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AERAULIC PLANT PRESSURE LOSSES AND PLANT SIZING

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OUTLINE

- Introduction
- Sizing an air system
  1. Definition of the design flow rate of an air system
  2. Duct and vents choice
  3. Pressure drop (localized/continuous)
- Example: a residential case study
- Tool presentation
- Requirements for the report

INTRODUCTION

Which is the scope of an air system installed in an environment? Full-air and primary air systems.

Full-air Systems

- Fulfillment of IAQ and thermal requirements
- No coupling with other systems
- High air volumes to be treated
  - ⇒ Higher energy, higher noise
- High volumes required (system)
- Challenging system control

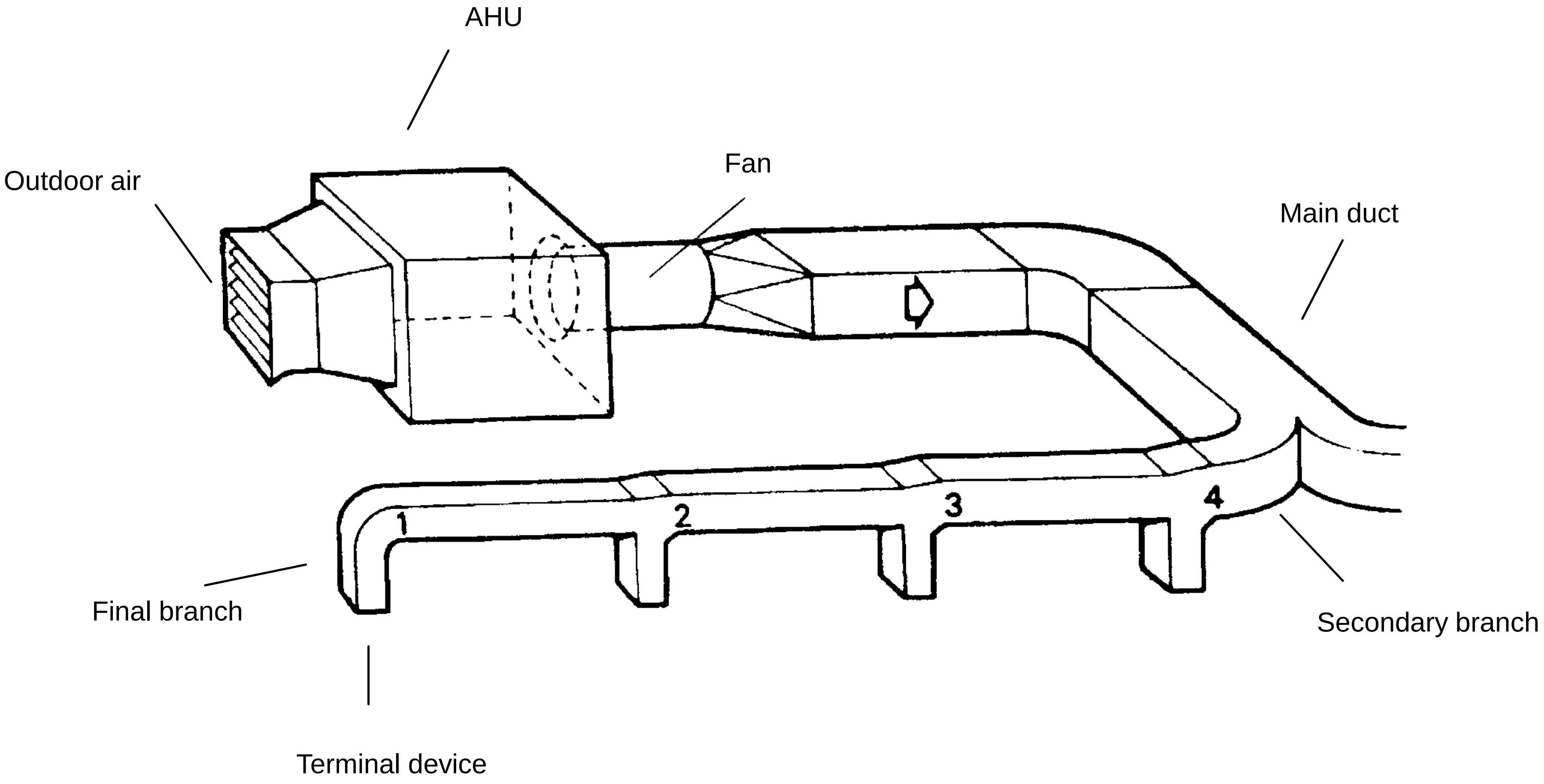
Primary Air Systems

- Low air volumes to be treated
- Presence of an alternative heating/cooling system
- More compact systems
- Split IAQ and thermal requirements control

Main elements of a full-air conditioning system

GENERATION SYSTEM	AHU Air Handling Unit (*UTA – unità di trattamento aria*)	AIR DISTRIBUTION SYSTEM	AIR TERMINAL UNIT
↓	↓	↓	↓
Gas boiler, chiller, heat pumps, etc.	Filters Air dampers (*serrande*) Heating/cooling coil *(batterie di riscaldamento/raffrescamento)* De/humidification sections Fans (*ventilatori*)	Air distribution ducts	Exhaust/supply/fresh air terminal device *(Bocchette)*

INTRODUCTION



SIZING AN AIR SYSTEM

What does it mean to *size* an air system?

It consists of the definition of the system layout and the choice of components for the proper supply of the air flow to fulfill the thermal and IAQ requirements of the environment.

THE SPACE AIR DIFFUSION IS NEGLECTED !!

