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Fire safety engineering — Selection of design fire scenarios and design fires — Part 2: Design fires

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Contents

Page

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Foreword

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The committee responsible for this document is ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

ISO 16733 consists of the following parts, under the general title, *Fire safety engineering — Selection of design fire scenarios and design fires*:

— *Part 1: Selection of design fire scenarios*

— *Part 2: Design fires*

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Introduction

This technical specification provides guidance for the specification of design fires for use in fire safety engineering analysis. A design fire is linked to a specific scenario that is tailored to the fire-safety design objective. There can be several fire safety objectives being addressed including safety of life (for occupants and rescue personnel), conservation of property, protection of the environment and preservation of heritage. A different set of design fire scenarios and design fires can be required to assess the adequacy of a proposed design for each objective.

The procedure for the selection of the design fire scenarios is described in ISO 16733-1. The design fire can be thought of as an engineering representation of a fire or a "load" that will be used to determine the consequences of a given fire scenario. The set of assumed fire characteristics are referred to as "the design fire".

It is important that the design fire be appropriate to the objectives of the fire-safety engineering analysis. It should challenge the fire safety systems in a specific built environment and result in a final design solution that satisfies performance criteria associated with all the relevant design objectives.

Users of this standard should be appropriately qualified and competent in the field of fire safety engineering. It is important that users understand the parameters within which specific methodologies may be used.

ISO 23932, General principles, provides a performance-based methodology for engineers to assess the level of fire safety for new or existing built environments. Fire safety is evaluated through an engineered approach based on the quantification of the behaviour of fire and based on knowledge of the consequences of such behaviour on life safety, property, heritage and the environment. ISO 23932 provides the process (necessary steps) and essential elements to design a robust performance-based fire safety program.

ISO 23932 is supported by a set of ISO fire safety engineering standards available on the methods and data needed for the steps in a fire safety engineering design summarized in ISO 23932:2009, Clause 4 and shown in Figure 1. This system of standards provides an awareness of the interrelationships between fire evaluations when using the set of ISO fire safety engineering standards.

Each International Standard includes language in the introductory material of the standard to tie the standard to the steps in the fire safety engineering design process outlined in ISO 23932. Selection of design fire scenarios and design fires form part of compliance with ISO 23932, and all the requirements of ISO 23932 apply to any application of this part of ISO 16733.

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Fire safety engineering — Selection of design fire scenarios and design fires — Part 2: Design fires

1 Scope

This part of ISO 16733 provides guidance for the specification of design fires for use in fire safety engineering analysis of building and structures in the built environment. The design fire is intended to be used in an engineering analysis to determine consequences in fire safety engineering analyses.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9705, *Fire tests — Full-scale room test for surface products*

ISO 13447, *Fire safety engineering — Guidance for use of fire zone models*

ISO 13943, *Fire safety — Vocabulary*

ISO 16730-1, *Fire safety engineering — Assessment, verification and validation of calculation methods — Part 1: General*

ISO 16732-1, *Fire safety engineering — Fire risk assessment — Part 1: General*

ISO 16733-1, *Fire safety engineering — Selection of design fire scenarios and design fires — Part 1: Selection of design fire scenarios*

ISO 16735, *Fire safety engineering — Requirements governing algebraic equations — Smoke layers*

ISO 16737, *Fire safety engineering — Requirements governing algebraic equations — Vent flows*

ISO 23932:2009, *Fire safety engineering — General principles*

ISO 24678-6, *Fire safety engineering — Requirements governing algebraic formulae — Part 6: Flashover related phenomena*

ISO/TS 29761, *Fire safety engineering — Selection of design occupant behavioural scenarios and design behaviours*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 apply.

3.1
design fire
quantitative description of assumed fire characteristics within a design fire scenario

Note 1 to entry: Typically, an idealized description of the variation with time of important fire variables, such as heat release rate and toxic species yields, along with other important input data for modelling such as the fire load density.

3.2
design fire scenario
specific fire scenario on which a deterministic fire safety engineering analysis will be conducted

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Note 1 to entry: As the number of possible fire scenarios can be very large, it is necessary to select the most important scenarios (the design fire scenarios) for analysis. The selection of design fire scenarios is tailored to the fire-safety design objectives, and accounts for the likelihood and consequences of potential scenarios.

3.3
fire scenario
qualitative description of the course of a fire with time, identifying key events that characterise the fire and differentiate it from other possible fires

Note 1 to entry: Adapted from ISO 13943.

Note 2 to entry: The fire scenario description typically includes the ignition and fire growth processes, the fully developed fire stage, the fire decay stage, and the environment and systems that will impact on the course of the fire. Unlike deterministic fire analysis, where fire scenarios are individually selected and used as design fire scenarios, in fire risk assessment, fire scenarios are used as *representative fire scenarios* (3.4) within *fire scenario clusters* (3.5).

3.4
fire scenario, representative
specific *fire scenario* (3.3) selected from a *fire scenario cluster* (3.5) such that the consequence of the representative fire scenario can be used as a reasonable estimate of the average consequence of scenarios in the fire scenario cluster

3.5
fire scenario cluster
subset of *fire scenarios* (3.3), usually defined as part of a complete partitioning of the universe of possible fire scenarios

Note 1 to entry: The subset is usually defined so that the calculation of fire risk as the sum over all fire scenario clusters of fire scenario cluster frequency multiplied by *representative fire scenario* (3.4) consequence does not impose an undue calculation burden.

3.6
target
a person, object or environment intended to be protected from the effects of fire and its effluents (smoke, corrosive gas, etc.) and/or fire suppression effluents

4 Symbols and abbreviated terms

A	area of an opening, m^2
h	height of an opening, m
	rate of mass loss of fuel, kg/s
	rate of entry of air into the enclosure, kg/s
	rate of heat release, kW
r	stoichiometric air requirement for complete combustion of fuel, expressed as the mass ratio of air to fuel
t	time, s
t_g	time required to reach the reference rate of heat release $\dot{Q}_D$, s

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5 The Role of Design Fires in Fire Safety Design

(This section contains a general overview of content and context of this technical specification.)

