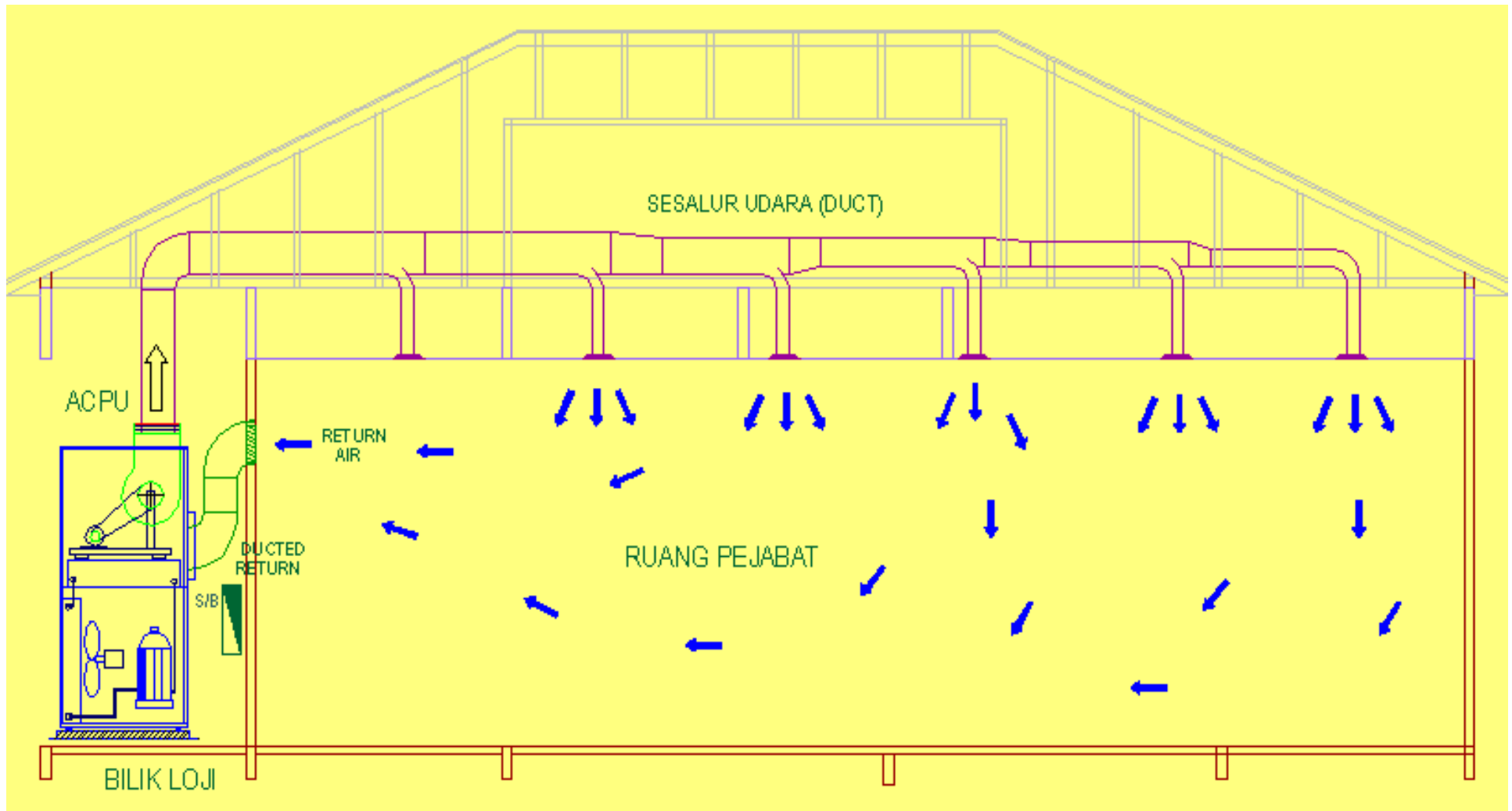
Static pressure class (in.wg)	Pressure range (in.wg)	Maximum velocity (fpm)
± 0.5	0 to 0.5	2000
± 1	>0.5 to 1	2500
± 2	>1 to 2	2500
± 3	>2 to 3	4000
± 4	>3 to 4	4000
± 6	>4 to 6	+