INPUT

- Case study *(which is the end use of the building I should supply?)*
- HVAC configuration *(Full-air or primary air? CAV or VAV?)*
- Thermal and IAQ requirements
  ⇨ *Primary air flows and thermal loads*
- Building scheme

OUTPUT

- Duct length and detailed design
- Choice of the machine of the system

SIZING AN AIR SYSTEM

What does it mean to _size_ an air system?

ASHRAE Handbook of Fundamentals (english)
Manuale del termotecnico – Nicola Rossi (italian)

1. Define the **thermal loads** (Q_i - [W]) of the building in the heating and cooling season and the **IAQ requirements** ($V_{req,i}$ - [m^3/h])
2. Define the **air flow rate** to supply to each environment ($V_{prog,i}$ - [m^3/h])
3. Chose the **vents** for each air inlet and outlet
4. Sketch the system on the case study (main ducts, risers, branches)
5. Determine the airflow in each part of the system, starting from the outlets and acting backwards
6. Set the in-duct velocity, define the ducts section (shape and dimension) and their length
7. Calculate the **pressure losses**
8. Choose the appropriate **machine** (adequate flowrate and enough prevalence!)

IAQ REQUIREMENTS: THE VENTILATION RATE

STANDARD EN 16798-1 (ANNEX B)

- Definition of ***fresh air*** flow rates to size the ventilation system;
- Minimum flow rate: 4 L/(s person).

Category	Level of expectation	
I	High	⇨ **High level for specific cases (elderly, sick people)**
II	Medium	⇨ **Medium/average value**
III	Moderate	⇨ **Lowest admissible value**
IV	Low	⇨ **To be avoided. Tolerated for limited time**

For healthy reasons. **the minimum flow rate** in occupied rooms **should never go below 4 L/(s px)**

$$\boxed{4\ \mathrm{L/(s\ px)} = 14.4\ \mathrm{m^3/(h\ px)}}$$

HEATING (q_H) AND COOLING (q_C) LOADS CALCULATED ACCORDING TO THE METHODS SHOWN IN THE PREVIOUS LECTURES

How to convert a **load** to an **air flow**?

STEP 1: Define environment setpoint

WINTER		SUMMER	
Humidity φ_A [%]	Temperature t_A [°C]	Humidity φ_A [%]	Temperature t_A [°C]
50	20-21	50	26

STEP 2: Define the limit supply temperature (t_S)

WINTER
$$|t_S - t_A| \leq 12 \div 20\ °C$$

SUMMER
$$|t_A - t_S| \leq 8 \div 12\ °C$$

STEP 3: Calculate the air flow rates (V_{load}) according to:

$$q_i = \rho_{air} \boxed{V_{load}} c_p(|t_S - t_A|)$$

NOT NECESSARILY FRESH AIR!!

DEFINITION OF THE DESIGN FLOW RATE

The design flow rate (V_{prog}) is the maximum value of the flows calculated in all the previous steps:

$$\boxed{V_{prog} = \max\left(V_{req}; V_{load,H}; V_{load,C}\right)}$$

EXAMPLE: Case study with 3 (j) rooms

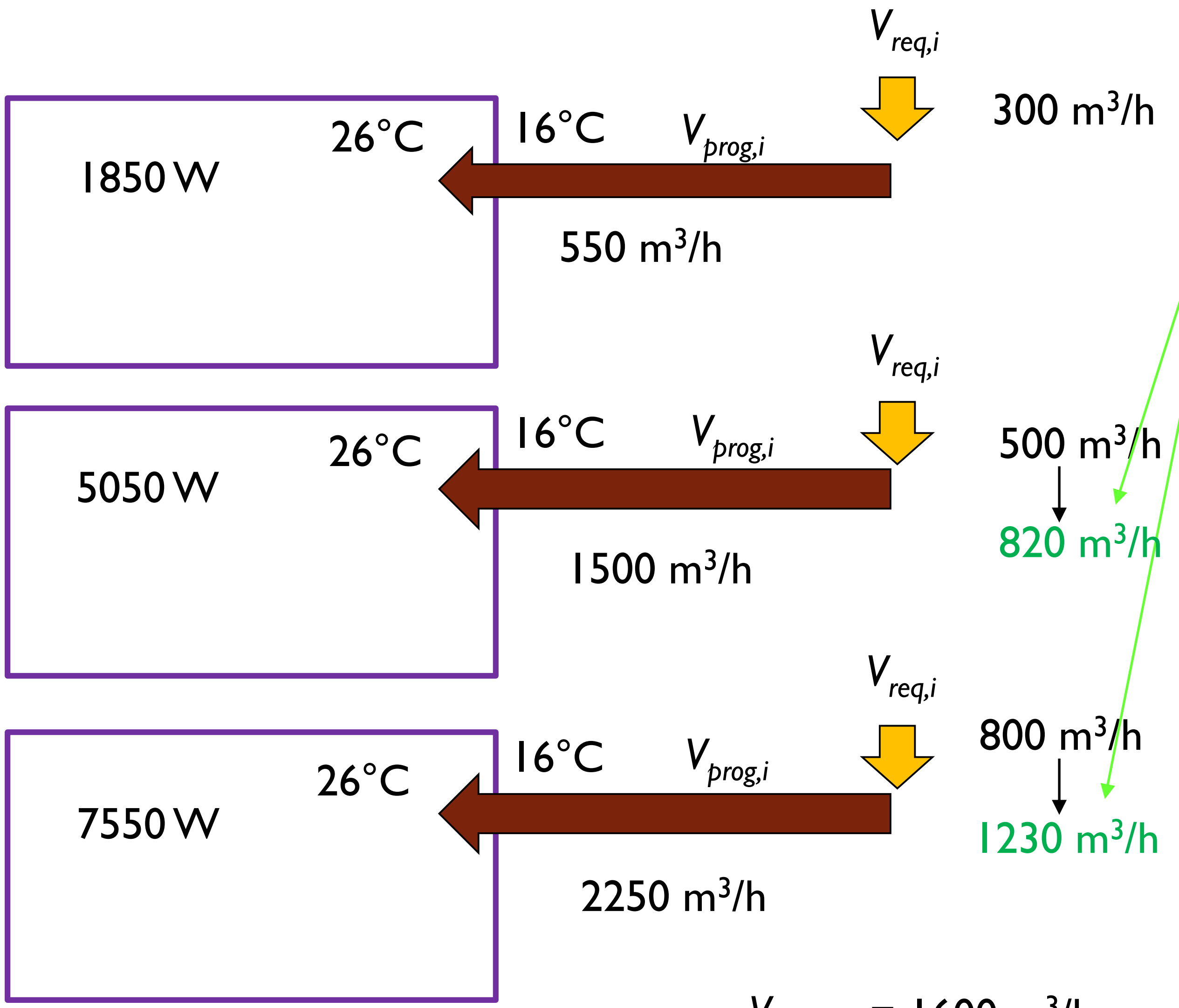
$$V_{prog,TOT} = \sum_{j} V_{prog,j}$$

The <u>share</u> of the **fresh air** over the **total** should be calculated room-by-room to determine the ratio (M). To simplify the sizing process, the <u>maximum</u> M-value will be assumed for all the environments

$$M_j = \frac{V_{req,j}}{V_{prog,j}}$$

$$M_{TOT} = \max_j(M_j)$$

DEFINITION OF THE DESIGN FLOW RATE - EXAMPLE



$$\boxed{M_1 = \frac{V_{req,1}}{V_{prog,1}} = 0.54}$$

$$M_2 = \frac{V_{req,2}}{V_{prog,2}} = 0.33$$

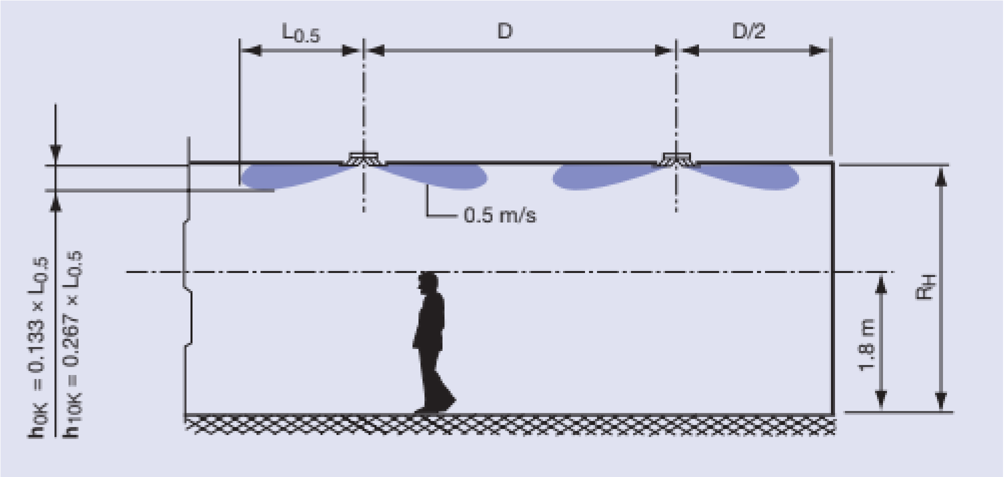
$$M_3 = \frac{V_{req,3}}{V_{prog,3}} = 0.36$$