Design fire specifications play a critical role in fire safety engineering. It is important that the procedures described in ISO 23932:2009 be followed. This will mean that the fire safety objectives and performance criteria are stated and the relevant design scenarios are identified using ISO 16733-1 for the fire scenarios and ISO/TS 29761 for the behavioural scenarios.

Figure 1 from ISO 23932:2009 illustrates the fire safety design process. The specification of design fires will follow the scenario selection step and provide input data for the selected engineering methods. Following identification of the design fire scenarios in accordance with ISO 16733 Part 1, it is necessary to describe the assumed characteristics of the fire on which the scenario quantification will be based. The assumed fire characteristics and the associated fire development over time are generally referred to as the "design fire".

Figure 1 — Flow chart illustrating the fire safety design process and selection of design fire scenarios (Source: ISO 23932:2009)

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(List the different approaches in this section to be described in more detail in subsequent sections).

This technical specification is applicable to design fires that are quantifiable in engineering terms and therefore intended to form part of a deterministic or combined deterministic/probabilistic analysis. A deterministic approach calculating the consequence of individual fire scenarios may also form part of an overriding probabilistic analysis. For example, where Monte Carlo simulation is used to quantify uncertainty using statistical techniques in both inputs and outputs.

This technical specification is also intended to accommodate a range of different analysis methods including use of computational fluid dynamics models (CFD), zone models, or simple hand calculation. Each approach may require different parts of this technical specification to be used. Some calculations may be handled within the analysis model e.g. determining the ventilation limit, or determining effect of suppression systems while simpler analysis methods may require those to be estimated separately. Where computer models are used for the analysis, it is important for the engineer to understand the model limitations and what fire or other phenomenon are and are not included.

The nature of the fire scenario may require the application of selected parts of this technical specification. For example, where the fire scenario predominantly concerns:

- a growing or developing fire - refer to clause 8.
- a smouldering fire - refer to clause 9.
- a fully developed fire affecting structure - refer to clause 10.

Clause 11 covers a number of specific correlations for external fire exposures.

Clause 12 discusses the use of fire tests …

Where analysis involving probabilistic aspects of design fires are envisaged readers should also refer to Clause 0 in additional to the relevant parts of subclause 8-12.

The design fire can include descriptions of the rate of heat release, gas temperature or heat fluxes as well as the yields of smoke and other combustion products. The most important parameter of the design fire is the rate of heat release and different approaches are available to develop a design fire curve for the time-varying rate of heat release from a fire. In general, the main approaches are:

1. To calculate the fire growth and heat release from first principles based on an understanding of the product materials and geometry, chemistry and underlying combustion processes.

   This is generally difficult and may not currently be considered reliable enough for general use in fire safety engineering. It is not discussed further in this Technical Specification.

2. To construct composite heat release rate curves from the individual components.

   This is more applicable when information is known regarding the exact contents and their arrangement within the built environment. This requires consideration and estimation of fire spread from the ignition source to other nearby items and the relevant timeline for this to occur.

3. To assume a generalised heat release rate curve (e.g. t2 fire).

   This may include a representative fire growth rate for different well-defined occupancies. This could be based on experimental data. It does not require fire spread from individual items to be assessed and is therefore very simple to apply. This approach may be prescribed in some codes of practice (see **Erreur ! Source du renvoi introuvable.**).

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Initially, the engineer should determine the design rate of heat release curve, without intervention, as would apply if the fire were allowed to develop in well ventilated open-air conditions. Interventions result in a potential change in the course of the fire. They could include:

- Manual fire-fighting actions by occupants or by trained fire-fighters
- Automatic or manually operated fire suppression systems
- Restricted ventilation or changes in ventilation during the course of the fire (e.g. glass breaking).
- Burning enhancement due to thermal feedback from the hot gases and enclosure surfaces to the fuel surface

The selected approach will depend on what is known about the fire scenario and the items involved. The method of analysis may also determine the approach being dependent of what input information is available.

A complete description of the design fire from ignition to decay is estimated using the specified initial conditions and a series of simple calculations to estimate parameters such as the sprinkler activation time, transition to flashover and duration of any fully developed burning.

Alternatively, the design fire can be a combination of quantified initial conditions and subsequent fire development determined iteratively or by calculation using more complex models that account for phenomena such as transient effects of changing ventilation on smoke production or thermal feedback effects from a hot layer to the fuel surface.

As with the design fire scenario, it is important that the design fire be appropriate to the relevant fire-safety objectives. For example, if safety of life is an objective, and the built environment includes a smoke control system, a design fire should be selected that challenges the smoke control system. If the severity of the design fire is underestimated, then the application of engineering methods to predict the effects of the fire can produce results that do not accurately reflect the true impact of fires and can underestimate the hazard. Conversely, if the severity is overestimated, unnecessary expense can result.

6 Considerations based on methods of analysis

It is common for fire models to include some of the dynamic changes and stage transitions expected over the duration of the fire. For example, when a fire model constrains the rate of heat release within a compartment to match the available oxygen supply. Other dynamic effects may not be included such as fracture and fallout of glazing within the compartment walls. The engineer is required to assess which elements of the design fire are required for a specific analysis allowing for those predicted by the fire model as well as those required as input to the model.

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Whereas most advanced models require the rate of heat release of fire as input to a calculation of the enclosure temperature or other fire properties, there is a class of models that is simpler in nature and requires less sophisticated input data. For example, the parametric fire curves for post-flashover fires discussed in subclause **Erreur ! Source du renvoi introuvable.** do not require estimates of the rate of heat release of the fire as input. Instead, the temperature is predicted directly, employing simpler information, such as the geometry of the enclosure and its ventilation openings, the thermal properties of room lining materials and the fuel load.

