FIRE SAFETY OBJECTIVES

When considering the fire safety of buildings, there are a number of key objectives to be achieved. The primary objective is clearly to prevent loss of life of occupants and fire fighters. A secondary objective is the limitation of damage of property [1] and the protection of the environment.

A fire safety assessment identifies the conditions needed to meet these objectives and looks at the balance of risk. However, in order to do that it is necessary to understand the different factors that will influence the outcomes in case of fire. On this basis it can be decided, whether the assessment should focus on a material, the products or the system or a combination.

RISK ASSESSMENT

- Is the product likely to be the source of ignition?
- Is the product likely to be the secondary ignited item?
- Is the product a potential significant fuel source even if not being the first or secondary ignited item?
- What is the potential avenue to contribute to the risk (and hazard)?
- How close are occupants and/or critical equipment to the origin of a fire?

Whether the assessment focuses on a material, product or system is determined by an investigation of the risk.

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1. Isopa Brochure: Performance of polyurethane (PUR) building products in fires
2. Dr. rer. nat. Georg Pleß (Institut der Feuerwehr Sachsen-Anhalt based on statistics of the World Health Organisation), Ständige Konferenz der Innenminister und -Senatoren der Länder, Forschungsbericht Nr. 145 (Teil 1)
Test methods can help to determine product behaviour in the case of a fire. For the assessment to be valid, it is necessary that the outcome of the fire test gives a valid estimate with regards to the specified fire scenario(s).

**FIRE SCENARIOS**

Fires can be initiated and develop in numerous ways, dependent on a number of factors, including:

- Type, intensity and location of the ignition source (see example in Figure 1)
- Primary and secondary ignited items
- Avenue of the fire
- Fire load density
- Building/room type and size
- Ventilation conditions
- Availability of passive (compartmentalisation, fire walls/doors, and natural ventings) and active (smoke extraction devices, sprinkler systems, intervening of the fire brigade) protection measures
- Degree of enclosure

Having an understanding of how a particular construction is likely to behave in a fire scenario is an important aspect of fire safety.
assessment. Eight different fire scenarios have been identified in an EU pre-normative research programme which was finalised in 1995 [3]: a small and large room, a vertical and horizontal cavity, a façade, a corridor, a staircase and a roof. All these scenarios presume a larger secondary ignited item.

The Room Corner Test ISO 9705 was chosen as the fire test scenario to simulate a fire in a small room. This test was used to help in development of the Euroclassification system in order to standardise the classification of construction products, especially with regard to flashover. However, the Room Corner Test was developed for internal lining products, which are directly exposed to the fire. This has led to some inconsistency when it comes to insulation, as the latter is rarely used as an internal lining product, but is almost always installed in a building element behind a fire resistant barrier (see section: European fire standards and national legislation). This is taken account of in the mounting and fixing standard (EN 15715), which allows for fire testing in simulated end-use applications.

The concept of fire scenarios is used extensively in fire safety engineering. The choice of the right fire scenario is vital for the correct assessment of the fire risks and the fire hazards. Scenario testing is application-related testing and follows the development of the fire until a late stage, possibly until an uncontrollable stage of fire spread. The use of specific application-related tests is increasing in EU countries in order to confirm that the product performance determined is in accordance with the level of fire safety applicable in specific countries (including in end-use applications). Examples include façade or insulated flat steel roof testing.

**INTERNAL FIRE DEVELOPMENT**

There are four key stages of fire development within a building:

- Ignition
- Growth
- Fully developed
- Decay

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Initially, a source of heat, fuel and oxygen is needed for ignition to take place. As flames spread and hot gases rise, the temperature of the room or compartment increases. Provided there is sufficient oxygen the fire starts to grow, and other sources of fuel become involved. With additional fuel, the level of heat released increases, and a layer of hot gas will form from the ceiling down. Towards the floor a cooler layer of gas will be found, and unless the compartment is sealed, the lower pressure of this cooler layer allows an exchange of air from outside, providing the oxygen required for the fire to continue to grow. It is at the growth stage that the reaction to fire of exposed materials is crucial in determining whether or not they will contribute to the fire development, with factors such as ignitability, heat release and flame spread coming into play.