$V_{req,TOT}$ = 1600 m^3/h $\longrightarrow$ 2350 m^3/h

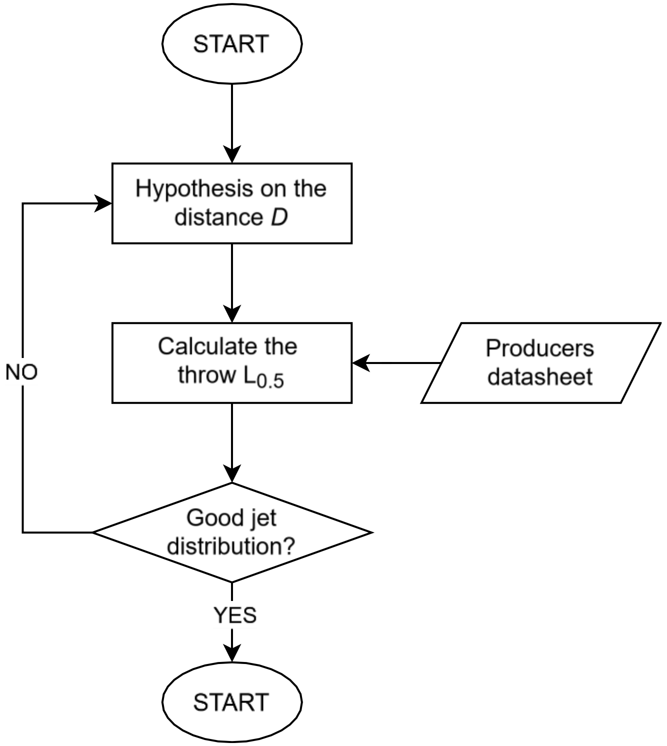
+47%

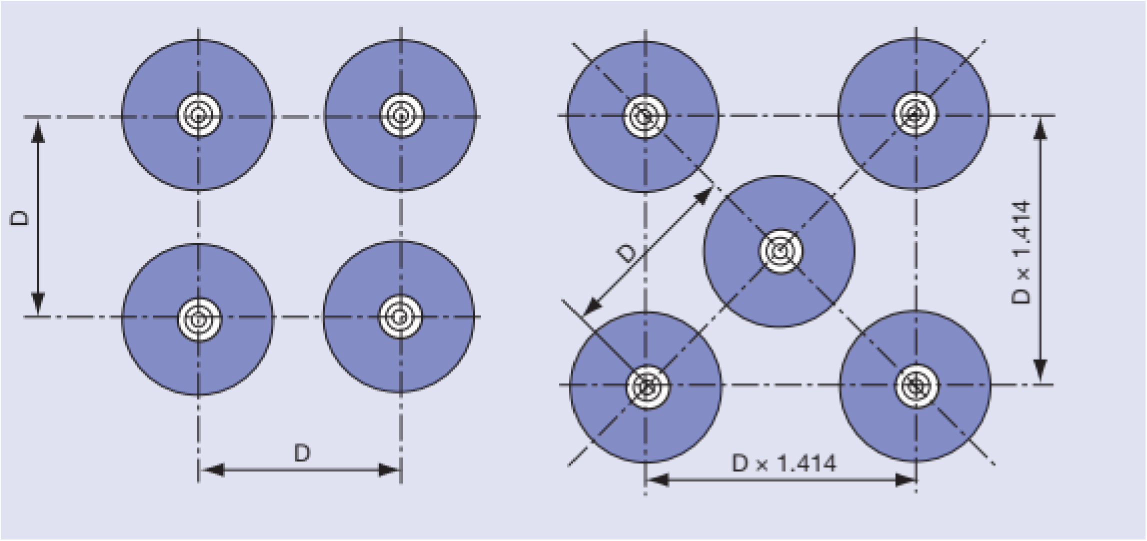
VENT CHOICE

The choice of the vents starts from the discretization of the room into a "grid" where the vents can be placed.
According to the vent shape, different grids can be created.



The choice of the vent is iterative!

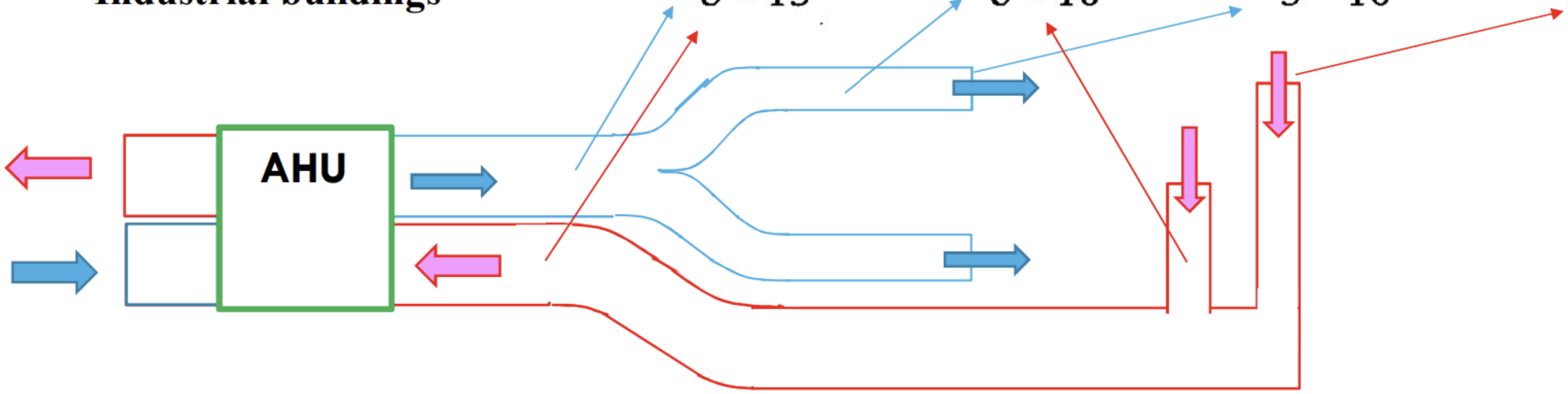




CHECK AIR VELOCITY!

Air velocity [m/s]

	Main ducts	Secondary ducts	Air inlet	Air outlet
Residential	4 - 5	3 - 4	2 - 3	1,5 - 2
Public buildings, schools	5 - 8	4 - 6	3 - 5	2 - 3
Offices	8 - 11	6 - 8	5 - 8	3 - 4
Industrial buildings	8 - 15	6 - 10	5 - 10	4 - 10

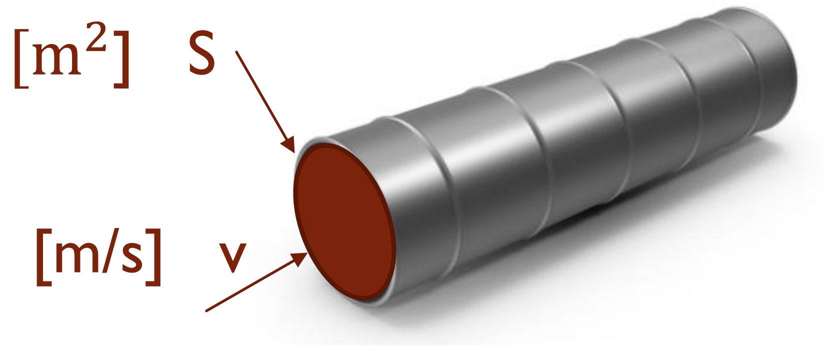


AIR VELOCITY AND DUCT SHAPE SELECTION

The two widespread ducts are the **round** and **rectangular** ductworks.

