technical handbook for the prevention of fires

P3ductal

preinsulated aluminium ducts system

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Introduction

As a result of an ever-increasing sensitivity to the subject of safety supported by a greater focus from a legislative point of view, modern construction has given more and more attention to the aspects regarding safety in the event of fire. Architects and designers can no longer neglect a series of considerations connected with the implementation of fire prevention systems, which involve a number of measures aimed at preventing the start of a fire or if the fire has already broken out, at detecting the fire as fast as possible, thus reducing to a minimum any damage to persons and objects. New projects must include adequate active protection consisting of installations and/or organisation which make it possible to take direct action to limit or put out the fire and passive protection systems which hinder the propagation and extension of fires even without taking any direct action. In order to be really effective, fire prevention must take into consideration the evaluation of the materials' reaction and resistance to fire. These two concepts are not synonymous with each other and constitute the two parameters used to assess the behaviour in the event of fire, which means the chemical-physical transformations that a particular material, component or constructional element undergoes (component or structure) if exposed to fire.

Ducts used for heating and air conditioning are not structural elements and do not limit or compartmentalise any room; therefore, they are only subjected to constraints dictated by their reactions to fire and not by their resistance to it; except if we consider their location for compartmentalisation purposes, such as fireproof walls.

The constant evolution of the materials used for insulation purposes and of technology in general, has led to a clear-cut distinction between homogeneous and composite materials. For the latter (which include preinsulated aluminium ducts), the Italian standard, for instance, has a twofold fire reaction classification, that is to say, a classification based on classes defined by the combination of two numbers identifying respectively the class of the finished product and the class of the insulating component alone. For a long time, fire prevention standards were much too general and with no coordination at an international level. The need to uniform the classification criteria on a European level finally led to a clear definition of an unequivocal testing system. The application of this method makes it possible to create a unified classification based on seven classes.

In Italy, governmental action was also needed in order to clear any sort of doubts or uncertainty deriving from this truly confusing situation. Indeed, the Ministerial decree dated 31-3-2003 clarified this in a definitive manner by doing away with any previously released rules, regulations and other parameters which had to be met, thus restoring to preinsulated ducts their right value in terms of quality and safety. The issuance of the above decree represents a fundamental goal, especially for P3, which actively participated during the technical analysis which gradually led to the release of this legislative dictate, offering its own ducts to be used for the most demanding tests, among which, the "room corner test".

This technical handbook is not only intended as an accurate guide for a better understanding of the principles which lie at the base of all fire prevention systems, but also aims to present in a systematic way the regulations currently in force and to make known the results of the testing done by P3 on its own P3ductal ducts. Therefore, the main objective of this text is to give an instrument to all those who day after day must face fire prevention problems.

1

Fire prevention principles

1.1 The fire triangle

Any deep study on the subject of fire prevention must necessarily start by pointing out certain essential concepts. So, the first step in this analysis will undoubtedly have to focus on the combustion phenomenon.

Combustion concerns a chemical oxidizing reaction entailing the development of flames, light and heat. In order for combustion to take place, it is crucial that three factors interact with each other:

- the presence of a comburent substance
- the presence of a combustible substance
- the presence of a triggering factor.

These three factors make up the so-called "fire triangle" (Fig. 1). This graphic representation shows clearly and in an immediate manner the fact that only the simultaneous presence and interaction of the three "sides" of the triangle may give rise to the combustion phenomenon. Should at least one of these elements be missing, the fire would simply die out.

The most common comburent substance – and almost the only one taken into consideration in the fire prevention literature on – is oxygen. However, it is also possible for fires to occur with different substances with a molecular structure characterised by a conspicuous presence of oxygen, such as explosives and celluloid.

The identification of combustible substances is based on the fact that, in order to be classified as such, these substances should undergo oxidation while combustion takes place, which means that they bind with one or more oxygen atoms. Another aspect to be evaluated, though external to this triangle, is speed. Only when speed exceeds certain parameters can the heat generated by oxidation of a molecule raise the temperature of the surrounding ones, thus triggering off a chain reaction leading to combustion. As shown in the triangle, the presence of a comburent element and of a combustible one is not enough in itself to generate combustion, even in ideal environmental conditions. Actually, it is necessary that the minimum temperature required to activate the molecular reaction (activation energy) should be reached for a sufficient length of time.

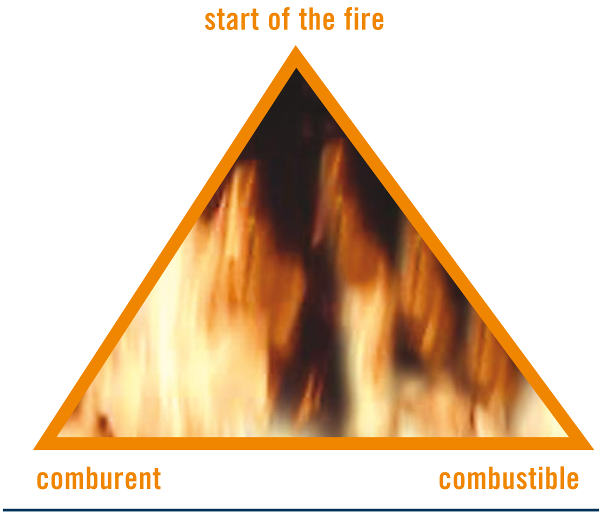


Fig. 1 - The fire triangle

One last component to bear in mind is of "geometrical" nature: if the surface of the combustible element is increased maintaining the same mass, the reaction speed will be higher, and in turn there will be an increase in the degree of lighting ease.

Three phases may be identified in the evolution of a fire (Fig. 2):

- start of the fire
- development
- decline

The sources which enable the fire to develop may be identified as follows:

- direct lighting – a spark, a flame or incandescent material comes into contact with a flammable material in the presence of a comburent substance, e.g. oxygen, which is an essential component of the air;
- indirect lighting – the heat released by the lighting propagates by convection, conduction or radiation; that is, with no direct contact;
- friction – the heat is generated by rubbing;
- self-combustion – the heat is generated inside the combustible material itself, in response to slow natural oxidation processes or as a result of particular chemical reactions.

During the starting and development phases, the flames tend to be mostly localised while the temperature shows a high degree of variability inside the room.
During the development phase, both ambient temperature and the fire fronts propagation speed rise considerably.
At this stage, the flames involve all the combustible surfaces in the surrounding areas and cause a general flare-up ("flash over") which leads to the conclusion of the development phase.
During this phase, the average temperature is very high (about 1000 °C) and by this time, the fire may be regarded as generalised.
After the highest temperature peak has been reached, the fire proceeds to its decline phase, characterised by the exhaustion of the combustible material and therefore, by a more or less slow reduction in temperature.
The fire may be considered extinguished when the ambient temperature goes down below 300 °C.