The transition from a growing to a fully developed fire can be extremely rapid depending on the fire load. The International Fire Training Centre gives the following definition of this mechanism: "In a compartment fire, there can come a stage where the total thermal radiation from the fire plume, hot gases and hot compartment..."
boundaries causes the generation of flammable products of pyrolysis from all exposed combustible surfaces within the compartment. Given a source of ignition, this will result in the sudden and sustained transition of a growing fire to a fully developed fire. This is called a Flashover." [4]

It is generally recognised that if a fire reaches flashover, the chances of escape for occupants in the vicinity becomes considerably less, as the most common cause of death in a fire is by being overcome by smoke and fumes, which occur in significantly greater quantity after flashover.

Once a fire is fully developed, the ability to resist fire becomes of the utmost importance by having the load-bearing, insulation and integrity capacity upon which the stability of the building and prevention of further fire spread may depend.

A fully developed fire releases the maximum amount of energy, but is generally limited by the amount of oxygen left available to it, and if oxygen remains in short supply and the available fuel is consumed the fire will fall into decay.

EXTERNAL FIRE DEVELOPMENT

Fires develop differently on external horizontal or vertical surfaces. The four key stages of the fire apply but the development is different as different factors influence the fire, for example wind effects, surroundings such as proximity of other buildings, design of wall or roof including type and design of the external cladding. Regulations take into account external fire scenarios and specific test standards exist, for example for façades and for roofs. Vertical and horizontal flame spread and break through inside the building or to other levels is considered important, while flashover is not relevant where there cannot be formation of a hot layer of fire effluents under the ceiling or roof.
Smoke is always toxic, irrespective of the material that is burning. The main steps to control smoke hazard are:

- to ensure fires remain small, by avoiding propagation;
- to limit visible smoke to allow safe evacuation of occupants;
- to avoid exposure and inhalation of smoke to allow safe evacuation and avoid injury.

**SMOKE AND SMOKE TOXICITY**

**THE RELEVANCE OF SMOKE**

Smoke is a significant hazard. UK and USA statistics have shown that the most common cause of death in a fire is to be overcome by smoke and gases. Smoke can originate from any burning object, and usually initially results from building contents (rather than structure) combustion, which may or may not be visibly flaming.

There are two key hazard aspects about smoke, namely loss of visibility during escape and intoxication after inhalation of a certain dose (concentration of effluents multiplied by the exposure time). Reduction or loss of visibility leads to delays in escape, disorientation and longer exposure times. Inhalation of smoke can lead to narcotic effects and irritation and can even result in incapacitation or death. The control of smoke is therefore considered an important element in buildings.

**SMOKE AND REGULATIONS**

The prime objective of fire (incl. smoke) related regulations, is life safety. In the building sector limitation of smoke generation and exposure to occupants is achieved by preventing ignition and limiting growth of fire and by ensuring adequate means of escape for occupants through appropriate building design (e.g. exit routes).

Depending on the country, for certain building applications there may...
be a requirement for the visible smoke performance of construction products, mainly for internal fire situations. For external fire situations, smoke is not considered a life hazard and in general there are no or low requirements. Smoke obscuration is part of the reaction to fire standards. There are no smoke toxicity standards for construction products in the EU. Prevention of exposure is mostly achieved nationally via the above measures and, in some cases, via fire safety engineering (FSE). Nevertheless, some national regulations may include certain rules, e.g. Germany for non-combustible products for escape routes or e.g. France for combustible insulation that is applied to the internal side of the building without thermal barrier lining.

