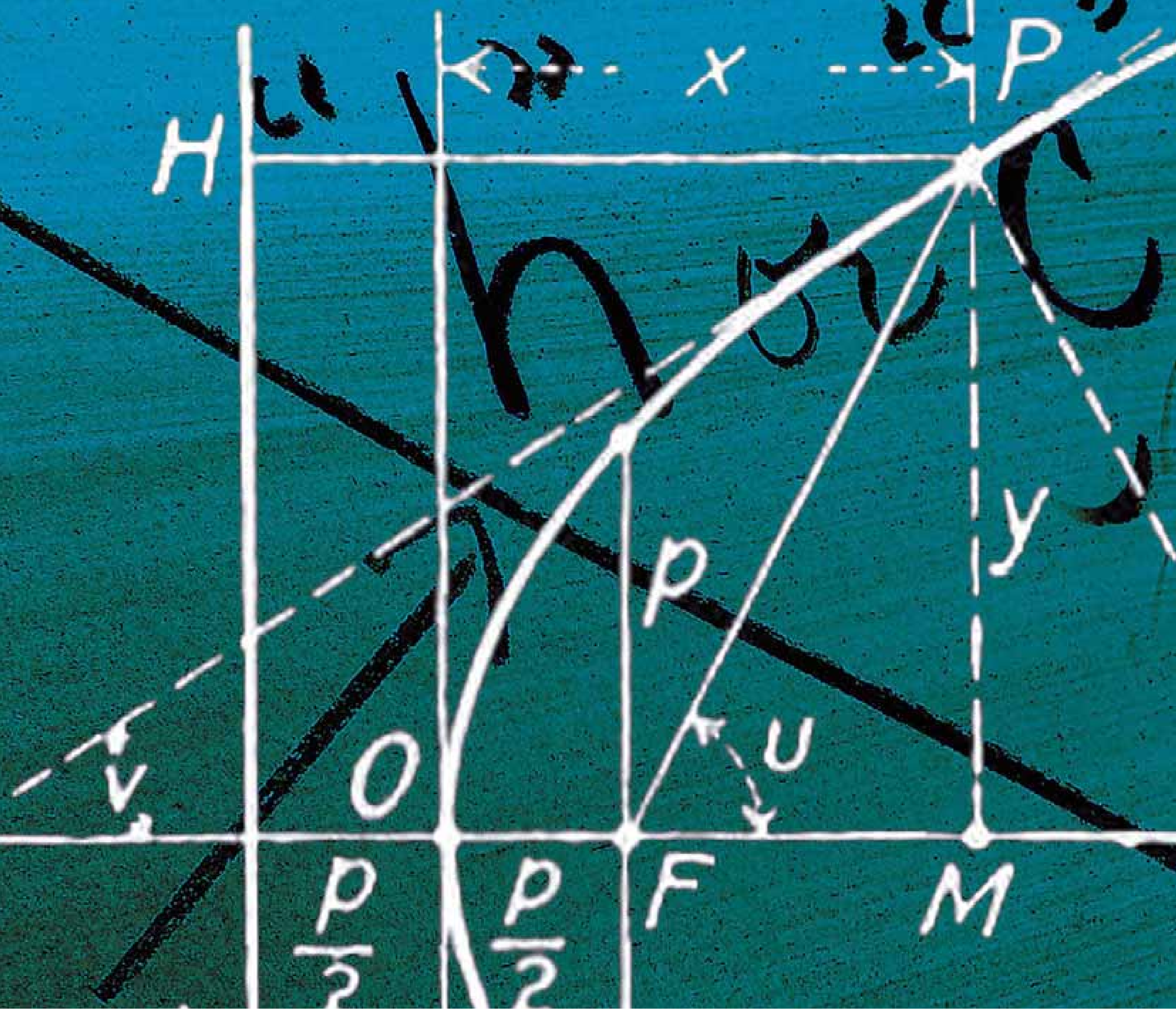

technical handbook

P3ductal

preinsulated aluminium ducts system

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Introduction

P3ductal has been developed through years of experience in the field of air distribution to create a product that combines the characteristics of reliability and functionality with the need to industrialize the construction process. P3ductal is the result of this philosophy: a pre-insulated aluminium duct with extraordinary performance, the assembly and laying system features specific procedures for each phase that simplify the work of the installer while ensuring the best technical, constructive and economic results at the same time.

The engineering sector is constantly evolving. Innovation is extended to design, application systems and materials used in order to satisfy the demand for higher and higher quality, greater respect for the environment, and increased savings in energy.
Many different materials and systems have been developed as alternatives to the sheet metal used traditionally. Pre-insulated aluminium ducts have proven to be the most advantageous among all, offering numerous technical and practical advantages.

The construction of ducts using sandwich panels began some twenty-five years ago in Italy. The first users were small installers who had trouble procuring duct construction materials in sufficient quantities in time for installation. The simplicity of the equipment required for the working of the panel and the possibility to cut the ducts to size directly at the work site are still two of the leading advantages offered by the system today, and make lightweight foam sandwich panels the preferred choice for practical installers everywhere.
The system has been steadily developed and spread around the world, as its application has been gradually extended to every type of air distribution system: industrial, civil, and commercial.
As a result of this growth in popularity, the number of producers has multiplied, and an assortment of different polyurethane foam panels is now available on the market, each offering different structures and performance from both the mechanical and physical points of view.
The great differences between one panel and another have made the formulation of standardised data impossible, and consultants find it often very difficult to find a reference criteria.
This has created the need for documentation that provides at least a minimum orientation for the construction of pre-insulated aluminium ducts and the technical data required to qualify the various types of system.

1 General requirements of air distribution ducts

1.1 The purpose of the duct

The achievement of predetermined environmental conditions lies in the control of certain parameters such as temperature, relative humidity, air distribution velocity and purity, in regard to changing heat loads entering or exiting the system and its crowding conditions or activity.

This control is generally achieved with the use of all-air or mixed air-water systems.

In both of the cases above, after the appropriate treatment in air conditioning systems, the air itself is the instrument required to ensure the supply of the desired characteristics.

Problems may arise in the phase that extends from the end of the air's treatment to its entry into the selected environment whenever the duct network proves incapable of efficiently maintaining the desired characteristics at the values established.

The main functions of an air distribution system may be summarised as follows:

- ensuring the distribution of the treated air without altering its parameters during its movement from the air treatment system to the selected environment;
- ensuring that there is no uncontrolled leakage in or out caused by excessive positive or negative pressure;
- limiting the generation and transmission of noise;
- maintaining the a.m. characteristics over time.

It is clearly visible that the air distribution system plays a fundamental role in guaranteeing a satisfactory performance of the entire air conditioning system. The air distribution system also accounts for a significant part of the installation and management costs, which assume greater and greater importance in proportion to the system's size (see Fig. 1.1).

Fig. 1.1 - The creation of an air-conditioning system

1.2
The “ideal” duct

The “ideal” duct will have to comply with the requirements summarized below:

1) Technical requisites

Thermal insulation: (see Chap. 3.1).
Air seal: (see Chap. 3.3).
Friction loss: (see Chap. 3.4).
Acoustics: (see Chap. 3.5).
Air quality and hygiene (see Chap. 3.7).
Life-span: (see Chap. 3.8).
Safety and conformity to regulations (see Chap. 3.6).

2) Executive requisites

Transport: easy transport, limited logistic problems.
Construction: rapid execution.
Installation: easy movement, possibility for on-site modification.
Procurement: possibility to procure materials easily.

3) Economic requisites

Easy estimate.
Reduced cost.
Energy savings.

If we assign a value from 1 to 5 (with 1 signifying poor performance and 5 signifying excellent performance) to correspondence to each of the requisites analysed in the previous chapters, we can plot a graph that summarises the performance offered by differing types of duct .

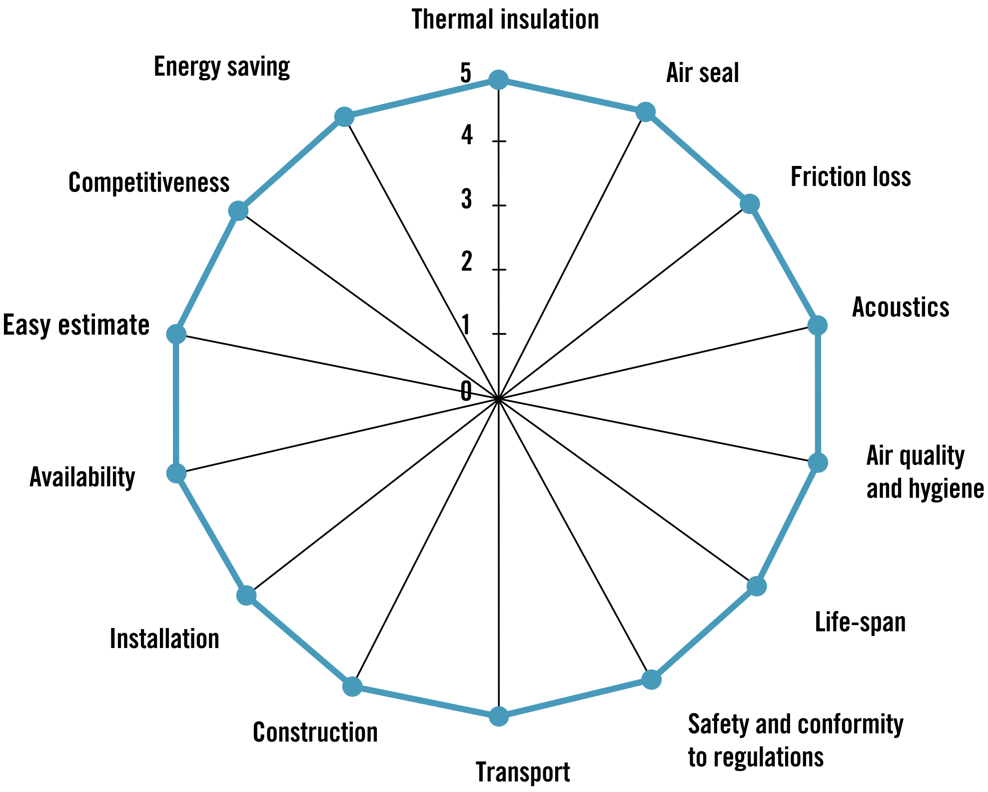


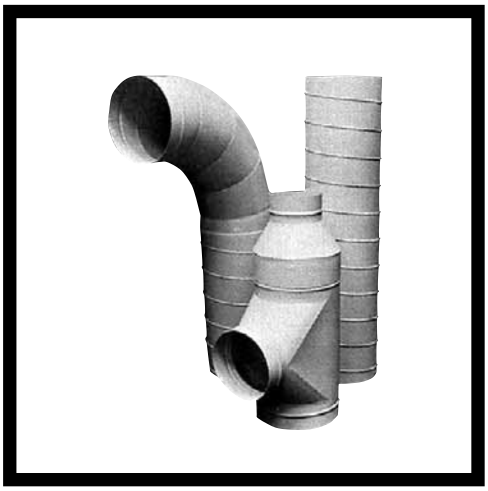
Fig. 1.2 - Graph obtained by P3 and based on performances detected by a panel of experts.

2 Ducts available on the market

2.1 Types of duct

The following types of duct are the most commonly available in the market.

rectangular zinc-plated sheet metal



spiral-type in zinc-plated sheet metal

circular flexible

pre-insulated aluminium

2.2
Comparisons

The tables underline the various aspects which apply to in different types of ducts, with reference to the most common applications.

Rectangular zinc-plated sheet metal ducts

Insulation	2
Air seal	2
Air seal	4
Acoustics	3
Air quality and hygiene	2
Life-span	3
Safety and conformity to regulations	4
Transport	3
Construction	3
Installation	2
Availability	5
Estimation ease	3
Competitiveness	4
Energy saving	3

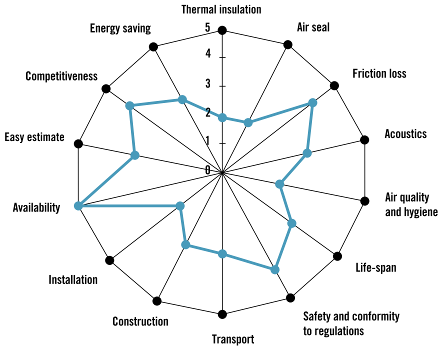


Fig. 2.1 - Performance rectangular zinc-plated sheet metal ducts

Spiral-type zinc-plated sheet metal ducts

Insulation	3
Air seal	3
Air seal	5
Acoustics	3
Air quality and hygiene	3
Life-span	3
Safety and conformity to regulations	4
Transport	1
Construction	3
Installation	3
Availability	4
Estimation ease	5
Competitiveness	2
Energy saving	3

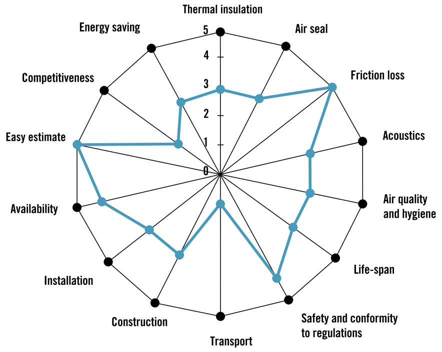


Fig. 2.2 - Performance of spiral-type zinc-plated sheet metal ducts

Flexible hose ducts

Insulation	3
Air seal	1
Air seal	1
Acoustics	3
Air quality and hygiene	1
Life-span	2
Safety and conformity to regulations	3
Transport	5
Construction	1
Installation	4
Availability	5
Estimation ease	5
Competitiveness	5
Energy saving	2

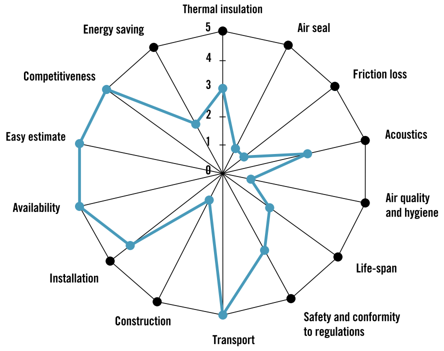


Fig. 2.3 - Performance of flexible hose ducts

Pre-insulated aluminium ducts

Insulation	5
Air seal	5
Air seal	4
Acoustics	3
Air quality and hygiene	5
Life-span	5
Safety and conformity to regulations	4
Transport	5
Construction	4
Installation	5
Availability	5
Estimation ease	5
Competitiveness	4
Energy saving	5

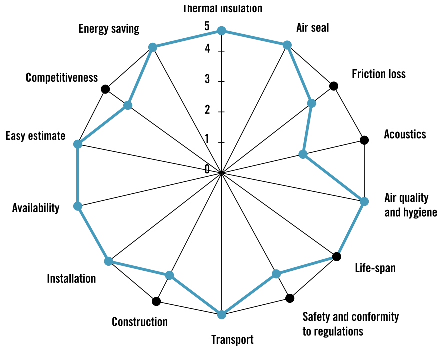


Fig. 2.4 - Performance of pre-insulated aluminium ducts

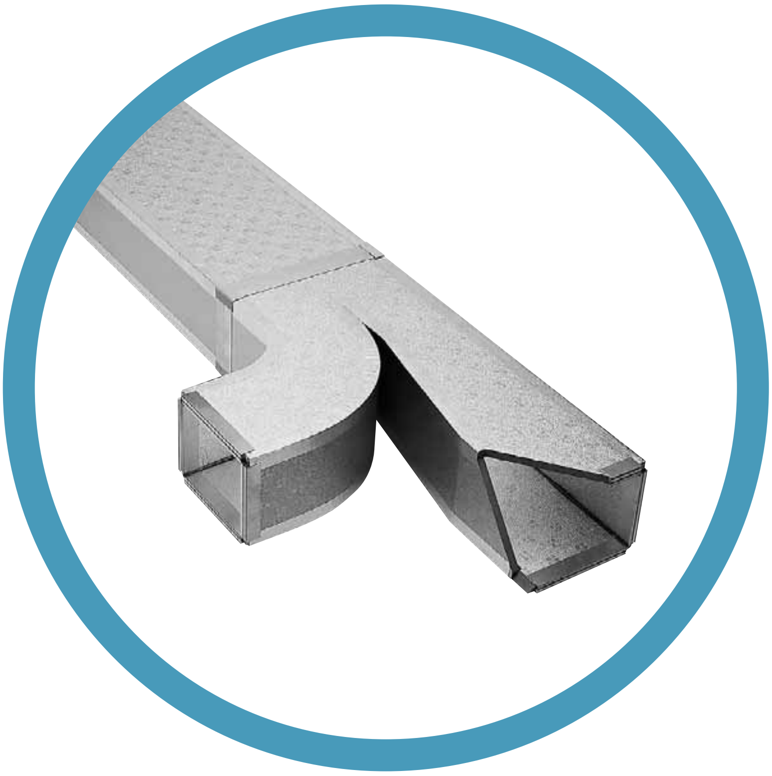
2.3
Characteristics of P3ductal ducts

The P3ductal system is a combination of procedures, materials and equipment (all carefully selected and inspected) for the construction and installation of pre-insulated aluminium duct.

P3ductal ducts are obtained from expanded cellular material sandwich panels, faced with aluminium foil.

P3ductal ducts have been designed on the basis of specific technical and economic necessities to permit the construction of air distribution systems that guarantee the highest standards of safety and confomirty to regulations in addition to the numerous advantages below:

- exceptional and uniform thermal insulation in all points of the ducts;
- no problems caused by the release of fibre or other contaminants thanks to the protection of the insulation material with a layer of aluminium foil that also eliminates all risk of erosion caused by air flow;
- the possibility to prepare pre-cut ducts for assembly directly at the work site for significant savings in shipping costs;
- reduction of air leaks thanks to the exceptional air seal guaranteed by the patented P3 invisible flanging system;
- extreme light weight with the consequent reduction of the load on the support structures, bracketing, hanging points, labor times and materials necessary for intallation;
- the possibility to install the ducts outdoors;
- the attractive aesthetic finish offered by the aluminium foil that can be painted in different colours or provided with texture coating or other facing treatments.



3 Technical characteristics of P3ductal ducts

3.1 Thermal insulation

A material's "insulation power" is its property to reduce the transmission of heat between two environments with different temperatures.

Expanded polyurethane, which is used for the production of Piral panels, is currently one of the best heat insulation materials available on the market.

3.1.1 Thermal conductivity

The quantity of heat Q transmitted between the opposing parallel faces of a flat layer of homogenous material in steady state be expressed using the equation below:

$$Q = \frac{\lambda\, S\, (t_1 - t_2)}{s}$$

where:

Q = heat flow [W];
S = surface area affected by the heat flow [m^2];
$t_1 - t_2$ = temperature difference between the two faces [°C];
s = thickness of the material [m];
λ = thermal conductivity [W/(m °C)].

The thermal conductivity λ, can therefore numerically be quantified as the heat flow that travels through a unitary surface, for a unitary thickness, when the difference in temperature between the two faces of the considered layer of material is still unitary.

3.1.2 Factors that influence thermal conductivity

In materials with cellular structure, heat exchange occurs primarily by means of conduction through the solid walls of the cells, radiation through the cells, and convection inside.
In the case of polyurethane, other factors and characteristics of both productive and environmental nature can significantly affect a material's conductivity, such as:

Density. Piral Series panels are produced with densities that range from 40 - 65 kg/m^3.
In this range, we find the lowest values of conductivity. At lower densities it is hard to create uniform and closed cells, while at higher densities, the greater effect played by the solid element decreases thermal performance.

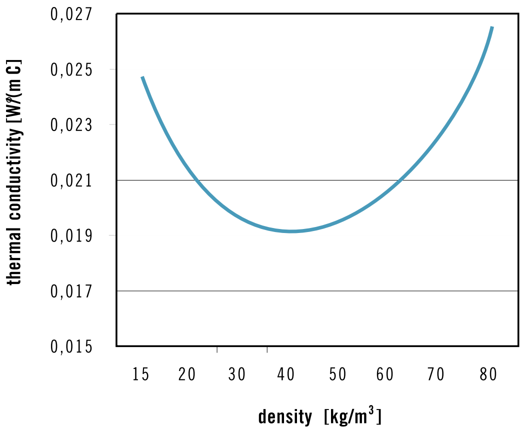


Fig. 3.1 - Thermal conductivity as a function of density

The cellular structure. The uniformity, diameter and orientation of the cells all play a big part in influencing the thermal conductivity value. Current production technologies permit the creation of extremely uniform foams and diameters of less than 1 mm that ensure the achievement of optimal thermal conductivity values.

The average test temperature.
The average test temperature is a decisive factor for the thermal conductivity value. Generally speaking, under normal Piral panel working conditions, conductivity increases in proportion with the increase in temperature. When expressed correctly, the λ value must always indicate the respective average test temperature at which it is rated. The average test temperatures principally utilised from different norms are 10, 20, 24 and 40 °C.

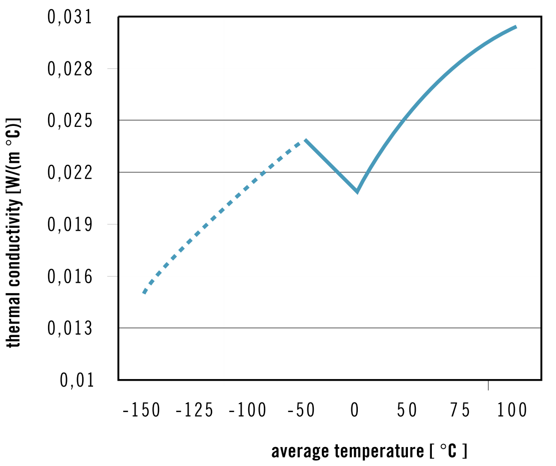


Fig. 3.2 - Thermal conductivity as a function of average test temperature

Ageing. For stiff polyurethane products the only significant factor that infulences the variation of insulating performance in time is the phenomenon of partial outwards diffusion of some components contained in the cells, and the simultanious diffusion of air into the cells.
However, the expanding agents responsible for the foams low thermal conductivity remain inside the cells for a longer period, well exceeding the products average life cycle.
It is clear that the change between the foam’s cell and the exterior cannot happen when the polyurethane is protected by a waterproof cover which prevents diffusion, such as, for example, the aluminium covers which characterise Piral panels.

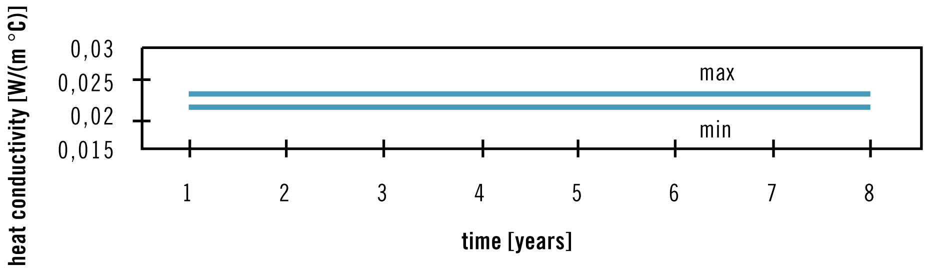


Fig. 3.3 - Heat conductivity as a function of time

3.1.3
A comparison between the various insulation materials

Type	Thermal conductivity (at10 °C) λ [W/(m°C)]
Cross-linked extruded polyethylene	0,033 - 0,035
Glass wool	0,038 - 0,040
P3ductal panels	0,024 - 0,026*

*Note: See the respective technical data sheets for the various types of panels

Tab 3.1

3.2
Water vapour condensation in ducts

The problem posed by water vapour condensation in the ducts is closely linked to the temperature of the duct's external surfaces and therefore depends on the degree of thermal insulation that duct's walls are capable of offering and the relative humidity in the room or area.