7 For a given design fire scenario, the parameters determined in subclause 8 can be employed to predict the temperature/heat flux evolution versus time and the associated effluents using various calculation methods ranging in their complexity from simple to advanced. In addition, it should be recognized that there may be some specific situations where it is necessary to use prescribed fires, not necessarily representative of the actual risk, in addition to the design scenarios identified.Elements of a Design Fire

7.1 General

Fire can grow from ignition through to a fully developed stage and finally decay and eventual extinction. The design fire is described by the values of variables, such as the rate of heat release and yield of combustion species, over the life of the fire.

A full specification of a design fire (see Figure 1) can include the following phases:

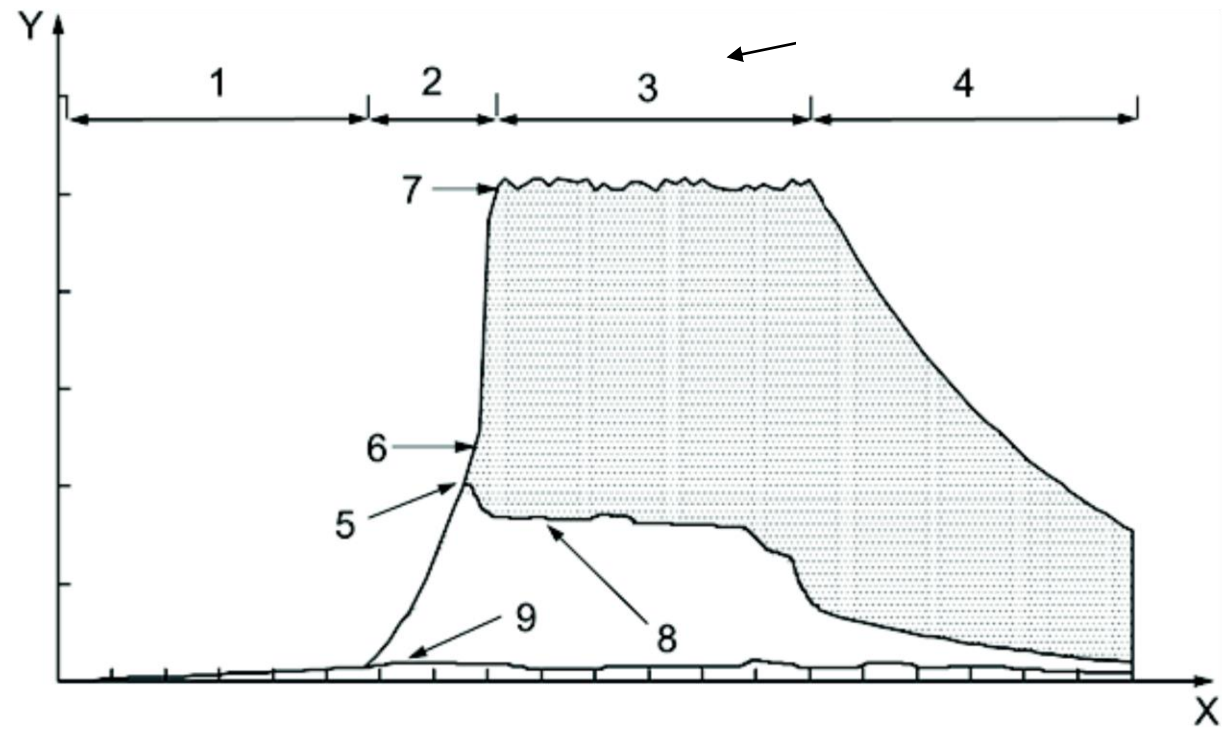
— incipient phase: characterized by a variety of sources, which can be smouldering, flaming or radiant;

— growth phase: covering the fire propagation period up to flashover or full fuel involvement;

— fully developed phase: characterized by a substantially steady burning rate

— decay phase: covering the period of declining fire severity;

— extinction: when there is no more energy being produced.



Key

X	time	5	sprinkler activation
Y	heat output	6	flashover
1	incipient	7	ventilation-controlled
2	growth	8	sprinkler-controlled
3	fully developed	9	smouldering
4	decay		

Figure 1 — Example of design fire

Design fire characteristics can be subsequently modified based upon the outcome of the analysis. For example, if the single-item fire grows sufficiently intense that flashover in an enclosure is likely, it is necessary to modify the design fire to reflect the characteristics of a ventilation-controlled or fuel-bed-controlled fully-developed fire. Similarly, events such as sprinkler activation and window breakage design fire.

— parameters provided by the design-fire scenario (size of the room, location of the fire, combustible material under consideration, …);

— parameters required to the fire development (rate of heat release and other parameters depending on the assessment model to be used);

— events that result in a change in any of the above parameters.

Design fires are usually characterized in terms of one or more of the following variables with respect to time (as needed by the fire safety objective(s) and consequently by the analysis):

— heat release rate;

— combustion product species generation rate;

— smoke production rate;

— flame height/volume;

— burning area;

— temperature/heat flux.

7.2 Rate of fire growth

The factors determining the characteristic rate of fire growth for flaming fires include the following:

— nature of combustibles;

— geometric arrangement of the fuel;

— geometry of the enclosure;

— ignitability of the fuel;

— ventilation;

— external heat flux;

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— exposed surface area (and surface area to mass ratio).

The initial rate of fire growth is subsequently modified by events that occur during the design fire scenario. These events can modify the heat release rate and smoke generation rate of the fire either positively or negatively. Typical events and their effects are the following:

— flashover	transition to a state of full involvement in the fire compartment;
— low hot layer interface	acceleration;
— sprinkler activation	steady or declining;
— manual fire suppression	steady or declining;
— fuel exhaustion	decay;
— changes in ventilation	transition between fuel control and ventilation control
— flaming debris	subsequent ignition(s) of other items.