SMOKE AND FSE

Smoke is the consequence of a fire and its generation is therefore always dependent on the fire scenario. Smoke can come from a number of ignited sources, and the building contents are likely to be important contributors to smoke emissions. The involvement of the building envelope, including insulation, in smoke production will vary hugely depending on the construction and the conditions under which the fire develops. Each of the distinct stages of a developing and developed fire carries a specific smoke hazard, which may be at its greatest during a non-flaming combustion stage. The following stages are important and are distinctly different in terms of smoke generation:

- smouldering fires or non-flaming fires
- well ventilated fires or developing flaming fires
- poorly ventilated fires
- post flashover fires

The evaluation of the smoke performance and determination of hazard in a building should take into account the relevant fire scenarios (risk assessment) [6]. Smoke is part of the fire risk assessment. Such an assessment looks at the complete building design and not just at the smoke performance of a building product in a smoke test. FSE is the best route to identify and manage potential risk from smoke, regardless of the type of insulation being used [7].
All organic materials produce smoke (visible and toxic) when burning. The amount produced is not an intrinsic material property, but is dependent on a number of parameters such as the amount and the type of material that is burning, the amount of oxygen available, the stage of the fire development, temperature (see Figure 3), and humidity content. Table 2 shows the visible smoke of polyurethane versus wood and other polymer materials in two different test standards with their specific conditions.

8 M Mann, W Pump, FW Wittecker: A contribution for the estimation of acute toxicity in fires (German), Zeitung für Forschung und Technik im Brandschutz (4/1995)
Smoke from fire is always highly toxic, irrespective of the materials that are burning. Combustion products of all materials include carbon monoxide (CO), carbon dioxide (CO₂) and water. Nitrogen containing materials, such as wool, silk, nylon and PU can also produce hydrogen cyanide (HCN) or nitrogen oxides. Halogen containing materials such as PVC and flame retarded materials can produce hydrogen chloride (HCl) or hydrogen bromide (HBr). Wood and cellulosic materials produce acroleine, which is one of the most toxic components in smoke.

Asphyxiants such as CO and HCN can cause narcotic effects or can even lead to incapacitation or death. A reduced level or lack of oxygen also causes asphyxiants effects. Halogen chlorides and acroleine are irritants. Intoxication can be an additional effect of different significant toxicants.

The dominant toxicant in fires is carbon monoxide (CO), which is produced from any burning organic material. Organic materials give off about 10 to 20 % of their weight in the form of CO when they are involved in a flashover fire. [10]

The chemical composition of the fire load is not the decisive
factor regarding tenability conditions (visibility, heat, toxic hazard) in the fire compartment. Nevertheless a number of comparative tests have been done, and all available test results have demonstrated that there are no distinct differences between synthetics like PUR foam, polystyrene, polyamide, polyvinylchloride, etc. and natural products like wood and wool. The smoke lethality of all materials investigated was in the same range, nitrogen-containing materials included. The influence of temperature and ventilation was comparable for the different materials involved. [11]

It has been shown that a low contribution of a material to the fire is in general more important than the differences in smoke toxicity of the materials. [12]

It should be noted that in common applications the PU insulation is protected and the contribution to fire is likely to be small during the evacuation period.

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FIRE SAFETY ASPECTS TO CONSIDER

- Fire safety assessments need to take into account a wide range of factors, including occupancy and use, not just building construction.
- Compartmentalisation can greatly increase the chances of controlling the spread and magnitude of a fire, but it is also quite possible to have a number of compartments involved, each at different stages of fire development.
- Smoke detectors greatly increase the likelihood of the fire being discovered early, allowing a safe evacuation and also the chances of the fire remaining smaller and being contained.
- Sprinkler systems ensure an early suppression in the developing stage of a fire.
- The time required to evacuate depends on the size and design of the building, and the purpose to which it is put, so for example a nursing home would need to allow for a longer period of evacuation than an office building, and a multi storey building would need longer than a single storey one.
- The Euroclassification of insulation materials is based on tests developed for internal lining products. A broader perspective is needed of insulation fire performance taking account of the context in which it is being used. This is gradually being developed, e.g. façades.
- PU insulation can meet the required standards for most applications.