As seen above, P3ductal panels provide remarkable insulation power, and in order for the water vapour to condense on the duct's external wall, the external surface temperature "ts" must be equal to or lower than the dew point tr., which is defined as the temperature at which the air reaches its respective saturation conditions t=tr through a cooling process at constant and specific pressure and humidity values. All subsequent cooling allows the formation of condensation, and for this reason every surface at a temperature of less than tr will be wet. Generally speaking, condensation does not usually produce dripping if the duct's external surface temperature is no more than 2 °C below the dew point of the air in the room or area.

If the relative humidity value (RH%) is known, the dew point can be calculated from the psychrometric diagram (see example).

The duct's flat external wall's surface temperature can be calculated using the following formula:

$$t_s = t_a - \frac{U}{\alpha_e}(t_a - t_i)$$

e

$$U = \frac{1}{\frac{1}{\alpha_i} + \frac{s_1}{\lambda_1} + \frac{s_2}{\lambda_2} \ldots \frac{s_n}{\lambda_n} + \frac{1}{\alpha_e}}$$

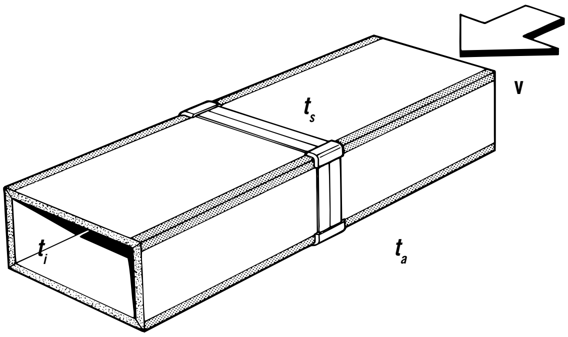


Fig. 3.4 - Condensation conditions

where:
t_s = temperature of duct external surface [°C];
t_a = temperature of air outside the duct (room temperature) [°C];
t_i = temperature of air inside the duct [°C];
U = duct wall transmittance [W/(m^2 °C)];
α_e = thermal diffusivity of external surfaces [W/(m^2 °C)];
s = thickness [m];
λ = thermal conductivity [W/(m °C)];
α_i = thermal diffusivity of internal surfaces [W/(m^2 °C)].

In addition to forming on the duct's external surfaces, you would think that condensation would also form inside the panel itself, but the aluminium foil that distinguishes the P3ductal panels is provided with an infinite resistance to the passage of water vapour μr. Thanks to the vapour barrier created by aluminium, condensation never forms inside ducts built using P3ductal panels.

Example of verification of the condensation conditions

If we must built a duct that passes through an area in which the air is not conditioned we must consider the possibility that condensation forms on the walls of the duct and the respective flanging and find a way to check this phenomenon.

Considering the following project design conditions:
$t_a = 40$ °C
$RH = 50\%$
$t_i = 14$ °C
v = 8 m/s (air speed inside)
s= 0,02 m

With stationary air, the following external thermal diffusivity value can be assumed:
$\alpha_e = 8{,}14$ W/(m^2 °C);
with an air velocity inside the duct of ≥ 4m/s internal thermal diffusivity
$\alpha_i = 2{,}33 + 10{,}47\sqrt{v}$
therefore, considering v = 8 m/s we obtain the following:
$\alpha_i = 31{,}94$ W/(m^2 °C).

Using the formulae provided for thermal transmittance and the temperature of the duct's external surfaces, the values provided in table 3.2 can be easily obtained:

Description	**s** **[m]**	**λ** **[W/(m °C)]**	**U** **[W/(m^2 °C)]**	**t_s** **[°C]**
P3ductal panel	0,02	0,024	1,01	36,8
PVC flange	0,02	0,160	3,58	28,6
Aluminium flange	0,02	221,23	6,49	19,3

Tab. 3.2

Using the psychrometric diagram provided in Fig. 3.5, we obtain a value of t_r= 27,5°C on the basis of the t_a and RH values.

After analysing the surface temperature "ts" provided in table 3.2 for the various components, we observe that only the aluminium flange at 19.3 °C has a temperature below the dew point temperature. Since condensation will form on this flange, we recommend you to use either flanges in PVC or insulating the aluminium flange with the appropriate polythene tape with the following specifications 8 mm, λ=0,038 W/(m°C) in order to obtain the result provided in table 3.3.

Description	**$s_{tot.}$ [m]**	**λ [W/(m °C)]**	**U [W/(m^2 °C)]**	**t_s [°C]**
Al. flange +polythene	0,028	0,038	2,74	31,2

Tab. 3.3

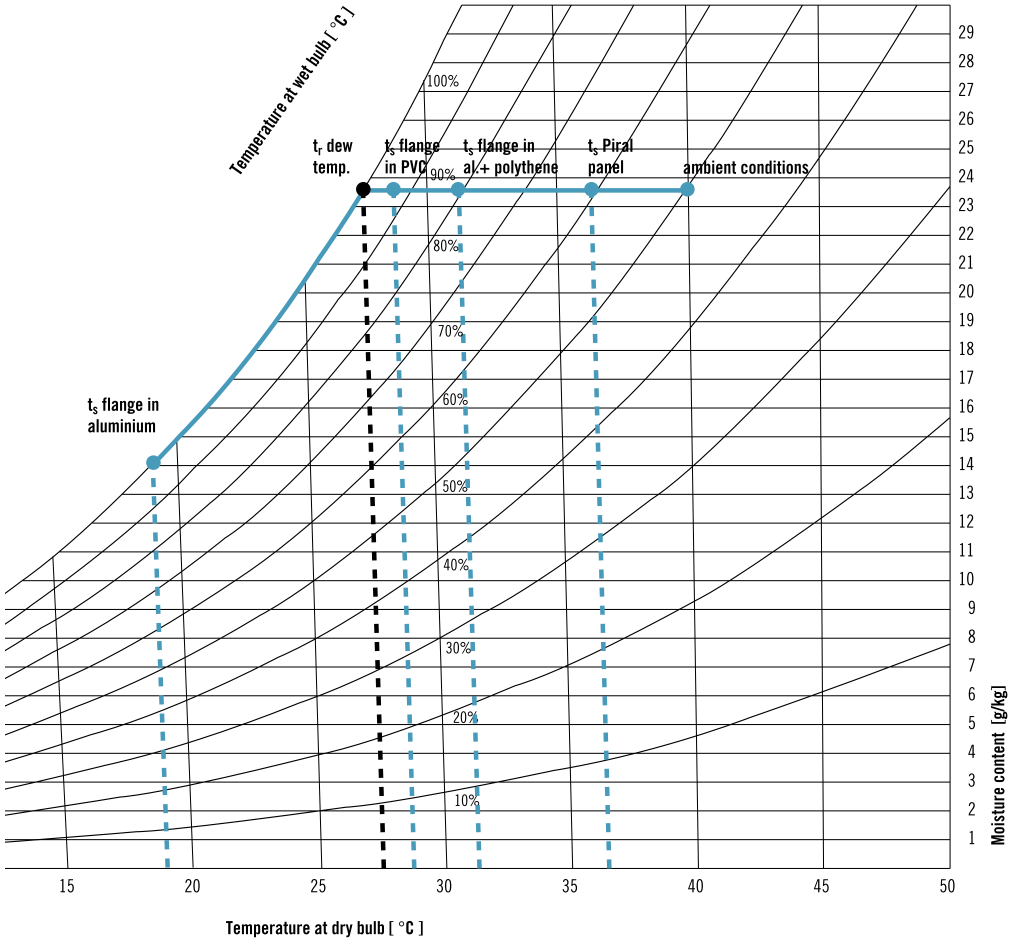


Fig. 3.5 - Psychrometric diagram

3.3
Air seal

In addition to causing needless energy waste, leaks from ducts compromise the distribution of air in the various rooms, and in more drastic cases lead to incorrect oversizing of the systems.

Leaks in an air distribution system can be considered as the difference between the volume of air supplied by the fan and the volume of air actually going into the room or area being served.

A series of tests conducted according to careful scientific methods has demonstrated that air leaks can reach values ranging from 10 to 30% of the total quantity of air conveyed by the supply ducts and from 20 to 40% of the air conveyed by the return ducts (see reference n°9 in bibliography).

The air leaks in a traditional duct system are located primarily along the longitudinal seams and transversal joints (or connections between ducts).

Ducts can be installed either inside or outside the air conditioned room or area (or separated by ceilings) and leaks can occur both going into or coming out of the room or area:

- Leaks occurring inside the room or are created imbalances in the quantities of air supplied to the areas and sometimes alter the desired thermohygrometric conditions, but gnerally, do not affect the system's performance and operating costs.

- Leaks occurring outside the room or area seriously compromise the system's efficiency and require the use of greater power that naturally increase both the system's initial investment and operating costs.

3.3.1

Compliance with standards

At the European level, the CEN (European Committee for Standardization) has published the EN 13403 Standard which provides definitions for classes of air duct sealing against air leaks in air distribution systems, as indicated in table 3.4. The table defines the three classes and the respective limits established for air leaks by basing the values adopted on the premise that leaks are proportional to the duct surface area and the total pressure p (average pressure in the duct) raised to the power of 0,65 and equivalent to:

$p = p_s + p_d$ [Pa]

where:

p_s = static pressure [Pa]

p_d = dynamic pressure [Pa]

it's defines such as $p_d = \rho \frac{v^2}{2}$

where:

ρ = air density [kg/m^3] (under standard conditions ρ=1,24 kg/m^3;

v = air velocity [m/s].

Air seal class	Permissible air leak (L/s for m^2 of duct surface area)
Low Pressure: Class A	0,027 x $p^{0,65}$
Medium Pressure: Class B	0,009 x $p^{0,65}$
High Pressure: Class C	0,003 x $p^{0,65}$

Tab. 3.4

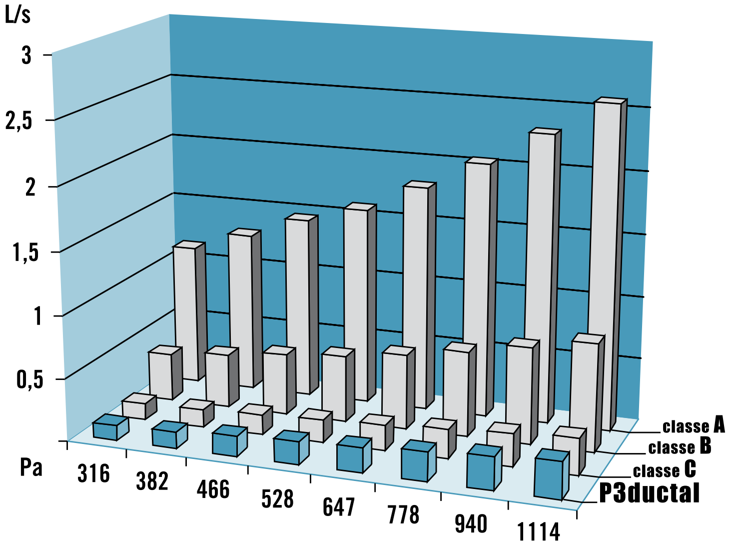


Fig. 3.6 A comparison between air leakage through P3ductal ducts and the leakage permissible by the regulations.

Thanks to the use of their exclusive patented flanging system, P3ductal ducts guarantee remarkable air seal by eliminating the possibility of longitudinal leaks and reducing leaks in the transversal joints, thereby satisfying the requisites for the best class of air seal (C) foreseen by the Standards, as shown in Fig. 3.6.

3.3.2
Infiltration through return ducts

Infiltrations that occur in return ducts (intakes) are greater in percentage than those that occur in delivery ducts. When return ducts are positioned outside the rooms conditioned, a quantity of air ranging from only 60 to 80% of the amount envisioned by the system's design returns to the air handling unit. The rest is composed of air derived from the non-conditioned areas the ducts traverse and consequently has different thermohygrometric conditions than the air in the rooms and will therefore be colder in the winter and warmer in the summer, thereby producing an increase in the room's thermal load and the need for the use of a system with greater power. This fact might seem strange, given that return ducts generally have shorter sections, a lower number of joints, and often reduced surface areas as well, but this is explained by the fact that they are given less care during construction and laying because they are mistakenly attributed lesser importance because they are not destined to convey "conditioned" air.

3.4
Friction losses

Knowledge of the extent of friction losses is essential for the designers of systems or equipment with fluids in movement in order to permit the calculation of the energy that is irreversibly lost inside the system.
There are two types of friction losses: linear or uniformly distributed friction losses and localised or accidental friction losses.

3.4.1
Linear or uniformly distributed friction losses

The linear friction losses of a fluid flowing through a duct are caused both by the friction generated by the fluid's viscosity (laminar motion) and the movement of its particles in turbulent motion.
Linear friction losses can be calculated using Darcy's equation:

$$\Delta p_{fr} = f\left(\frac{L}{D_h}\right) p_d$$

where:

$\Delta p_{fr} =$ is the friction loss due to friction [Pa]
$f =$ is the nondimensional coefficient of friction
$L =$ is the length of the duct [m]
$D_h =$ is the hydraulic diameter [m]
$p_d =$ dynamic pressure [Pa]

The hydraulic diameter of a non-circular shaped duct can be calculated using the following formula:

$$D_h = \frac{4A}{p}$$

where:

A	the are of the section transversal to the flow [m^2];
p	the perimeter of the transversal section (wet perimeter) [m];

The friction coefficient “f” can be obtained as a function of the Reynolds number and the relative roughness can be obtained using the Colebrook and White formula:

$$\frac{1}{\sqrt{f}} = -2 \log \left(\frac{\varepsilon}{3{,}7\, D_h} + \frac{2{,}51}{Re \sqrt{f}} \right)$$

We provide a simplified formula for the calculation of the friction coefficient “f” below:

$$f1 = 0{,}11 \left(\frac{\varepsilon}{D_h} + \frac{68}{Re} \right) 0{,}25$$

if $f_1 > 0{,}018$ then $f = f_1$
if $f_1 < 0{,}018$ then $f = 0{,}85 f_1 + 0{,}0028$

the following symbols have been adopted in the formula:

Re = nondimensional Reynolds number
ε = absolute roughness of the material [m] (see Table 3.5).

The Reynolds number is obtained from:

$$Re = D_h \frac{v}{\upsilon}$$

where:
υ = kinematic viscosity [m^2/s]
D_h = hydraulic diameter [m]
v = velocity [m/s].

The Reynolds number for air in standard conditions can be calculated using the formula below:

$Re = 66.400\, D_h\, v$ (International System)

Material	ε [mm]
Unclad, clean carbon steel	0,03
PVC pipe	
Aluminium	
Zinc-plated steel, longitudinal seam, flanging every 1200 mm	0,09
Zinc-plated steel and spiral seam with 1, 2 and 3 ribs and flanging every 3600 mm	
Pre-insulated aluminium P3ductal ducts	0,12
Zinc-plated steel, longitudinal seam, flanging every 750 mm	0,15
Stiff fibre-glass ducts	0,9
Ducts with internal fibre-glass facing	3,0
Flexible metal pipe (when completely extended)	
Flexible pipe (all types)	
Concrete	

Tab. 3.5

3.4.2
Localised or accidental friction losses

Whenever the flow changes direction inside the ducts, or there are variations in section, conversions or separations of streamlines, and so on, accidental friction losses are created that must be added to the uniformly distributed friction losses already calculated.

The ducts shape is of fundamental importance, while the effect of the Reynold's number is much less significant because in dynamic losses the motion is always highly turbulent and a corrective coefficient is introduced only in the event that it amounts to less than Re 150.000.
Consider the behaviour of a fluid in an elbow: the velocity profile of the particles, due to the change of direction they must adopt, tends to change by itself as indicated in figures 3.7. The effect obtained can be compared to restriction of a section, and consequently the friction loss is higher by a quantity "D_{p1}" compared to the friction loss there would be in a rectilinear section of length "L" equivalent to the length of the elbow's axis.
Immediately after the elbow, the air streams tend to assume the typical distribution of rectilinear duct sections and consequently faster-moving masses collide with slower-moving masses which introduce a new friction loss "D_{p2}".
In the event of two special pieces positioned very near one another (less than 6 times the hydraulic diameter), the flow characteristics utilised as reference for the first piece are not valid for the second. Reliable data for cases such as these are not available.

Vortexes can form in transversal duct sections due to the centrifugal force that tends to shift the particles from the central area towards the lateral surfaces, with the result that another friction loss is created "D_{p3}".

It must also be remembered that the existence of other forces (whose effects are partially opposed by the presence of other particles) creates vector distribution speeds in the transversal section of an elbow that are entirely different from those present in an undisturbed area in the rectilinear section of the duct.

In conclusion, the friction losses that occur between the two ends of an elbow can be expressed by the formula below:

$$\Delta p_t = \Delta p_{fr} + \Delta p_1 + \Delta p_2 + \Delta p_3$$

Generally speaking, accidental (or concentrated) friction losses cannot be calculated theoretically through resort to the fundamental equations of flow dynamics, but must be calculated only through experiment.

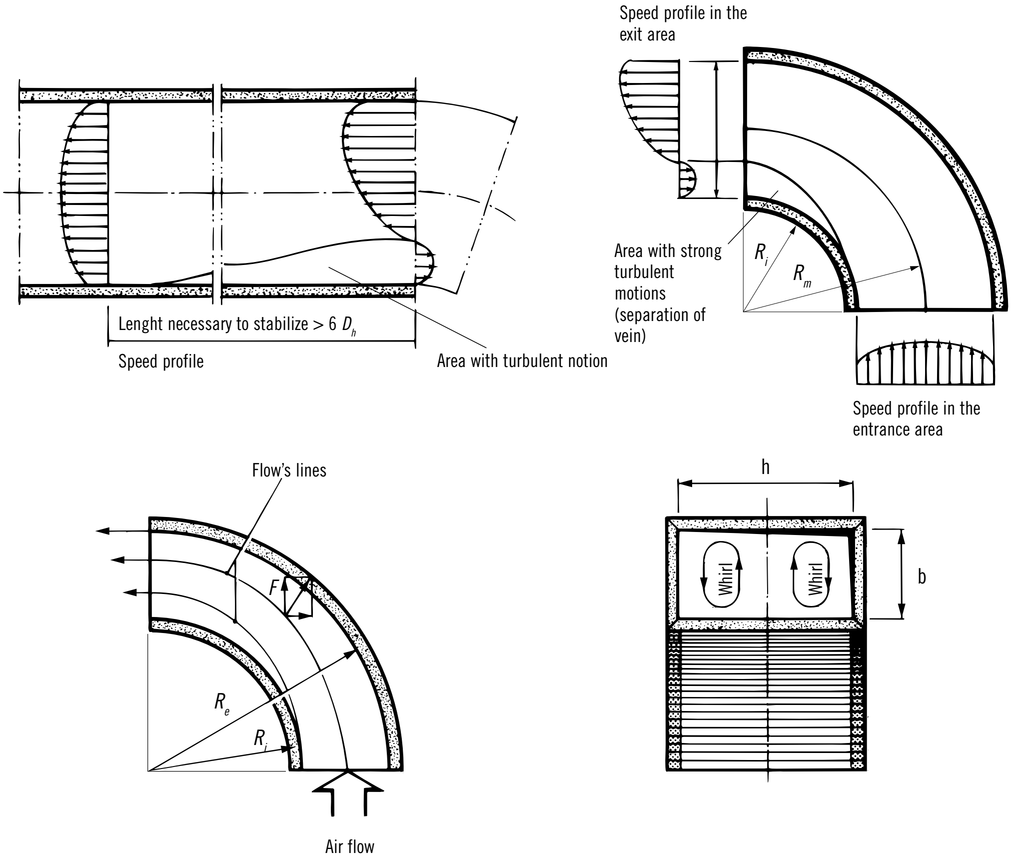


Fig. 3.7 - Phenomenon referring to localised friction loss

A quick way to calculate localised friction losses in air conditioning and heating systems is the "equivalent length" method. As the name suggests, an equivalent length expressed in linear meters is assigned to every elbow, branch or any other section that causes a variation in the air's direction and/or speed. When multiplied by the pressure drop per linear meter or feet of the respective duct's length, this equivalent lenght provides the value of the localised friction loss observed in the duct section under examination.

Figure 3.8 provides equivalent length values (in linear meters) for the components of an air distribution system that are responsible for the creation of localised friction losses.

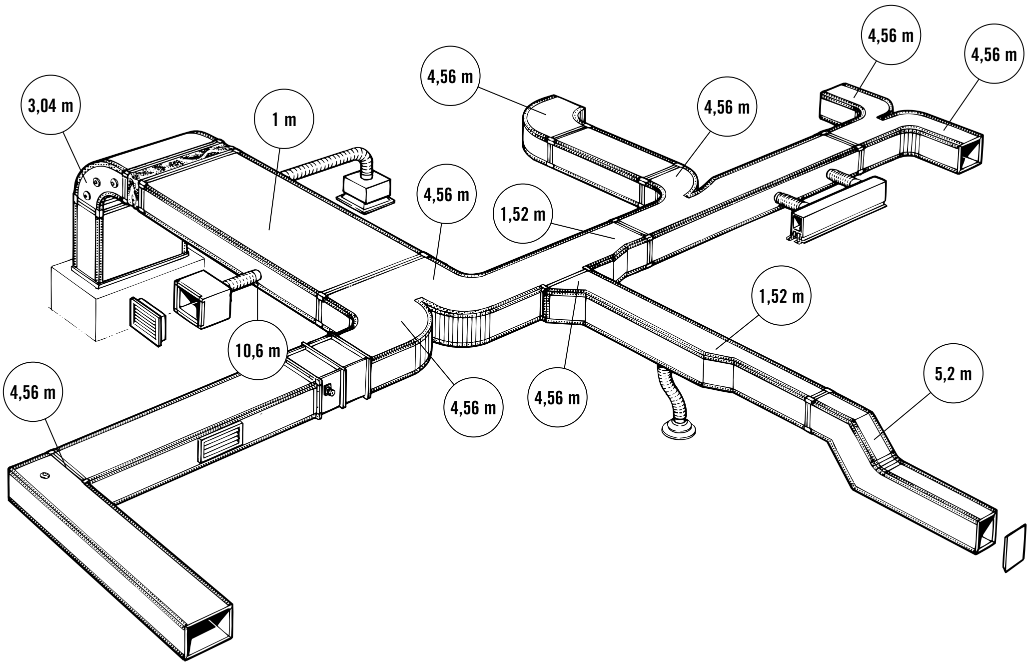


Fig. 3.8 - Equivalent lengths for the dynamic losses present in an air distribution system

3.5
Noise in ducts

Nearly all surveys regarding office comfort indicate excessive noise levels in the air conditioning system as the leading cause of complaint among all others included under those of environmental nature excluding temperature-related causes.
Excessive noise can be caused by an initial incorrect system design, subsequent errors in system revision performed to reduce costs without taking operating noise into account, or inadequate installation. In order to minimise the possibility that choices in system design create problems with noise and vibration, the designers must consider the noise factor in every phase of system design: from its initial configuration to its detailed specifications and subsequent installation.