It is important that a determination of the rate of initial fire growth includes these aspects. Fire models are available that can predict rate of fire growth on simple fuel geometries under defined conditions. Experimental data are also available [1] [2] to assist in the determination of rate of fire growth on typical fuel packages.

Further guidance on determining the fire growth rate and rate of heat release for single or multiple fuels is given in subclause 8.3, and for power law design fire curves in subclause 8.3.4.

7.3 Flashover

Flashover is the rapid transition from a localized fire to the involvement of all exposed surfaces of combustible materials within an enclosure. It occurs somewhat commonly in small and medium size enclosures. In large volume compartments flashover may not occur. In these cases, the fire could either remain localised or progressively spread to adjacent fuel (travelling fires). Depending on the purpose of the assessment, such non-uniform fires may also need to be selected as a complementary design fire (see for example section 10 on structural design fires).

The effect of flashover on the design fire is to modify the heat release rate and other characteristics to those appropriate to a fully developed fire. This may include changes in the yields of species generated by the fire. For example, the rate of generation of carbon monoxide and soot will increase as the combustion environment becomes ventilation-limited.

Further guidance on determining the time for the occurrence of flashover is given in subclause 8.3.5.

Species yields are discussed in clause 9.

7.4 Fully developed fires

Typically following flashover, fires tend to rapidly reach a fully developed stage where the rate of heat release is a maximum and is limited either by the fuel or the available ventilation.

The ventilation-controlled rate of burning in a compartment can be determined from consideration of air/oxygen flowing into the compartment, whereas the burning rate of fuel-bed-controlled fires is dependent upon the nature and surface area of the fuel.

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The duration of burning will be mainly dependent on the amount of fuel available and the rate at which it can be .

Further guidance on determining the maximum rate of heat release and the duration of burning is given in subclause 1.1 and subclause 8.7 respectively.

7.5 Events that change a design fire

7.5.1 Suppression systems

Suppression systems, if installed, could be either automatically or manually operated. Suppression systems can operate at any time during the fire but are normally expected to operate during the pre-flashover stage. Depending on the type of suppression system and other circumstances the fire may be affected in one of the following ways:

a) Fire continues to grow at a reduced rate;

b) Fire growth stops and the heat release rate remains constant;

c) Fire growth stops and the heat release rate decreases.

The performance of a suppression system can be affected by factors, including the height of installation, particularly for sprinkler systems. There could be shielding of the combustibles from the suppression agent, and the volume of the compartment and location and size of ventilation openings including leakage paths could be important, particularly for gaseous fire suppression systems.

The heat-release rate following activation of a sprinkler system can be taken as remaining constant, unless it can be demonstrated that the sprinkler system has been designed to suppress the fire within a specified period. In the latter case, the heat-release rate can be assumed to decrease in a linear manner over the specified period.

Similarly, activation of a total flooding gaseous fire suppression system designed in accordance with the relevant ISO or national standard can be assumed to suppress the fire soon after the design concentration of extinguishing agent has been reached.

Further guidance on determining the effect of suppression systems on the design fire curve is given in subclause 8.6.1.

7.5.2 Intervention by fire services

The fire services may intervene at any time during the development of the fire, but it is likely that they can control the fire only if it is within the capabilities of the appliances in attendance. The effect of the fire services on the fire will be dependent on factors such as the means of notification of the fire, the location and distance of the built environment from fire stations, the resources available to the fire services, site access conditions and adequacy of the water supplies. It is important that the design fire challenges the capability of fire services to carry out rescue and firefighting activities and therefore it may differ from other design fires intended to challenge other fire safety systems. For example, a longer fire growth stage can result in more challenging conditions at the time of fire service arrival compared to a fire that is in decline. It can also be necessary to consider the effect of the fire on fire services personnel to assess their effectiveness in carrying out rescue or fire-fighting activities.

Further guidance on determining the effect of intervention by fire services on the design fire curve is given in subclause 8.6.2.

7.5.3 Changes in ventilation

[6–8]

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Further guidance on determining the effect of changes in ventilation on the design fire curve is given in subclause 8.6.3.

7.5.4 Enclosure effects

Fire growth rates can be influenced by thermal feedback from the flames, hot gases and other surfaces to the surface of the fuel. Care is required interpreting fire test data which is often obtained under well ventilated open burning conditions and therefore relevant to large well-ventilated rooms (compared to the size of the fire). In smaller confined enclosures, radiation feedback to the fuel may accelerate the fire growth and increase the mass loss rate and total heat release rate from the fuel. Conversely under conditions where the combustion products mix with the incoming vent flow and reduce the oxygen concentration in the air feeding the flame the mass loss rate may reduce.

Further guidance on determining the effect of the enclosure on the pyrolysis of the fuel is given in section 8.6.4.

7.6 Decay

When most of the fuel in an enclosure has been consumed, or when the fire fails to spread to adjacent items, the rate of burning will eventually decrease.

In the absence of specific information, the heat-release rate of the design fire may be taken to commence decay when 80 % of the available fuel has been consumed. The rate of decay may be taken as a linear decline over a time period such that the integral of the heat release rate over the decay period equals the 20 % of remaining energy in the available fuel.

Further guidance on determining the decay part of the design fire curve is given in subclause 8.8.

8 Constructing a design fire curve

8.1 Procedure

A design fire curve for the rate of heat release should be constructed using the following procedure.

Step 1 – identify relevant parameters provided by the design fire scenario.

Step 2 – identify an appropriate rate of heat release for the first item ignited. Either use data for individual items or use a general power law growth rate appropriate to the situation. If using individual item data, determine if and when other items ignite and develop a composite design fire curve.

Step 3 – determine flashover occurs.

Step 4 – determine the maximum rate of heat release based on the available ventilation and the configuration of fuel.

