Air Duct Calculation

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Air Ducts

Basic Concepts

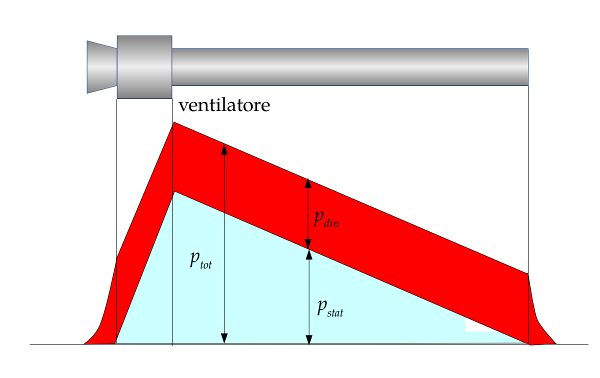
- With constant cross-section in segments (section changes are localized).
- Composed of different branches, with splits and mergers that cause variations in flow rate.
- The air velocity in the ducts must be chosen based on the system's use and the location of the ducts to limit noise.
- Velocity is also important because it determines the pressure distribution within the ducts.
- In junctions and branches, all arms have the same static pressure value.

Dynamic and Total Pressure

$$P_{dyn} = \frac{1}{2}\rho v^2 > 0 \quad [Pa]$$

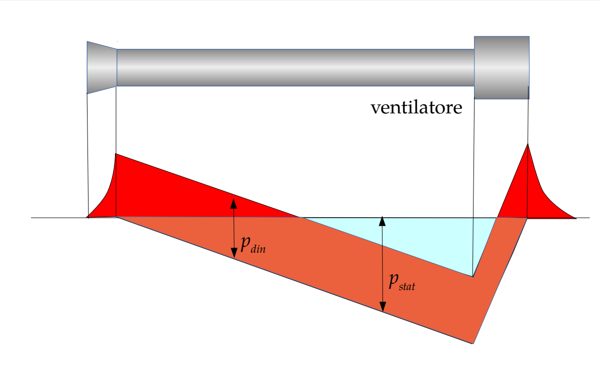
$$P_{tot} = P_{dyn} + P_{stat}$$

Pressure Trend in a Duct



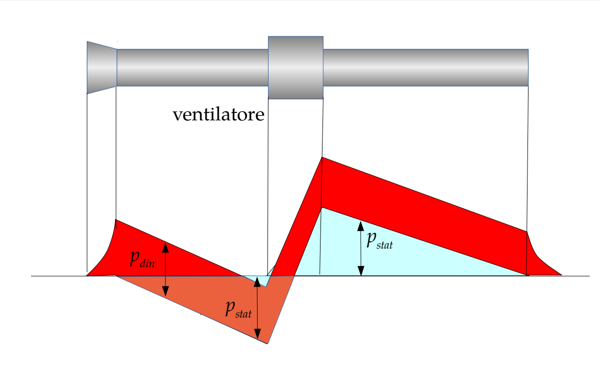
Pressure and Fans

Suction

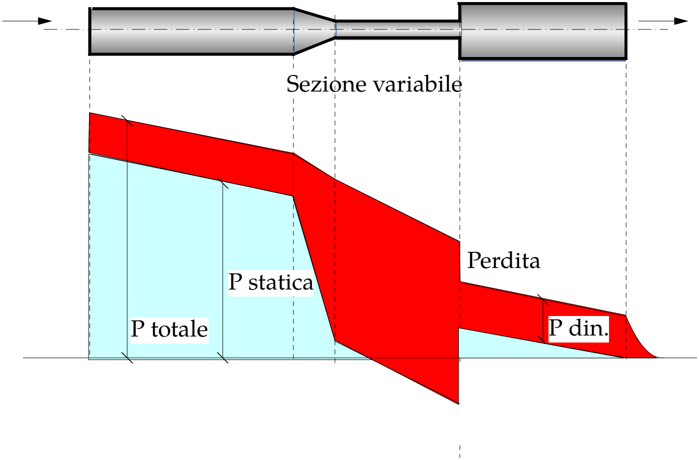


Pressure and Fans

Intermediate Fan



Variable Cross-Section



dict air velocity

Componente	Impianti		
	residential (m/s)	commercial (m/s)	industrial (m/s)
external inlet	2,5-4,0	2,5-4,5	2,5-6,0
Filteers	1,3-1,5	1,5-1,8	1,8-2,5
cold coil	1,5-2,0	2,0-2,5	2,5-3,8
hot coil	2,3-2,5	2,5-4,0	3,5-5,0
ventilator inlet	3,5-4,5	4,0-5,0	5,0-7,0
ventilator outlet	5,8-8,5	6,5-11,0	8,0-14,0
principal air duct	3,5-6,0	5,0-8,0	6,0-11,0
derivated air duct	3,0-5,0	3,0-6,5	4,5-9,0

Pressure losses

Continuous pressure losses

$$\Delta P_{dist} = \frac{f_a}{D_h}\rho\frac{v^2}{2}L \; = \; \frac{f}{D}P_{dyn}L$$

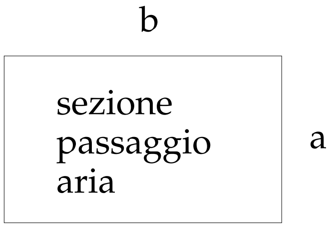
f_a friction factor

ρ fluid density

L duct length

D_h duct diameter if circular

Rectangular section



Equivalent Diameter

$$D_{eq} = 1,3\frac{(ab)^{0,625}}{(a+b)^{0,25}}$$

$$1 \;\leq\; \frac{b}{a} \;\leq\; 4$$

Standard duct sizes

lunghezza del lato [mm]	100	150	200	250	300	400	500	600	800	1000	1200	
200	0,02	0,03	0,04									A_c