All too often acoustic design is limited to the addition of silencers in the ducts, acoustic insulation, and the use of vibration damping supports; measures that are employed subsequently after the system designer has virtually completed his work.
These acoustic treatments provided at the last minute, as it were, can keep noise and vibration levels under control, but if they are not correctly integrated into the whole can also reduce system performance, and even create additional noise and vibration problems whenever they are incorrectly applied. Consequently, the definition of the measures to be adopted for noise control must be performed during both the design of the system's initial configuration and its detailed specifications, and conscientiously maintained throughout all the remaining design phases.

The more attention given to noise and vibration control at the start of the design process, the less interventions will be required subsequently.

The most important moment in the design phase is the completion of the structural design. Delaying due consideration of noise levels until after the structural phase has been nearly completed leaves insufficient space to the design team for the definition and positioning of the most convenient and effective sound absorption systems and materials. Whenever attempts to solve noise-related problems in an air conditioning system are made subsequently, the positions of the structural sound traps and their respective baffles, beams, columns, or wind braces often make the ideal solution either extremely costly or sometimes even impossible. If the decisions regarding the system's sound absorption capacity are made together with its structural designer, problems of this kind can be avoided at the start, and the cost of the materials destined for acoustic insulation can be kept at a minimum. Correct acoustic design requires close co-operation between architects, structural designers, mechanical and electrical engineers, and acoustic insulation experts. In order to achieve these results, the design team must start working together even as early as in the following phases:

1) selection of the type of system;
2) preliminary selection of the machinery;
3) sizing of the technical spaces;
4) planning of the technical spaces.

3.5.1 How noise is transmitted in a ventilation system

Any problem regarding sound attenuation can be represented in the simplified flow diagram shown in Fig. 3.9, which indicates the following two possibilities:

1. **Reduce the intensity of the sound emitted at the source.**
2. **Obstruct the flow of sound along its route of propagation.**

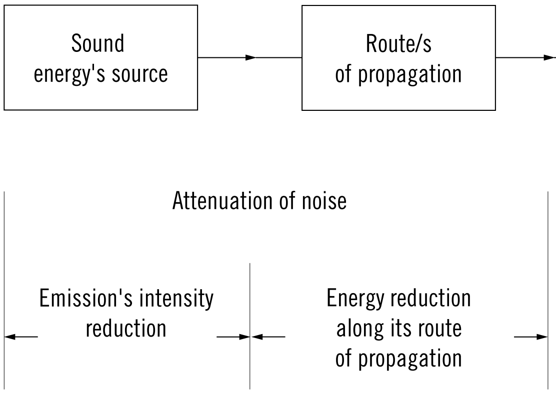


Fig. 3.9 - Sound energy flow diagram

We provide the flow diagram for acoustic energy in a ventilation system below.

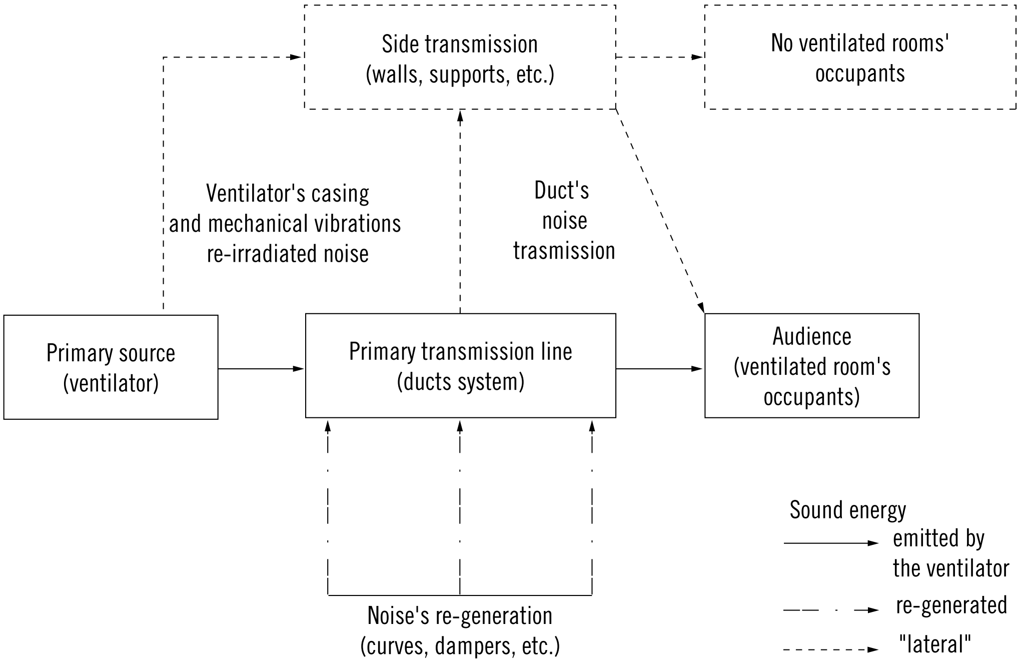


Fig. 3.10 - Noise transmission in a ventilation system

Given that the fans are the primary source of noise in an air distribution system, the air ducting systems must be designed with acoustics in mind with the objective of preventing excessive noise from being generated or transmitted along the route.

The acoustic properties of an air ducting system are identified by the following parameters:

1) sound attenuation (along the route);
2) resistance to noise leakage (“break-in” and “break-out”);
3) self-generation of noise.

3.5.2 Sound attenuation along the route

a) Attenuation in straight duct sections

It may come as a surprise to learn that sound can be attenuated during its passage through a duct of constant section. The reason that a certain attenuation occurs is that a duct’s walls are not perfectly stiff, and the fluctuating sound pressure inside the duct causes these walls to vibrate.
For this reason, stiff ducts such as circular metal ducts offer very low sound attenuation coefficients.
A part of this energy will be re-irradiated in the form of aerial noise outside the duct, and this can create problems in the areas traversed by the duct, as will be seen in section 3.5.3 (noise leakage).

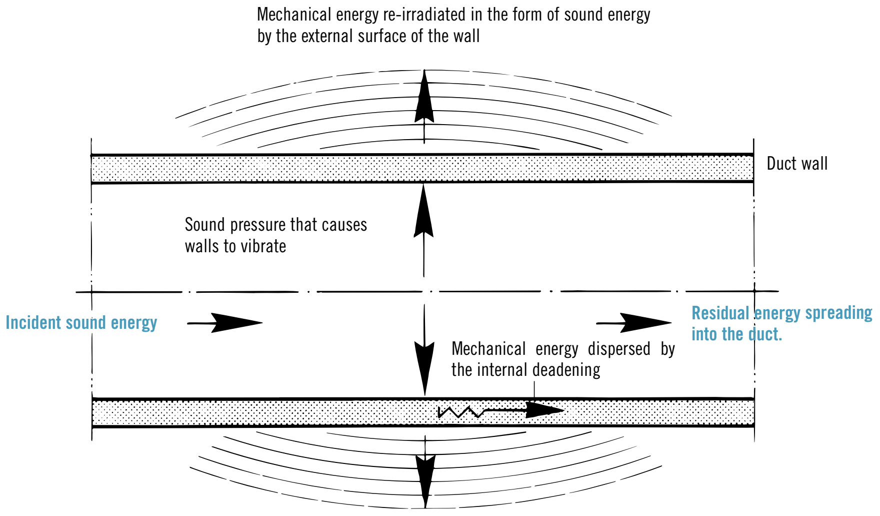


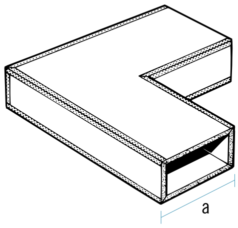
Fig. 3.11 - The sound attenuation process for a duct with constant section

The predictable attenuation values in [dB/m] per octave band [Hz] for straight sections of rectangular section pre-insulated aluminium duct are provided in the P3 technical data sheets.

b) Attenuation in elbow duct sections

Unlike the straight duct sections, where attenuation occurs through absorption, in elbow duct sections the reduction in sound is due to reflection in the direction of the source.
As a general rule, the lower the aerodynamic resistance of the elbow, the lesser the attenuation of the acoustic energy it provides will be.

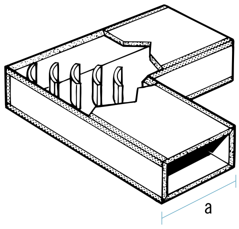
The tables below permit the assessment of the attenuation in [dB] possible in various types of elbows.



Sharp angle elbow

	Frequency [Hz]							
a [m]	63	125	250	500	1000	2000	4000	8000
0,15 - 0,30	0	0	1	4	6	6	4	3
0,30 - 0,60	0	0	4	6	6	4	3	3
0,60 - 1,2	1	3	7	6	4	3	3	3

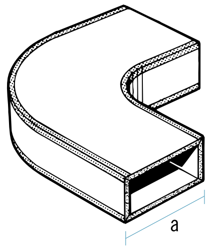
Tab. 3.6



Elbow with splitters

	Frequency [Hz]							
a [m]	63	125	250	500	1000	2000	4000	8000
0,15 - 0,30	0	0	0	2	3	4	3	3
0,30 - 0,60	0	0	2	3	4	3	3	3
0,60 - 1,2	0	1	4	4	3	3	3	3

Tab. 3.7



Radius elbow

	Frequency [Hz]							
a [m]	63	125	250	500	1000	2000	4000	8000
0,15 - 0,30	0	0	0	0	1	2	3	3
0,30 - 0,60	0	0	0	1	2	3	3	3
0,60 - 1,2	0	0	1	2	3	3	3	3

Tab. 3.8

c) Take-offs, tap-ins, and branches in ducts

No real attenuation of acoustic energy is caused by duct branches, but the energy coming from the main duct divides into the branch ducts in the same way that the air flow is divided.

In terms of sound level, the attenuation that occurs in a branch duct can be calculated using the formula below:

$$\Delta L_w = 10\log\left(\frac{m_1}{m_2}\right) \quad [\mathrm{dB}]$$

where:

m_1 : air flow in the main duct upstream from the branch duct [m^3/s];
m_2 : air flow in the branch duct [m^3/s].

The table 3.9 provides the sound attenuation in dB corresponding to the respective duct branches.

m_2/m_1	0,01	0,02	0,04	0,06	0,08	0,1	0,2	0,4	0,5	0,6	0,8
ΔL_w [dB]	20	17	14	12	11	10	7	4	3	2	1

Tab 3.9

d) Sound attenuation filters

Whenever the attenuation of the sound level obtained naturally in the delivery and return circuits is insufficient to ensure the achievement of the noise levels required in the areas, sound attenuation filters or sound traps can be used.

Sound traps are usually composed of a duct section (straight, or even sharp right angle elbows) in which the appropriate sound dampers (usually in the form of baffles) are inserted to permit elevated sound attenuation.

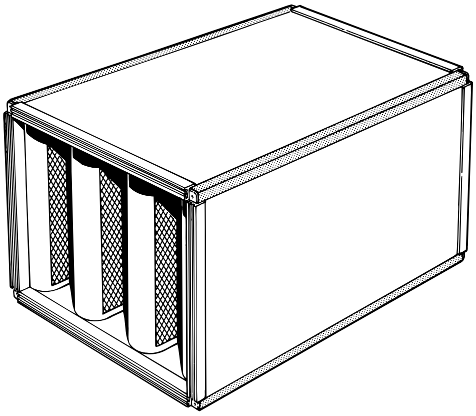


Fig. 3.12 - Sound attenuation filter

The attenuation produced by a sound trap depends on various factors:

- the type of baffles employed: exclusively sound damping baffles in mineral wool lined with high sound absorption fibre-glass are particularly indicated for frequencies of 500 Hz up; "resonator" type sound traps constructed in the same way as standard baffles but with an extra layer of aluminium lining on half the surface are especially indicated for lower frequencies;
- construction: the thickness of the baffles and the respective narrowness of the air passages play decisive roles in the amount of attenuation created;
- length: the longer the sound trap is, the greater is the sound attenuation produced is.

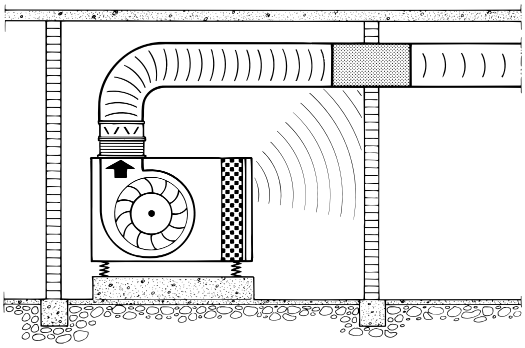
In summary:

To increase attenuation:	1) reduce the air passage sections; 2) increase sound trap length.
To decrease friction losses:	1) increase height; 2) increase width (by increasing the number of modules).

N.B. In regard to sound traps, the term "module" is used to indicate an air passage plus the thickness of the its respective lining.
In order to reduce friction losses to a minimum, sound traps with baffles having dimensions larger than those of the duct must often be used, and therefore the appropriate connectors with aerodynamic ends must be adopted.
The various models of sound trap differ by dimensions and therefore air flow in regard to the friction loss and the air speed. In consequence, if the maximum air flow and speed (or friction loss) is known, the air flow rate that the sound trap must have can be calculated using the diagrams provided by the manufacturer.
Finally, the air flow data tables must be used to choose, from among the sound traps that provide the degree of sound attenuation required, the model that has a flow rate coefficient equal or slightly superior to the desired value. From among the various models that might be employed, the sound trap with the most convenient dimensions must be selected.

Where the sound traps must be installed.

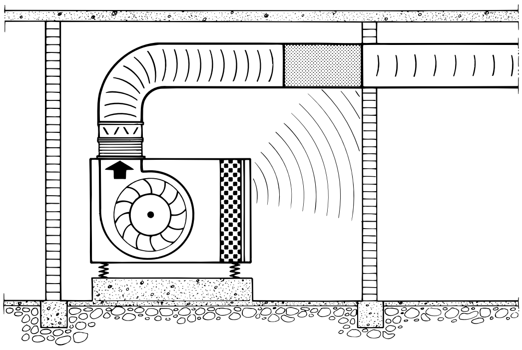
The exact location of the sound traps depends on the type of machinery present and their proximity to critical areas. When the noise level in the air handling unit is high, we recommend positioning the sound trap in the section of the duct immediately before its exit from the room; in this way, all the noise produced by the air handling unit that enters the duct, even through the walls, will be dampened by the sound trap before it can reach the system's outlets into the rooms as shown in figure 3.13. Positioning the sound traps too close to fans or other components can create excessive turbulence with a corresponding increase in excessive friction loss and self-created noise.



Centered in wall

Best solution

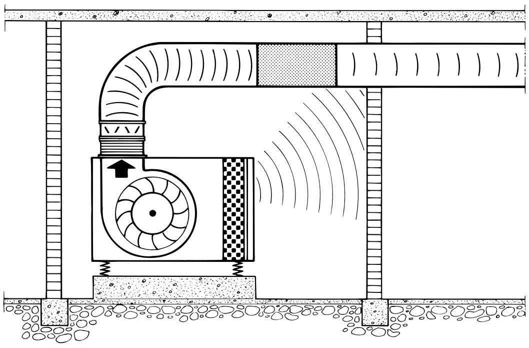
Controls duct borne noise and mechanical room noise that “breaks into” duct.



Outlet at wall

Very good

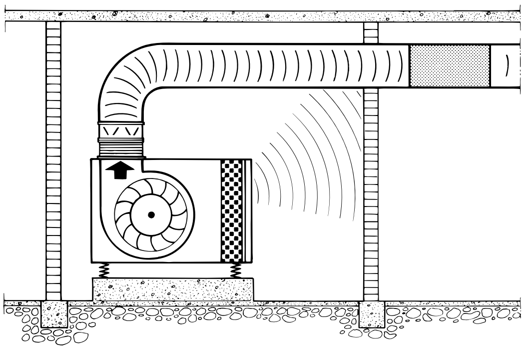
Practical alternate where fire damper is required at wall.



Inside mechanical room

Fair

Mechanical room noise “breaks into” duct without reduction through sound trap.



Outside of mechanical room

Poor

All noise in duct “breaks out” over occupied space before being reduced by sound trap.

Fig. 3.13 - Positioning of sound trap near the dividing wall of a machine room

3.5.3
Resistance to noise leakage ("break-in" and "break-out").

Air distribution ducts can become noise emission sources. Depending on the sound-damping properties of the materials composing the duct, one part of the sound emitted into the duct is irradiated outward through the walls of the duct itself. The noise generated inside the duct and transmitted outwards through its walls is known as "break-out" noise. The ducts can traverse rooms where noisy machinery is located that transmit a part of the noise produced to the inside of the duct., where it is subsequently propagated. This phenomenon is known as "break-in" noise.

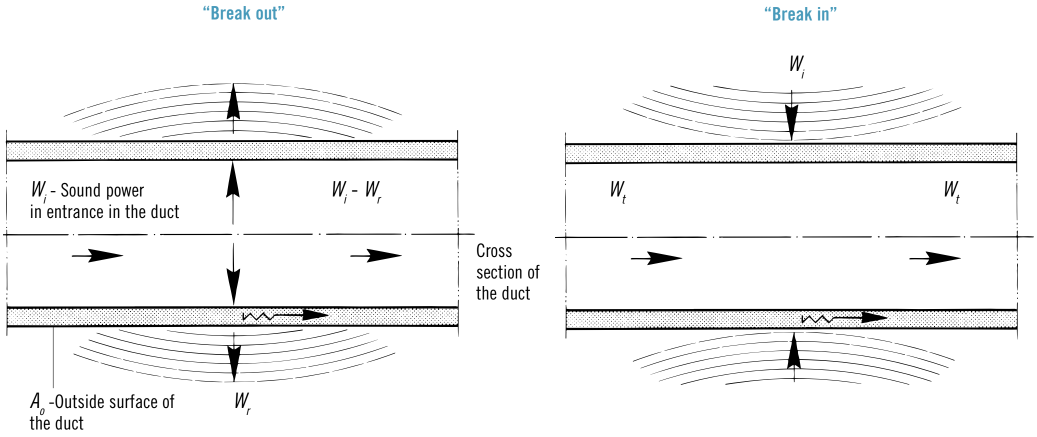


Fig. 3.14 - "Break in" and "break out"

The total level of sound power L_{WD} that crosses the walls of rectangular ducts and is emitted into the listening area can be approximately provided by the following formula:

$$L_{WB} = L_{WD} - R - 10\log(S_p/S_D) \text{ [dB]}$$

where:

L_{WB} = sound power level emitted into the room or area [dB]
L_{WD} = average sound power level inside the duct for the section included in the listening area [dB]
R = sound-absorption power of the walls of the duct [dB] (data available from P3)
S_p = total surface area of the walls of the duct emitting sound into the listening area [m^2]
S_D = section of the duct [m^2].

It is immediately evident that when 10log (S_p/S_d) is equal or superior to the sound absorption value, the respective equation indicates that the entire sound power level L_{WD} or even more acoustic energy than the amount originally present inside the duct escapes outwards. In these conditions, it is obvious that the hypotheses that lead to this particular equation are no longer valid, and the equation itself can no longer be applied. Whenever this happens, it must be considered that one half of the acoustic energy breaks out of the duct and the other half remains inside the system.

The sound power level calculated L_{WB} can be used as a prediction of the sound level L_p in any listening area by utilising the following formula:

$$L_p = L_{WB} + 10\log(Q / 4 \pi r^2 + 4 / R_c) \text{ [dB]}$$

where:
r : distance form the sound source [m]
Q : directivity factor, non-dimensional
R_c : constant of the room or area [m^2]

$$\text{with} \quad R_c = \frac{\overline{\alpha}\, S_a}{1-\overline{\alpha}}$$

with:
$\overline{\alpha}$: average absorbtion coefficient of room
S_a: total internal surface area of room.

Note that S_p includes all the irradiating surfaces in the room or area, even if the duct is closer or further from the respective walls. The echo effects must also be taken into account by assigning an appropriate value to the directivity factor as follows:

$Q = 2$ when the duct is installed at the centre of the ceiling
$Q = 4$ when the duct is installed near a junction between ceiling and wall.

Instead of crossing the room exposed, ducts are often installed above the ceiling: in order to evaluate the effective level of the sound emitted into the room in these cases, the so-called “insertion loss” contributed by the installation above the ceiling must be subtracted from the sound.

3.5.4
Self-generated noise

The factors that lead to the autonomous generation of noise are the solid bodies exposed to the movement of the air that are capable of generating greater or lesser turbulence.
The effect of the flow of turbulence over a solid surface produces rapid fluctuations in pressure in the immediate vicinity; if these pressure fluctuations are strong enough, they can create a not insignificant sound level. In ventilation systems this happens often, especially in high-speed systems.

The various generators of noise can be grouped in two categories:

1) Elements that produce “self-created” acoustic energy in the duct:

- duct sections
- elbows
- branches
- reductions
- dampers
- accessories (heating batteries, mixer boxes etc.).

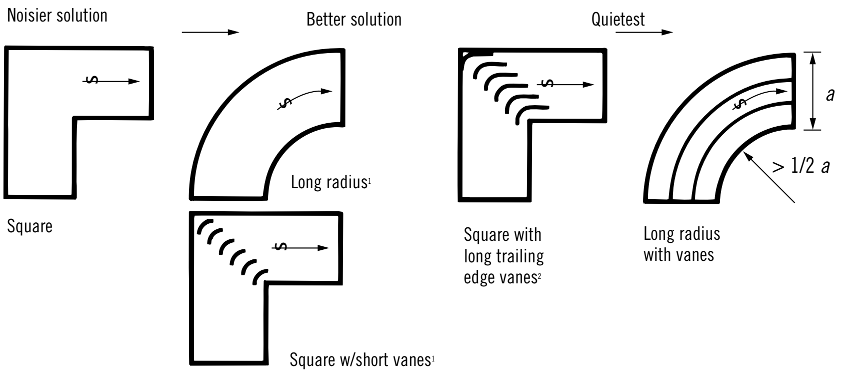
2) Outlets that irradiate secondary acoustic energy directly into the room or area:

- grilles (with or without built-in dampers)
- diffusers
- terminal units
- other outlets.

The most important parameter that influences the quantity of noise generated by a duct element is therefore the speed of the air flowing inside, and the first question to be asked is whether or not this speed can be reduced.
The ratio that links the sound pressure produced to the sixth power of the speed indicates that even only a 12% reduction in speed can provide a 4 dB attenuation in noise.
In any case, there will always be a limit beneath which the speed cannot be reduced.
If the secondary noise is still too high, other sound damping methods must be considered.
The most obvious solution is the use of the dissipating silencers described previously.
It is common practice to install the main silencer in the machine room, and the so-called secondary silencers in one or more outlet ducts as required, especially in high-speed systems.
In order for these measures to be effective, all the secondary sources of noise must be positioned at a distance from the outlet sufficient to permit the installation of the silencer.
This holds particularly true for the dampers used for the dosing of the quantity of air that must pass through the grills and diffusers.
The noise produced by these outlets is virtually uncontrollable, given that it involves sources that emit directly into the area occupied. The same can also be said of the terminal units in the area. The only choice the system designer has in this case is the use of the most silent duct elements possible.
It is therefore very important to make sure that the data provided by the manufacturer are real experimental data obtained for determined load conditions. In extreme cases, the outlets can be oversized.