Step 5 – modify the design fire curve if events occur that impact on the fire development (eg. sprinkler activation, barrier or glazing failure, manual fire-fighting etc).

Step 6 – determine the duration of burning until the start of the decay stage.

Step 7 – determine the duration of the decay period and time of extinguishment (when the fuel is totally consumed).

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8.2 Step 1 - Parameters provided by the design fire scenario

Design fire scenarios can be determined from the application of ISO 16733-1.

For each of the design scenarios identified, a specific location(s) in the room or major space will also be identified for that scenario. The most likely location can be identified through fire risk assessment or inferred by engineering judgment from the typical locations of the already-identified initial fuel items. The most challenging location will be one where special circumstances adversely affect the performance of fire safety measures. Examples include the following:

— locations very close to room occupants (sometimes referred to as "intimate with ignition"), particularly vulnerable property, or exposed structural elements (for example, in a parking garage), such that there is insufficient time and space for fire safety measures to act effectively;

— locations in corners or other spaces where partial enclosure leads to an enhanced fire growth rate;

— locations that are shielded from fire-safety systems, or where the performance of fire safety systems may be adversely affected by the spatial configuration of the built environment, e.g. spaces with a significant ceiling height;

— locations near doorways or other openings connecting spaces, that permit fires to spread to multiple spaces before compartmentalization provisions can effectively respond.

8.3 Step 2 - Fires involving single or multiple fuels

8.3.1 General

When the fuel package for the design fire scenario is well defined and unlikely to change over the design life of the built environment, then the actual burning characteristics of the fuel package can be used as the design fire.

The heat-release characteristics for a range of common items have been determined by a number of laboratories using apparatus such as the furniture calorimeter or oxygen consumption based calorimetry [9-11]. These measurements are generally undertaken by burning the object under an instrumented hood under well ventilated conditions. It should be noted that the rate of fire growth on objects such as upholstered furniture in actual fires within an enclosure can readily exceed that determined under free burning conditions in the open (such as under a hood). The preheating and radiation feedback from the hot layer can enhance the fire growth rate and possibly lead to under ventilated fires with increased smoke and toxic species production. See subclause 8.6.4.

The design fire can be based on the actual burning characteristics of a reference fuel package if it can be demonstrated that

— the fire characteristics are unlikely to be exceeded during the design life of the built environment by the actual fuel package (or the probability of exceedance is acceptability small),

— the conditions under which the fire characteristics have been determined are representative of the conditions likely to exist during the design fire scenario being analysed,

— fire is unlikely to spread to other fuel packages that have not been considered.

8.3.2 Develop design fire curve for first item

8.3.3 Ignition of other items

To be written

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8.3.4 Power law design fire curves

Most fires that do not involve flammable liquids, gases or light-weight combustibles such as polymeric foams grow relatively slowly at first. As the fire increases in size, the rate of fire growth accelerates. This rate of fire growth is generally expressed in terms of an energy-release rate. For design purposes an exponential or power-law rate of energy release is often used. This should represent an upper bound to the large range of possible, actual fire growth rates in the scenario. The most commonly used relationship is what is known as a "t^2 fire" with a power law coefficient n=2. In such a fire, the rate of heat release is given by Formula (2):

$$\dot{Q}(t) = \alpha t^2, \quad 0 \leq t < t_{grow} \tag{2}$$

where:

$\alpha =$ fire growth coefficient (kW/s²)

$t =$ time (s)

$t_{grow} =$ time at which the heat release rate reaches a maximum value (s)

$\dot{Q}(t) =$ heat release rate (kW)

t^2 fires can lead to values that exceed the maximum possible rate of heat release from the fuel within a given compartment, therefore the maximum value of $\dot{Q}$ for rate of heat release within a compartment should be limited by $\dot{Q}_{max}$, which is the lower of the values established for ventilation- or fuel-bed-controlled fires. Furthermore, in large fuel beds, the fuel first ignited can be burnt out before the last part of the fuel package is ignited. These factors should be considered.

Four categories of fire growth rate are commonly used in fire safety engineering, as indicated in Table 1. Readers should be aware that, depending on the exact composition and configuration of the fuel, there could be a range of possible growth rates

Table 1 - Typical fire growth categories of various fuel types

Fuel type examples	Fire growth category	Alpha (kW/s^2)
Upholstered furniture or stacked furniture against combustible linings; lightweight furnishings; Packing materials in piles; non-FR retarded plastic foam storage; cardboard or plastic boxes in stored vertically	Ultrafast	0.19
Bedding; displays and padded workstation partitioning	Fast	0.047
Office furniture; shop counters;	Medium	0.012
Floor coverings	Slow	0.003

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Design fire scenario	Category
Upholstered furniture or stacked furniture near combustible linings	Ultra fast
Light-weight furnishings	Ultra fast
Packing material in rubbish pile	Ultra fast
Non-fire-retarded plastic foam storage	Ultra fast
Cardboard or plastic boxes in vertical storage arrangement	Ultra fast
Bedding	Fast
Displays and padded work-station partitioning	Fast
Office furniture	Medium
Shop counters	Medium
Floor coverings	Slow

Fire growth rate	α-valu (NFPA
Slow	0,003
Medium	0.012
Fast	0.047
Ultra-fast	0,19
tα is defined as the tim NOTE: The designer s The fire growth rate to l	

It is necessary that the selection of the appropriate category for a scenario the factors described above. Considerable engineering judgement is required in selecting the appropriate category of fire growth.

For well-defined design fire scenarios, where the geometric arrangement of the fuel is known, selection of the category can be based on experimental data or numerical simulation using an appropriate flame spread model.

Guidance on the rate of fire growth in stored goods may also be obtained from NFPA 204 [12] and SFPE Handbook [13]].