	133	171	200									d_h
	149	186	218									d_e
	0,6	0,7	0,8									A_l
250	0,025	0,038	0,05	0,063								A_c
	143	188	222	250								d_h
	165	206	241	273								d_e
	0,7	0,8	0,9	1								A_l
300	0,03	0,045	0,06	0,075	0,09							A_c
	150	200	240	273	300							d_h
	180	224	262	296	327							d_e
	0,3	0,9	1	1,1	1,2							A_l
400	0,04	0,06	0,08	0,1	0,12	0,16						A_c
	160	218	267	308	343	400						d_h
	205	255	299	337	373	436						d_e
	1	1,1	1,2	1,3	1,4	1,6						A_l
500		0,075	0,1	0,13	0,15	0,2	0,25					A_c
		231	286	333	375	444	500					d_h
		283	331	374	413	483	545					d_e
		1,3	1,4	1,5	1,6	1,8	2					A_l
600		0,09	0,12	0,15	0,18	0,24	0,3	0,36				A_c
		240	300	353	400	480	545	600				d_h
		307	359	406	448	524	592	654				d_e
		1,5	1,6	1,7	1,8	2	2,2	2,4				A_l
800			0,16	0,2	0,24	0,32	0,4	0,48	0,64			A_c
			320	381	436	533	615	686	800			d_h
			410	463	511	598	675	745	872			d_e
			2	2,1	2,2	2,4	2,6	2,8	3,2			A_l

lunghezza del lato [mm]	100	150	200	250	300	400	500	600	800	1000	1200	
1000				0,25	0,3	0,4	0,5	0,6	0,8	1		A_c
				400	462	571	667	750	889	1000		d_h
				512	566	662	747	825	965	1090		d_e
				2,5	2,6	2,8	3	3,2	3,6	4		A_l
1200					0,36	0,48	0,6	0,72	0,96	1,2	1,44	A_c
					480	600	706	800	960	1091	1200	d_h
					614	719	812	896	1049	1184	1308	d_e
					3	3,2	3,4	3,6	4	4,4	4,8	A_l
1400						0,56	0,7	0,84	1,12	1,4	1,68	A_c
						622	737	840	1018	1167	1292	d_h
						771	871	962	1125	1270	1403	d_e
						3,6	3,8	4	4,4	4,8	5,2	A_l
1600						0,64	0,8	0,96	1,28	1,6	1,92	A_c
						640	762	873	1067	1231	1371	d_h
						819	925	1022	1195	1350	1491	d_e
						4	4,2	4,4	4,8	5,2	5,6	A_l
1800							0,9	1,08	1,44	1,8	2,16	A_c
							783	900	1108	1286	1440	d_h
							976	1078	1261	1424	1573	d_e
							4,6	4,8	5,2	5,6	6	A_l
2000							1	1,2	1,6	2	2,4	A_c
							800	923	1143	1333	1500	d_h
							1024	1131	1323	1494	1650	d_e
							5	5,2	5,6	6	6,4	A_l