- When there are no space constraints, *round ductwork is preferable*: they have lower mass, lower perimeter, the flow inside is more regular, they rarely have problems with rumble and present an excellent resistance to low-frequency break-out noise.
- When the space constraint is important, you can find in the literature graphs for the choice of the duct shape, according to the available space, the design flow rate and the acceptable pressure losses. *(ASHRAE Handbook of Fundamentals, Chapter 21: Duct design)*

The ducts' section should be chosen (in each branch) considering the in-duct air velocity limits for the acoustic requirements.



$$[m^3/s] \quad V = S \cdot v$$

PRESSURE DROP

To guarantee the fluid motion inside a duct, a pressure difference between inlet and outlet sections must be supplied by a fan, which should fill the fluid pressure losses:

$$\Delta P = \Delta P_k + \Delta P_p + \boxed{\Delta P_f}$$

$$\boxed{\Delta P_f = \Delta P_{f,C} + \Delta P_{f,L}}$$

ΔP_k: kinetic energy variation

ΔP_p: potential energy variation

ΔP_f: friction pressure loss

Friction pressure loss (or pressure loss) is due to two components:

- Localized pressure drop: occurs whenever flow meets discontinuity in its path
- Continuous pressure drop: occurs because of fluid-wall interactions

CONTINUOUS PRESSURE DROP

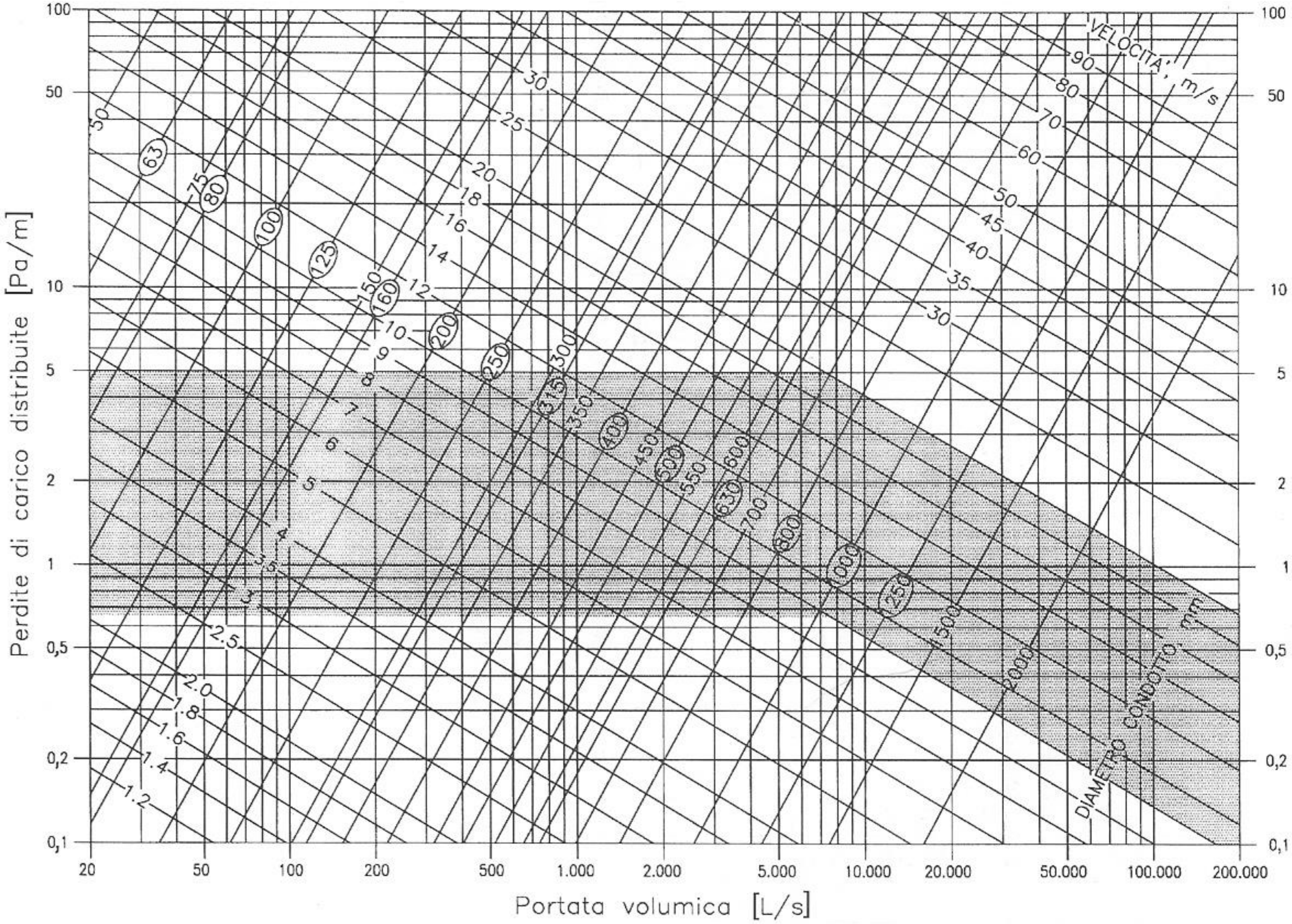
$$\Delta P_{f,C} = f\,\frac{\rho\, v^2}{2}\frac{L}{D} \qquad [\text{Pa}]$$

- ρ : fluid density $\left[\frac{\text{kg}}{\text{m}^3}\right]$
- v : mean fluid velocity $\left[\frac{\text{m}}{s}\right]$
- f : friction factor [-]
- L : pipe length [m]
- D : pipe diameter [m]

The friction factor ***f*** is determined either analytically of via appropriate diagrams.
It depends on:

- Fluid density, viscosity and velocity ➡ Reynolds Number *(Re)*
- Duct diameter and roughness

CONTINUOUS PRESSURE DROP



Diametri canali circolari normalizzati secondo Norma UNI 10381-2

Fig. 1 - Abaco per la determinazione delle perdite di carico distribuite (massa volumica 1,204 kg/m^3, rugosità ε = 0,09 mm)