8.3.5 Wall and ceiling linings

Combustible wall and ceiling linings have the potential to significantly increase the rate of fire growth and the potential for flashover within an enclosure and this should be considered. It is common to assume an ignition source located within a corner as it represents a more severe exposure to the adjoining wall surfaces producing a longer flame. If the corner flame reaches the ceiling it may spread radially outward from the corner and spread across the ceiling.

The burning characteristics of wall and ceiling lining materials may be determined using the ISO 9705 room fire test.

8.4 Step 3 – Flashover

8.4.1 General

The general criteria for assuming the occurrence of flashover within an enclosure or room are the following: [17-18]

— 15 to 20 kW/m^2 for radiation flux from a hot upper gas layer to the floor;

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— 500 °C to 600 °C for the temperature in the upper layer of gases is normally sufficient to generate the radiation flux required and is a simpler criterion.

These conditions are usually enough to increase the rate of surface flame spread and to ignite common combustible materials in a short time [19].

4

8.5 Step 4 – Maximum heat release rate

To be edited and added to.

The transition from a fuel-bed controlled regime to a ventilation-controlled regime occurs approximately as given by Formula (C.1):

$$\dot{m}_{\mathrm{f}} \gg \frac{\dot{m}_{\mathrm{air}}}{r} f \quad \mathrm{kg/s} \qquad \text{(C.1)}$$

More specific criteria have been developed for particular fuels such as burning timber cribs.[7]

In determining structural response, post-flashover fires are characterized in terms of fire-gas temperatures. The convective and radiative heat transfer characteristics of the environment can also have a major impact on the heating of structural members and bounding elements of enclosures and it is important to select them carefully.

WHAT ABOUT FUEL-BED CONTROLLED FIRE?

8.5.1 Fuel-bed controlled fires

To be edited and added to.

Fuel-bed-controlled fires occur less frequently than ventilation-controlled fires and can be expected only in particular situations, such as storage-type occupancies with a high level of ventilation or fuel configurations where surface of combustibles is limited in respect to the volume of the enclosure.

The burning rate of fuel-bed-controlled fires is dependent upon the nature and surface area of the fuel. In most practical applications, these factors are difficult to determine. For simple, well defined geometries such as timber cribs, relationships have been developed relating fuel pyrolysis rate to initial fuel mass per unit area and the remaining fuel mass per unit area. [5]

The maximum heat release rate for a fuel-controlled fire can be estimated from either:

— full scale tests where the peak heat release rate can be directly measured; or

— small scale tests to determine the heat release rate per unit area for the product or material in question. The maximum heat release rate is then given by:

$$\dot{Q}_{max} = \dot{Q}'' \ A_f \qquad (4)$$

where

$\dot{Q}_{max}$ maximum heat release rate (kW)

$\dot{Q}''$ heat release rate per unit area (kW/m^2)

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A_f horizontal burning area of the fuel (m^2)

If the mass loss rate per unit area data is provided, the maximum heat release rate is given by:

$$\dot{Q}_{max} = \dot{m}'' \ A_f \, \Delta H_{eff} \quad (5)$$

$$\Delta H_{eff} = \chi \, \Delta H_c$$

where

$\dot{m}''$ mass loss rate per unit area (kg/s/m^2)

ΔH_{eff} effective heat of combustion (kJ/kg)

ΔH_{eff} is given by:

$$\Delta H_{eff} = \chi \, \Delta H_c \quad (6)$$

where

χ combustion efficiency (-)

ΔH_c chemical heat of combustion (kJ/kg)

Heat release rate per unit area or mass loss rate per unit area data may be measured with negligible radiation feedback from the surroundings. These effects may need to be should be considered as discussed in subclause 8.6.4.

Where multiple items are present, adding the respective maximum heat release rates per unit for all products and assuming all items are burning at the same time provides a conservative estimate of the maximum rate of heat release.

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If peak heat release rates have been measured in full-scale tests for the products in question, calculating the peak heat release rate for the fuel-controlled fire is an easy task. It is simple derived by looking at the peak heat release rates for each product and adding them to a total peak heat release rate, provided that all fuels are assumed to reach its peak release rate at the same time. If some of the fuel has reached its decay stage, this must be taken in consideration. The conditions during the fire test must also be similar to the conditions in the design fire scenario, see Chapter 7 for more information in that subject.

The peak heat release rate for the fuel-controlled fire can also be estimated by looking at values for heat release rates per unit area, HRRPUA, for the product in question and by estimating the maximum area of the fire. The peak heat release rate is then given by:

$$\dot{Q} = \dot{Q}'' A_f \tag{10.8}$$

where:

$\dot{Q}$ = total heat release rate [kW]
$\dot{Q}''$ = heat release rate per unit area [kW/m²]
A_f = horizontal burning area of the fuel [m²]

Sometimes the mass loss rate per unit area is given for the fully involved combustible, the peak release rate can then be estimated by:

$$\dot{Q} = \dot{m}'' A_f \Delta H_{eff} \tag{10.9}$$

where:

$\dot{Q}$ = total heat release rate [kW]
$\dot{m}''$ = mass loss rate per unit area [kW/m²]
A_f = horizontal burning area of the fuel [m²]
ΔH_{eff} = effective heat of combustion [kJ/kg]

Limits: Values for heat release rate per unit area and mass loss rate per unit area is usually given for fully involved combustible assuming negligible radiative feedback from the surroundings. Thus, when using Equation (10.8) and Equation (10.9), influences from a possible hot gas layer must be taken under consideration.

ΔH_{eff} is given by [22]:

$$\Delta H_{eff} = \chi \Delta H_c \tag{10.10}$$

where:

χ = combustion efficiency [-]
ΔH_c = complete heat of combustion [kJ/kg]

8.5.2 Ventilation-controlled fires

The ventilation-controlled rate of burning in a compartment can be determined from consideration of air flowing into the compartment. Research has indicated [6] that the rate of air flow into a fire compartment is proportional to the ventilation factor, $A\sqrt{h}$.