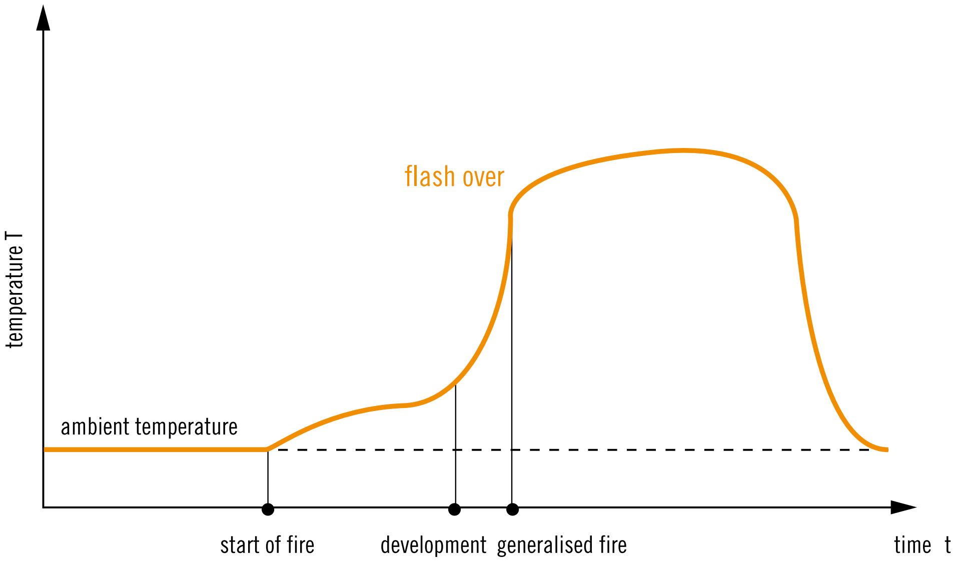


Fig. 2 - Stages in the evolution of a fire

1.3 Fire prevention systems

Fire prevention comprises all those actions which allow us to prevent a fire from starting, or if a fire does start and/or develop, all those measures which make it possible to detect it as fast as possible and to take prompt action to fight it, thus limiting the damage the fire may do to persons or things. Practicable fire prevention systems may be distinguished as follows:

- active protection systems
- passive protection systems

1.3.1. Active protection

Active protection systems (Table 1) include all those installation and organisational elements whose action makes it possible to act directly in order to limit or put out the fire.
Among the active protection systems, we can mention the on-site availability of fire extinguishers, of automatic extinction systems or the presence of fire-fighting squads. Also some forms of alarm systems involving contact with the Fire Brigade constitute a means of active protection against fires.
On the basis of the above, it is interesting to mention that, even today, water represents one of the most suitable agents for extinguishing a fire. As the triangle shows, in order to stop the phenomenon it is necessary to eliminate at least one of the three fundamental elements.
Throwing water over the flammable substances or elements enables us to limit the action of the comburent, i.e. the ambient air, as the water jet tends to prevent the comburent and the combustible material from entering into contact.
By absorbing large amounts of heat during its evaporation, water allows cooling of the combustible material, thus limiting the chain effect of oxidation of the molecules, a phenomenon which - as we have already said – develops when very high temperatures occur.

1.3.2. Passive protection

The passive protection systems (Table1) include all those elements related to design or structure which, by themselves, act as an obstacle to the development and propagation of a fire without the need for direct action.
There are various choices for passive protection systems and these range from the convenient use of safety distances, to spotting and identifying fire exits, to the application of compartmentation or fireproof structures.
It is obvious that the choice of materials is one of the essential steps in achieving a proper passive protection. In order to be really effective, this choice must be carefully considered and must invariably take into account all relevant fire reaction and resistance assessments.

Active protection	Passive protection
• availability of fire extinguishers	• proper layout with use of safety distances
• automatic fire extinction systems	• spotting fire exits
• availability of fire-fighting squads	• compartmentation
• alarm systems connected to the fire brigades	• fireproofing structures
	• materials fire reaction
	• fire resistance of structures

Tab. 1 - Active and passive protection systems

2 Materials fire reaction

As already pointed out in the previous chapter, a correct passive fire prevention is based on the assessment of the fire reaction and resistance of the different materials.
These concepts constitute the basis of the various national and international rules and regulations which analyse the fire behaviour.
By fire behaviour we mean the set of chemical-physical transformations which a material or a constructional element (a component or a structure) undergoes under the effect of fire.

2.1 Definition

The fire reaction of a material may be considered as the degree of participation that the material has during the combustion.
Assessments concerning the reaction to fire, therefore, analyse the features of the different materials present inside a room in connection with both flammability (ease of lighting) and propagation of the fire, if it occurs.
For example, if a small fire starts in a waste-paper basket full of paper, the curtains, the wall-to-wall carpeting, the sofa and any other accessories which may be close to it should not catch fire very easily and, in any case, when and if they do catch fire, they should be able to limit propagation of the flames, that is, they must cause the fire to die out in a short time and far away from the fire source.
Assessments of the materials fire reaction take on special importance almost exclusively in the triggering and development phases. In effect, once the "flash over" has been reached and therefore, while the generalised fire is in progress, all combustible materials burn and increase the fire.

2.2 National and international standards

In many countries nowadays, the fire reaction performance of a material is generally classified by means of conventional numbers such as 0 (zero) and 1 (one) in the case of materials which are most unlikely to catch fire and most likely to stop propagation of a fire; and using higher numbers such as 3 (three) and 4 (four) for those materials which are most likely to catch fire and which are not able to stop propagation of the flames. Indeed, these latter materials themselves encourage flammability and propagation by means of different phenomena, including dripping of burning parts, incandescence, etc.

France	M0, M1, M2, M3, ...	
Germany	A1, A2, ...,	"A" = non flammable
	B1, B2, B3, ...	"B" = flammable
Great Britain	0, 1, 2, 3, ...	
Italy	0, 1, 2, 3, 4, ...,	other than padded or stuffed materials
	1 IM, 2 IM, ...	"IM" ("I" "M") stans for "IMbottiti" the Italian word for padded/stuffed

Tab. 2 - International classification criteria regarding materials' reaction to fire

This classification based on numbers may or may not be accompanied by an alphabetical notation according to the country considered and may take on different meanings in different nations (Table 2).

For a long time, the regulations governing this delicate subject were rather loose and lacked coordination on an international scale.

In reply to different technical, economic and legal requirements, the CEN (i.e. European Committee for Standardization where not only the European Union member states are represented but also other non-EU countries which are members of the International Standards Organization; i.e. ISO) did not manage in the past to come to a definitive agreement on the reaction to fire testing methods and classification to be adopted on a supranational level.