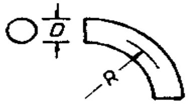
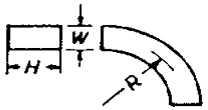
LOCALIZED PRESSURE DROP

$$\Delta P_{f,L} = \xi \frac{\rho\, v^2}{2} \qquad \text{[Pa]}$$

- ρ : fluid density $\left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right]$
- v : mean fluid velocity $\left[\frac{\mathrm{m}}{s}\right]$
- ξ : localized pressure drop coefficient [-]

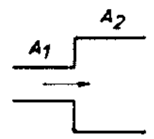
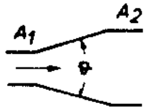
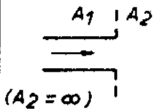
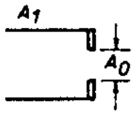
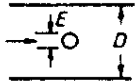
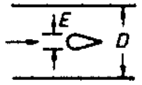
ξ coefficient is established on the basis of the particular type of loss, usually tabulated for the most common circuit elements (curves, branches etc.)

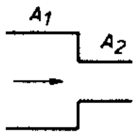
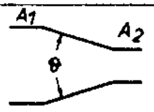
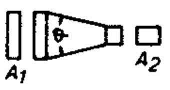
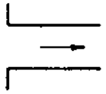
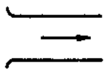
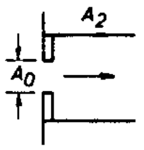
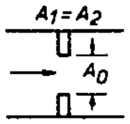
LOCALIZED PRESSURE DROP - 1

TIPO	FIGURA	CARATTERISTICHE	PERDITA DI PRESSIONE C	L/D	L/W
CURVA A N°		RETTANGOLARE O ROTONDA ; CON O SENZA ALETTE	N°/90 x PERDITA DI UNA CURVA UGUALE A 90°		
CURVA A 90° SEZIONE ROTONDA		GOMITO	1,30	65	
		R/D = 0,5	0,90		
		0,75	0,45	23	
		1,0	0,33	17	
		1,5	0,24	12	
		2,0	0,19	10	
CURVA A 90° SEZIONE RETTANGOLARE		H/W R/W			
		0,25 GOMITO	1,25		25
		0,5	1,25		25
		0,75	0,60		12
		1,0	0,37		7
		1,5	0,19		4
		0,5 GOMITO	1,47		49
		0,5	1,10		40
		0,75	0,50		16
		1,0	0,28		9
		1,5	0,13		4
		1,0 GOMITO	1,50		75
		0,5	1,00		50
		0,75	0,41		21
		1,0	0,22		11
		1,5	0,09		4,5
		4,0 GOMITO	1,38		110
		0,5	0,96		65
		0,75	0,37		43
		1,0	0,19		17
		1,5	0,07		6

		R/W	R_1/W	R_2/W			
CURVA A 90° SEZIONE RETTANGOLARE CON DEFLETTORI		GOMITO	0,5				28
		0,5	0,4		0,70		19
		0,7	0,6				12
		1,0	1,0		0,13		7,2
		1,5			0,12		
		GOMITO	0,3	0,5			22
		0,5	0,2	0,4	0,45		16
		0,75	0,4	0,7	0,12		
		1,0	0,7	1,0	0,10		
		1,5	1,3	1,6	0,15		
GOMITO CON ALETTE	 DA LAMIERA AERODINAMICHE	C = 0,10 ÷ 0,35 SECONDO LA COSTRUZIONE					
GOMITO A T CON ALETTE		CONSIDERARLO UGUALE AD UNA CURVA ANALOGA. PERDITA BASATA SULLA VELOCITA' IN ENTRATA					
T CURVILINEO							

LOCALIZED PRESSURE DROP - 2

TIPO	FIGURA	CARATTERISTICHE	COEFFICIENTE	
ESPANSIONE BRUSCA		A_1/A_2	C_1	C_2
		0,1	0,81	81
		0,2	0,64	16
		0,3	0,49	5
		0,4	0,36	2,25
		0,5	0,25	1,00
		0,6	0,16	0,45
		0,7	0,09	0,18
		0,8	0,04	0,06
		0,9	0,01	0,01
ESPANSIONE GRADUALE		ϑ	C_r	
		5°	0,17	
		7°	0,22	
		10°	0,28	
		20°	0,45	
		30°	0,59	
		40°	0,73	
EFFLUSSO BRUSCO		$A_1/A_2 = 0{,}0$	1,00	
ORIFIZIO DI EFFLUSSO A SPIGOLI VIVI		A_0/A_1	C_0	
		0,0	2,50	
		0,2	2,44	
		0,4	2,26	
		0,6	1,96	
		0,8	1,54	
		1,0	1,00	
SBARRA ATTRAVERSO IL CANALE		E/D	C	
		0,10	0,7	
		0,25	1,4	
		0,50	4,0	
TUBO ATTRAVERSO IL CANALE		E/D	C	
		0,10	0,20	
		0,25	0,55	
		0,50	2,0	
SBARRA A PROFILO AERODINAMICO ATTRAVERSO IL CANALE		E/D	C	
		0,10	0,07	
		0,25	0,23	
		0,50	0,90	

TIPO	FIGURA	CARATTERISTICHE	COEFFICIENTE
CONTRAZIONE BRUSCA SPIGOLI VIVI		A_2/A_1	C_2
		0,0	0,34
		0,2	0,32
		0,4	0,25
		0,6	0,16
		0,8	0,06
CONTRAZIONE GRADUALE		ϑ	
		30°	0,02
		45°	0,04
		60°	0,07
TRASFORMAZIONE AD AREA COSTANTE		$A_1 = A_2$	C
		$\vartheta \leq 14°$	0,15
INGRESSO A FLANGIA		$A = \infty$	C
			0,34
INGRESSO A CANALE		$A = \infty$	C
			0,85
INGRESSO GRADUALE		$A = \infty$	C
			0,03
ORIFIZIO DI INGRESSO A SPIGOLI VIVI		A_0/A_2	C_0
		0,0	2,50
		0,2	1,96
		0,4	1,39
		0,6	0,96
		0,8	0,61
		1,0	0,64
ORIFIZIO A SPIGOLI VIVI NEL CANALE		A_0/A	C_0
		0,0	2,50
		0,2	1,86
		0,4	1,21
		0,6	0,64
		0,8	0,20
		1,0	0,0