The mass rate of fuel burning can then be estimated from the combustion reaction under ventilation-controlled conditions the fuel/air ratio is greater than the stoichiometric ratio. The energy release rate can be determined [7] from consideration of the effective heat of combustion of the fuel.

The above approach based on the ventilation factor underestimates fire severity in compartments with separate ventilation openings at floor and ceiling levels. It also might not be appropriate for large compartments.

The maximum heat release rate may either be determined based on the available ventilation or a pre-defined maximum value based on literature, experiments or as specified in national regulations.

The ventilation-controlled heat release rate for a single compartment can be estimated from the following formula:

$$\dot{Q}_v = 1500\, A_o \sqrt{h_o} \tag{7}$$

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Where:

$\dot{Q}_v =$ ventilation-controlled heat release rate (kW)

$A_o =$ sum of the area of all openings (m^2)

$h_o =$ average height of openings (m)

For more complicated arrangements (e.g. connected compartments) where equation 7 is not valid the ventilation-controlled heat release rate may instead be derived from the available oxygen in the compartment.

8.5.3 Mechanical ventilation

To be written.

8.6 Step 5 - Modifying the design fire curve

8.6.1 Suppression systems

To be edited and added to.

When a fire sprinkler system is installed, the rate of heat release may be adjusted to account for the effect the sprinkler system has on the heat release rate of the fire. It is important however, that the fire sprinkler system is designed, installed and maintained in a manner appropriate to the occupancy and fuel sources in the building and that it complies with the relevant national standards.

The maximum rate of heat release can generally be taken as the heat release of the fire when the sprinkler activates. The response time for a sprinkler should be determined assuming the rate of heat release for the growing fire as described in subclause 6.1.2. Computer models are available to calculate sprinkler response time.

Following activation of the sprinkler, the rate of heat release should remain constant.

If a building is equipped with a fire sprinkler system, the designer could use a sprinklered design fire which reflects the effects the sprinklers have on the HRR.

NOTE: The performance of sprinkler systems should be verified by EN 12845 (conventional sprinkler systems) or INSTA 900 (residential sprinkler systems).

Design fire when sprinkler activates at a heat release rate of **less than 5 MW**:

- The heat release rate remains constant for 1 (one) minute.
- During the next one minute, the heat release rate decreases linearly to one-third of the heat release rate at the time of sprinkler actuation.
- The heat release rate is kept constant at this level in order to reflect the fact that the system does not always completely put out the fire.

Design fire when sprinkler activates at a heat release rate of **more than 5 MW**:

- The heat release rate should remain constant at the time of sprinkler activation.

8.6.2 Fire service intervention

To be written.

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8.6.3 Changes in ventilation

8.6.4 Enclosure thermal feedback effects

8.7 It should be noted that the rate of fire growth on objects such as upholstered furniture in actual fires within an enclosure can readily exceed that determined under free burning conditions in the open (such as under a hood). The preheating and radiation feedback from the hot layer can enhance the fire growth rate and possibly lead to under ventilated fires with increased smoke and toxic species production.

8.7 Step 6 - Fire duration and decay

8.7.1 Duration of the fire growth stage

Using the heat release rate for the growing fire described in subclause 6.1.2 and the maximum heat release rate from subclause 6.1.34, the duration of the growing fire stage for a "t^2 fire" can be given as:

$$\tau_{grow} = \sqrt{\frac{\dot{Q}_{max}}{\alpha}} \ \text{(s)}$$

The mass of fuel burned during the growth phase may be calculated as:

$$m_{growth} = \frac{\int_{\tau_0}^{\tau_{grow}} \dot{Q} \, d\tau}{H_{eff}}$$

Duration of the steady burning stage

To be edited and added to.

[use fire load energy density values with the area under the HRR curve to work out the duration.]

The duration of the steady burning stage may be calculated as:

$$\tau_{steady} = \frac{0.8(m_{total} - m_{growth})}{\dot{Q}_{max}/H_{eff}}$$

8.8 Step 7 - Decay

To be edited and added to.

Something can be done with the remaining fuel calculated as $0.2(m_{total} - m_{growth})$

9 Species production

9.1 Smouldering fires

A smouldering fire typically produces very little heat but can, over a sufficiently long period, fill an enclosure with unburned combustible gases, toxic products of combustion such as carbon monoxide and soot. Entrainment into these smouldering fires is low, resulting in high rates of release of smoke and toxic species per unit of mass burned. [17][10]

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The following factors affect the likelihood of onset of smouldering combustion:

— nature of the fuel;

— limitation on ventilation;

— strength of the ignition source.

Smouldering fires can readily transform into flaming fires, particularly when ventilation is increased. Smouldering fires can also readily transport fire from the initial fire location to another place, for example through wood beams included in plaster walls.

The principal hazard associated with smouldering fires is the production of carbon monoxide as a result of incomplete combustion. The development of untenable conditions due to poor visibility is also a significant hazard that it is important to consider in the analysis, particularly in residential occupancies.

There are at present no quantitative methods available for the prediction of potential for smouldering. It is important that consideration be given to the presence of materials that are prone to smouldering such as upholstered furniture, bedding and cellulosic materials (particularly those treated with chemicals). It is also important that consideration be given to the presence of potential ignition sources capable of promoting smouldering, such as cigarettes, hot objects and electrical sparks.

may be calculated asThe mass loss rate for a smouldering fire may be calculated as: [18][11]

$$\dot{m}_s = \begin{cases} 0.1t + 0.0185t^2, & 0 < t < 60 \\ 73 & 60 \leq t \leq 120 \end{cases}$$

Where:

$\dot{m}_s =$ mass loss rate for smouldering combustion (g/min)

$t =$ time (min)

9.2 Species yields

To be edited and added to.

See reference [2]

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Table 10.6. Suggested yield values for different types of occupancies [13].