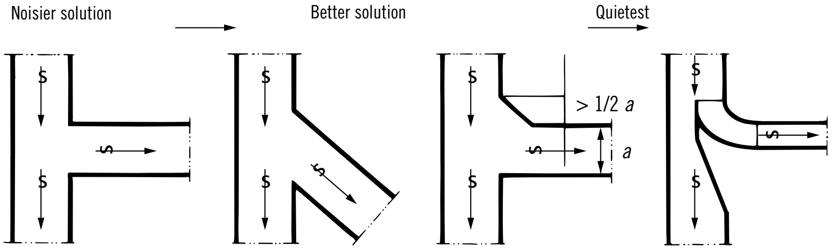
Below we provide the solutions recommended for the limitation of self-generated noise.

Guidelines for minimizing self generated noise in elbows.

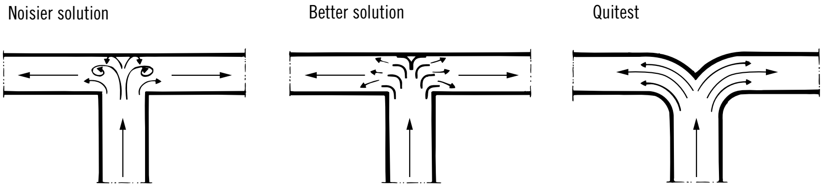


1 Airflow velocity and proximity of upstream and downstream fittings and fans determine which type is preferable.
2 Trailing edge length should be at least 3 times the vane spacing.

Guidelines for minimizing self generated noise in the takeoffs.



Guidelines for minimizing self generated noise in duct tees.



Guidelines for minimizing self generated noise in transitions and offsets.

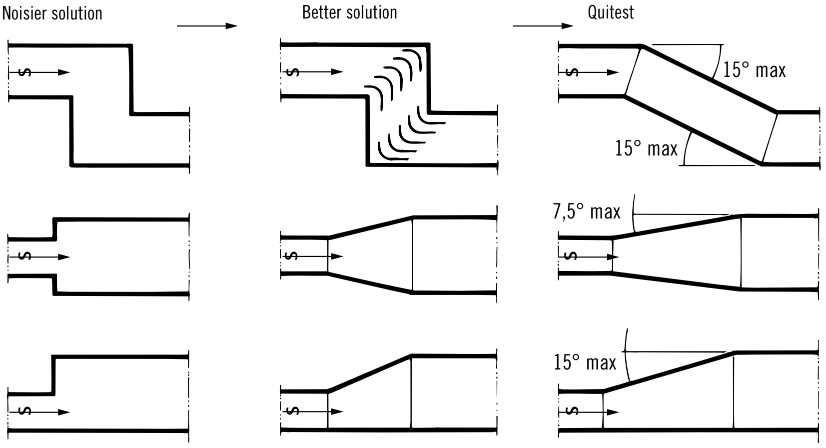


Fig. 3.15 - Guidelines for the limitation of self-generated noise

3.6
The fire reaction of insulation materials

“Fire reaction” must be considered as the combination of various physical and chemical transformations that materials and structures used in the building undergo when exposed to fire.

The need to protect buildings from the consequences of fires requires their reaction to fire to meet determined standards.

Fire reaction is also considered by the various laws that regard both the prevention of fires and accidents.

3.6.1
The development and propagation of a fire

Figure 3.16 illustrates the way in which a fire develops and spreads. A fire begins with a sparking phase produced by the addition of heat that a combustible material receives from a nearby source (usually heating or cooking equipment, electrical short-circuits, cigarettes, or arson).

Transmission through conduction, convection or radiation (or a combination of the three) induces the combustible material to develop gases that burn with a fire and give rise to the further creation of heat ad temperature.

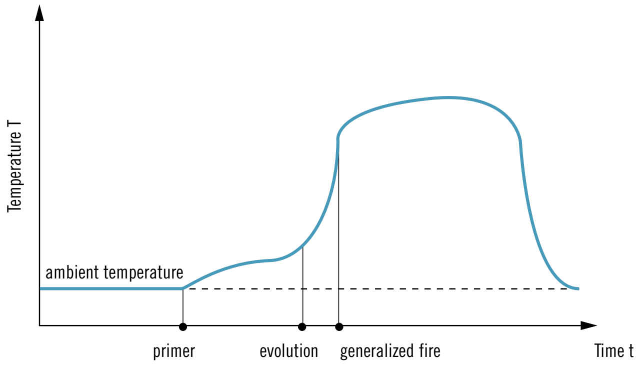


Fig. 3.16 - Evolution of a fire

The development phase proceeds in this way, and the fire is characterised by a faster and faster increase in both temperature and fire propagation speed. This phase comes to conclusion with a general “flash over” caused by the extremely rapid increase in fire propagation speed that involves all the combustible surfaces present.

The general fire begins from this moment on, and the entire room will burn at the highest temperature possible unless measures are taken. The fire comes to conclusion with a phase of decline characterised by a more or less slow decrease in temperature and the production of heat as all the remaining material capable of combustion is gradually consumed. Obviously, in order to prevent fires from starting inside the building or at least toobstruct its propagation, the use of materials and components capable of providing valid opposition to both the sparking or fire and its subsequent propagation assumes fundamental importance.

3.6.2
The safety offered by P3ductal ducts wherever risk of fire is present

All around the world, “Fire prevention” measures are adopted to prevent the occurrence of conflagration through various active protection measures, while also attempting to limit the consequences using various passive measures of protection. The primary objective of both active and passive measures is ensuring the rapid and complete evacuation of all people present inside the building without creating any additional risks for firefighters. Many methods and systems contribute to guarantee this objective; we provide the most important below:

- The **FIRE REACTION OF THE MATERIALS** is universally recognised as one of the most important disciplines on which **ACTIVE PROTECTION** against risk of fire is based.
- The **FIRE REACTION (OR UNINFLAMMABILITY) OF THE STRUCTURES** is universally recognised as one of the most important disciplines on which **PASSIVE PROTECTION** against risk of fire is based.
- The limitation of the **OPACITY AND TOXICITY OF THE SMOKE** generated by the combustion of the materials is the most modern discipline that lies at the basis of many safety measures and technical developments finalised for the purpose of guaranteeing safe and rapid escape from buildings during fires.
- The **DEVICES** used to reveal the presence of smoke or fire, to extinguish fire, and to eliminate flue gases, etc. are other technological measures that contribute to the creation of adequate fire prevention safety, but in any case constitute “an additional and expensive” solution to the problem, while the three systems above represent an intrinsic solution to the materials involved in the fire.

3.6.3
Fire reaction of the materials

Consider for example a building composed of numerous rooms, storage spaces and corridors. A fire can start and spread in any of these areas for any number of reasons.
The study of the fire reaction of the materials deals with the characteristics that the various materials inside the building display in regard to both inflammability (the ease with which they catch fire) and their propensity to sustain the propagation of an existing fire to the rest of the area.

Fore example, if a waste-paper basket catches fire, the carpeting, the curtains, and the armchairs in the vicinity must not catch fire easily. If they ado eventually catch fire, they must be made in such materials as to restrict the propagation of the fires (or in other words, they must self-extinguish) even when they are positioned in the immediate vicinity of the fire.

The characteristics of a material’s fire reaction are currently classified in many nations around the world with the use of conventional numbers, such as 0 (zero) and 1 (one) for the materials that catch fire with greatest difficulty and prevent the propagation of fire most easily, and higher numbers, such as 3 (three) and 4 (four) for the materials that catch fire most easily and are incapable of preventing the spread of fire because they contribute to the propagation of fires themselves through the dripping of burning parts and incandescence, etc.

Depending on the nation considered, these numbers are either preceded or followed by a number of conventional letters or in some cases these letters stand alone, for example:

France	M0, M1, M2, M3, ...	
Germany	A1, A2, ...,	"A" = incombustible
	B1, B2, B3, ...	"B" = combustible
U.K.	0, 1, 2, 3, ...	
U.S.A.	V0, V1, V2, ...,	"V" = "Vertical" test position
	H0, H1, H2, ...	"H" = "Horizontal" test position
Italy	0, 1, 2, 3, 4, ...,	other than stuffed materials
	1 IM, 2 IM, ...	"IM" (i and m) stand for "Stuffed"materials

Tab. 3.10

Because this classification has been obtained using different test methods, the classification systems adopted in different nations cannot be strictly compared.

The future standardised European fire reaction system foresees the formulation of different Euroclasses expressed with different letters, or rather A and B for the best materials, C for the intermediate materials, D and E per the worst materials, and F for materials that cannot be classified.

Unfortunately, due to a series of technical, economic and legal reasons, the CEN (the European Committee for Standardisation) that represents all the member nations of the European Union and features the participation of observers from other non-European nations, members of the ISO (International Standards Organisation), has still not reached a definite agreement on the precise fire reaction test methods and corresponding classification to be adopted and a single classification system valid for all the European nations has not yet been created.

In the meantime, P3 has already certified and homologated its own products classified in the best fire reaction classes, such as in Classes 1 (one), 0-1 (zero-one), 0-2 (zero-two) in Italy, in Classes M1 ("M" "one") and M2 ("M", "two") in France, B1 ("B", "one") and B2 ("B", "two") in Germany, and so on. In this way, the users and operators in the sector are provided with the certainty that the product is not only safe but also officially approved by the competent control organisations.

Our effort to obtain approval for all our products therefore represents scrupulous attention and responsibility towards all final users that is also guaranteed by our achievement of the prestigious ISO 9001 certification granted to all companies that operate under controlled quality systems.

3.6.4 Fire resistance of the structures

Fire reaction studies attempt to quantify and classify the duration of the structures and the compartmentalisation of the respective constructions in the hypothesis of standard fires; in other words, assuming that a fire of a certain degree has developed in a given area, it is necessary that the structures such as walls, floors, beams, pillars, fire-doors, and fire barriers, etc. that delineate the area are all capable of resisting both the static loads and thermal dilatation. These structures must also prevent flames or high-temperature gases from leaving the area, and must also not transmit heat through thermal conduction to the external sides of the area in which the fire has developed. Walls in wood, or wall facings in fabric or paper positioned in the room next to the area where the fire has developed could catch fire only due to the effect of the overheating of the walls or the incandescent gas that might seep through the cracks or penetrate the room due to the collapse of the wall itself or a communicating door.

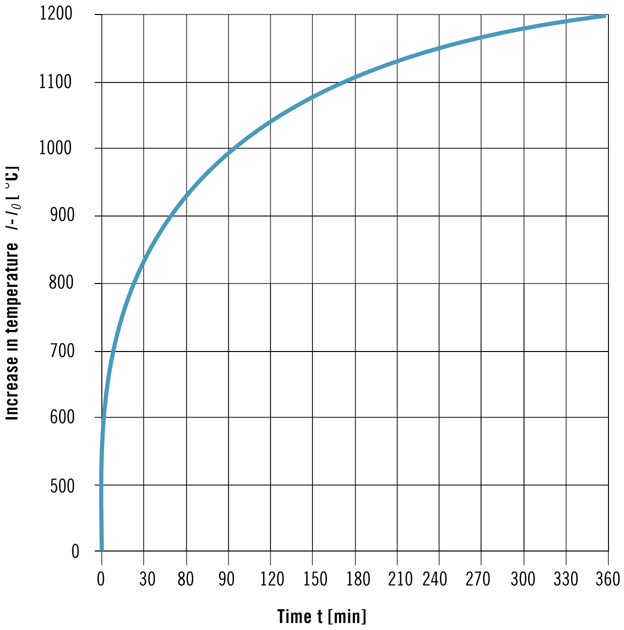


Fig. 3.17 - Temperature-time sample curve

ISO 834	
time **t** **[min]**	**average furnace** **temperature** **[°C]**
5’	≈576
10’	≈678
15’	≈739
30’	≈842
45’	≈902
60’	≈945
90’	≈1006
120’	≈1049
180’	≈1110
360’	≈1214

Tab. 3.11

Figure 3.17, provides the curve of the increase of teperature T - T_0 , as a function of the time T [min], where T is the average furnace temperature described by International Standard ISO 834, see the following formula:

T [°C] = 345 $\log_{10}$ (8* t_{min} + 1) +20
and
T_0 = 20 °C

Purely by way of example, Table 3.11 indicates the average temperatures of the test furnace as defined by the same international Standard ISO 834.

As known, ventilation and heating ducts are not considered structural elements and do not delineate or compartmentalise rooms or areas, and are therefore subject to fire reaction characteristics restrictions only when they traverse compartmentalised structures such as firewalls, in which case they must be provided with fireproof barriers and firewalls.

Up until a few years ago, the ambiguous use of the term “fire-resistant” created no little amount of confusion due to the delay in standardising fire reaction terminology. This ambiguity has now been clarified and the term “fire resistant” must only be used in regard to bearing and/or dividing structural elements.
It is now widely known that whenever any type of duct traverses “stairwells or elevator shafts” or “rooms that present risk of fire or explosion” or “escape routes”, the passage of the ducts through such areas is only permitted if they are enclosed in other structures that have a fire reaction classifications that are at least equivalent to the area being crossed.

Unless specified otherwise, the fire resistance of an article generally indicates the lowest of the “resistance and stability”, “fire and gas seal”, and “thermal insulation” values determined by the manifestation of the following phenomena:

- the passage of fire and smoke, which determines the time value of the “fire and gas seal”;
- the average temperature of 150 °C on the other side of the wall of the room on fire or a localised peak value of 180 °C on the same surface, which determines the time value of the “thermal insulation”;
- the loss of stability and/or sag, which determines the time value of the “resistance and stability”.

These values are specified individually in the test reports.

The test methods used to determine the fire resistance of the structures are similar all around the world, and differ only by the conventionalised letters that accompany the numbers that indicate the resistance over time in minutes. By way of example, in Italy, “REI 30” indicates that an article’s “resistance and stability R”, “fire ad gas seal E” and “thermal insulation I” are guaranteed for 30 minutes. Even if the extended form might read R 90 , E 60 , I 30, the article’s weakest resistance is always used for classification in order to ensure the greatest safety.

Articles with a fire resistance of less than 15 (fifteen) minutes are considered NOT fire resistant.

The considerations above indicate that ventilation and heating ducts built in sheet steel are not fire resistant at all; on the contrary, due to its high thermal conductivity, sheet steel does not even succeed in reaching 3 (three) minutes of fire resistance, even when these traditional sheet metal ducts are insulated with sponge or fibrous Class 1 materials or even incombustible fibrous materials capable of ensuring 10 minutes of fire resistance.

In addition, these traditional heavy metal ducts pose a serious risk to both the people escaping the building and the rescue teams when they collapse as a result of the fire.

3.6.5 The fire load

One of the primary principles of fire resistance regards the determination of the fire load inside the room to be compartmentalised, or rather, the quantity of heat that the combination of the combustible materials present in the room could potentially develop (this value is usually given in proportion to the square meters of surface area or cubic meter of volume, and depends on the higher heating power of the materials present and the quantities in which they exist.).

For example, a storage room that contains only ceramic tiles and concrete glass brick does not require particular fire resistance because the quantity of combustible material stored inside is virtually non-existent. On the other hand, if the same storage room is used to store textiles, it will require particular fire resistance and also efficient elimination systems for the flue gas (white and black smoke) that textiles release in great quantity.

Due to the fact that they are composed of a thin and lightweight core of polyurethane insulation material (faced with a layer of aluminium foil) and in addition to the fact that they pose no risk to the sparking and propagation of a fire, P3ductal heating and ventilation ducts make no significant contribution to the room's fire load whatsoever.

By way of a numerical example, let us consider a large storage room for clothing, a room with a 10 by 10 meter area crossed by a duct with a net section of 50 cm by 50 cm = 0,25 m^2 , which is more than ample for the room's air distribution system.

- For every meter of duct, the use of approx. 2,08 m^2 of 20 mm, thick polyurethane is easily calculated for a 10 m long duct for a total volume of polyurethane of approx. 0,416 m^3;
- Given a specific weight of approx. 49 kg/m^3 and a superior heating power of less than 6.000 kcal/kg (5.600 kcal/kg to be precise), it can be easily demonstrated that the addition made to the room's fire load is less than 1.224 kcal/m^2;
- Given that the fire load typical to a room like this is generally around 240.000÷360.000 kcal/m^2, the insulating component of a P3ductal duct makes an addition of less than 0,5% to the fire load;
- This percentage value is much less even than the value given for the margin of error used to calculate the quantity of combustible material present and is not even of significant value for the prescription of the fire resistance of the compartmentalisation.
- If we consider a small hotel room 4,5 m x 3,5 m = 15,75 m^2 in size with a typical fire load equal to approx. 100.000 kcal/m^2 and a P3ductal duct with a free section of 25 cm x 25 cm, the contribution to the fire load can be easily calculated as being no more than 2%.
- In fact, the four sides of the (25+2) cm duct multiplied by 4,5 m of length multiplied by 0,020 m of thickness, multiplied by a specific weight of 49 kg/m^3, multiplied by 6.000 kcal/kg(PU), divided by the 15,75 m^2 area of the room make a total of approx. 1.815 kcal/m^2, which is less than 2% of a fire load of 92.000 kcal/m^2.

From this point of view, P3ductal ducts contribute to the improvement of the building's overall safety.

3.6.6 Toxicity and opacity of the smoke

It has been known for some time that most of the deaths and injuries that occur during a fire are caused by intoxication after inhalation of poisonous flue gases and the panic spread by the black smoke that swiftly invades the room even when no fires are present, and not by burns or the collapse of supporting structures in the burning building.

For this reason, in recent years great attention has been given to the definition of the materials used and their tendency to produce toxic fumes and black smoke, especially in transport vehicles such as planes, trains, and high-speed watercrafts where help cannot be provided quickly, the volumes of the rooms are small, and the passengers cannot easily abandon the vehicle without high risk.

In these cases as well however, there are many different tests and classification methods which differ not only nation by nation but also from one context to another: the most-commonly adopted standards currently are the French AFNOR standards for railways, and the US FAR and European AIRBUS standards for air travel. These and other standards are used for sea travel.

In any case, and in proof of the extreme risk posed by flue gases, all these test methods consider primarily the very first minutes of the development of a fire (usually just the first four minutes) because it is generally considered that after such period the quality and quantity of the gases produced by any combustible material are so strong that they cause fainting and serious risk of death to all those who have not yet escaped or been provided with some form of protection.
Given the considerable technological effort that has been made in the development of materials with good characteristics in regard to flue gas toxicity and opacity, for years researchers worked under the principle (not always reliable) that "what doesn't burn doesn't make smoke", and for many years these characteristics were neglected (in favour of the characteristic of fire resistance) by both legislators and creators of supply specifications. Today, with the advent of new technological instruments and awareness, P3 has stepped to the vanguard in this highly delicate sector as well by certifying its materials to the different standards governing flue gas toxicity and opacity.

While refraining from a technical description of the complex chemical substances that characterise dangerous flue gases, the situation can be simplified by noting that in the examples of the storage room containing textiles and the hotel room used above, P3ductal ducts will produce flue gases that are less toxic and opaque in lower quantities than the materials and decor present.

The example would be all the more dramatic if the same storage room were used to store hobby supplies (with paints and glues) or toys (usually made with PVC) or sporting goods (generally composed of nylon and synthetic rubber), etc.

The advantages of using P3ductal ducts would also be much more evident if the same hotel room were luxuriously decorated or rather a cinema or a theatre with stuffed armchairs, wall hangings and sound-absorption carpeting.

P3ductal ducts do not produce flue gases that contain instantly incapacitating substances, heavy metals, vinyl derivatives, dioxin, or other carcinogens.

3.7
Air quality and hygiene

Indoor air quality has become an issue of vital importance in the past few years, the term "Acceptable Indoor Air Quality" commonly accepted by all and as specified by ASHRAE 62-1989 regulations is defined as: "....air in which recognised contaminants are not present in dangerous concentrations as prescribed by the competent authorities and is deemed satisfactory by the majority (at least 80%) of the people breathing such air".

The air distribution system plays an important part in limiting the contamination of the air conveyed.

There are two leading factors that can lead to the existence of contaminants in the ducts:
- the release of contaminants from the materials used for duct construction;
- the degree of cleanliness of the ducts.

3.7.1
Release of contaminants by duct construction materials

P3ductal ducts are built with sandwich panels faced with aluminium foil on both sides.
The use of aluminium as the internal surface of the duct ensures good hygiene and easy cleaning, while also preventing the release of fibre from the insulation material that is still inserted in some ducts today.
Particles are continuously detached from the insulation through natural ageing and then conveyed along with the air into the rooms conditioned.
P3ductal ducts in various conditions were subjected to the respective hygiene tests in order to determine the extent of global migration phenomena when placed in contact with foods. On the basis of these test results, the aluminium sample was proved amply suitable for such purpose (For further information, request the respective technical documentation from P3).

3.7.2
The degree of cleanliness of the ducts

In the past, ventilation duct maintenance was performed exclusively for recovery of ventilation efficiency in terms of energy, nowadays however, great importance is being placed on the cleanliness of the system and its effect on human health.
In addition to dirt, an enormous variety of micro-organisms can proliferate inside ventilation systems and then reach the rooms conditioned along with the air conveyed.
Accurate and regular duct cleaning guarantees health conditions in the rooms served by the air distribution system. In order to maintain the correct level of cleanliness, interventions must be performed on all the system's elements, otherwise the cleaning of the ducts alone will not be capable of providing the results desired. Shortcomings are often attributed to the ducts when the fault lies instead with other components of the air distribution system that have not been taken into consideration.
As already mentioned, P3ductal ducts are provided with internal facing in aluminium foil that do not promote micro-organisms from nesting or the deposit of dust. Correct cleaning performed by companies specifically certified for the purpose permit levels of cleanliness of up to 96-97% to be achieved, compared to the 46-47% level reached by ducts with insulation material inside.
Pre-insulated aluminium ducts are also distinguished by the ease with which they can be worked, and this permits the insertion of numerous inspection doors for comfortable and efficient access, even in ducts that were laid years ago.

3.7.3
How to clean P3ductal ducts

After performing an initial inspection and then analysing the dust extracted from the critical areas inside the ducts, the ducts can be cleaned but only after first placing the system in negative pressure. The most commonly-used cleaning techniques are listed below:

- cleaning with rotating brushes: this is the most traditional technology and is usually utilised only by itself when there is only a slight amount of dirt. It is important to use only brushes with the right hardness and diameter in order to avoid damaging the aluminium walls;
- cleaning with jets of compressed air: this is indispensable whenever access to the duct is difficult due to either reduced dimensions or the presence of barriers or obstacles; the pressure and the flow rate of the jet of air must vary with the dimensions of the duct. This force must be calibrated in order to remove all dust and encrustation without damage.