Friction factor computation

Colebrook

$$\frac{1}{\sqrt{f_a}} = -2\log\left(\frac{\varepsilon}{3,7\cdot D} + \frac{2,51}{\mathrm{Re}\cdot\sqrt{f_a}}\right)$$

Atshul e Tsaal

$$\begin{aligned} f' =& 0,11\cdot\left(\frac{\varepsilon}{D_h} + \frac{68}{Re}\right)^{0,25} \\ se\ \ f' \geq& 0,018: \quad f_a = f' \\ se\ \ f' <& 0,018: \quad f_a = 0,85\cdot f' + 0,0028 \end{aligned}$$

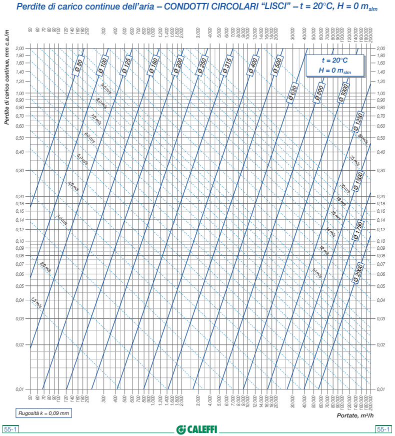
ε duct rugosity

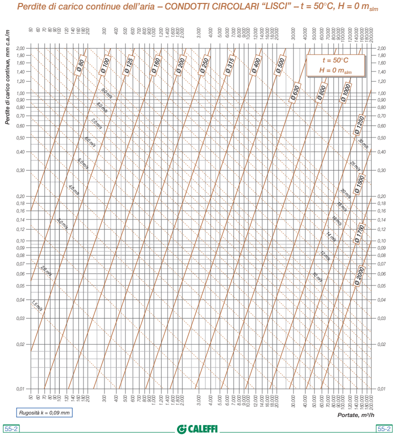
Re Reynolds number

rugosity

material	typology	rugosità ε [mm]
PVC		0,01-0,05
Alluminium	smooth	0,01-0,05
Steel		0,05
galvanized steel		0,05-0,10
galvanized steel continuous	medium	0,06 - 0,12
galvanized spiral duct		0,09 - 0,12
metal flexible	rough	1,2-2,1
not metal flexible		1,0-4,6