Lay out ductwork from AHU

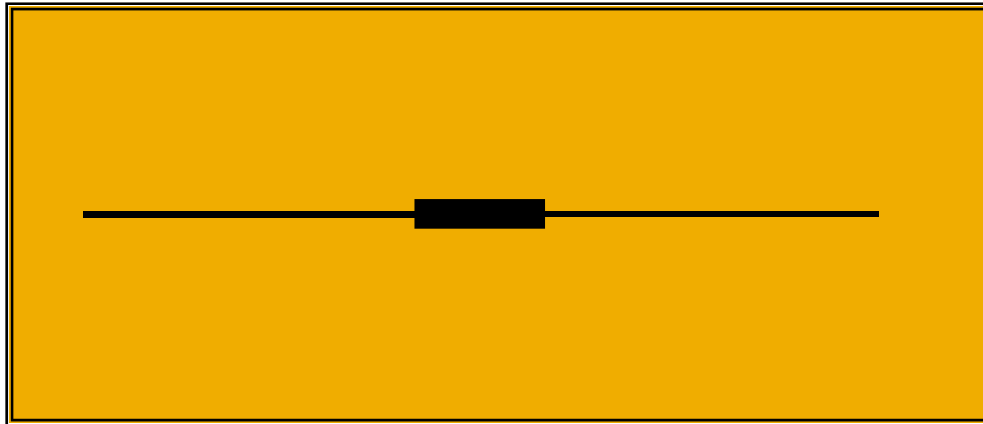


Design step 5

Lay out ductwork from AHU



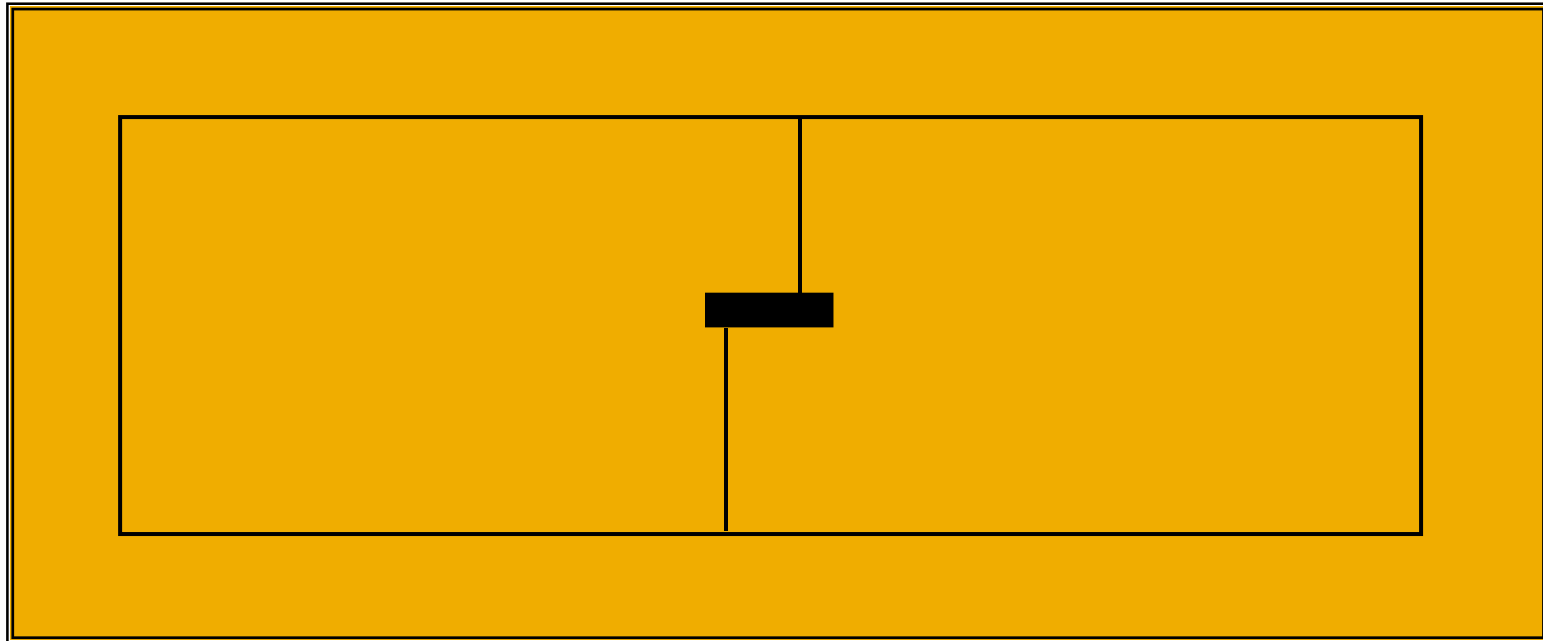
Trunk layout to fit the building



SPINE DUCT LAYOUT

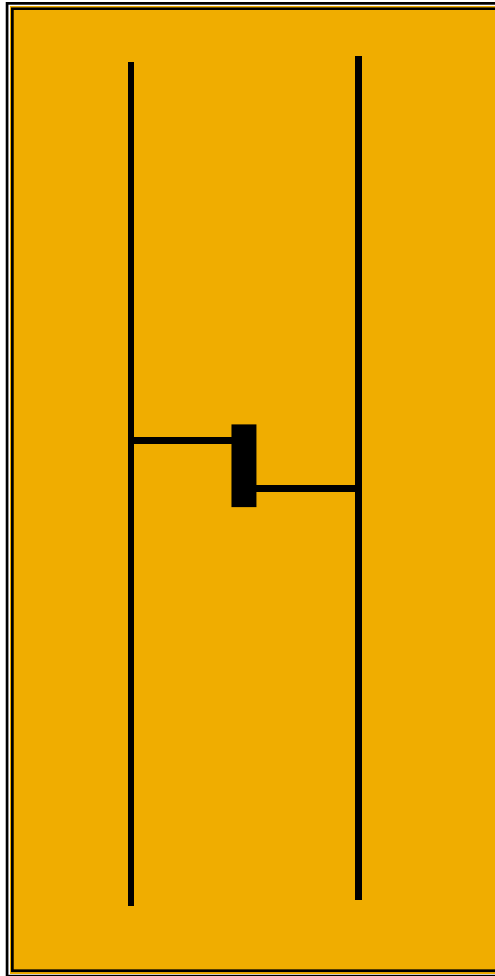
Trunk layout to fit the building

“LOOP” DUCT LAYOUT



Trunk layout to fit the building

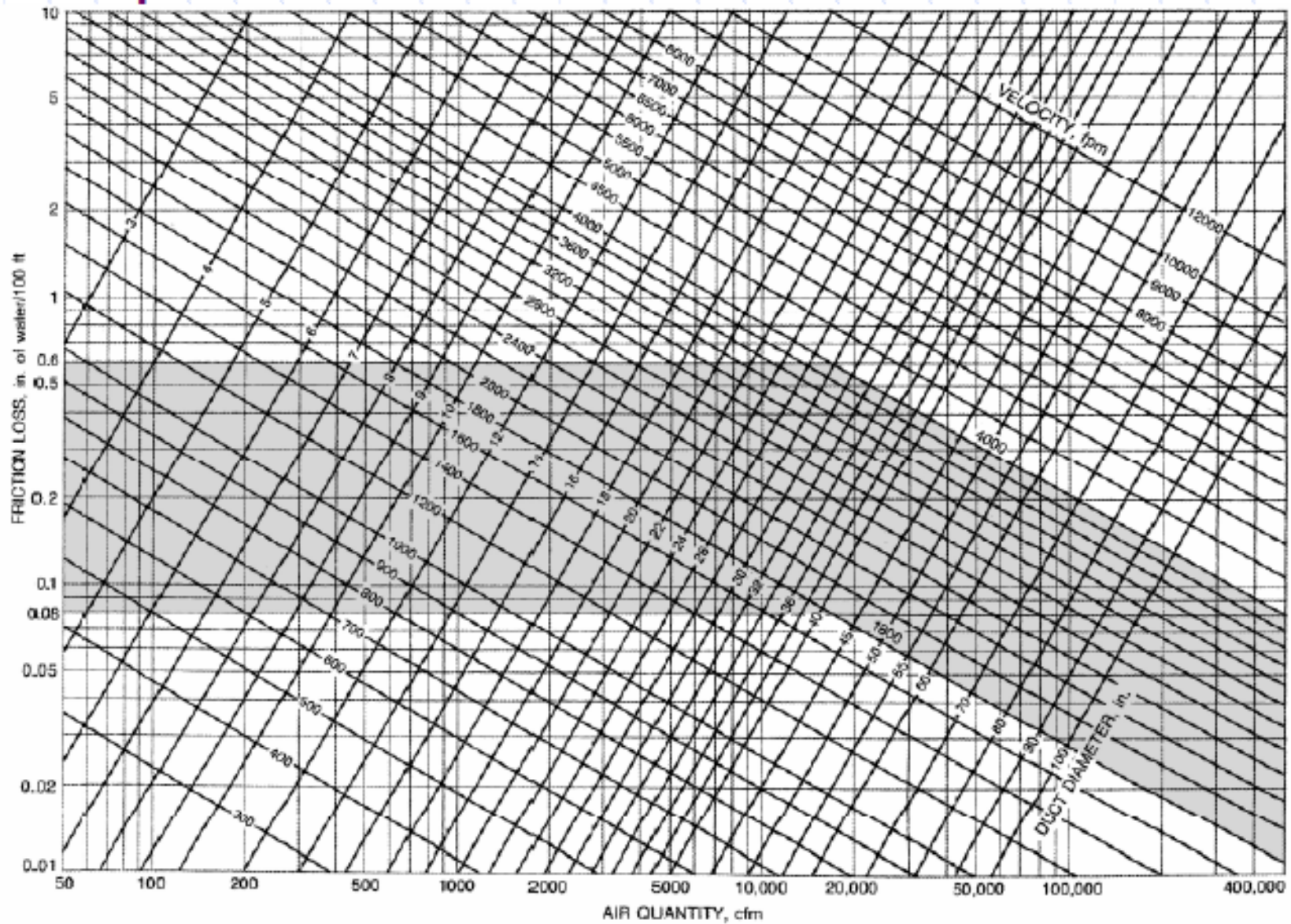
“H” PATTERN DUCT
LAYOUT



Sizing with the friction chart

- Select desired velocity in first duct section
- Enter friction loss chart, read duct diameter at intersection of cfm and velocity line
- Read resulting friction loss and verify that it is acceptable
- If sizing round duct, you have completed sizing the first duct section, proceed to the next duct section using desired friction rate.
- If sizing rectangular duct, you must correct round sizes to equivalent rectangular sizes using table 2

Equal Friction Chart



Maximum Duct Velocity