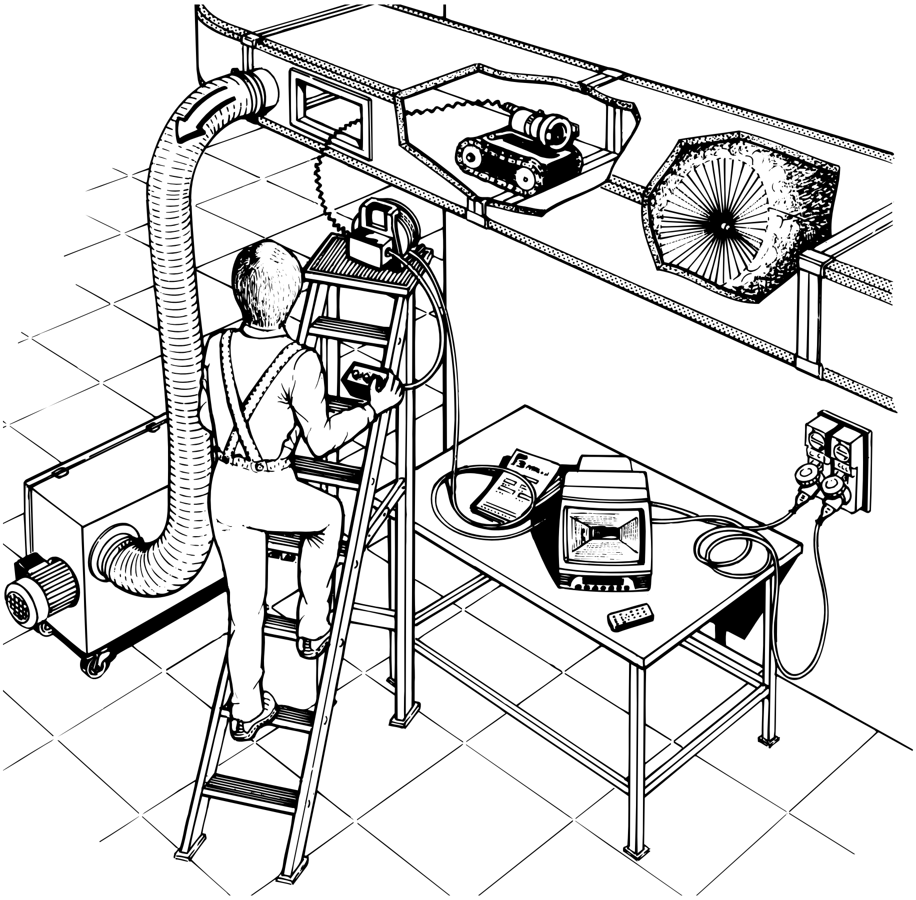


Fig. 3.18 - The P3ductal duct cleaning process

3.8 How long do P3ductal ducts last?

The duration in time (in technical terms) of any component depends on the function that it has been designed to perform.
P3ductal ducts designed for the distribution of air only, must possess the following fundamental requisites:

- corrosion resistance,
- erosion resistance,
- deformation resistance.

3.8.1 Corrosion resistance

Corrosion can be defined as the destruction of a metal or an alloy by the chemical or electrochemical reactions created by agents present in the area where the metal or alloy is used. P3ductal ducts, within the limits of their designated field of use (see “Where P3ductal ducts are installed), ensure good corrosion resistance thanks to their aluminium foil facing. As a further guarantee against corrosion, P3ductal ducts are coated with a special polyester-based anti-oxidation paint to keep all duct surfaces bright and shiny over the years. P3 has also developed a special panel provided with aluminium foil coated with a 13 micron thick layer of polyester film for systems to be installed in particularly aggressive atmospheres (cheese seasoning rooms, marine environments) and matching flanges in PVC for the connection of these ducts.

3.8.2 Erosion resistance

Given that pre-insulated aluminium P3ductal ducts have been designed for the distribution of air exclusively in air conditioning and heating systems, and that the maximum recommended air flow speed does not exceed 15 m/s, they guarantee such good erosion resistance that the aluminium sheet undergoes virtually no thinning whatsoever over time.

3.8.3 Deformation resistance

P3, in collaboration with a number of distinguished research centres, has conducted an in-depth investigation for the purpose of establishing the limits of use for pre-insulated aluminium ducts. The research was performed for the purpose of gathering information on the structural performance of the elements comprising the duct, or in other words, the maximum stress compatible with the resistance of the elements themselves, and the maximum deformation to be tolerated within the limits established. The draft version of the latest European Standards prescribes that the maximum deformation on the sides of rectangular ducts must not exceed 3% of the duct’s transversal dimension, and in any case, never be more than 30 mm. The results of the research have permitted the development of a system for the verification of duct performance under various operating conditions (with different pressures, side dimensions, and temperatures).

The data collected in graphic form indicates the need to insert the appropriate stiffening in the ducts. Thanks to this stiffening composed of special aluminium bars inserted inside the duct, ducts capable of transporting air at both positive and negative pressures of up to 1500 Pa can be constructed.

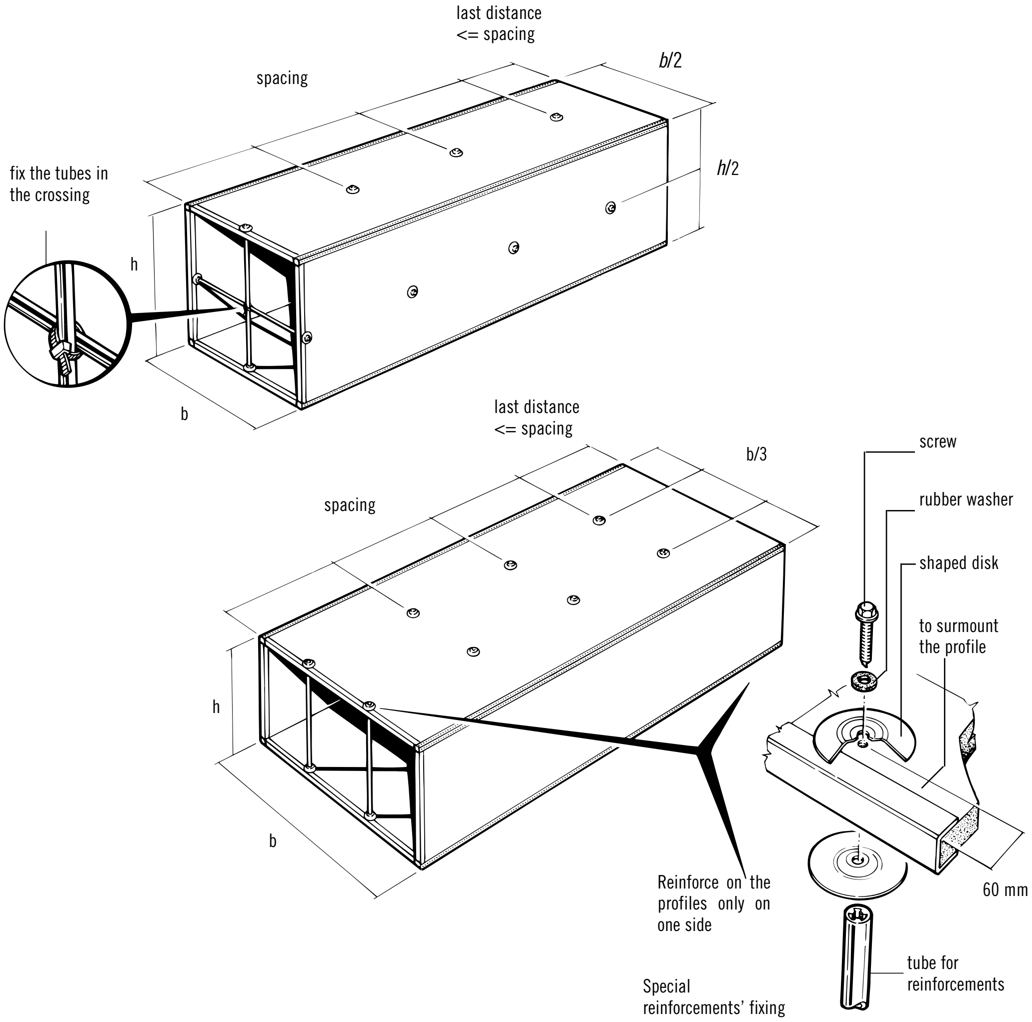


Fig. 3.19 - P3ductal ducts reinforcing system

4 Duct system sizing

The accurate sizing of an air distribution system always requires time and experience, while also dedicating ample attention to the problems involved in the construction of the ducts, their installation at the work site, the initial costs, the subsequent system management costs, and the control of noise levels, smoke and fire reaction.
The installation of dampers also assumes fundamental importance in order to permit the balancing of the pressures inside the system after correct sizing has been performed.
The following pages provide a few basic notions for the sizing of the duct network through the use of the "constant friction loss" method.

4.1
The constant friction loss method

The constant friction loss method is one of the most amply-tested sizing methods used and has been successfully applied for years, especially in the low-medium pressure systems where P3ductal ducts are most commonly employed. In practical terms, the duct network is sized by keeping the friction loss per linear meter constant. This method "automatically" reduces the speed in the air flow direction through the selection of a reasonable initial speed in such way that the self-generated noise created by higher air flow speeds are reduced or eliminated at the start.
In the example provided, certain procedures have been intentionally simplified while maintaining satisfactory reliability constant at the same time.
We remind you that P3 has developed a special software package (Ductware) for the sizing of air distribution systems that provides a valid and practical aid to systems designers everywhere.

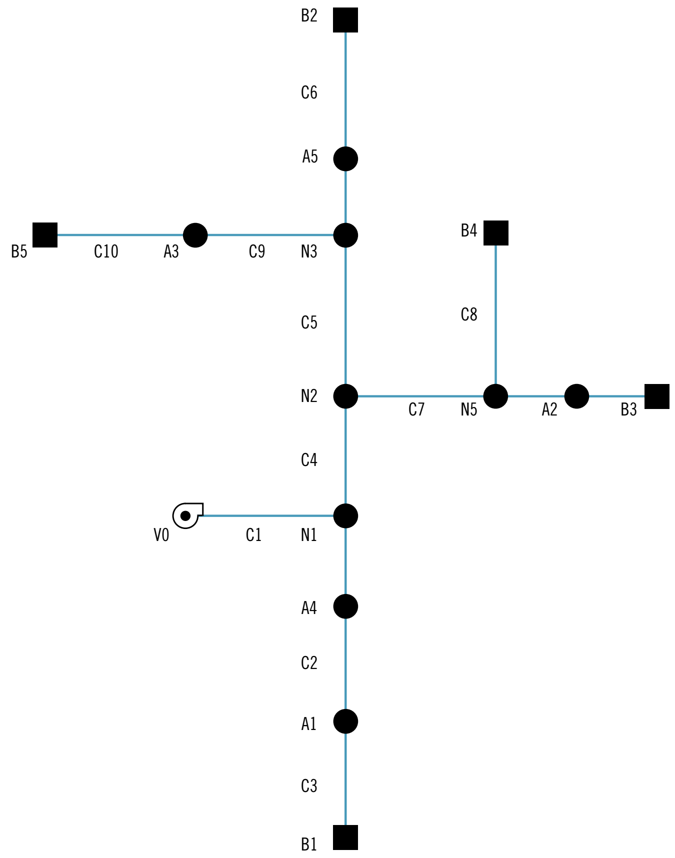
4.2
An example of sizing

The procedure required for the sizing of distribution systems can be divided in the phases below:

1. First of all, certain fundamental data must be known:

- The system's route
- The flow rate of every outlet and/or diffuser.

Figure 4.1 provides the single line drawing of an air distribution system for an office block that we will use as an example.



A = fittings (elbows, dampers, displacements and so on)
B = outlets, diffusers and so on
C = straight ducts
N = confluence (two and three way branches)
V = fan

Fig.4.1 - The single line drawing

Table 4.1 shows the flow rates fixed for each outlet and/or diffuser in the system considered.

Reference	B1	B2	B3	B4	B5	Totale
Flow rate [m^3/s]	0,2	0,2	0,15	0,15	0,15	0,85

Tab. 4.1

2.The speed of the air in the section of duct downstream from the fan must be defined. Tables 4.2 and 4.3 provide the speeds recommended for the various types of duct.
It must be remembered that together with inaccurate duct construction, the speed of the air inside the duct is the leading cause of self-generated noise (see the chap. “Noise in the ducts”).

Type of duct	Recommended air flow speed		
	Residential buildings [m/s]	Public buildings/Schools [m/s]	Indust. buildings [m/s]
Main ducts	3,5-4,5	5-6,5	6-9
Secondary ducts	3	3-4,5	4-5
Secondary columns	2,5	3-3,5	4
External air inlets	2,5	2,5	2,5

Tab. 4.2

Type of duct	Maxiumum speed		
	Residential buildings [m/s]	Public buildings/Schools [m/s]	Indust. buildings [m/s]
Main ducts	4-6	5,5-8	6,5-10
Secondary ducts	3,5-5	4-6,5	5-9
Secondary columns	3,25-4	4-6	5-8
External air inlets	4	4,5	6

Tab. 4.3

In the system under consideration, we will set a speed of 5 m/s for the V0-NI branch.

3. The linear friction loss can then be determined using the graph in fig. 4.2 by intersecting the quantity of air foreseen in the branch 0,85 m^3/s, and the speed selected (5 m/s).
In the system considered, the value of the friction loss is approx. 0,57 Pa/m.

4. The same graph can be used to obtain the equivalent diameter value (De), which in this example is approx. 470 mm in the V0-N1 branch.
The formula below or the tables provided in the following pages can be used to calculate the dimensions axb of a rectangular duct knowing the equivalent diameter (De).

$$De = 1{,}3 \frac{(a\ b)^{0{,}625}}{(a+b)^{0{,}250}}$$

Note: for "equivalent" we mean that it generates the same friction loss at the same flow rate.

In the table, the "a" and "b" values have been standardised in order to obtain the optimisation of the materials and therefore a reduction in costs, but this does not mean that P3ductal ducts cannot be created in intermediate dimensions.

It is important to remember the following when performing duct system sizing:

- The dimensions of the sides (a and b) must be multiples of 50 mm.
- Reductions must be avoided whenever they create a variation of less than 50 mm; in other words, the original section should be maintained until the next diffuser or branch is reached.
- Savings in installation costs can be made by inserting a reducer on one end of the duct or the other, but never on both ends.
- We discourage exceeding the ratio of *a*/*b*=4 for both economic and aerodynamic reasons

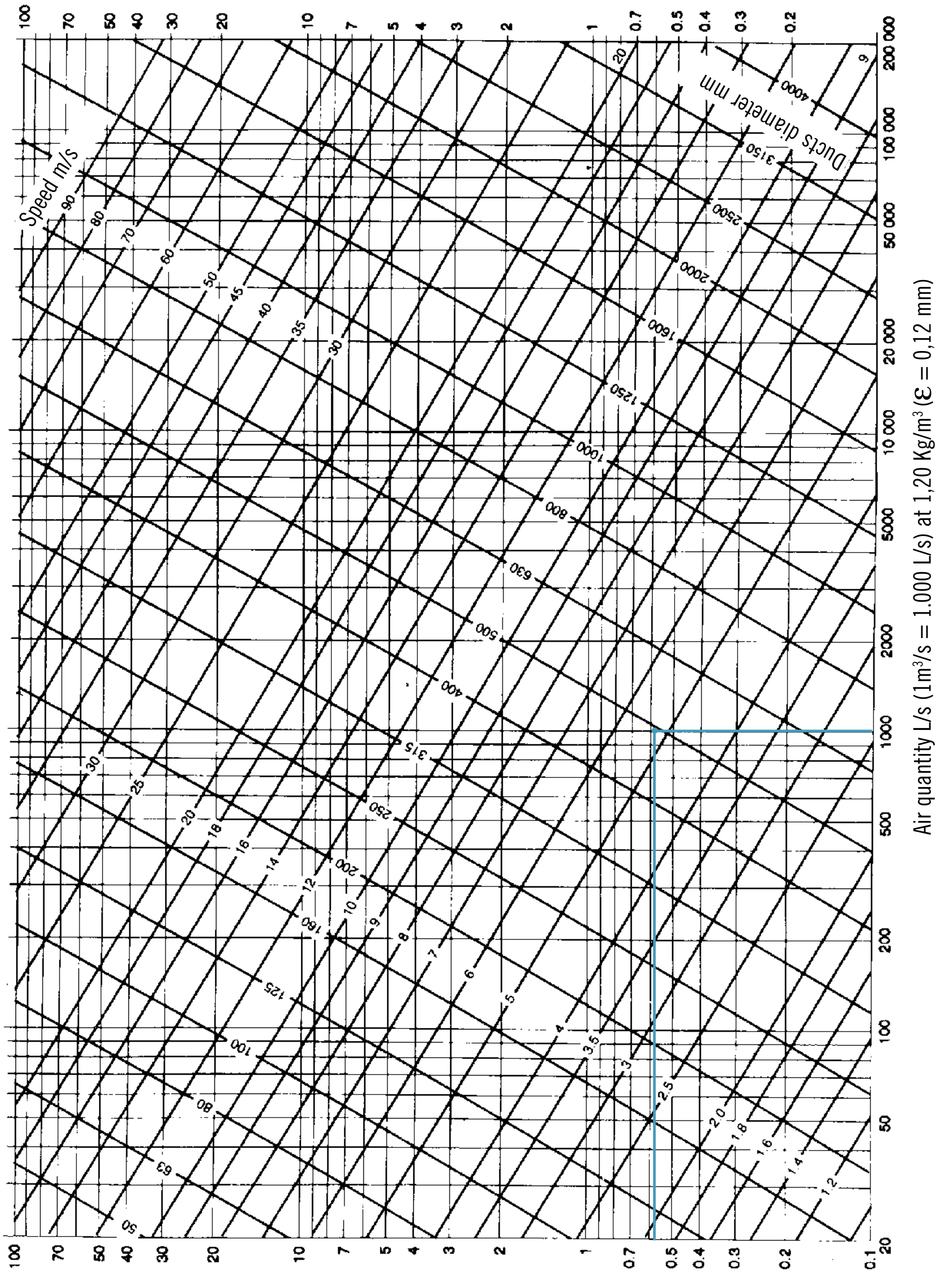


Fig. 4.2- Friction loss in the P3ductal ducts

	150		200		250		300		350		400		450		500	
	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]
150	164	0,0211														
200	189	0,028	219	0,0376												
250	210	0,0346	244	0,0467	273	0,0585										
300	229	0,0412	266	0,0555	299	0,0702	328	0,0845								
350	245	0,0471	286	0,0642	322	0,0814	354	0,0984	383	0,1152						
400	260	0,0531	305	0,073	343	0,0924	378	0,1122	409	0,1313	437	0,1499				
450	274	0,0589	321	0,0809	363	0,1034	400	0,1256	433	0,1472	464	0,169	492	0,19		
500	287	0,0647	337	0,0892	381	0,114	420	0,1385	455	0,1625	488	0,1869	518	0,2106	547	0,2349
550	299	0,0702	352	0,0973	398	0,1243	439	0,1513	477	0,1786	511	0,205	543	0,2315	573	0,2577
600	310	0,0754	365	0,1046	414	0,1345	457	0,1639	496	0,1931	533	0,223	567	0,2524	598	0,2807
650	321	0,0809	378	0,1122	429	0,1445	474	0,1764	515	0,2082	553	0,2401	589	0,2723	622	0,3037
700	331	0,086	391	0,12	443	0,1541	490	0,1885	533	0,223	573	0,2577	610	0,2921	644	0,3256
750	341	0,0913	402	0,1269	457	0,1639	506	0,201	550	0,2375	592	0,2751	630	0,3116	666	0,3482
800	350	0,0962	414	0,1345	470	0,1734	520	0,2123	567	0,2524	609	0,2911	649	0,3306	687	0,3705
850	359	0,1012	424	0,1411	482	0,1824	534	0,2238	582	0,2659	626	0,3076	668	0,3503	706	0,3913
900	367	0,1057	435	0,1485	494	0,1916	548	0,2357	597	0,2798	643	0,3246	686	0,3694	726	0,4138
950	376	0,111	445	0,1554	506	0,201	561	0,2471	612	0,294	659	0,3409	703	0,388	744	0,4345
1000	384	0,1158	454	0,1618	517	0,2098	574	0,2586	626	0,3076	674	0,3566	719	0,4058	762	0,4558
1050	391	0,12	464	0,169	528	0,2188	586	0,2696	639	0,3205	689	0,3727	735	0,4241	779	0,4764
1100	399	0,125	473	0,1756	538	0,2272	598	0,2807	652	0,3337	703	0,388	751	0,4427	795	0,4961
1150	406	0,1294	481	0,1816	548	0,2357	609	0,2911	665	0,3471	717	0,4036	766	0,4606	812	0,5176
1200	413	0,1339	490	0,1885	558	0,2444	620	0,3018	677	0,3598	731	0,4195	780	0,4776	827	0,5369
1250			498	0,1947	568	0,2533	631	0,3126	689	0,3727	744	0,4345	795	0,4961	843	0,5579
1300			506	0,201	577	0,2613	642	0,3235	701	0,3857	757	0,4498	808	0,5125	857	0,5765
1350			514	0,2074	586	0,2696	652	0,3337	713	0,3991	769	0,4642	822	0,5304	872	0,5969
1400					595	0,2779	662	0,344	724	0,4115	781	0,4788	835	0,5473	886	0,6162
1450					604	0,2864	672	0,3545	735	0,4241	793	0,4936	848	0,5645	900	0,6359
1500					612	0,294	681	0,3641	745	0,4357	805	0,5087	860	0,5806	913	0,6544
1550					621	0,3027	691	0,3748	756	0,4487	816	0,5227	873	0,5983	926	0,6731
1600							700	0,3847	766	0,4606	827	0,5369	885	0,6148	939	0,6922
1650							709	0,3946	776	0,4727	838	0,5513	897	0,6316	952	0,7114
1700							718	0,4047	785	0,4837	849	0,5658	908	0,6472	964	0,7295
1750							726	0,4138	795	0,4961	859	0,5792	919	0,663	976	0,7478
1800							735	0,4241	804	0,5074	869	0,5928	930	0,6789	988	0,7663
1850							743	0,4334	814	0,5201	879	0,6065	941	0,6951	1000	0,785
1900							751	0,4427	823	0,5317	889	0,6204	952	0,7114	1012	0,804
1950							759	0,4522	831	0,5421	899	0,6344	963	0,728	1023	0,8215
2000							767	0,4618	840	0,5539	908	0,6472	973	0,7432	1034	0,8393
2050							775	0,4715	849	0,5658	918	0,6615	983	0,7585	1045	0,8572
2100							782	0,48	857	0,5765	927	0,6746	993	0,774	1055	0,8737
2150							790	0,4899	866	0,5887	936	0,6877	1003	0,7897	1066	0,892
2200							797	0,4986	874	0,5996	945	0,701	1013	0,8055	1076	0,9089
2250							805	0,5087	882	0,6107	954	0,7144	1022	0,8199	1087	0,9275
2300							812	0,5176	890	0,6218	963	0,728	1031	0,8344	1097	0,9447
2350							819	0,5265	898	0,633	971	0,7401	1041	0,8507	1107	0,962
2400							826	0,5356	905	0,6429	980	0,7539	1050	0,8655	1116	0,9777
2450							833	0,5447	913	0,6544	988	0,7663	1059	0,8804	1126	0,9953
2500							840	0,5539	920	0,6644	996	0,7787	1068	0,8954	1136	1,013
2550									928	0,676	1004	0,7913	1076	0,9089	1145	1,0292
2600									935	0,6863	1012	0,804	1085	0,9241	1154	1,0454
2650									942	0,6966	1020	0,8167	1094	0,9395	1163	1,0618
2700									950	0,7085	1028	0,8296	1102	0,9533	1173	1,0801
2750									957	0,7189	1036	0,8425	1110	0,9672	1181	1,0949
2800									964	0,7295	1043	0,854	1119	0,9829	1190	1,1116
2850									970	0,7386	1051	0,8671	1127	0,9971	1199	1,1285
2900									977	0,7493	1058	0,8787	1135	1,0113	1208	1,1455
2950									984	0,7601	1066	0,892	1143	1,0256	1216	1,1607
3000									991	0,7709	1073	0,9038	1151	1,04	1225	1,178