The need for functional uniformity of the classification criteria on a European level finally led to the creation of a univocal testing method called S.B.I., contained in the standard EN 13823, which is used together with other methods already in use on an international level such as EN ISO 1182, EN ISO 1716 and EN_ISO 11925-2 (a provision passed by the European Commission and published in the 23-2-2000 issue of the European journal, in response to the EU Construction Products Directive 89/106/EEC).

Application of this method makes it possible to create a uniform classification based on seven classes (for a more thorough analysis of the subject, please refer to chapter 7).

The new European standards surpass the old national and international classification criteria, whose results, anyway, may still be used for reference.

In Italy, the standard states that in the case of materials which may be hit by flames only on one side, two testing methods may me applied: the UNI 8457 (CSE RF 2/75/A) and UNI 9174 (CSE RF 3/77).

The former assesses the starting phase of the fire while the latter mainly concentrates on the development phase.

A combination of the results obtained in these two tests provides the fire reaction class to which the material belongs in a scale which goes from 1 to 5 (the lower the value, the more unlikely it is that material will start and develop a fire).

In order to achieve classification under class 0, the Italian standards require that a material should also pass the non-flammability tests included in ISO 1182.2.

For composite insulating materials, such as P3ductal ducts, composed of an insulating layer of polyurethane faced with aluminium sheets, the Italian standards include a double classification, that is to say, a double number whose figures refer to the behaviour of the material as a whole in the event of fire and to the behaviour of the insulating component without facings.

Since there were no univocal assessment criteria, P3 had its own products certified and approved classifying them among the higher-ranking fire reaction classes; for instance, 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.

After the introduction of this European testing method and, in particular, of the S.B.I. method, P3 brought itself ahead of time not only by testing its own products according to new protocols but also trying to encourage the reception of this discipline by the Italian set of regulations.

In this way, by using P3’s products, the users and staff involved in the sector are certain that they are actually using products which are not only safe, but also officially approved by the competent controlling bodies.

3 Fire resistance of structures

3.1 Definition

The fire resistance of a structure may be defined as the ability of the structure to maintain the required properties of stability, tightness and insulation over a certain length of time. Fire resistance values, therefore, aim at quantifying and classifying the duration of structures and compartmentation of buildings in the event of a normalised fire starting and developing. This means that, if a fire of a certain magnitude starts in a room, it is necessary that the structures (walls, floors, beams, pillars, doors and fire dampers) which enclose that room withstand the static loads (Fig. 3). It is also necessary that these structures should not let out either flames or gases at high temperatures and that they should not convey heat by conductivity towards the outside of the room where the fire developed. It should be borne in mind, in effect, that walls lined with wood, fabric or paper which are situated in an adjacent room to that where the fire is already in progress, might catch fire and start a new fire simply as a result of over-heating, following the crumbling down of the walls or as a consequence of the presence of incandescent gases which might filter through fissures, or by the crumbling down of a partition wall or communicating door which may cause the two adjacent rooms to be in full communication with each other.

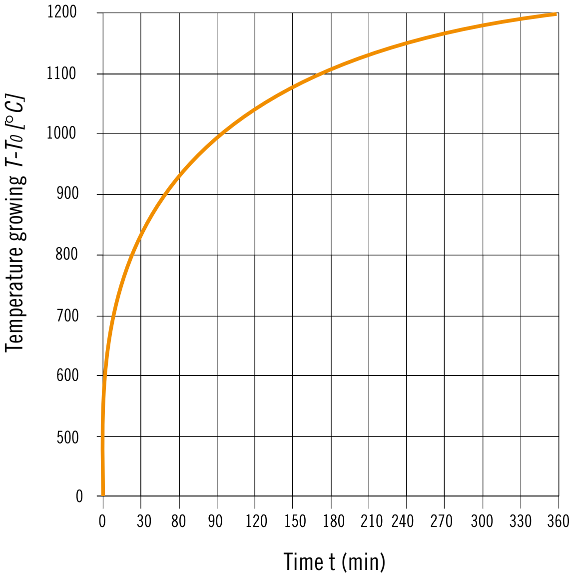
Fig. 3 Door

The structures' resistance to fire is generally identified by the abbreviation REI, where:

• R = stability	i.e., the ability of a building element to preserve its mechanical resistance to the effects of a fire
• E = tightness	i.e., the capacity of a building element, in the event of fire, to prevent the formation of hot vapours or hot gases or to stop those vapours or gases from filtering through to the non exposed side
• I = thermal insulation	i.e., the ability of a building element to reduce the heat transfers within a certain range.

These parameters are obtained and taken into consideration in the ISO 834 resistance to fire test. In this test, the element to be tested is fitted in order to form a wall or part of it, or the ceiling, of a room in which burning elements are placed in order to increase the internal temperature according to the graph and table on the following page (Table 3). It is interesting to analyse, as a function of time t [min], the temperature-increase-curve T-T_0, where T is the average temperature of the testing furnace described by the international standard ISO 834. The mathematical relation which emerges is the following:

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



ISO 834	
time (t) [min]	av. temp. of the furnace [°C]
5’	≈576
10’	≈678
15’	≈739
30’	≈842
45’	≈902
60’	≈945
90’	≈1006
120’	≈1049
180’	≈1110
360’	≈1214

Tab. 3 - Average temperature curve in the testing furnace

Just by way of example, the table indicates the average temperature values of the furnace as defined by the international standard ISO 834. Even in recent times, there has often been confusion over the ambiguous use of the expression “material resistant to fire”. This was caused by the late definition in clear terms of the discipline which rules the fire reaction. Now this ambiguity has been overcome and the term “resistant to fire” must be used to refer only to structural elements which are “supporting and/or partitioning”. Not being considered structural elements which enclose or compartmentalize any room, ventilation ducts are not liable to have any limits in their features of resistance to fire. Only when they are located in such a way that they pass through compartment structures - such as fireproof walls - does it become necessary to use fire dampers (Fig. 4) and where needful, the penetration can be implemented by insulating the duct around the damper provided that the same EI performances are maintained. Indeed, it is known that ducts are allowed to go through “stairs or lifts” or through “places at risk of fire, explosion or blasts” or “exits”, only if they are enclosed in other fire resistant structures classed in a category which must be at least equal to that of the room they go through.