Friction chart

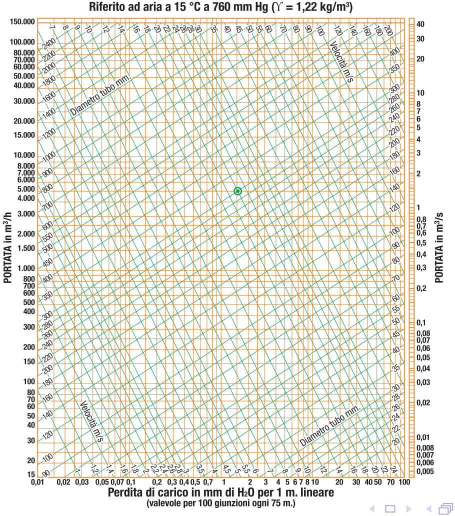




fonte Caleffi

Friction chart

> Diagramma perdite di carico <



fitting losses

Direct method

$$\Delta P_{conc} = \xi \frac{\rho v^2}{2} \ [Pa]$$

$$\Delta P_{conc} = \xi_1 \frac{\rho v_1^2}{2} = \xi_2 \frac{\rho v_2^2}{2}$$

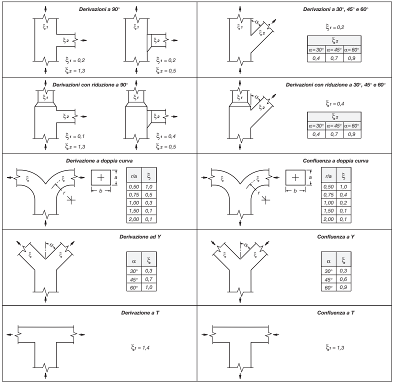
equivalent length

$$L_{eq} = f\left(\frac{L}{D}\right)$$

$$L_{tot} = L_{effettiva} + \sum L_{eq}$$

fitting losses

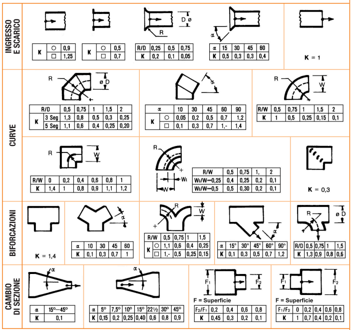
Canali rettangolari - valori indicativi dei coefficienti ξ - derivazioni e confluenze



> Tabella resistenze accidentali <

Pressione dinamica $\quad pd = \dfrac{\gamma C^2}{2\,g} \quad$ Per $\dfrac{\gamma = 1{,}22 \text{ kg/m}^3}{g = 9{,}81 \text{ m/s}^2}$

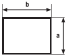
Perdite accidentali Δp = **K x pd** (pd riferita alla velocità nel punto →)



C m/s	pd mm H_2O
4	1
5	1.6
6	2.2
7	3
8	4
9	5
10	6
12	9
14	12
16	16
18	20
20	25
22	30
24	36
26	42
28	49
30	56
35	76
40	100
45	126
50	155
55	188
60	224
65	263
70	305
75	350
80	398
90	504
100	622

Tubazioni rettangolari - Diametri equivalenti a parità di Perdita per attrito e di Portata d'aria

a \ b	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1200	1400	1600	1800
150	210	230	245	260	275	290	300	310	320	Diametri equivalenti										
200	245	265	285	305	320	340	350	365	380	390	400	415								
250	275	300	325	345	365	380	400	415	430	445	455	470	480	495	505	520				
300		330	355	370	400	425	440	460	475	490	505	520	535	550	560	575	620			
350			380	410	435	455	475	495	515	535	550	565	585	600	615	625	680	725		
400				440	465	490	515	535	555	575	590	610	625	645	660	675	730	780	830	870
450					490	520	545	565	590	610	630	650	670	685	705	720	780	835	885	935
500						545	575	600	625	645	665	685	710	725	745	760	830	880	940	990



Esempio: La tubazione ∅ 300 mm. per una portata di 5000 m^3/h ha una perdita di carico di 1,6 mm. H_2O per metro. Per la medesima portata e uguale perdita di pressione si dovranno usare le seguenti tubazioni rettangolari: **a x b = 150x550, 200x400, 250x300 mm.**

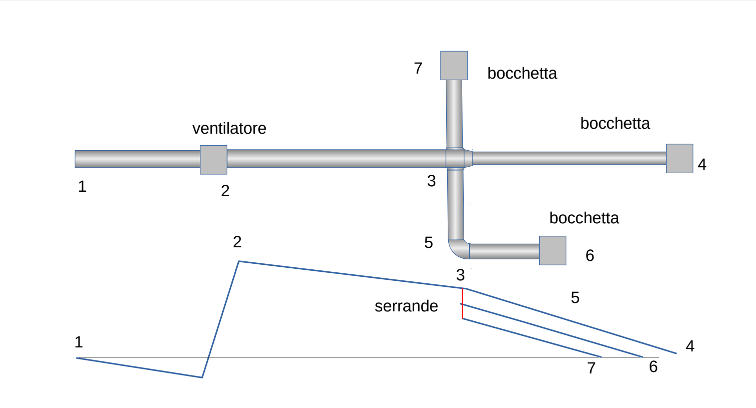
Duct sizing

Equal friction method

- quick and simple method
- ideal for symmetrical systems with similar distances between vents and fans
- the ducts are sized with the same pressure loss per unit of length
- it must be checked that the pressure at the vents is sufficient
- they must be balanced
  - chnage sizes
  - dampers insertion