Tab. 4.4

	550		600		650		700		750		800		850		900		950		1000	
	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]
150																				
200																				
250																				
300																				
350																				
400																				
450																				
500																				
550	601	0,2835																		
600	628	0,3096	656	0,3378																
650	653	0,3347	683	0,3662	711	0,3968														
700	677	0,3598	708	0,3935	737	0,4264	765	0,4594												
750	700	0,3847	732	0,4206	763	0,457	792	0,4924	820	0,5278										
800	722	0,4092	755	0,4475	787	0,4862	818	0,5253	847	0,5632	875	0,601								
850	743	0,4334	778	0,4751	811	0,5163	842	0,5565	872	0,5969	901	0,6373	929	0,678						
900	763	0,457	799	0,5011	833	0,5447	866	0,5887	897	0,6316	927	0,6746	956	0,717	984	0,760				
950	783	0,4813	820	0,5278	855	0,5739	889	0,6204	921	0,6659	952	0,7114	982	0,757	1011	0,802	1039	0,847		
1000	802	0,5049	840	0,5539	876	0,6024	911	0,6515	944	0,6995	976	0,7478	1007	0,796	1037	0,844	1065	0,890	1093	0,938
1050	820	0,5278	859	0,5792	897	0,6316	932	0,6819	967	0,734	1000	0,785	1031	0,834	1062	0,885	1091	0,934	1120	0,985
1100	838	0,5513	878	0,6051	916	0,6587	953	0,7129	988	0,7663	1022	0,8199	1055	0,874	1086	0,926	1117	0,979	1146	1,031
1150	855	0,5739	896	0,6302	936	0,6877	973	0,7432	1009	0,7992	1044	0,8556	1078	0,912	1110	0,967	1141	1,022	1172	1,078
1200	872	0,5969	914	0,6558	954	0,7144	993	0,774	1030	0,8328	1066	0,892	1100	0,950	1133	1,008	1165	1,065	1196	1,123
1250	888	0,619	931	0,6804	973	0,7432	1012	0,804	1050	0,8655	1086	0,9258	1122	0,988	1156	1,049	1188	1,108	1220	1,168
1300	904	0,6415	948	0,7055	990	0,7694	1031	0,8344	1069	0,8971	1107	0,962	1143	1,026	1177	1,088	1211	1,151	1244	1,215
1350	919	0,663	964	0,7295	1007	0,796	1049	0,8638	1088	0,9292	1126	0,9953	1163	1,062	1199	1,129	1233	1,193	1267	1,260
1400	934	0,6848	980	0,7539	1024	0,8231	1066	0,892	1107	0,962	1146	1,031	1183	1,099	1220	1,168	1255	1,236	1289	1,304
1450	949	0,707	996	0,7787	1041	0,8507	1084	0,9224	1125	0,9935	1165	1,0654	1203	1,136	1240	1,207	1276	1,278	1311	1,349
1500	963	0,728	1011	0,8024	1057	0,877	1100	0,9499	1143	1,0256	1183	1,0986	1222	1,172	1260	1,246	1297	1,321	1332	1,393
1550	977	0,7493	1026	0,8264	1072	0,9021	1117	0,9794	1160	1,0563	1201	1,1323	1241	1,209	1279	1,284	1317	1,362	1353	1,437
1600	991	0,7709	1041	0,8507	1088	0,9292	1133	1,0077	1177	1,0875	1219	1,1665	1259	1,244	1298	1,323	1336	1,401	1373	1,480
1650	1005	0,7929	1055	0,8737	1103	0,955	1149	1,0364	1193	1,1173	1236	1,1992	1277	1,280	1317	1,362	1356	1,443	1393	1,523
1700	1018	0,8135	1069	0,8971	1118	0,9812	1164	1,0636	1209	1,1474	1253	1,2325	1295	1,317	1335	1,399	1375	1,484	1413	1,567
1750	1031	0,8344	1082	0,919	1132	1,0059	1180	1,093	1225	1,178	1270	1,2661	1312	1,351	1353	1,437	1393	1,523	1432	1,610
1800	1043	0,854	1096	0,943	1146	1,031	1195	1,121	1241	1,209	1286	1,2982	1329	1,387	1371	1,476	1412	1,565	1451	1,653
1850	1056	0,8754	1109	0,9655	1160	1,0563	1209	1,1474	1256	1,2384	1302	1,3307	1346	1,422	1388	1,512	1430	1,605	1470	1,696
1900	1068	0,8954	1122	0,9882	1174	1,0819	1224	1,1761	1271	1,2681	1318	1,3636	1362	1,456	1405	1,550	1447	1,644	1488	1,738
1950	1080	0,9156	1135	1,0113	1187	1,106	1238	1,2031	1286	1,2982	1333	1,3949	1378	1,491	1422	1,587	1465	1,685	1506	1,780
2000	1092	0,9361	1147	1,0328	1200	1,1304	1252	1,2305	1301	1,3287	1348	1,4264	1394	1,525	1438	1,623	1482	1,724	1523	1,821
2050	1104	0,9568	1160	1,0563	1213	1,155	1265	1,2562	1315	1,3574	1363	1,4583	1410	1,561	1455	1,662	1498	1,762	1541	1,864
2100	1115	0,9759	1172	1,0783	1226	1,1799	1279	1,2841	1329	1,3865	1378	1,4906	1425	1,594	1470	1,696	1515	1,802	1558	1,906
2150	1126	0,9953	1184	1,1005	1239	1,2051	1292	1,3104	1343	1,4159	1392	1,5211	1440	1,628	1486	1,733	1531	1,840	1574	1,945
2200	1137	1,0148	1195	1,121	1251	1,2285	1305	1,3369	1356	1,4434	1406	1,5518	1455	1,662	1501	1,769	1547	1,879	1591	1,987
2250	1148	1,0346	1207	1,1436	1263	1,2522	1318	1,3636	1370	1,4734	1420	1,5829	1469	1,694	1517	1,807	1563	1,918	1607	2,027
2300	1159	1,0545	1218	1,1646	1275	1,2761	1330	1,3886	1383	1,5015	1434	1,6142	1484	1,729	1532	1,842	1578	1,955	1623	2,068
2350	1169	1,0728	1230	1,1876	1287	1,3002	1343	1,4159	1396	1,5298	1448	1,6459	1498	1,762	1546	1,876	1593	1,992	1639	2,109
2400	1180	1,093	1241	1,209	1299	1,3246	1355	1,4413	1409	1,5584	1461	1,6756	1512	1,795	1561	1,913	1608	2,030	1655	2,150
2450	1190	1,1116	1252	1,2305	1310	1,3471	1367	1,4669	1422	1,5873	1474	1,7056	1526	1,828	1575	1,947	1623	2,068	1670	2,189
2500	1200	1,1304	1262	1,2502	1322	1,3719	1379	1,4928	1434	1,6142	1488	1,7381	1539	1,859	1589	1,982	1638	2,106	1685	2,229
2550	1210	1,1493	1273	1,2721	1333	1,3949	1391	1,5189	1446	1,6414	1500	1,7663	1553	1,893	1603	2,017	1652	2,142	1700	2,269
2600	1220	1,1684	1283	1,2922	1344	1,418	1402	1,543	1459	1,671	1513	1,797	1566	1,925	1617	2,053	1667	2,181	1715	2,309
2650	1230	1,1876	1294	1,3144	1355	1,4413	1414	1,5695	1471	1,6986	1526	1,828	1579	1,957	1630	2,086	1681	2,218	1729	2,347
2700	1240	1,207	1304	1,3348	1366	1,4648	1425	1,594	1483	1,7264	1538	1,8569	1592	1,990	1644	2,122	1695	2,255	1744	2,388
2750	1249	1,2246	1314	1,3554	1376	1,4863	1436	1,6187	1494	1,7521	1550	1,886	1604	2,020	1657	2,155	1708	2,290	1758	2,426
2800	1259	1,2443	1324	1,3761	1387	1,5102	1447	1,6436	1506	1,7804	1562	1,9153	1617	2,053	1670	2,189	1722	2,328	1772	2,465
2850	1268	1,2621	1334	1,397	1397	1,532	1458	1,6687	1517	1,8065	1574	1,9448	1630	2,086	1683	2,224	1735	2,363	1786	2,504
2900	1277	1,2801	1344	1,418	1408	1,5562	1469	1,694	1529	1,8352	1586	1,9746	1642	2,117	1696	2,258	1748	2,399	1800	2,543
2950	1286	1,2982	1353	1,437	1418	1,5784	1480	1,7195	1540	1,8617	1598	2,0046	1654	2,148	1709	2,293	1762	2,437	1813	2,580
3000	1295	1,3165	1363	1,4583	1428	1,6008	1490	1,7428	1551	1,8884	1609	2,0323	1666	2,179	1721	2,325	1774	2,471	1827	2,620

	1050		1100		1150		1200		1250		1300		1350		1400		1450		1500	
	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]
150																				
200																				
250																				
300																				
350																				
400																				
450																				
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550																				
600																				
650																				
700																				
750																				
800																				
850																				
900																				
950																				
1000																				
1050	1148	1,035																		
1100	1175	1,084	1202	1,134																
1150	1201	1,132	1229	1,186	1257	1,240														
1200	1226	1,180	1256	1,238	1284	1,294	1312	1,351												
1250	1251	1,229	1281	1,288	1310	1,347	1339	1,407	1366	1,465										
1300	1275	1,276	1306	1,339	1336	1,401	1365	1,463	1393	1,523	1421	1,585								
1350	1299	1,325	1330	1,389	1361	1,454	1391	1,519	1420	1,583	1448	1,646	1476	1,710						
1400	1322	1,372	1354	1,439	1385	1,506	1416	1,574	1446	1,641	1475	1,708	1503	1,773	1530	1,838				
1450	1344	1,418	1377	1,489	1409	1,558	1440	1,628	1471	1,699	1500	1,766	1529	1,835	1557	1,903	1585	1,972		
1500	1366	1,465	1400	1,539	1433	1,612	1464	1,683	1495	1,755	1526	1,828	1555	1,898	1584	1,970	1612	2,040	1640	2,111
1550	1388	1,512	1422	1,587	1455	1,662	1488	1,738	1519	1,811	1550	1,886	1580	1,960	1610	2,035	1639	2,109	1667	2,181
1600	1409	1,558	1444	1,637	1478	1,715	1511	1,792	1543	1,869	1574	1,945	1605	2,022	1635	2,099	1665	2,176	1693	2,250
1650	1430	1,605	1465	1,685	1500	1,766	1533	1,845	1566	1,925	1598	2,005	1629	2,083	1660	2,163	1690	2,242	1719	2,320
1700	1450	1,651	1486	1,733	1521	1,816	1555	1,898	1589	1,982	1621	2,063	1653	2,145	1684	2,226	1715	2,309	1745	2,390
1750	1470	1,696	1507	1,783	1542	1,867	1577	1,952	1611	2,037	1644	2,122	1677	2,208	1708	2,290	1739	2,374	1770	2,459
1800	1489	1,740	1527	1,830	1563	1,918	1598	2,005	1633	2,093	1667	2,181	1700	2,269	1732	2,355	1763	2,440	1794	2,527
1850	1509	1,788	1546	1,876	1583	1,967	1619	2,058	1654	2,148	1689	2,239	1722	2,328	1755	2,418	1787	2,507	1819	2,597
1900	1527	1,830	1566	1,925	1603	2,017	1640	2,111	1676	2,205	1710	2,295	1744	2,388	1778	2,482	1810	2,572	1842	2,664
1950	1546	1,876	1585	1,972	1623	2,068	1660	2,163	1696	2,258	1732	2,355	1766	2,448	1800	2,543	1833	2,638	1866	2,733
2000	1564	1,920	1604	2,020	1642	2,117	1680	2,216	1717	2,314	1753	2,412	1788	2,510	1822	2,606	1856	2,704	1889	2,801
2050	1582	1,965	1622	2,065	1661	2,166	1699	2,266	1737	2,369	1773	2,468	1809	2,569	1844	2,669	1878	2,769	1911	2,867
2100	1600	2,010	1640	2,111	1680	2,216	1719	2,320	1756	2,421	1793	2,524	1830	2,629	1865	2,730	1899	2,831	1933	2,933
2150	1617	2,053	1658	2,158	1698	2,263	1738	2,371	1776	2,476	1813	2,580	1850	2,687	1886	2,792	1921	2,897	1955	3,000
2200	1634	2,096	1676	2,205	1716	2,312	1756	2,421	1795	2,529	1833	2,638	1870	2,745	1906	2,852	1942	2,961	1977	3,068
2250	1651	2,140	1693	2,250	1734	2,360	1775	2,473	1814	2,583	1852	2,693	1890	2,804	1927	2,915	1963	3,025	1998	3,134
2300	1667	2,181	1710	2,295	1752	2,410	1793	2,524	1832	2,635	1871	2,748	1909	2,861	1947	2,976	1983	3,087	2019	3,200
2350	1684	2,226	1727	2,341	1769	2,457	1810	2,572	1851	2,690	1890	2,804	1929	2,921	1966	3,034	2003	3,149	2040	3,267
2400	1700	2,269	1744	2,388	1786	2,504	1828	2,623	1869	2,742	1909	2,861	1948	2,979	1986	3,096	2023	3,213	2060	3,331
2450	1716	2,312	1760	2,432	1803	2,552	1845	2,672	1887	2,795	1927	2,915	1966	3,034	2005	3,156	2043	3,277	2080	3,396
2500	1731	2,352	1776	2,476	1820	2,600	1862	2,722	1904	2,846	1945	2,970	1985	3,093	2024	3,216	2062	3,338	2100	3,462
2550	1747	2,396	1792	2,521	1836	2,646	1879	2,772	1922	2,900	1963	3,025	2003	3,149	2043	3,277	2081	3,400	2119	3,525
2600	1762	2,437	1808	2,566	1852	2,693	1896	2,822	1939	2,951	1980	3,078	2021	3,206	2061	3,335	2100	3,462	2139	3,592
2650	1777	2,479	1823	2,609	1868	2,739	1912	2,870	1956	3,003	1998	3,134	2039	3,264	2079	3,393	2119	3,525	2158	3,656
2700	1792	2,521	1839	2,655	1884	2,786	1929	2,921	1972	3,053	2015	3,187	2057	3,322	2097	3,452	2137	3,585	2177	3,720
2750	1806	2,560	1854	2,698	1900	2,834	1945	2,970	1989	3,106	2032	3,241	2074	3,377	2115	3,512	2156	3,649	2195	3,782
2800	1821	2,603	1869	2,742	1915	2,879	1961	3,019	2005	3,156	2048	3,293	2091	3,432	2133	3,572	2174	3,710	2214	3,848
2850	1835	2,643	1883	2,783	1930	2,924	1976	3,065	2021	3,206	2065	3,347	2108	3,488	2150	3,629	2191	3,768	2232	3,911
2900	1849	2,684	1898	2,828	1945	2,970	1992	3,115	2037	3,257	2081	3,400	2125	3,545	2167	3,686	2209	3,831	2250	3,974
2950	1863	2,725	1912	2,870	1960	3,016	2007	3,162	2053	3,309	2097	3,452	2141	3,598	2184	3,744	2226	3,890	2268	4,038
3000	1877	2,766	1927	2,915	1975	3,062	2022	3,210	2068	3,357	2113	3,505	2158	3,656	2201	3,803	2243	3,949	2285	4,099

	1550		1600		1650		1700		1750		1800		1850		1900		1950		2000	
	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]	Diam. [mm]	Sect. [m^2]
150																				
200																				
250																				
300																				
350																				
400																				
450																				
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1400																				
1450																				
1500																				
1550	1694	2,253																		
1600	1721	2,325	1749	2,401																
1650	1748	2,399	1776	2,476	1804	2,555														
1700	1774	2,471	1803	2,552	1831	2,632	1858	2,710												
1750	1800	2,543	1829	2,626	1857	2,707	1885	2,789	1913	2,873										
1800	1825	2,615	1854	2,698	1883	2,783	1912	2,870	1940	2,954	1968	3,040								
1850	1849	2,684	1880	2,775	1909	2,861	1938	2,948	1967	3,037	1995	3,124	2022	3,210						
1900	1874	2,757	1904	2,846	1934	2,936	1964	3,028	1993	3,118	2021	3,206	2049	3,296	2077	3,386				
1950	1897	2,825	1929	2,921	1959	3,013	1989	3,106	2019	3,200	2048	3,293	2076	3,383	2104	3,475	2132	3,568		
2000	1921	2,897	1952	2,991	1984	3,090	2014	3,184	2044	3,280	2073	3,373	2102	3,468	2131	3,565	2159	3,659	2186	3,751
2050	1944	2,967	1976	3,065	2008	3,165	2039	3,264	2069	3,360	2099	3,459	2128	3,555	2157	3,652	2185	3,748	2213	3,844
2100	1967	3,037	1999	3,137	2031	3,238	2063	3,341	2093	3,439	2124	3,541	2154	3,642	2183	3,741	2212	3,841	2240	3,939
2150	1989	3,106	2022	3,210	2054	3,312	2086	3,416	2118	3,522	2148	3,622	2179	3,727	2208	3,827	2238	3,932	2266	4,031
2200	2011	3,175	2044	3,280	2077	3,386	2110	3,495	2141	3,598	2173	3,707	2203	3,810	2233	3,914	2263	4,020	2292	4,124
2250	2033	3,245	2067	3,354	2100	3,462	2133	3,572	2165	3,680	2197	3,789	2228	3,897	2258	4,002	2288	4,109	2318	4,218
2300	2054	3,312	2088	3,422	2122	3,535	2155	3,646	2188	3,758	2220	3,869	2252	3,981	2283	4,092	2313	4,200	2343	4,309
2350	2075	3,380	2110	3,495	2144	3,608	2178	3,724	2211	3,838	2243	3,949	2275	4,063	2307	4,178	2338	4,291	2368	4,402
2400	2096	3,449	2131	3,565	2166	3,683	2200	3,799	2233	3,914	2266	4,031	2299	4,149	2330	4,262	2362	4,380	2393	4,495
2450	2116	3,515	2152	3,635	2187	3,755	2222	3,876	2256	3,995	2289	4,113	2322	4,233	2354	4,350	2386	4,469	2417	4,586
2500	2137	3,585	2173	3,707	2208	3,827	2243	3,949	2277	4,070	2311	4,193	2344	4,313	2377	4,435	2409	4,556	2441	4,677
2550	2157	3,652	2193	3,775	2229	3,900	2264	4,024	2299	4,149	2333	4,273	2367	4,398	2400	4,522	2432	4,643	2464	4,766
2600	2176	3,717	2213	3,844	2250	3,974	2285	4,099	2320	4,225	2355	4,354	2389	4,480	2422	4,605	2455	4,731	2487	4,855
2650	2196	3,786	2233	3,914	2270	4,045	2306	4,174	2342	4,306	2376	4,432	2411	4,563	2445	4,693	2478	4,820	2510	4,946
2700	2215	3,851	2253	3,985	2290	4,117	2327	4,251	2362	4,380	2398	4,514	2432	4,643	2466	4,774	2500	4,906	2533	5,037
2750	2234	3,918	2272	4,052	2310	4,189	2347	4,324	2383	4,458	2419	4,594	2454	4,727	2488	4,859	2522	4,993	2556	5,129
2800	2253	3,985	2292	4,124	2329	4,258	2367	4,398	2403	4,533	2439	4,670	2475	4,809	2510	4,946	2544	5,081	2578	5,217
2850	2272	4,052	2311	4,193	2349	4,332	2386	4,469	2423	4,609	2460	4,751	2496	4,891	2531	5,029	2566	5,169	2600	5,307
2900	2290	4,117	2329	4,258	2368	4,402	2406	4,544	2443	4,685	2480	4,828	2516	4,969	2552	5,113	2587	5,254	2621	5,393
2950	2308	4,182	2348	4,328	2387	4,473	2425	4,616	2463	4,762	2500	4,906	2537	5,053	2573	5,197	2608	5,339	2643	5,484
3000	2326	4,247	2366	4,394	2406	4,544	2444	4,689	2482	4,836	2520	4,985	2557	5,133	2593	5,278	2629	5,426	2664	5,571

5. The linear friction loss value (Δp_l) obtained for the first branch (in the example, 0.57 Pa/m) must be maintained constant for all the subsequent branch in the system.
The calculation must be performed for each branch by repeating the operation above (the recommended values must lie within the range of 0,6 and 0,8 Pa/m.
By intersecting the friction loss (ordinate) and the branch's flow rate (abscissa), the graph can be used to obtain the equivalent diameter value (*De*) for every branch, while the conversion tables can be used to determine the dimensions *a* e *b* .
The following calculation will be performed for the system under consideration:

Branch [mm]	Flow rate [m^3/s]	Δp_l [Pa/m]	*De* [mm]	Section (*a* x *b*)
B5-N3	0,15	0,59	240	200 x 250
B4-N5	0,15	0,59	240	200 x 250
N5-N2	0,3	0,49	490	300 x 300
B3-N5	0,15	0,59	240	200 x 250
B2-N3	0,2	0,57	270	250 x 250
N3-N2	0,35	0,57	340	200 x 500
N2-N1	0,65	0,60	420	300 x 500
B1-N1	0,2	0,57	270	250 x 250
N1-V0	0,85	0,57	470	250 x 800

Tab. 4.5

The slight differences in linear friction loss values are due to the fact that the dimensions of rectangular ducts are standardised, and for this reason it is difficult to obtain a section with exact equivalent diameter that corresponds to these standard values; in such cases, the value nearest to standard is adopted.

6. The system has now been correctly sized, but the friction losses for which the fans must compensate must also be calculated. The system's friction losses calculated are those that regard the branch with the highest friction loss.
The friction loss can be calculated for each branch by proceeding as follows:

$$\Delta p_{t\,\mathrm{Ba\text{-}V0}} = \Delta p_l\,(Leq_{1a} + Leq_{2a} + Leq_{3a} + \ldots + Leq_{na})$$

where:
$\Delta p_{t\,Ba\text{-}V0}$ = friction loss branch Ba-V0 [Pa]
Δp_l = friction loss per meter [Pa/m]
Leq = equivalent length [m] of each branch element (straight duct, elbow, branch, reductions, etc.).

The equivalent length values expressed in meters or feet for the various elements can be calculated using the diagram provided in Fig. 4.3.