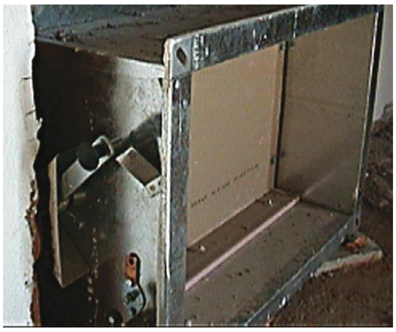


Fig. 4 - Fire dampers

Unless otherwise stated, the fire resistance of structures usually indicates the lowest value among those of “stability”, “tightness” and “thermal insulation “; determined by the occurrence of the following phenomena:

- passage of fire and smoke, which determines the time value related to “tightness to gases and flames”;
- average temperature of 150 °C on the opposite side to that of exposure to fire or a localised peak of 180 °C on that surface; which determines the time value of “thermal insulation”;
- loss of stability and/or collapse, which determines the time value of “resistance and stability”;

3.2 National and International standards

The testing methods applied for determination of the resistance to fire of structures are quite similar almost all over the world; though they differ in the letters – used by convention – which accompany the numbers indicating the time resistance. To give but an example, in Italy, “REI 30” means that for the first 30 minutes “R-type resistance and stability are guaranteed”, “type E tightness to gases and flames” and “type I thermal insulation” is guaranteed for a structure which is hypothetically classed as R90, E60, I30. Structures with resistance to fire below 15 (fifteen) minutes are regarded as “NON resistant to fire”. In addition, all of the above shows that, when constructed with steel sheets, metallic ventilation ducts are not “resistant” to fire at all. On the contrary, due to the high degree of thermal conductivity, a metal sheet would never even reach 3 (three) minutes of resistance to fire. Something quite similar happens when traditional metallic ducts are insulated using spongy or fibrous materials belonging to “Italian class 1”, and even with insulation elements made of non-combustible fibrous materials (resistance to fire is about 10 minutes).

4 Fire load

The fire load, which represents one of the main issues of fire resistance theory, quantifies the heat amount that the whole set of combustible materials in a room might develop. As a rule, this value, is related to a square metre of surface or to a cubic metre of volume, and depends on the upper calorific potential of the materials being considered and on the quantity of material present.

For instance, a warehouse containing only ceramic tiles and glass bricks does not require any particularly fire resistant protection as the amount of combustible material in it is next to none.

On the contrary, the same warehouse used for keeping fabrics or textile materials in general not only requires protection with a special (high) degree of protection to fire but also effective installations for the elimination of smoke (toxic and dark) which textiles, whether natural or synthetic, release in large amounts when exposed to combustion.

Made of a thin and low density insulating polyurethane core (faced with an aluminium foil), P3ductal ventilation ducts are not only risk-free from an ignition and fire-propagation point of view, but also do not contribute in any significant way to the fire load in a room.

Let us give one first numerically tangible example, considering in a clothing warehouse, a 10 m x 10 m room, equal to 100 m^2 through which a duct passes with an internal section of 50 cm x 50 cm, which is more than enough for the requirements of the room:

- for each linear metre of duct 2.08 m^2 of 20 mm thick polyurethane panels are used. A 10-metre long duct requires a polyurethane volume of about 0.416 m^3;
- with a density of about 50 kg/m^3 and an upper calorific potential of about 6,000 kcal/kg, the duct's contribution to the fire load is of 1,248 kcal/m^2;
- since the fire load for such a type of room of this type is usually about 240,000 ÷ 360,000 kcal/m^3, the insulating component of a P3ductal duct affects the fire load by less than 0,5%;
- this percentage is much lower than that of the margin of error used for determining the amount of combustible items present in a room and it is not even significant for the standards concerning to the fire resistance of the compartments.

As a second example, let us consider a small hotel room of 4.5 m x 3.5 m, i.e. 15.75 m^2, with a typical fire load equivalent to approximately 100,000 kcal/m^2. A P3ductal duct with an internal section of 25 cm x 25 cm contributes a small percentage of no more than 2% to the fire load. Indeed, 4 sides of this duct of (25+2) cm, multiplied by the 4.5 m in length, by 0.020 m of thickness with a density of 50 kg/m^3, by 6,000 kcal/kg and divided by the 15.75 m^2 of the room gives about 1,815 kcal/m^2, a value which is below 2% of a fire load of 100,000 kcal/m^2.

Therefore, also from this point of view, P3ductal ducts give their contribution, increasing considerably in the degree of overall safety in a building.

5 Toxicity and opacity of combustion fumes

As previously mentioned, as a result of the oxidation process that occurs during a fire, the molecules of a combustible substance combine with those of the oxygen present in the air (comburent substance).

The most common combustible substances are characterised by a significant carbon content. When combustion takes place, substances such as carbon monoxide and carbon dioxide are released in the air. Anyway, it is not possible to point out in advance all the substances that will develop during a fire accident, as these depend largely on the elements that burn and on the conditions in which combustion takes place. Besides these, there are many substances, others than ones mentioned previously, that can develop during a combustion process such as hydrochloric acid, nitric acid and phosgene.

All these gases have an irritating effect on man and, in some cases, may have even more serious consequences. We should not neglect the production of smoke (unlike gases, these are composed of extremely fine solid particles scattered in the ambient by currents of air and by the circulation of hot gases) which cause irritation, blurred vision and loss of sense of direction. The generation of gases and smoke takes on great importance especially because most of the victims and of the casualties after a fire accident, complain not so much of the burns caused by the flames or by the collapsing of structures, as they do of the intoxication and the panic brought about by these combustion products, which quickly invade all the rooms, including those where no flames are present. Precisely for this reason, in these last few years especially in public transport such as planes, trains, hydroplanes and fast boats (where first aid is not readily available, where the volume of the rooms is rather limited and the escape is impossible if not a very high risk), great attention has been given to the features characterising the reduced tendency to produce toxic and opaque smoke by the materials used

Also in this case, however, there are numerous methods used for testing and classification purposes and these differ not only from one country to another but also the sectors where they are applied.

Currently, the most widely applied standards are the French AFNOR, in the railway field, the American FAR or the European AIRBUS in the aeronautical field; while these and other standards are applied in the naval field. In any case, as a demonstration of the very high degree of danger involved with combustion fumes, all these testing methods consider the very first minutes after the start and development of a fire (usually only four minutes) as it is claimed that after this short length of time, the amount and quality of the gases produced by any type of flammable material are in any case so incapacitating to cause fainting and serious risk of death to those persons who have not reached a position of safety or who do not have some sort of adequate protection.

Considering the remarkable use of technology which lies at the base of the manufacturing of materials with adequate features in terms of the toxicity and opacity of gases during the combustion, for years it was thought (incorrectly) that “what does not burn does not produce smoke” and, therefore, these features were for many years neglected (in favour of fire reaction characteristics) both by legislators and by the persons in charge of drafting the supply specifications.

Another standard used as reference, is the English NES 713, employed to determine the toxicity of combustion fumes.

6 International standards

Before achieving an European harmonization, each nation had it's own referring fire prevention standards.
We are now considering only those ones relevant to materials for construction.

6.1 United Kingdom

If we take in to consideration the United Kingdom, the technical standard used is the BS476 part 6 and 7.

Part 6 regarding the fire propagation test method;
Part 7 considering the lateral flame spread using a radiating panel.

Five classes are determined, from class 0 (the best) to class 4 (the worst).