INPUT

Number of secondary branches → Number of final branches

Final branches air flow

Size of the ducts

Materials of the ducts

Lengths of the ducts

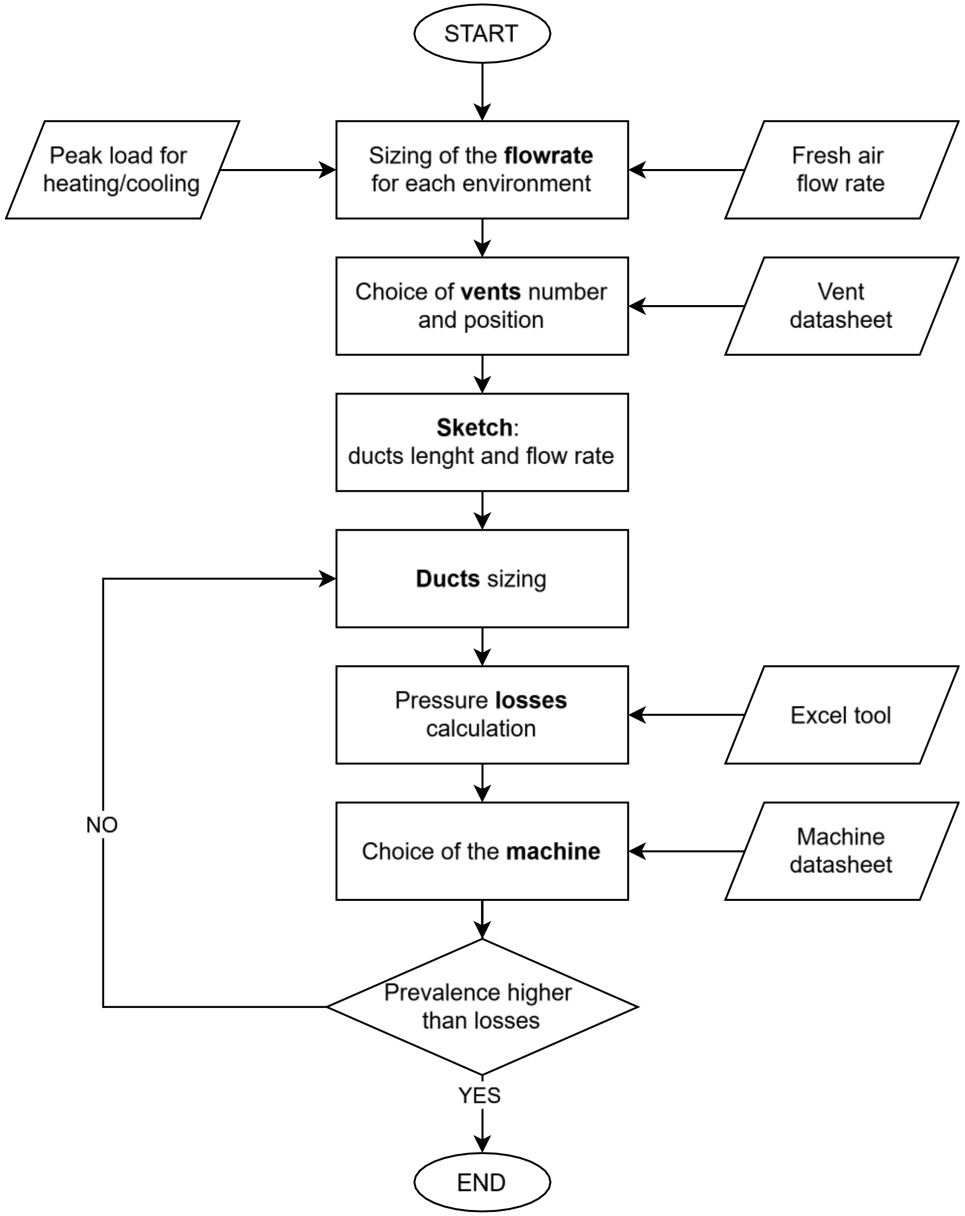
Particular circuit elements (curves, collars, etc.)

The Tool does not substitute the sizing process: it only helps in the pressure loss calculation

OUTPUT

Pressure losses of the circuit

SIZING GENERAL PROCEDURE



INSTRUCTIONS FOR THE REPORT

For this part of the project, you will be divided into groups of 3 people. Each group will receive a specific case study