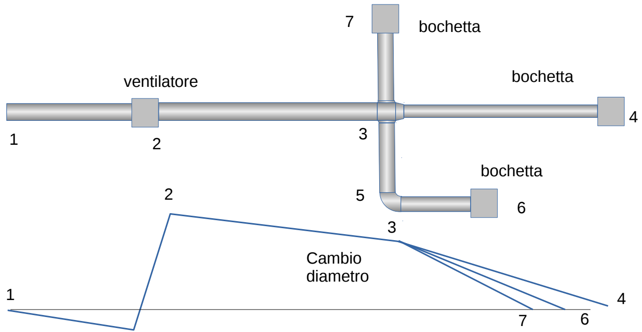
Equal friction method

system balancing with dampers



Equal friction methods

system balance by changing duct diameter

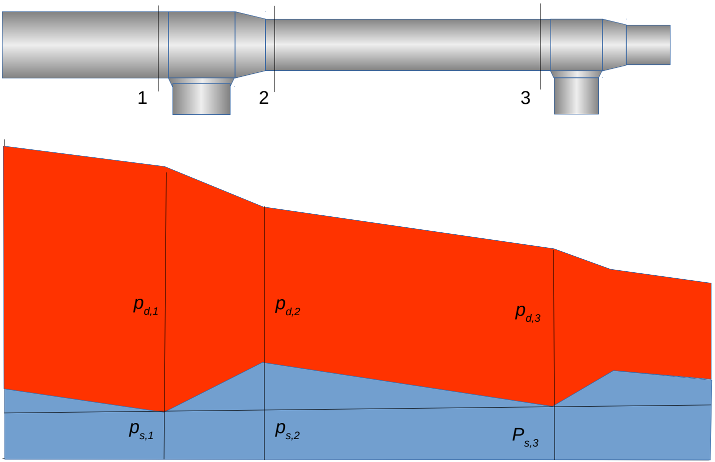


pressure balance

Static regain method

- at each section change the dynamic pressure is transformed into static pressure
- the value of P_{stat} is maintained at the beginning of each section
- the static pressure is kept constant
- can be used to maintain low pressures on the duct wall
- iterative solution
- more balanced network

Pressure distribution



Duct sizing

pressure

$$p_{t,1} = p_{s,1} + p_{d,1}$$
$$p_{t,3} = p_{s,3} + p_{d,3}$$

static pressure

$$p_{s,1} = p_{t,1} - p_{d,1}$$
$$p_{s,3} = p_{t,3} - p_{d,3}$$

constant static pressure

$$p_{s,1} - p_{s,3} = p_{t,1} - p_{t,3} - (p_{d,1} - p_{d,3}) = 0$$
$$p_{s,1} - p_{s,3} = (p_{t,1} - p_{t,2}) + (p_{t,2} - p_{t,3}) + (p_{d,3} - p_{d,1}) = 0$$

Duct sizing

parts of the relation

$(p_{t,1} - p_{t,2})$ pressure loss due to diverging fitting
$(p_{t,2} - p_{t,3})$ friction pressure loss between section 2 and 3
$(p_{d,3} - p_{d,1})$ velocity pressure difference between section 3 and 1

different static pressure

- ducts sizes are limited
- usually static pressure are not equal
- the diameter must be changed with a trial and error approach
- example : $p_{s,1} - p_{s,3} > 0$

$$p_{s,1} - p_{s,3} = (p_{t,1} - p_{t,2}) + (p_{t,2} - p_{t,3}) + (p_{d,3} - p_{d,1}) > 0$$

Duct sizing

Increase duct diameter of section 2-3

$(p_{t,1} - p_{t,2})$	pressure loss must be computed from fittings tables
$(p_{t,2} - p_{t,3}) \Downarrow$	friction pressure loss decreases since the diameter increased
$(p_{d,3} - p_{d,1}) \Downarrow$	decrease, $p_{d,3}$ decreases due to the lower velocity
$(p_{s,1} - p_{s,3}) \Downarrow$	decrease, before $(p_{s,1} - p_{s,3}) > 0$

$$p_{s,1} - p_{s,3} = (p_{t,1} - p_{t,2}) + (p_{t,2} - p_{t,3}) - (p_{d,1} - p_{d,3}) \Downarrow$$

Pressure difference is corrected

$$p_{s,1} - p_{s,3} = (p_{t,1} - p_{t,2}) + (p_{t,2} - p_{t,3}) - (p_{d,1} - p_{d,3}) \simeq 0$$