6.2 Germany

In Germany, the fire behaviour of materials is considered by the DIN 4102 – Part.1 standard which defines the following classes:

DIN 4102 A: non combustible materials.
DIN 4102 B: burning materials.

Class B is further divided in:

B1 hardly flammable materials, with high "self-extinguishing" properties;
B2 normally flammable materials, with "self-extinguishing" properties;
B3 easily flammable materials.

The material is firstly tested using a small flame for B2 and only if positively classified as B2, tested also using the B1 chimney. If it does not pass the B2 test it is automatically classified as B3.

6.3 France

In France the reference standard is the AFNOR NFP 92-501. The test foresees the use of a radiating panel, the so called "Epiradiateur", with the simultaneous presence of a pilote flame. 6 classes are determined: the M0 class is the best (non-combustible materials as usually all inorganic materials) while the M5 is the worst.
The best level for organic materials results the M1 Class "Fire retarded" followed by the Classement M2 (both accepted for structural elements, the second for complementary elements).

M0 – incombustible material (mostly inorganic materials)
M1 – non-flammable material
M2 – hardly flammable material
M3 – moderately flammable material
M4 – highly flammable material
M5 – extremely flammable material

6.4 Italy

Italian rules are particularly articulated and can be found in the Ministerial Decree dated 26th June 1984 (later modified and integrated by the Decree dated 3rd September 2001).
As article 1 states, this decree aims to establish the standards, the criteria and the procedures needed during the reaction to fire classification and the approval of materials from a fire prevention point of view.

The testing methods used for determining the reaction to fire class established by the standards are the following:

- UNI ISO 1182 Fire testing – Building materials – Non-flammability tests;
- UNI 8456 Combustible materials liable to be hit by flames on both sides. Reaction to fire assessed by application of a small flame;
- UNI 8457 and UNI 8457/A1 Combustible materials liable to be hit by flames on only one side – Reaction to fire assessed by application of a small flame.
- UNI 9174 and UNI 9174/A1 Reaction to fire of materials which undergo the effects of a starting flame in the presence of radiating heat;
- UNI 9175 and UNI 9175/FA1 Reaction to fire of padded furniture subjected to a small flame.

To classify the materials used in air conditioning ductwork, the relevant tests are UNI 8457, UNI 9174 and UNI ISO 1182.

As already stated above, the tests envisaged by UNI 8457 aim to assess by simulation the action of a triggering flame and the reaction to fire during the initial phase of a fire.
UNI 9174 instead, aims to create the typical conditions of a fire in its development phase by means of a flame and a radiating panel. Lastly, standard UNI ISO 1182 checks the non-combustibility of the material considered.

In general (on the basis of the results of these tests), the Italian standards attribute to the material a fire reaction class designated by a number from 1 to 5, where the lowest number represent a material having the lowest degree of participation.
To the Class 0 is given to those materials which pass the test UNI ISO 1182. The same law identifies some materials, such as metals, which fall under class 0 and for which there is no need for testing.

The evolution of the materials used for insulation purposes and of technology in general led Italian legislators to make a distinction between homogeneous and composite insulated materials.
For the latter – among which are the P3ductal products – the classification is twofold, which means that it is defined by the combination of two numbers, referring respectively to the fire reaction class of the finished product and the one of the insulating component alone.

7 The European classification method

7.1 The seven Euroclasses

The issue dated 23-02-2000 of the European journal “Gazzetta Europea” contains an Annex with a detailed classification table, exactly corresponding to the one in EN 13501-1.
7 classes of reaction to fire are identified by letters in alphabetical order. To be more precise, the letters are:

A1 and A2	which identify non-combustible inorganic materials
B-C-D-E	which identify combustible materials with different reaction to fire behaviuor
F	which identifies flammable materials whose reaction to fire is not determined.

Testing method for combustible materials (EN 13823 – SBI) analyse the material’s behaviour in the event of fire by monitoring the following parameters during the 20 minutes test:

- increase in temperature
- duration of fire
- rate of increase of the fire
- propagation of fire
- mass loss
- gross calorific potential
- total release of heat
- dripping and opacity of fumes

TABLE 1 - Classes of reaction to fire performance for construction products excluding floorings

Class	Testing method	Classification criteria	Additional classification
A1	prEN ISO 1182	$\Delta T \leq 30$ °C $\Delta m \leq 50\%$ $t_f = 0$ (non-persistent fire)	-
	prEN ISO 1716	PCS $\leq$ 2,0 MJ·kg^{-1} (1) PCS $\leq$ 2,0 MJkg^{-1} (2) PCS $\leq$ 1,4 MJ·kg^{-2} (3) PCS $\leq$ 2,0 MJ·kg^{-1} (4)	-
A2	prEN ISO 1182	$\Delta T \leq 50$ °C $\Delta m \leq 50\%$ $t_f \leq 20$ s	-
	prEN ISO 1716	PCS $\leq$ 3,0 MJ·kg^{-1} (1) PCS $\leq$ 4,0 MJkg^{-1} (2) PCS $\leq$ 4,0 MJ·kg^{-2} (3) PCS $\leq$ 3,0 MJ·kg^{-1} (4)	Generation of fumes (5) Drops/burning particles (6)
	EN 13823	FIGRA $\leq$ 120 W·s^{-1} LFS < margin of sample THR$_{600s} \leq$ 7,5 MJ	Generation of fumes (5) Drops/burning particles (6)

B	EN 13823	$\text{FIGRA} \leq 120\ W \cdot s^{-1}$ LFS < margin of sample $THR_{600s} \leq 7{,}5$ MJ	Generation of fumes (5) Drops/burning particles (6)
	prEN ISO 11925-2 (8) exposure 30 s	Fs ≤ 150 mm within 60 s	Generation of fumes (5) Drops/burning particles (6)
C	EN 13823	$\text{FIGRA} \leq 250\ W \cdot s^{-1}$ LFS < margin of sample $THR_{600s} \leq 15$ MJ	Generation of fumes (5) Drops/burning particles (6)
	prEN ISO 11925-2 (8) exposure 30 s	Fs ≤ 150 mm within 60 s	Generation of fumes (5) Drops/burning particles (6)
D	EN 13823	$\text{FIGRA} \leq 750\ W \cdot s^{-1}$	Generation of fumes (5) Drops/burning particles (6)
	prEN ISO 11925-2 (8) exposure 30 s	Fs ≤ 150 mm within 60 s	Generation of fumes (5) Drops/burning particles (6)
E	prEN ISO 11925-2 (8) exposure 15 s	Fs ≤ 150 mm within 20 s	Drops/burning particles (7) Drops/burning particles (6)
F	reaction not determined		

Symbols used

ΔT	increase in temperature
Δm	mass loss
tf	duration of fire
PCS	gross calorific potential
FIGRA	rate of increase of fire
THR600s	total release of heat
LFS	lateral propagation of fire
SMOGRA	rate of increase of fumes
TSP600s	total production of fumes
Fs	propagation of fire