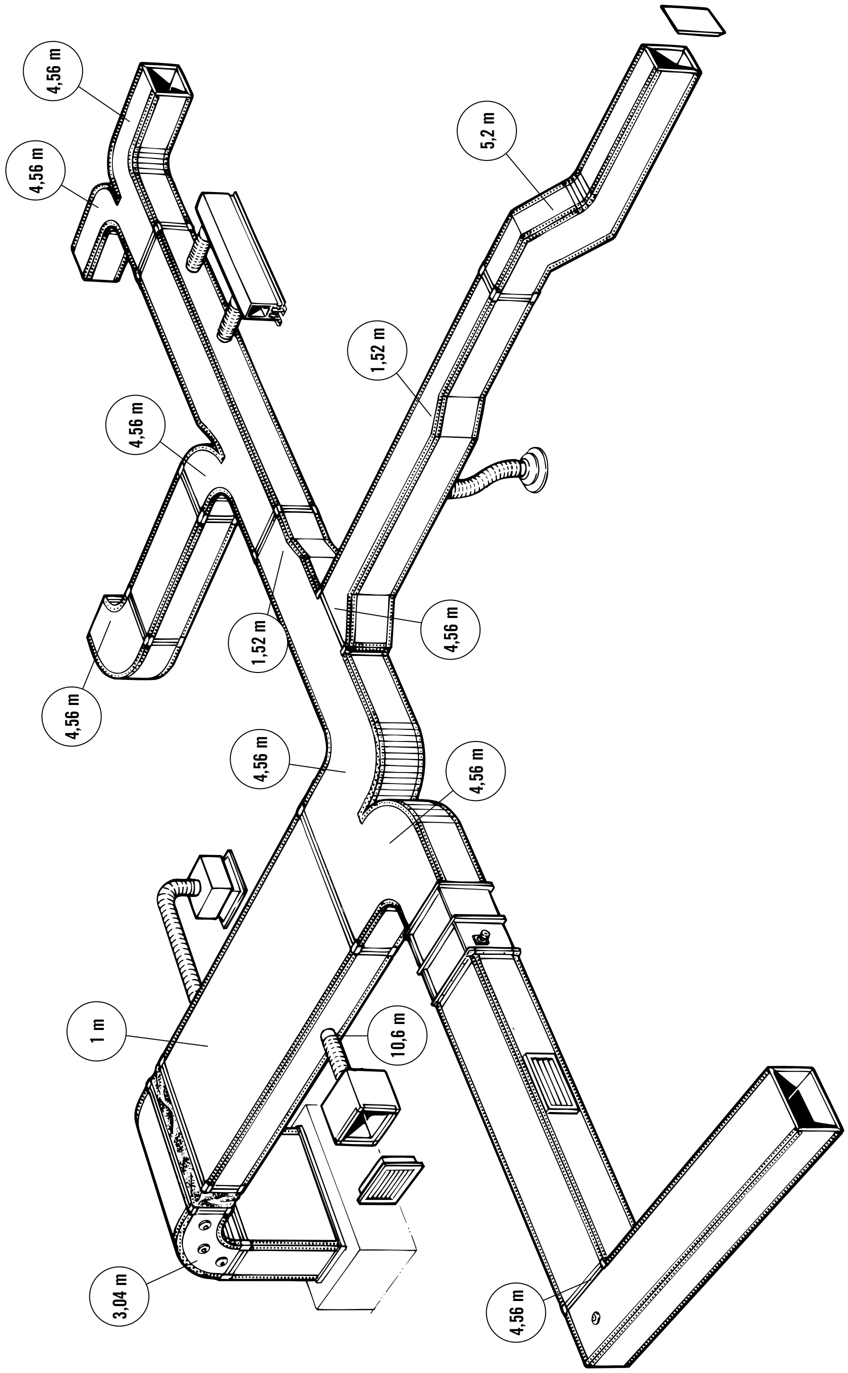

Fig. 4.3 - Equivalent length of elements (transitions, fittings, etc.) of air distribution system

In the system considered, the least favoured section is "B5-V0", formed by the sum of branches "B5-N3", "N3-N2"; "N2-N1"; "N1-V0" (see Table 4.6).

Branch	ΔL_p [Pa/m]	*Leq* [m]	Δp_t [Pa]
B5-N3	15	Outlet B5	
	0,59	C10 = 13	
		A3 = 5	
		C9 = 5	
		N3 = 10	
		Tot. = 33	19,5
N3-N2	0,57	C5 = 3	
		N2 = 1,52	
		Tot. = 4,52	2,58
N2-N1	0,60	C4 = 3	
		N1 = 4,56	
		Tot. = 7,56	4,54
N1-V0	0,57	C1 = 10	
		Tot. = 10	5,7
		$\Delta p_{t\,B5\text{-}V0}$	47,32

Tab. 4.6

We recommend increasing the friction loss value by approx. 10% for precautionary reasons, (but no more) and then using the volume damper positioned downstream from the air handling unit if necessary during subsequent pressure balancing.
Our imaginary system's air handling unit must therefore have a useful static pressure of at least 52 Pa.

7. At this point, the system must be checked to see if it is balanced, or rather, if the friction losses for each branch into which the main duct divides are the same at every branching point.

8. If this condition is not met, we will an increase of speed in the branch with a decreased friction loss and an undesired increase in flow rate as a result. If the pressure difference value is lower than 10 Pa the correction required can be made using the volume dampers positioned in the diffusion elements, but if the pressure difference value is greater than 10 Pa the correction must be made on the dimensions of the duct or more simply through the insertion of a volume damper that must be appropriately set during the balancing phase.

In the system considered, we find a pressure difference between branch B5-N1 and branch B1-N1. (see Table 4.7).

Branch	Δp_l [Pa/m]	*Leq* [m]	Δp_t [Pa]
B5-N3		Outlet B5	15
	0,59	C10 = 13	
		A3 = 5	
		C9 = 5	
		N3 = 10	
		Tot. = 33	19,5
N3-N2	0,57	C5 = 3	
		N2 = 1,52	
		Tot. = 4,52	2,58
N2-N1	0,60	C4 = 3	
		N1 = 4,56	
		Tot. = 7,56	4,54
		$\Delta p_{t\,B5\text{-}N1}$	41,62
Outlet B1			10
B1-N1	0,57	C3 = 3	
		A1 = 4,56	
		C2 = 6	
		N1 = 4,56	
		Tot. = 18,12	10,33
		$\Delta p_{t\,B1\text{-}N1}$	20,33

Tab. 4.7

The pressure difference proves to be 41,62-20,33=21,29 Pa.
In this case, the simplest thing to do is to insert a volume damper in the B1-N1 branch immediately downstream from the N1 branch (indicated by A4 in the drawing).

5 Measuring the surface area of P3ductal ducts

5.1 Glossary

There are many methods used today to measure the surface area of a duct network. They are often complicated and nearly always provide different results. Given that only a draft version of the European standards to be applied is available at the moment, P3 has developed a system of its own for pre-insulated aluminium ducts that is both accurate and easy to use even on site to calculate the total surface area of P3ductal panels required for the installation of any air distribution system at all.

While making optimised use of all panel area, this measurement system also takes the scraps that are inevitably formed during the process into account.

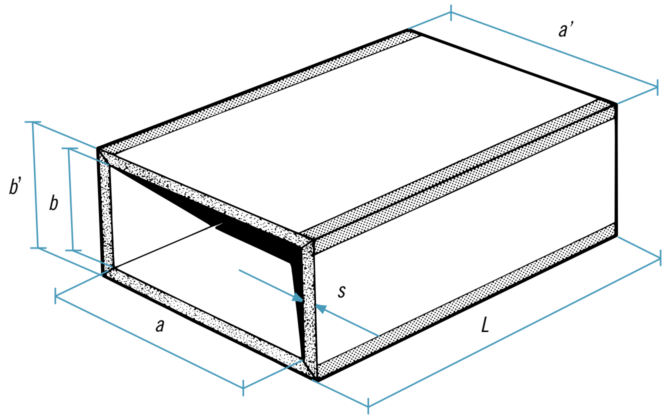

Fig. 5.1- Calculation parameters

1. **Nominal dimensions:** the internal measurements of duct sides a and b [m];

2. **Air passage section:** obtained by mulitplying the nominal dimensions,
Sp = a x b [m^2].

3. **External dimensions:** the external measurements of duct sides a' and b' where:
$a' = a + 2 \times s$ [m];
$b' = b + 2 \times s$ [m].

4. **Material thickness:** the thickness of the sandwich panel composing the duct s [m].

5. **Effective length:** the physical length of the piece L [m].

6. **Useful length:** the fictitious length used for the calculation of the apparent surface area L_u [m].

7. **Apparent surface area:** the useful surface area used for the calculation S_{app} [m^2].

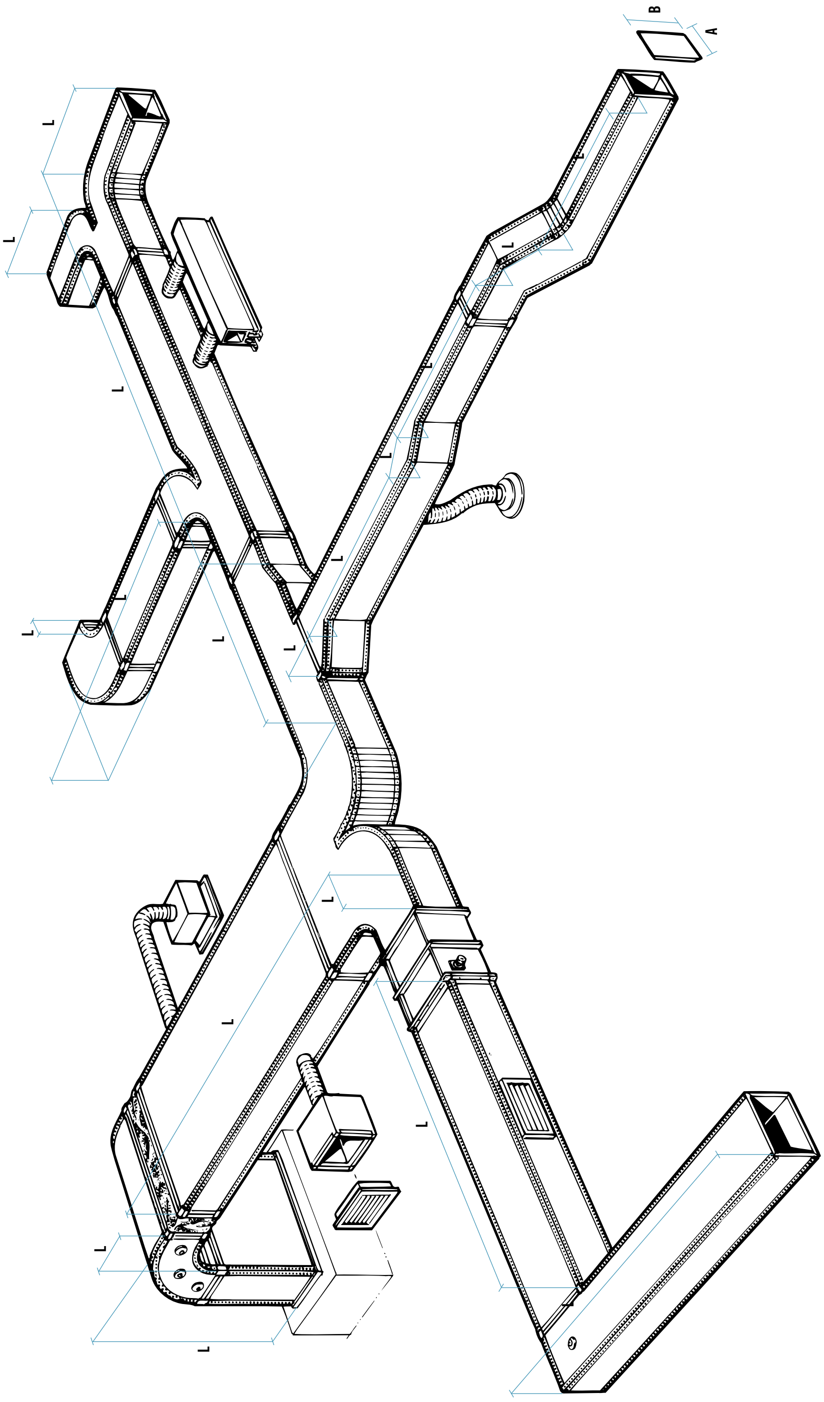

Fig. 5.2 - Measurement of P3ductal ducts.

5.2
Straight ducts

$L = L_u$

$S_{app} = (a' + b') \times 2 \times L_u\ [m^2]$

If an end cap is present, the surface area value is as follows:

$S_{app} = a' \times b'\ [m^2]$

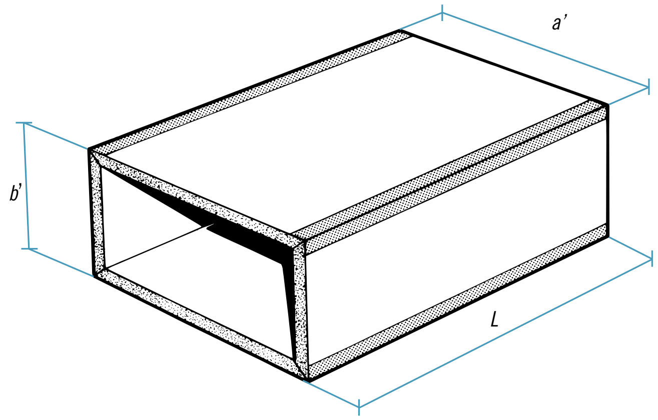

Fig. 5.3 - Straight ducts

5.3
Elbows

$L_u = L_1 + L_2\ [m]$

$S_{app} = (a' + b') \times 2 \times L_u\ [m^2]$

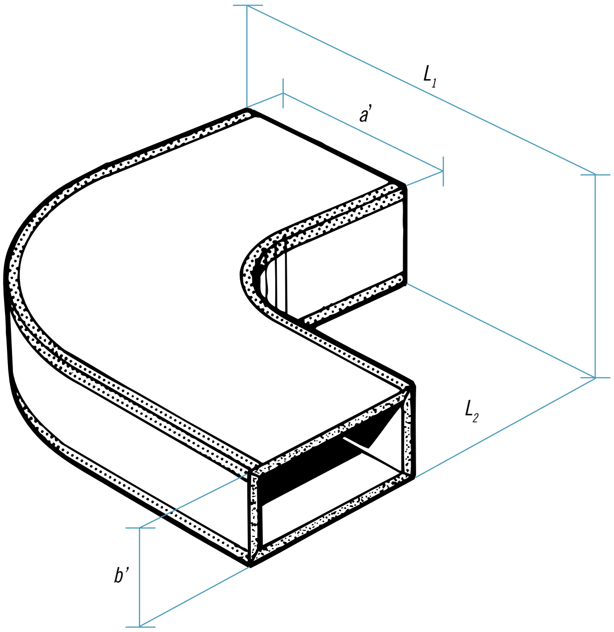

Fig. 5.4 – Elbows

5.4 Splitters in elbows

The general surface area S_{app} of the “n” splitters is:

$$S_{app} = \sum_{i=1}^{n} [(r + a_i) \times 6{,}28/4 + 0{,}3] \times b \, [m^2]$$

where 0.3 is a coefficient that compensates for the greater surface area of the splitter and r=0,15 m.
As provided in Table B.1 (Positioning of the splitters) of prEN 1505 (see reference n°9 in bibliography), the following applies when 2 splitters are present:

$a_1 = a/4$ [m];
$a_2 = a/2$ [m].

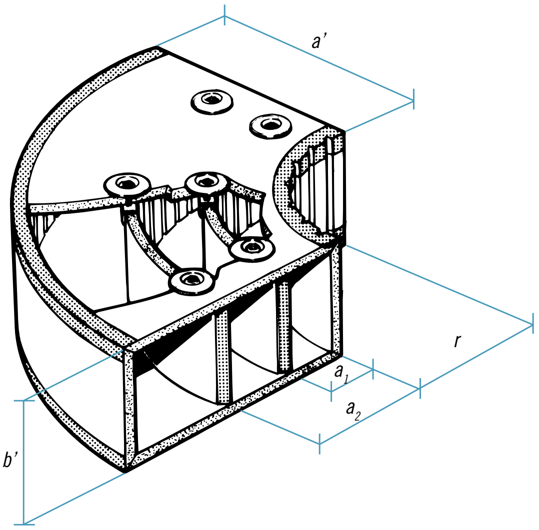

Fig. 5.5 - Splitters in elbows

5.5 Reducers

The apparent surface area is calculated as follows, regardless of whether reduction is performed on one or more sides:

$$L_u = L_1 / \cos \alpha \, [m]$$
$$S_{app} = (a' + b') \times 2 \times L$$

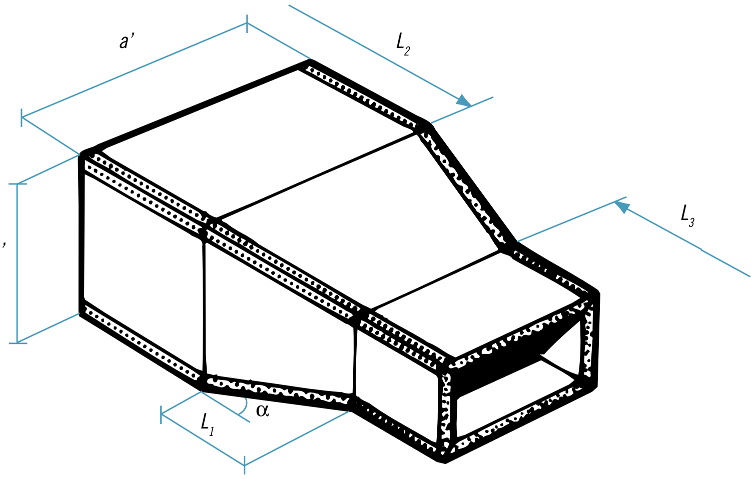

Fig. 5.6 - Reducers

The pieces of reductions illustrated in Fig. 5.6 and quoted with “L_2“ and “L_1“ must be considered straight ducts, therefore their area must be calculated as specified in cap.5.2.

5.6 Take-offs and tap-ins

$L_u = a'/4 + 0{,}05$ [m]

$S_{app} = (5a'/4 + b') \times 2 \times L_u$ [m^2]

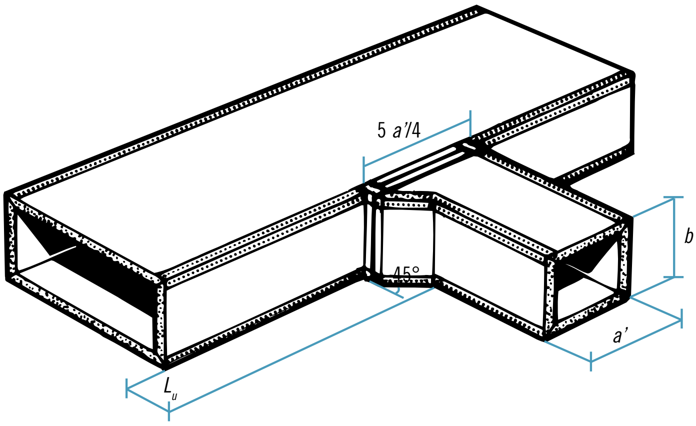

Fig. 5.7 –Take-offs and tap-ins

5.7 Offsets

$L_u = L_1$ [m] where $L_1 = L_2/\cos\alpha$ [m]

$S_{app} = (a' + b') \times 2 \times L_u$ [m^2]

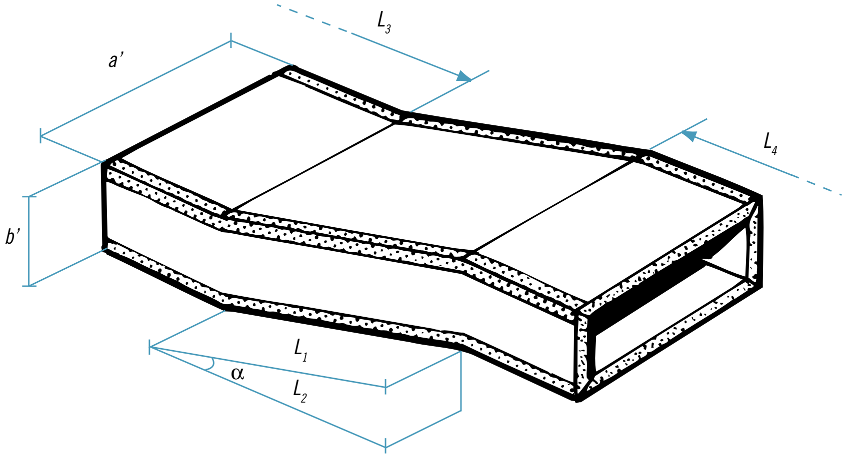

Fig. 5.8 - Offsets

As in the case of the reduction, the pieces indicated with L_3 and L_4 on picture 5.8 have to be considered as straight ducts.

$$S_{app} = (a' + b')\ \mathrm{x}\ 2\ L_1 + (c' + d')\ \mathrm{x}\ 2\ \mathrm{x}\ L_2\ [\mathrm{m}^2]$$

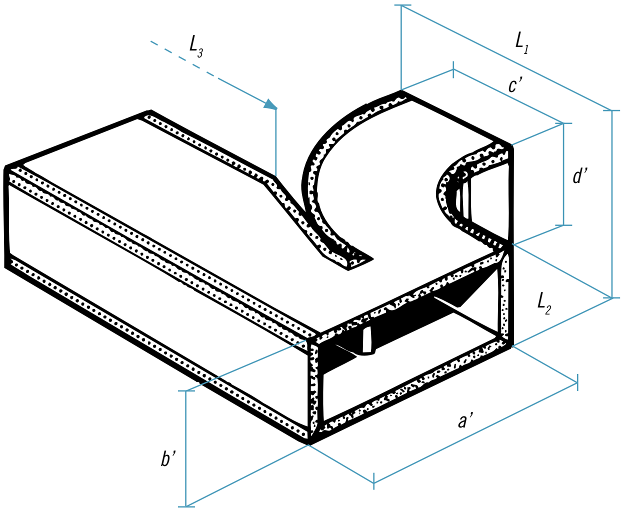

Fig. 5.9 - Diverging junctions

Once again, the piece of ducts indicated with L_3 in fig. 5.9 must be considered a straight duct.

$$a' = a_1 + a_2\ [\mathrm{m}]$$
$$S_{app} = (a_1 + b')\ \mathrm{x}\ 2\ \mathrm{x}\ L_1 + (a_2 + b')\ \mathrm{x}\ 2\ \mathrm{x}\ L_2 + (c' + d')\ \mathrm{x}\ 2\ \mathrm{x}\ L_3 + (e' + f')\ \mathrm{x}\ 2\ \mathrm{x}\ L_4\ [\mathrm{m}^2]$$

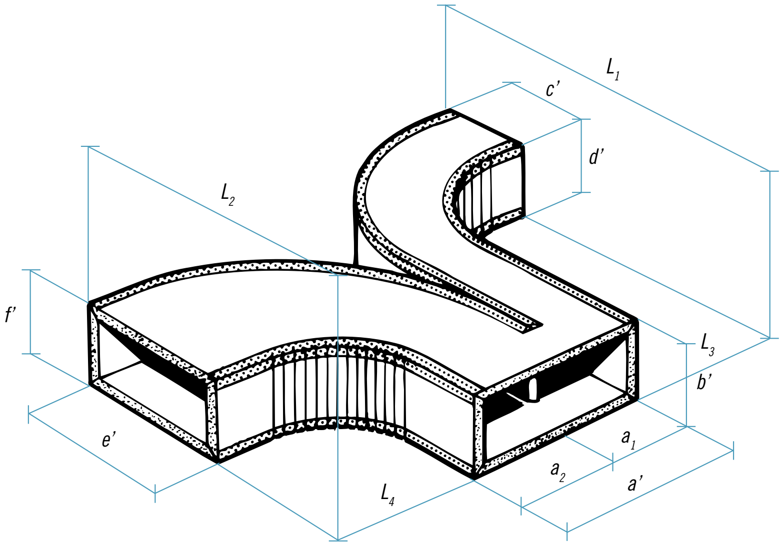

Fig. 5.10 - Asymmetrical diverging junction

$L_1 = L_3$ [m];
$L_3 = L_4$ [m];
$S_{app} = (a' + b') \times 2 \times L_1 + ((c' + d') \times 2 \times L_2) \times 2$ [m^2]

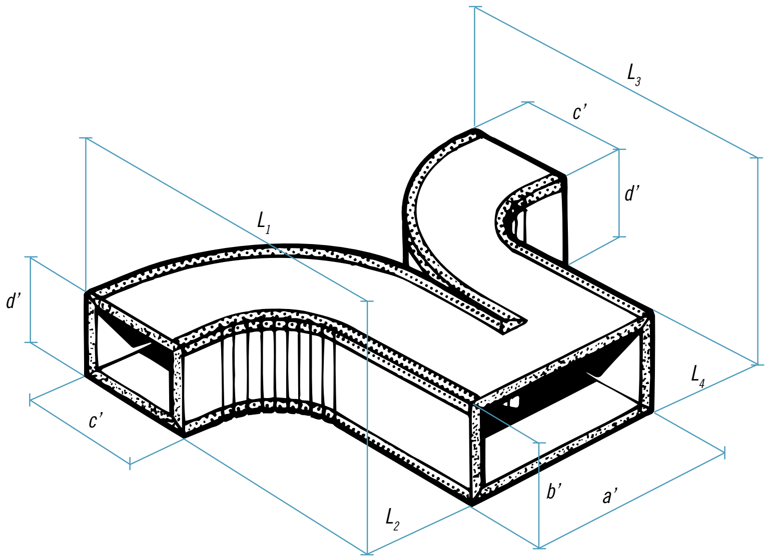

Fig. 5.11 - Symmetrical diverging junction

6 Economic factors

6.1. Energy savings provided by the use of insulation

In addition to the initial investment, when designing an air distribution system it is also important to consider the operating costs.
As with all the other components of the system, the duct network can play a big role in creating economic savings.
Carefully energy unit conservation obtained through:

- good insulation
- low leakage

multiplied by the surface area involved, the number of hours of system operation per day, and the number of operating days of the year can ensure significant savings indeed.
The following example should clarify this idea.
Consider a duct network of approx. 500 m^2 in area equivalent to 4.000-4.500 kg of sheet metal for a system that delivers approx. 9.000-9.500 m^3/h of air to an office of approx. 600-650 m^2 in size.