Application	Controlling Factor Noise Generation Main Ducts	Controlling Factor - Duct Friction			
		Main Ducts		Branch Ducts	
		Supply	Return	Supply	Return
Residences	600	1000	800	600	600
Apartments	1000	1500	1300	1200	1000
Hotel Bedrooms					
Hospital Bedrooms					
Private Offices	1200	2000	1500	1600	1200
Directors Rooms					
Libraries					
Theatres	800	1300	1100	1000	800
Auditoriums	1500	2000	1500	1600	1200
General Offices					
High Class Restaurants					
High Class Stores					
Banks	1800	2000	1500	1600	1200
Average Stores					
Cafeterias					
Industrial	2500	3000	1800	2200	1500

* From Carrier Air System Design Manual

Rule of thumb

FPM	Air should travel from air conditioner throughout the system at an average velocity of about 700 ff./min
SP	On average most system resistance to airflow is approximately 0.08 (0.075) static pressure (0.10) supply air, 0.05 return air)
CFM	In general, 1CFM of air is required to heat or cool 1 or 1-1/4 sq. ft of floor area

Rectangular sizes using table 2

Table 2 Equivalent Rectangular Duct Dimensions														
Circular Duct Diameter, in.	Length One Side of Rectangular Duct (<i>a</i>), in.													
	4	5	6	7	8	9	10	12	14	16	18	20	22	24
	Length Adjacent Side of Rectangular Duct (<i>b</i>), in.													
5	5													
5.5	6	5												
6	8	6												
6.5	9	7	6											
7	11	8	7											
7.5	13	10	8	7										
8	15	11	9	8										
8.5	17	13	10	9										
9	20	15	12	10	8									
9.5	22	17	13	11	9									
10	25	19	15	12	10	9								
10.5	29	21	16	14	12	10								
11	32	23	18	15	13	11	10							
11.5		26	20	17	14	12	11							
12		29	22	18	15	13	12							
12.5		32	24	20	17	15	13							
13		35	27	22	18	16	14	12						
13.5		38	29	24	20	17	15	13						
14			32	26	22	19	17	14						
14.5			35	28	24	20	18	15						
15			38	30	25	22	19	16	14					
16			45	36	30	25	22	18	15					