Note

(1) for homogeneous products and essential components of non-homogeneous products

(2) for any inessential outside component of non-homogeneous products

(3) for any inessential inner component of non-homogeneous products

(4) for the product as a whole

(5) s1=SMOGRA ≤ 30m2.s-2 and TSP600s ≤ 50m2
s2=SMOGRA ≤ 180m2.s-2 and TSP600s ≤ 200m2
s3 not s1 o s2

(6) d0 = absence of drops/burning particles in EN 13823 (SBI) within 600 sec
d1 = absence of drops /burning particles lasting over 10 sec in EN 13823 (SBI) within 600 sec
d2 not d0 or d1 – combustion of paper in EN_ISO 11925-2 gives rise to classification under d2

(7) Passing of the test = absence of combustion of paper (unclassified).
Failure in test = combustion of paper (classified as d2)

(8) When the flames hit the surface and, if suitable for final conditions of application of the product, the side of an object.

7.2 S.B.I. Single Burning Item

Fig. 7 - SBI test

The lack of coordination and uniformity amongst the various international standards in force led the European Commission to establish its own testing and classification concerning reaction to fire of materials. As far back as the early 90's, the European Commission, supported by the "Group of National Fire Regulators" had tried to give a step ahead in this direction by suggesting a classification system based both on already existing testing methods and on new ones, amongst which is the "Single Burning Item Test". Ahead of the European Standards, P3 has already proceeded in performing the envisaged tests on its own P3ductal panels.

8 Room Corner Test

8.1 Studies on air distribution ductworks

The testing methods envisaged in the Italian, UK, French, etc. standards and the european SBI test simulate a small or medium scale scenario and, as a result of this, they do not reproduce the true conditions of a fire accident. In order to make the results of these evaluation techniques more reliable, there is a tendency to make cross-references between these results and those provided by specific large scale tests. The reference test belonging to this category is the Room Corner Test (ISO 9705).

Focusing our attention on the tests concerning ventilation ducts, it certainly becomes interesting to assess the difference between P3 preinsulated aluminium ducts and by galvanised steel sheet ducts insulated with glass fibre and tested with this specific method.

8.2 The choice of the fire model

This test is only practicable in special labs and using a diffusion burner placed in a corner of the floor facing the entrance door. The test is capable of reproducing the real conditions of temperature and duration of an actual fire in a 2.4 m X 3.6 m room, with a height of 2.4 m.

Placing a burner which can develop 300 KW in a corner makes it possible to make a faithful reconstruction of real conditions.

The ducts used for testing purposes are fitted along two adjacent walls of the room, that is, creating an “elbow-like” layout (Fig. 8).

The ducts used for air conditioning ductwork, are in fact usually laid and fitted along the perimeter of the walls and, if they run through rooms, suspended from the ceiling with special brackets.

This type of installation, in case of fire, makes it possible for the ducts to be hit by the flames directly either from below or on the sides. However, we should add the consequences of an increasing cushion for hot fumes, under the ceiling.

The room corner test consists in simulating two thermal attacks of increasing degree of seriousness. The first step involves the use of the burner adjusted to generate 100 kW for 10 minutes in order to recreate the typical conditions of a fire in its development phase; then, for another 10 minutes, the power is raised to 300 kW in order to simulate the conditions of a generalised fire.

Thus, the fire created leads the combustible material of the ducts (the insulating material, in the case of preinsulated aluminium ducts and both the bonding agent and the external facings in the case of metallic ducts insulated with fibre glass) to a condition of pyrolysis.

Fig. 8 - Layout of the room used for the room corner test

Fig. 9 - Simulation of a fire with the room corner test

One of the most important results of the room corner test has been the possibility to verify how the deterioration of materials affects the fire, both from a propagation point of view and from a point of view of the damage to the ducts themselves and subsequent diffusion of harmful gases into the air distribution system.

8.3 Measuring the degree of fire propagation in the ducts

It is particularly hard to valuate the degree of this deterioration, i.e. measuring the extent of propagation of the fire through the ducts, because of the shape of the duct and because of the layout of the room used for testing. This difficulty may be overcome by using instrumental measurements on the smoke collected by a special suction system (hood and exhaust smoke collection ducts). This measurement is based on the percentages of oxygen, carbon dioxide and carbon monoxide, on the temperature and on the extent of the fumes as well as on the optical transmission of said fumes.

It is then possible to proceed to the measurement of the SPR (Smoke Production Rate) index, which gives a quantified value of the smoke produced and of the RHR (Rate of Heat Release) index, which gives the amount of heat related to the effects of combustion and, as a result, to the participation of the ducts in the fire.

The RHR index is calculated using the following equation:

$$RHR = E \cdot V_{298}(t) \cdot x_{a\_O_2} \cdot \left(\infty \quad \frac{\phi(t)}{1+0{,}105 \cdot \phi(t)} \right)$$

with:

$$V_{298}(t) = c \cdot A \cdot \frac{K_1}{K_2} \cdot \sqrt{\frac{\Delta p(t)}{T_{ms}(t)}}$$

$$x_{a\_O_2} = x^a_{O_2} \cdot \left[1 - \frac{H}{100 \cdot p} \cdot \exp\left(\infty \quad 23{,}2 - \frac{31816}{T_a - 46} \right) \right]$$

$$\phi(t) = \frac{x^a_{O_2} \cdot \left(1 - x_{CO_2}(t)\right) - x_{O_2}(t) \cdot \left(1 - x^a_{CO_2}\right)}{x^a_{O_2} \cdot \left(1 - x_{CO_2}(t) - x_{O_2}(t)\right)}$$

By determining the RHR index, it is possible to calculate the overall amount of heat generated during the test; i.e. the THE (Total Heat Evolved) index.
This calculation requires the use of the following equation:

$$THE = \int_{t_0}^{t_f} RHR \cdot dt$$

In order to calculate the already mentioned SPR index for the amount of generated fumes, the following equation may be used:

$$SPR = \frac{V(t)}{L} \; 1n \left(\infty \; \frac{I_0}{I(t)} \right)$$

with

$$SPR = V_{298}(t) \; \frac{T_{ms}}{298}$$

These calculations and their results enable us to assess the overall amount of smoke produced during the test, that is, the TSP (Total Smoke Production) index:

$$TSP = \int_{t_0}^{t_f} SPR \cdot dt$$

Symbols used

RHR	power generated by combustion (kW)	K_1	speed profile factor
xa_{O_2}	molar fraction of oxygen on a dry basis with burner turned off	V(t)	volume capacity of exhaust fumes (m3/s)
E	heat released per unit of volume of oxygen consumed (Kj/m3)	K_2	Reynolds' correction factor (=1,08 for bidirectional tubes)
H	relative humidity rate (%)	L	light's free pathway (distance between emitter and receiver in m)
V_{298} (t)	volume capacity of exhaust fumes at 298 K (m3/s)	Δp (t)	kinetic pressure read by a sensitive element (Pa)
p	barometric pressure (Pa)	I_0	intensity of the luminous signal with no fumes(%)
$x_{a\text{-}O_2}$	molar fraction of oxygen in the air on a humid basis	T_{ms} (t)	temperature of the exhaust gases read in the measurement section (K)
T_a	ambient temperature (K)	I(t)	intensity of the luminous signal with fumes (%)
ϕ (t)	oxygen consumption factor	THE	amount of heat released during combustion (MJ)
$x^a{}_{CO_2}$	molar fraction of CO2 in the air on a dry basis with burner turned off	SPR	amount of smoke produced per unit of time (m2/s)
c	coefficient = 22,4 (K 0,5 m 1,5 kg -0,5)	t_0	initial instant of test (s)
x_{CO_2} (t)	molar fraction of CO2 in the exhaust fumes on a dry basis	TSP	amount of smoke produced during combustion (m2)
A	section area of the exhaust duct (m2)	t_f	final instant of test (s)
x_{O_2}	molar fraction of oxygen O2 in the exhaust fumes on a dry basis		

8.4 Measuring the diffusion of smoke in air distribution ducts

One of the risks posed by ductwork systems in the event of fire is the possible mixture between the conditioned air (distributed around the rooms and perhaps not even touched by the flames) and the smoke generated by the combustion.
Unless evident structural collapse occurs, it becomes difficult with the room corner test to assess the degree of integrity of the ducts.
However, it is possible to use indirect measuring by inserting thermocouples both inside and outside the duct, as these can provide constant monitoring of the temperature and its changes.
This makes it possible to check any collapse which might take place. This is because, as a direct result of this phenomenon – i.e. the variation in position with respect to the flames and the different mixing between the combustion fumes and the fresh air conveyed by the ducts - it is immediately possible to detect a considerable variation in temperature distribution, with a relative increase in the internal temperature value.

Fig. 10 - Detail of the ventilation system

8.5 Ducts tested

P3 performed the testing on its own ducts made with P3ductal panels according to the procedure suggested by the room corner test. Thus, it was possible to detect and compare the different responses and behaviour to fire both for preinsulated aluminium ducts and for those made of galvanised steel insulated with fibre glass. Ducts made of preinsulated aluminium were manufactured using P3ductal sandwich panels (made of expanded polyurethane faced with 0.08 mm aluminium sheets) whose class of reaction to fire was 0-1. The section of the obtained duct was 30x40 cm (Fig. 11). The duct was fitted according to the technical standard UNI 10376, obtaining a rectangular section duct of the same size (30x40 cm) having a steel thickness of 0.8 mm. In addition, the metal sheet duct was insulated with a “mattress-like” layer in fibre glass covered with “craft” paper coupled with a thin aluminium layer (Fig. 12).

Fig. 11 - Fitting of the preinsulated aluminium P3ductal duct

Fig. 12 - Fitting of the duct made of galvanised steel insulated with fibre glass

The two main branches of the ductwork were fitted using three pairs of ceiling brackets, leaving a distance of 10 cm both from the wall and from the ceiling.
At the end of the ducts system, a fire damper was fitted for closing the air flow when and if the temperature of the smoke reached a value of 70° C (Fig. 13).

Fig. 13 - Detail of damper

8.6 Testing procedures

The room corner test carried out on P3ductal ducts and on the metallic ones was performed at the LSF Laboratory in Montano Lucino (prov. of Como) following the procedure described below:

1. Adjustment of air flow in the exhaustion system (2.5 m^3/sec) and of the ducts to be tested (0.24 m^3/sec)
2. Turning on the data acquisition system and functional checking of the sensors
3. Identification of the initial levels and recording for the first 120 seconds of testing of all the signals coming from the section used for measurement and from the thermocouples placed inside the testing room
4. Turning on the diffusion burner and adjustment of heat generation at 100 kW
5. Recording of data for 10 minutes (from 120 to 720 sec) at 100 kW
6. Increase of the burner's power up to 300 kW
7. Recording of data for another 10 minutes (from 720 sec to 1320 sec) at 300 kW
8. Turning off the burner
9. Recording of data for another 2 minutes (from 1320 sec to 1440 sec)
10. Data saving

8.7 Results

As already shown in the procedure, while the room corner test was being performed on the ducts air distribution, two thermal attacks were simulated so as to recreate the conditions of a fire during its development and in the generalised phase, respectively.

Thermal attack in the first 10 minutes (burner at 100 kW – fire in its development phase)

Fig. 14 - 100 kW thermal attack (development phase)

P3ductal ducts show a good behaviour, although the flames touch in more than one occasion both the lower and the lateral surfaces. Despite the fact that the temperature around the duct exceeds 400 °C, the temperature detected inside the duct remains almost unchanged. The heat generation RHR index does not rise above 35 kW, while the amount of heat released during combustion (THE index) is assessed around 8.7 MJ (7.7 MJ in the case of a second test).

Thanks to the fact that pyrolysis was localised only in the areas directly hit by the flames and also thanks to the moderate oxidation reaction which took place, the production of smoke is certainly acceptable.

In the case of the metallic sheet duct, heat generation reaches values of 23 kW, while the heat released is 5 MJ.

This makes it clear that, although the metal sheet is classified as 0, the insulating material contributes to the propagation of fire. Indeed, one can detect propagation of the flame on the paper and aluminium coating and also the obvious pyrolysis of the bonding agent added to the glass fibre.

Thermal attack in the following 10 minutes (burner at 300 kW – generalised fire)

In this phase (Fig. 15) the temperature rises above 700 °C around the elbow of the P3ductal duct, while the inside temperature shows only a slight increase and stays at about 80 °C in the spot undergoing the most severe thermal stress. In any case, the average temperature stays below 70 °C, which shows that the infiltration of combustible gases in the air conditioning system is virtually non-existent.


Fig. 15 - 300 kW thermal attack (generalised fire)

The RHR index reaches its peak after about 840 seconds of testing, showing a maximum value around 311 kW. The THE index remains within the 57 MJ range (50 MJ in a the second test).

In spite of all this, part of the insulation material becomes charred, participating to the fire.

The contribution of the P3ductal duct to combustion diminishes by 1/3 (one-third) after 100 seconds, remaining steady until the end of the test. Indeed, the phenomenon remains limited to the area around the elbow, that is, the area where the testing conditions are truly critical for the whole duration of the testing procedure.

In the case of sheet metal ducts, the temperature inside the section reaches a value of 70 °C, with a heat generation value of around 60 kW and a THE index of about 17 MJ.

This shows a remarkable contribution to fire, especially in relation to the amount of combustible material found on the surface.