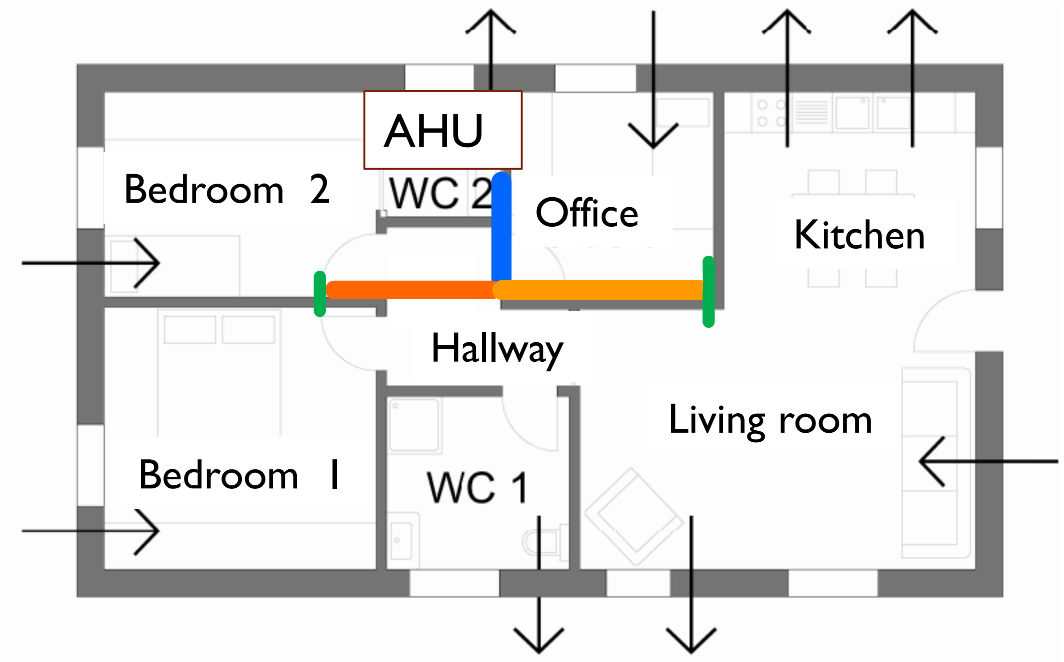
You are asked to provide the **sizing** of a **full-air system with recirculation** for your case study.

In the report you should submit, the information to provide are as follows:

- Calculation of the design and fresh-air flow rates: methodology and results (*)
- Choice of the vents, their number and position
- Schematic layout of the air distribution system, position of the AHU, duct sizing.
- Calculation of the continuous and localized pressure losses for all the ducts (*)

(*) for these sections, it is <u>compulsory</u> to provide the excel with the calculations!

CASE STUDY



N.	Name	Area [m^2]	Volume [m^3]
1	Living room	22.7	61.3
2	Office	9.0	24.3
3	Kitchen	11.0	29.7
4	Bedroom 1	15.4	41.6
5	Bedroom 2	12.0	32.4
6	Bathroom1	6.8	18.4
7	Bathroom 2	3.2	8.6
8	Hallway	5.0	13.5
	Total	**85.1**	**229.8**

In this example, we NEGLECT the presence of thermal loads to be fulfilled and we only size the supply path.

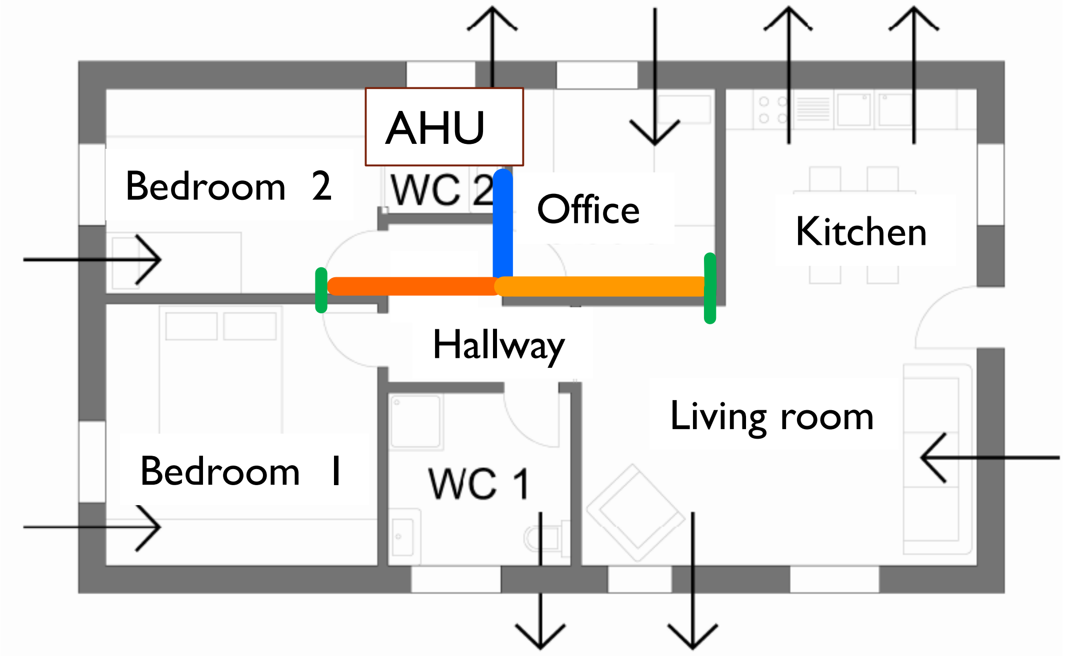
ALERT!! Do not forget to verify the air flow mass balance!!

CASE STUDY

Level	L/(s m²)	h^{-1} (ACH)
I	0.49	0.7
II	0.42	0.6
III	0.35	0.5
IV	0.23	0.4

	Resulting flow rate	
Level	m³/h	
I	150	161
II	129	138
III	107	115
IV	70	92

$q_{i,C} = q_{i,H} = 0 \Rightarrow V_{des,TOT} = V_{IAQ,TOT}$



Name	Area [m²]	Volume [m³]	$V_{prog,i}$ [m³/h]
Living room	22.7	61.3	55
Office	9.0	24.3	20
Kitchen	11.0	29.7	-
Bedroom 1	15.4	41.6	35
Bedroom 2	12.0	32.4	30
Bathroom1	6.8	18.4	-
Bathroom 2	3.2	8.6	-
Hallway	5.0	13.5	-
Total	**85.1**	**229.8**	**140.0**

Some examples for the definition of the ventilation flow rate can be found on EN 16798 – 2, Annex B, Section B.3.2.5