Approximate Ductwork Cost

Dimension	Gauge*	lb/SF
Up to 12"	26	0.906
13" to 30"	24	1.156
31" TO 54"	22	1.406
55" TO 84"	20	1.656
84" and Over	18	2.156

Galvanized Steel = \$8.25 per lb**

* Source: Uniform Mechanical Code

** Source: Recent bids – includes fittings & everything

Economical Duct Design

- ◆ Minimize aspect ratio (a/b)
- ◆ Minimize total pounds of sheet metal and
- ◆ Minimize number of reductions (2-inch rule)

CHART 5—OPERATING COST VS ASPECT RATIO

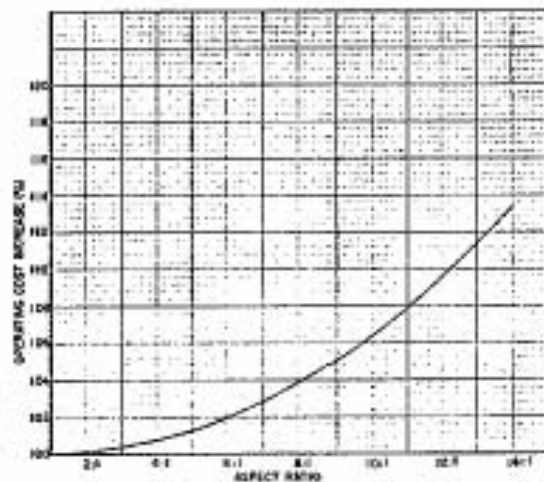
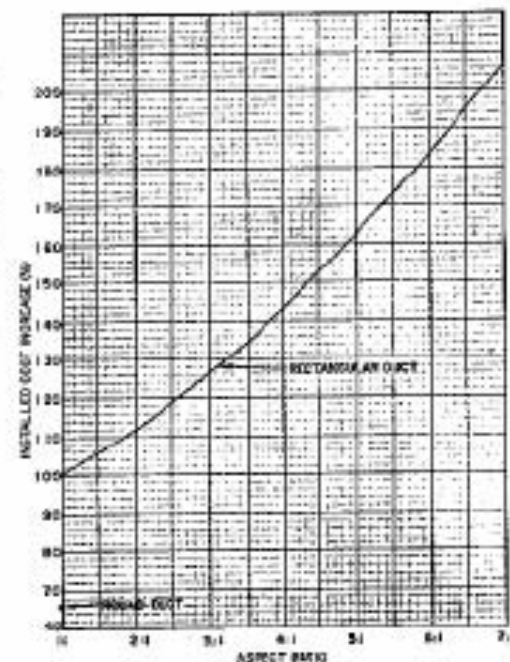


CHART 4—INSTALLED COST VS ASPECT RATIO



Frictional Loss Calculation (Pengiraan Kejatuhan Geseran)

- **Velocity Reduction Method**

Velocity at the fan discharge is pre-selected. The duct system is designed to provide progressively lower duct velocities as the air proceeds from the main duct to the branches.

- **Static Regain Method**

The ducts are sized so the increase in static pressure at each take-off offsets the pressure loss of the succeeding section of ductwork.

- **Equal Friction Method**

The duct is sized to result in a constant pressure loss per unit length of duct.

Equal Friction Method

Equal Friction Method

Frictional Losses, Δp , can be approximated:

$$\Delta p = 0.03 f \left(\frac{L}{d^{1.22}} \right) \left(\frac{V}{1000} \right)^{1.82}$$

Rectangular Ductwork is converted to round:

$$D_e = 1.30 \frac{(ab)^{0.625}}{(a+b)^{0.25}}$$

TAJUK : PEMILIHAN SAIZ SALUR UDARA

TUJUAN PENGAJARAN :- (Instructional Aims)

1. Ukur luas bilik.
2. Kira cooling capacity.
3. Kira flow rate.
4. Pilih saiz salur udara.

LUKISAN, DATA DAN JADUAL :

1. Gambarajah 1 : Layout salur udara Bilik Kuliah Institut Perguruan Sultan Azlan Shah, Ipoh, Perak.
2. Jadual 1 : Design and cooling load check figure.

Arahan Umum :

Kertas kerja ini bertujuan untuk memberikan latihan kepada pelajar mengukur, mengira cooling capacity dan flow rate serta memilih saiz salur udara yang bersesuaian.