In the case of the sheet metal ducts there is also considerable propagation of the flames along the ducts themselves.

Summing up, during the first testing step (100 kW) there were no substantial differences between the two types of ducts. These differences, however, become apparent when the testing conditions become more severe.

The main differences can be seen from a structural point of view. Unlike sheet metal ducts, P3ductal ducts do not allow propagation of the fire and limit combustion to the area directly hit by the flames. In addition, this advantage generates greater safety due to the lack of propagation of fumes and toxic gases inside the ducts (Fig. 16 and Fig.

17). The combined action of the thermal conductivity of the aluminium sheets and that of the formation of a layer of charred polyurethane - which creates an effective barrier against the inward propagation of heat - as well as the presence of conditioned air inside the duct enable the duct to maintain its high standard of functional performance.

Fig. 16 - The P3ductal duct shows the effects of the fire only in the area hit directly by the flames

Fig. 17 -The metallic duct participates considerably to the fire propagation.

9 Advantages of Hydrotec

The P3 commitment: clean air... continuously

In an era in which quality is synonymous of progress, P3 has always tried to improve its products in order to stay hand in hand with the growing requirements of the market. Piral HD Hydrotec panel is the fruit of this effort; it is in fact produced by P3 using, the international patent EP 1115771 B1, for which P3 has obtained exclusive rights, that allows the countersigning of Hydrotec panel with the mark ODP=0 (ozone depletion potential = 0), as to say not harmful for the ozone. Environmental compatibility is ensured by the use of water as the foaming agent instead of cfc and hcfc or the hydrocarbons usually used in insulation foams, responsible for the destruction of the ozone layer of the atmosphere.

Conformity of the Hydrotec panels to the European regulations

P3 has anticipated by more than three years the application of the European Regulation which has banned as of January 1st 2003 the use of CFC and HCFC gasses in production of stiff PUR. Water foaming enables ODP and VOC (volatile organic substances during production) emission to be reduced to zero, thereby minimising the Greenhouse Effect, or GWP (global warming potential) to an insignificant value of 0.0001.

Hydrotec panels: technically perfect

When chlorinated gases such as cfc and hcfc emitted into the atmosphere are struck by UV radiation, they release chlorine radicals through photo-dissociation. The chlorine radicals then react with the ozone causing its destruction. The usual polyurethane foaming technology is based on heat generated during the exothermic reaction between polyols and the isocyanate to evaporate a liquid with a low boiling point previously added to the mixture. A large part of these gases remains trapped inside the cellular structure of the polyurethane polymer being formed. In time, the composition of the gas contained in the cells can alter the natural tendency towards equilibrium with the external environment. This process is significantly affected by both the type of external facing given to the foam, its density, operative temperature, formulation, and the type of gas, etc.. In the new P3 technology however, foaming is achieved exclusively through the gas generated by the reaction between isocyanate and water in the presence of the same reaction between polyols and isocyanate, with the consequent formation of the polyurethane chain.

$Cl\bullet + O_3$	$ClO\bullet + O_2$
$ClO\bullet + O$	$Cl\bullet + O_2$
$O + O_3$	$2O_2$

Hydrotec quality always pays off

The exclusive water foaming technology applied by P3, allows the production of an environmental friendly panel, therefore complying with the current European regulation on one side, whilst on the other it considerably reduces the products cost, at no expense to the qualities of classic P3 panels: heat insulation capacity $\lambda u(10°C) = 0{,}024$ W/(m °C), dimensional stability, adhesion, workability, and the elevated percentage of closed cells all remain the same. Fire reaction is still ranked in 0-1 Class, among the highest prescribed in D.M. 26/6/84 regarding "fire reaction classification and the homologation of materials for fire prevention purposes".

10 Conclusions

This handbook aims to show how fire prevention takes on crucial importance in the design and proper use of public areas.
Fire prevention involves all the components used, among which are also the ducts intended for air distribution systems.

From an International point of view, the standards which can be found around the world, are rather non homogeneous. Even if at an European level there has been the tendency to harmonize the situation, each nation continues to have specific standards which utilize criteria's and functional parameters which are often different.

As already mentioned in the manual, the P3ductal duct has been tested voluntarily according to the different testing methods used in France, England and Germany. The P3ductal duct therefore guarantees an incredibly high level of safety in the event of fire, meeting all the requirements of the European SBI standard.

But it is also thanks to the excellent results obtained during the Room Corner Test, which is the only test able to simulate the behaviour of a duct during a large scale fire, that we can highlight the indisputable high performance of the P3ductal duct. Performance which, for example in Italy, has brought to the definition of new standards in which the pre-insulated aluminium solution is considered perfectly usable in all environments which are subject to fire prevention.
This heralds a new era for designers, who can be assured that they can rely without reserve on P3ductal ducts from a technical, quality and safety point of view.

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Reference standards

EN ISO 13501-1	European standard; Fire classification of construction products and building elements – Part 1 – Classification using test data from reaction to fire tests.
EN ISO 13823	European testing method; Reaction to fire tests for building products – Building products excluding floorings exposed to the thermal attack by a Single Burning Item.
EN ISO 11925-2	European testing method; Reaction to fire tests for building products – Part 2 – Ignitability when subjected to the direct impingement of flame.
EN ISO 1182	European testing method; Non-combustibility test.
EN ISO 1716	European testing method; Gross calorific potential test.
D.M. 26/06/1984	Italian Ministerial Decree; Classificazione di reazione al fuoco ed omologazione ai fini della prevenzione incendi.
UNI 8457, UNI 8457/A1	Italian testing method; Reazione al fuoco dei materiali che possono essere investiti da una piccola fiamma su una sola faccia.
UNI 9174, UNI 9174/A1	Italian testing method; Reazione al fuoco dei materiali sottoposti all'azione di una fiamma d'innesco in presenza di calore radiante.
D.M. 31/03/2003	Italian Ministerial Decree; Requisiti di reazione al fuoco dei materiali costituenti le condotte di distribuzione e ripresa dell'aria degli impianti di condizionamento e ripresa.
BS476, part 6	British Standard; Test for the determination of fire propagation.
BS476, part 7	British Standard; Test for the determination of the surface spread of flame of products.
NES 713	British Naval Engineering Standard; Determination of smoke toxicity.
ISO 9705	Room Corner Test.
AFNOR NF-P 92-501	French standard; Réaction au feu des produits et d'aménagement (Association Française de Normalisation).
AFNOR NF-F 16-101	French standard; Matériel roulant ferroviaire, Comportement au feu, Choix des matériaux.
DIN 4102, part 1	German standard; DIN normen, Brandverhalten von Baustoffen und Bauteilen

Notes

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SINCERT

CERMET SISTEMA DI GESTIONE CERTIFICATO
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REG. N. 221-E
UNI EN ISO 14001:2004

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