The materials most commonly-used for duct construction are:

solution type 1) Ducts in zinc-plated sheet metal faced with 8 mm thick neoprene thermal insulation liner λ=0,033 W/(m °C).
solution type 2) Ducts in zinc-plated sheet metal faced with 15 mm thick glass wool thermal insulation liner facing aluminium foil, λ=0,038 W/(m °C).
solution type 3) P3ductal ducts with 20 mm thickness, λ=0,022 W/(m °C).

The quantity of heat Q dispersed or absorbed by the duct network (depending on whether the ducts convey air that is respectively hotter or colder than the outdoor temperature) is directly proportional to the transmittance "*U*", the surface area involved "*S*", and the inside/outside temperature difference $t_1 - t_2$.

$$Q = U\,S\,(t_1 - t_2)$$

The transmittance values "*U*" provided on Line A of Table 6.1 represent the quantity of heat per unit of time that passes through the duct wall per square meter (or square foot) when the difference between the inside/outside temperature is 1°C. This value takes account of the fact that the air inside the duct is moving and therefore encourages thermal dispersion, while the insulating effect contributed by the zinc-plated sheet metal has not been taken into consideration because it is considered insignificant.
If the system is used in the warmer months, the ducts must be considered as being installed in the ceiling or, as usually occurs, not in the same room to which the air is supplied, and the difference in the temperature of the inside air approx. 17°C and the outside air approx. 32°C will be around 15°C.

The table below provides the heat transmitted every hour by the various types of system considered (Line B).
Considering that the system considered works 8 hours a day, 5 days a week 4 months a year for a total of approx. 670 hours, the following table is obtained:

	Solution	UM	Type 1	Type 2	Type 3
	Thickness s	m	0,008	0,025	0,020
	Thermal conductivity λ	W/(m °C)	0,033	0,038	0,024
	Insulation material res.	(m^2 °C)/W	0,242	0,658	0,83
	Inside air surf. film ther. res.	(m^2 °C)/W	0,043	0,043	0,043
	Outside air surf. film ther. res.	(m^2 °C)/W	0,122	0,122	0,122
	Total resistance	(m^2 °C)/W	0,407	0,82	0,99
A	Thermal transmittance U	W/(m^2 °C)	2,46	1,22	1
	Surface area S	m^2	500	500	500
	Difference in temp. $(t_1 - t_2)$	°C	15	15	15
B	Hourly dispersion	kW	18,45	9,15	7,5
C	Dispersion x 670 hours	kWh	12361	6130	5025
D	Dispersion	%	100	50	41
E	Savings	%	0	50	59

Tab. 6.1

As shown by Line C, the energy dispersion is considerably less when pre-insulated aluminium ducts are used.
The savings % (Line E) is obtained from the difference between the dispersion % values (Line D).

6.2
Aspect ratio

The cost of an air distribution network can often be significantly reduced by adopting a few simple measures:

1) reducing the number of special pieces to the absolute minimum;
2) dedicating correct importance to the aspect ratio.

The number of special pieces (unions, reductions, diverging junctions) can be reduced by careful study to make the air distribution duct route as straight as possible.
Inspect the site in order to identify all the obstacles that are not evident from the drawing, such as existing technological systems, height differences, and waterspouts, etc.
This will help avoid the need for on-site modifications and the resulting waste of material, time, and money. Particular attention must be given to the aspect ratio, or rather, the relationship between the duct's greatest and smallest size.
As shown by the table, the cost of the ducts increases in proportion to this ratio because more material must be used per unit of duct length, hydraulic diameter being equal. We generally discourage exceeding an aspect ratio of 4-1, also from the aerodynamic point of view.

Dim. a [mm]	**Dim. b [mm]**	**Section [m^2]**	**De [mm]**	**CF**	**Surface area [m^2]**	**Increase %**
500	500	0,25	545	1:1	2,16	0
700	350	0,25	539	2:1	2,26	5
900	300	0,27	550	3:1	2,56	19
1150	250	0,29	546	4,6:1	2,96	37

Tab. 6.2

7 Places where P3ductal ducts can be installed

7.1 Appropriate use

Each installation of an HVAC (heating, ventilation air conditioning) system requires specific design criteria and the corresponding constructive particulars and suggestions provided below based both on extensive laboratory testing and over twenty years experience with sandwich panels in operating systems installed.
Thanks to the wide range of panels available, ducts for air distribution can be easily built to measure and installed by following the P3ductal procedures.

P3ductal panels must NOT be used under the following conditions:

- for the distribution of corrosive gases or dust;
- for the extraction of cooking fumes;
- whenever directly connected to electric heaters or heat generators with temperatures of more than 65 °C or at distances from the same of less than 200 mm.
- whenever the maximum speed foreseen inside the duct is more than 15m/s;
- whenever air at temperatures of less than – 30 °C or more than + 65 °C must be distributed with continuous operation;
- whenever the system must be subjected to positive or negative working pressures of more than 1.500 Pa (see Fig. 7.1).

Note: maximum duct working pressure varies depending on the type of panel utilized (Rigidity class) and the number of reinforcements inserted (see "Reinforcements" in the Construction Manual).

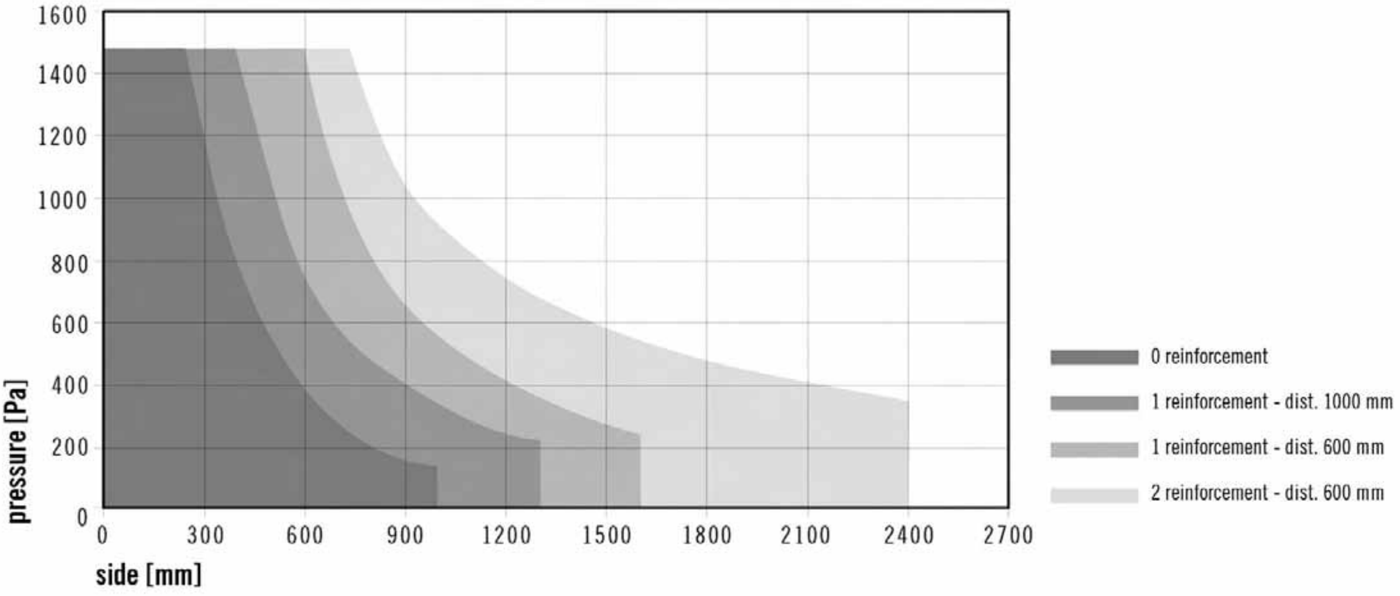

Fig. 7.1 - P3ductal panel maximum working pressure (rigidity class 200.000)

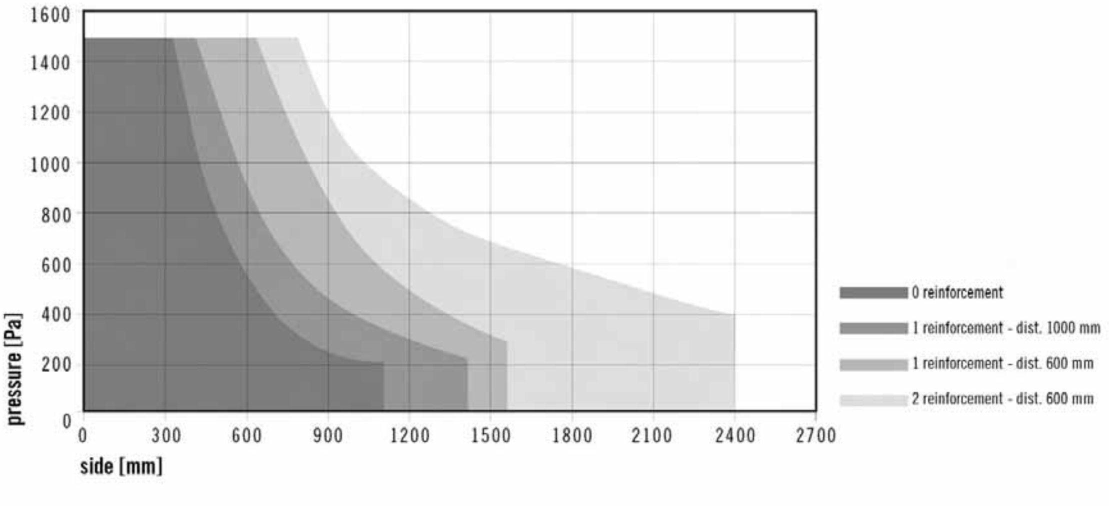

Fig. 7.2 - P3ductal panel maximum working pressure (rigidity class 300.000)

7.2 Outside installations

P3 has developed special panels (Outside) with specific mechanical and insulation characteristics for ducts to be installed outdoors.
All the ducts that are exposed directly to inclement weather and sunlight must be built using the appropriate panels selected from the P3ductal (Outsider series) range, provided with secure mechanical connections, and subjected to a sealing treatment.

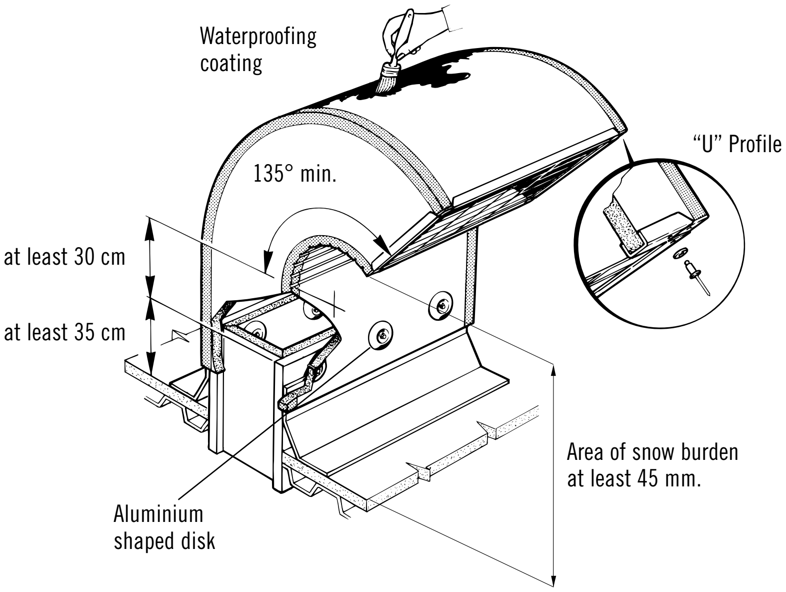

Fig. 7.3 - Outside installation of a P3ductal duct

The duct's external sealing treatment consists in the application of another special product Gum Skin (see technique documentation of P3), that provides an airtight, water-tight seal, permits operation within a temperature range of -35 °C and +80 °C, and guarantees resistance against dilation. If the duct will be directly exposed to the sun, it must also be capable of resisting ultra-violet radiation and ozone.

Bitumin-based compounds must never be used for duct sealing.

The ducts must be bracketed and raised from the ground using the appropriate bracing; when positioned horizontally, they must be installed with sufficient stope to permit water drainage.

When the insertion joints to provide insulation against vibrations caused by machinery in the vicinity, these joints must be water-proof.

Whenever the outdoor air inlet or outlet ducts cross the roof, they must be provided with curvature at the ends to prevent the entry of water and snow. System designers specifying constructive criteria must bear in mind that the elevation of the duct system may be affected by the snowfall, wind force and direction in the installation area, while also considering the aesthetic aspect as well.

Duct openings must be provided with screens against the entry of flying animals (see Figure 7.3).

The ducts must be raised from the ground and bracketed at least every 2 m while also adopting the appropriate measures to prevent lifting by wind. Whenever positioned horizontally, the ducts must be given a sufficient inclination to permit water drainage. The internal duct pressure and any loads of snow and/or wind must also be considered as being directly applied to the bracketing system.

In order to reduce the stress created by snow and/or wind on the sides of the duct, we recommend using only square sectioned ducts for outside installations.

The graph in figure 7.4 permits the calculation of the load limits for Outsider panels for the side of the duct subjected to such forces for both negative pressure (return) and positive pressure (delivery) ducts.

Note: the curves in the graph have been plotted with the system switched off, and therefore with no internal pressure

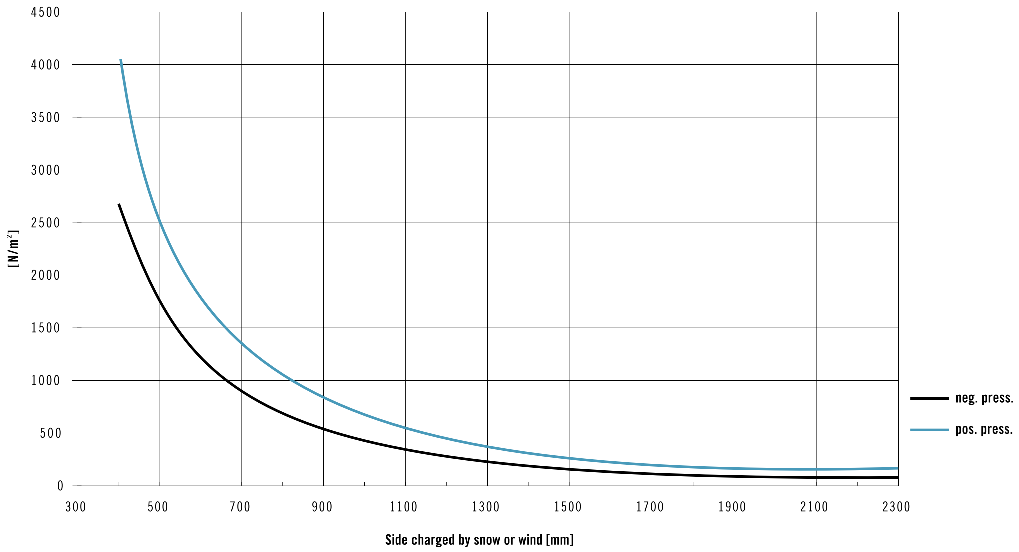

Fig. 7.4 - Loads applied by snow and/or wind to Piral HD Outsider Panels (Rigidity Class R = 900.000)

Note: Considering it's asymmetric structure, ducts made with Outsider panels having an R = 500.000 Rigidity Class, must be constructed using the curves provided for panels with 300.000 Rigidity Class in Fig. 7.2

7.3
Underground installations

P3ductal ducts can be installed underground by adopting the measures indicated in the drawing below. In particular, steps must be taken to make sure that the filling material used, earth or sand, does not apply pressure against the walls of the duct, and that the duct housing space permits the drainage of any water that might seep in from outside.
For underground systems, we recommend using Outsider Series panels with aluminium foil facing for greater mechanical resistance to the impact that sometimes occurs during installation.

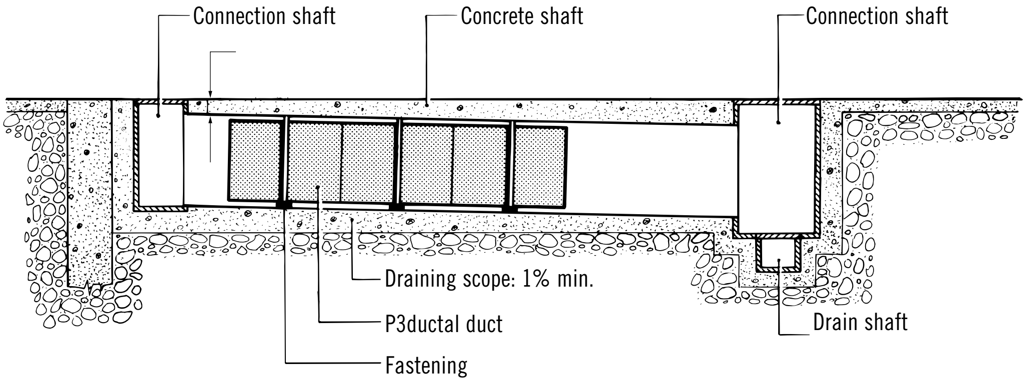

Fig. 7.5 - Under ground installation of a P3ductal duct.

Guidelines for writing specifications

We provide guidelines for the drafting of duct system specifications below. All the underlined **or bold-face headings refer to generic examples and must be adapted to each specific project design by providing the respective data.**

Heating, ventilation and air conditioning ducts in pre-insulated aluminium **installed inside the hospitals or the in-patient wards,** will be constructed using **PIRAL HD HYDROTEC** sandwich panels with the following characteristics:

- external aluminium: thickness of **0,08 mm** embossed and protected with polyester lacquer;
- internal aluminium: thickness of **0,08 mm** smooth and protected with polyester lacquer;
- insulation component: water foamed polyurethane without use of CFC, HCFC, HFC or HC, density of **50-54 kg/m**^{3};
- thickness: **20,5 mm**;
- initial thermal conductivity: **0,022 W/(m °C) at 10 °C**;
- stiffness class: **R 200.000**;
- % closed cells > 95%;

Panels must be in conformity to the following international standard specifications:

1) English certification BS 476, Part 6 & 7 – class 0;
2) French certification for fire classification: reaction class M1;
3) Italian certification for fire classification: reaction class 0-1;
4) British Naval Engineering Standard NES 713, Toxicity index (average) below 6,7;
5) Toxicity and opacity of combustion smoke: F1 class according to NF F 16-101
6) ISO 9705 Room corner test

- Ducts will be constructed according to P3ductal type standards and in conformity to UNI EN 13403.
- Wherever necessary, ducts must be provided with the appropriate reinforcements to guarantee sufficient mechanical seal against a maximum internal pressure of **500 Pa** during operation. The maximum deformation of ducts must never exceed 3% of its width or 30 mm in any case.
- Joints between one duct and the next will be performed using the special “invisible” flanges with unexposed bayonet coupling and ensure the appropriate pneumatic and mechanical seal.
- Elbows and special pieces will be provided with turning vanes wherever indicated.
- The maximum length of each single duct will not exceed 4 m.
- Ducts will be supported by the appropriate supports at intervals of no more than 4 m whenever the greater side of the duct is less than 1 m, and intervals of no more than 2 m whenever the greater side of the duct is more than 1 m.
- Accessories such as volume dampers, fire barriers, and duct coils, and so on, will be provided with independent support in such a way that their weight does not bear on the ducts.
- Wherever indicated, ducts will also be provided with the appropriate test points for the velocity sensors and inspection doors for cleaning and inspection all along the route. Inspection doors can be built using the same sandwich panels used for the duct in combination with the appropriate section bars, and will be equipped with liners that ensure sufficient pneumatic seal.
- Connections between air handling units and ducts will be made using the appropriate vibration damping joints in order to reduce all vibrations. Ducts will be provided with independent support in order to prevent the weight of the ducts from being transferred to the flexible couplings. Connection to air handling unit will also permit easy uncoupling for normal system maintenance. Whenever the vibration damping joints are positioned outside, they will be rendered waterproof.

In all sections installed outside, ducts must be built using sandwich type **PIRAL HD HYDROTEC OUTSIDER** panels with the following characteristics:

- external aluminium: thickness of **0,2 mm** embossed and protected with polyester lacquer;
- internal aluminium: thickness of **0,08 mm** embossed and protected with polyester lacquer;
- insulation component: water foamed polyurethane without use of CFC, HCFC, HFC or HC, density of **46-50 kg/m^3**;
- thickness: **30,5 mm;**
- initial thermal conductivity: **0,022 W/(m °C) at 10 °C;**
- stiffness class: **R 900.000**;
- % closed cells: > 95%;

- Ducts will be protected with waterproofing resin (Gum Skin type). Bitumen-based compounds must not be used.
- Ducts positioned outside will be bracketed every 2 m and raised from the ground using the appropriate wind braces, and whenever positioned horizontally they must be at a slight angle in order to allow water drainage.
- Whenever ducts penetrate the building's roof, they will be provided with "gooseneck" elbows at the ends in order to prevent the entry of snow and water.
- All the openings of ducts facing outside (external air inlet, internal air expulsion, and so on) will be equipped with the appropriate screens to prevent the entry of flying animals.
- Ducts must be constructed according to P3ductal type standards.
- Wherever necessary, ducts must be provided with the appropriate reinforcements to guarantee sufficient mechanical seal against a maximum internal pressure of **500 Pa** during operation. Ducts must support a limit load of snow and/or wind equivalent at **400 N/m^2.**

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