Alat, Kelengkapan dan Bahan :

1. Duct calculator
2. Calculator

LANGKAH KERJA

BUTIRAN KERJA

1. Ukur luas bilik

a. Lihat gambarajah 1.

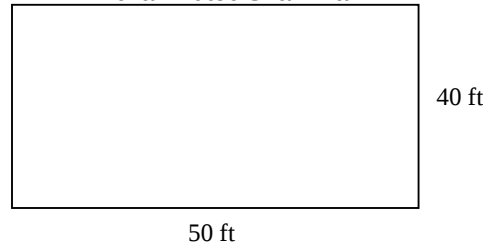
b. Dapatkan panjang dan lebar bilik tersebut.

- Panjang = 60 ft Lebar = 80 ft

c. Dengan menggunakan calculator, darabkan panjang dengan lebar bilik kuliah tersebut.

d. Formula luas bilik = panjang x lebar
= 50 ft x 40 ft
= **2 000 ft²**

Bilik Kuliah Adtec Shah Alam



2. Kira cooling capacity

a. Lihat gambarajah 1. Pastikan application bagi bilik tersebut.

b. Lihat jadual 1. Lihat ruangan application.

c. Pilih application yang sesuai bagi bilik tersebut.

Application = **classroom**

DESIGN AND CO						
Applications	Occupancy Sq Ft / Person			Lighting Watts / Sq Ft		
	Lo	Avg	Hi	Lo	Avg	Hi
Apartments (Flats)	150	100	50	1.0	2.0	4.0
Auditoriums, Theaters	15	10	5	1.0	2.0	3.0
Educational Facilities						
Classrooms	30	25	20	2.0	4.0	6.0
Laboratories	75	60	40	2.0	3.0	6.0
Cafeteria-Coffee House	20	15	10	1.5	3.0	4.5

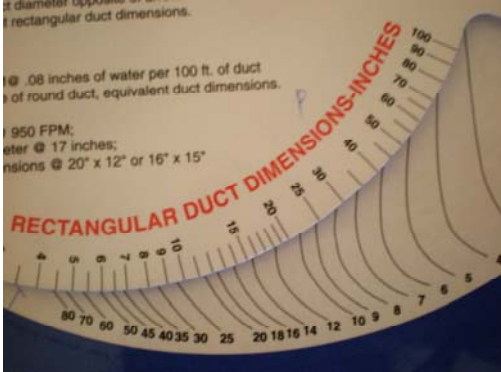
d. Lihat ruangan Grand Total. Terdapat 3 bahagian di dalam ruangan grand total iaitu low, average dan high. Pilih Grand total = **80 Btu/ft²**.

DESIGN AND COOLING LOAD CHECK FIGURES																
Applications	Occupancy Sq Ft / Person			Lighting Watts / Sq Ft			Fresh CFM / Person			Air CFM / Sq Ft			Room Sensible Btu/h / Sq Ft			Grand Total Btu/h / Sq Ft
	Lo	Avg	Hi	Lo	Avg	Hi	Lo	Avg	Hi	Lo	Avg	Hi	Lo	Avg	Hi	
Apartments (Flats)	150	100	50	1.0	2.0	4.0	25	20	10	40	35	20	25	45	20	60/400
Auditoriums, Theaters	15	10	5	1.0	2.0	3.0	1.0	1.0	1.0	30	30	1.5	2.0	20	50	80/120/200
Educational Facilities																
Classrooms	30	25	20	2.0	4.0	6.0	5.0	7.5	10	30	30	40	50	35	60	110/120/130
Laboratories	75	60	40	2.0	3.0	6.0	10	15	20	35	40	60	35	40	60	110/120/130
Cafeteria-Coffee House	20	15	10	1.5	3.0	4.5	7.5	10	15	40	80	80	25	45	55	80/110/120
Factories																
Public Areas	200	150	100	0.5	1.0	1.0	10	15	20	15	15	35	50	40	50	80/120/130
Light Manufacturing	300	200	100	0.5	1.0	1.0	10	15	20	15	15	35	50	40	50	80/120/130
Heavy Manufacturing	20	15	10	1.0	1.0	1.0	10	15	20	15	15	35	50	40	50	80/120/130
Hospitals																
Patent Rooms	100	80	40	1.0	2.0	3.0	7.5	10	15	10	10	25	35	25	35	60/120/130
Public Areas	100	80	40	1.0	2.0	3.0	7.5	10	15	10	10	25	35	25	35	60/120/130
Laboratories	100	80	40	1.0	2.0	3.0	7.5	10	15	10	10	25	35	25	35	60/120/130
Libraries	100	80	40	1.0	2.0	3.0	7.5	10	15	10	10	25	35	25	35	60/120/130
Doctors Clinics	100	80	40	1.0	2.0	3.0	7.5	10	15	10	10	25	35	25	35	60/120/130

LANGKAH KERJA	BUTIRAN KERJA
3. Kira flow rate	e. Kira cooling capacity. Formula : Luas (ft²) x grand total (Btu/ft²) Cooling capacity = 2 000 ft² x 80 Btu/ft² = 160 000 Btu/h f. Tukarkan unit Btu/h kepada watt dan kilowatt. Btu/h kepada watt 160 000 Btu/h x 0.293 = 46 880 watt Watt kepada Kilowatt 46 880 watt ÷ 1000 = 46.88 kw @ 47 kw a. Kira fow rate menggunakan formula: Formula = $\frac{\text{cooling capacity}(kw)}{\text{density}(\rho) \times \text{spesific heat} \times \Delta\text{temperature}(K)}$ Flow rate (Q) = $\frac{47 \text{ kw}}{1.2 \times 1.01 \times 10}$ = 3.88 m³/s Tukarkan m³/s kepada m³/h : darabkan dengan 3600 = 3.88 x 3600 = 13 968 m³/h Tukarkan m³/h kepada CFM : bahagikan dengan 1.7 = $\frac{13968}{1.7}$ = 8 216 cfm

LANGKAH KERJA	BUTIRAN KERJA
4. Pilih saiz salur udara	a. Cari cfm bagi setiap diffuser. - Jumlah flow rate = 8 216 cfm. - bahagikan jumlah flow rate dengan jumlah diffuser. $\text{Flow rate setiap diffuser} = \frac{\text{jum. flow rate (cfm)}}{\text{bil. diffuser}}$ $= \frac{8216}{12}$ $= \mathbf{684 \text{ cfm}}$ b. Kira flow rate bagi salur udara utama (main duct). - Kiraan bermula dari hujung salur udara. - Tambahkan nilai flow rate bagi setiap diffuser. F : $684 + 684 = 1368$ E : $1368 + 684 + 684 = 2736 \text{ cfm}$ D : $2736 + 684 + 684 = 4104 \text{ cfm}$ C : $4104 + 684 + 684 = 5472 \text{ cfm}$ B : $5472 + 684 + 684 = 6840 \text{ cfm}$ A : $6840 + 684 + 684 = 8208 \text{ cfm}$

LANGKAH KERJA	BUTIRAN KERJA
	c. Pilih saiz salur udara berdasarkan nilai flow rate yang diperolehi. i. Ambil duct calculator yang telah diberikan. ii. Lihat duct calculator. Terdapat beberapa perkara yang perlu dilakukan sebelum boleh memilih saiz salur udara. iii. Lihat pada kawasan air quantity (cfm). Ambil nilai air quantity (cfm) daripada flow rate bagi A,B,C,D,E dan F yang telah dibuat pengiraan sebelum ini. iv. Pusingkan duct calculator yang mana air quantity hendaklah diletakkan setentang dengan nilai frction loss. Nilai friction loss adalah tetap iaitu 0.08 inches of water.  ** Nilai friction loss adalah tetap mengikut syarikat pembuat penyaman udara. v. Lihat pada duct diameter. Saiz salur udara bagi jenis bulat akan dapat diperolehi.  Saiz salur udara bulat: - A = 32 in - B = 30 in - C = 28 in - D = 25 in - E = 21 in - F = 16 in - G = 12.5 in

LANGKAH KERJA	BUTIRAN KERJA
	vi. Lihat saiz salur udara segiempat. Bacaan adalah lebar x tinggi.  Saiz yang dipilih adalah: - A = 50 x 18 in - B = 40 x 18 in - C = 35 x 18 in - D = 30 x 18 in - E = 20 x 18 in - F = 18 x 12 in - G = 11 x 12 in Pemilihan saiz salur udara hendaklah bersesuaian dengan keadaan.