Occupancy	Yield of species [kg/kg]	
	y_{CO}	y_{soot}
Offices, schools, hotels and nursing homes etcetera	0.01	0.03
Dwellings, shopping centres, entertainment centres	0.02	0.06

Table 10.7. Suggested yield values for different types of fires.

Fire type	Yield of species [kg/kg]			
	y_{CO}	y_{CO_2}	y_{O_2}	y_{soot}
Post-flashover, primary wooden fuels	0.3 [22]	1.1 [22]	0.9 [22]	-
Enclosure fires, involving materials such as computer consoles, TV monitors, electric cables, padded chairs.	0.2 [22]	1.5 [22]	1.8 [22]	-
Smouldering fire	0.50 [13]	-	-	0.15 [13]

Table 10.8. Suggested yield of soot for different types of material [17]. Yields are for well-ventilated conditions [17].

Material	Yield of soot, y_{soot} [kg/kg]	
	Flaming	Smouldering
Cellulosic	<0.01-0.025	0.01-0.17
Plastics	<0.01-0.17	<0.01-0.19

10 Design fires for structural fire engineering

10.1 General

An overview of the most commonly used design fires (noting that the review is not exhaustive) for the purposes of structural fire analysis will be presented. This section only describes fire scenarios/models that are relevant to the conventional building environment (office, residential, stadiums, arenas etc). As a result, different types of fires that could occur in other structures in the built environment such as tunnels, bridges etc are not covered here.

For zone and CFD models, the reader is directed to the relevant literature [REF Karlsson, Quintiere, other refs] since they are outside the scope of the current document.

10.2 Localised fires

A localised fire can be considered where flashover is unlikely to occur and a travelling fire is not possible. Depending on the fire size and the dimensions of the compartment, a localised fire may or may not impinge on the ceiling of the compartment. Various localised fire models have been published in the literature. Currently, the most widely used are those of EN1991-1-2:2001 to determine when flames do not (such as a bin fire in an airport or an open air fire) and when they do impinge the ceiling (such as in a car park). These models have been derived from experimental tests and therefore are semi-empirical.

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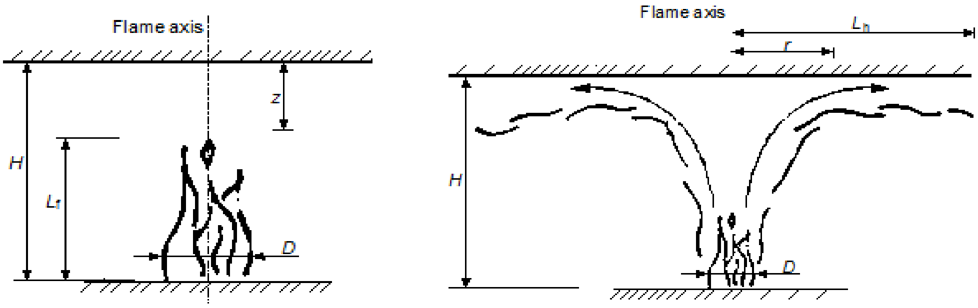

FigureXXX. Flame does not impinge the ceiling (left), flame impinges the ceiling (right)

10.2.1 Flames not impinging the ceiling

For fires not impacting the ceiling of a compartment, the following calculation model can be used Note that the output of the method is temperatures rather than heat fluxes.

The flame height can be calculated as:

$$\mathrm{L_f} = -1.02\mathrm{D} + 0.0148\ \mathrm{Q}^{2/5}$$

Where:

D is the diameter of the fire (m)

Q is the total rate of heat release of the fire (W)

In this case, the temperature in the plume along the vertical flame axis is given as:

$$\Theta_{(\mathrm{z})} = 20 + 0.25\ \mathrm{Q}_c^{2/5}(\mathrm{z} - z_0)^{-5/3} \leq 900°\mathrm{C}$$

With:

$$z_0 = -1.02\ \mathrm{D} + 0.00524\ \mathrm{Q}^{2/5}$$

Where:

Q_c is the convective part of the rate of heat release (W), typically between $0.66Q\ to\ 0.8Q$ (EN1991-1-2 suggests the use of 0.8);

Z is the height along the flame axis (m);

z_0 is the virtual origin of the axis (m).

Note that EN1991-1-2 puts limitations to the use of the method, the diameter of the fire D ≤ 10 m; and the rate of heat release of the fire Q ≤ 50 MW.

10.2.2 Flames impinging the ceiling

The following model can be used to determine the heat flux received by the surface area at the ceiling level when flames impact the ceiling. This heat flux often needs to be converted to temperature for structural fire purposes. The model does not consider the ceiling jet temperatures.

The horizontal flame length, L_H, can be determined as:

$$\mathrm{L}_H = (2.9H(Q_H^*)^{0.33}) - H$$

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With:

$$Q_H^* = \frac{Q}{1.11 \times 10^6 \mathrm{H}^{2.5}}$$

Where:

L_H is the horizontal flame length (m);

H is the distance between the fire source and the ceiling (m);

Q_H^* is a non-dimensional rate of heat release;

Q is the total rate of heat release of the fire (W).

The heat flux q''' (W/m²) received at a distance r from the flame axis at ceiling level can be determined as:

$$q'' = 100{,}000 \text{ for } y \leq 0.30$$

$$q' = 136{,}300 \; to \; 121{,}000y \text{ for } 0.30 < y < 1.0$$

$$q' = 15{,}000y^{-3.7} \text{ for } y \geq 1.0$$

With:

$$y = \frac{r + H + z'}{L_h + H + z'}$$

Where:

r is the horizontal distance from the vertical flame axis to the point along the ceiling where the thermal flux is calculated (m);

z' is the vertical position of the virtual heat source as given in Annex C of EN1991-1-2;

The net heat flux at ceiling level, hq'''_{net}, can be determined as:

$$-\Phi \varepsilon_m \varepsilon_f \sigma[(\theta_m + 273)^4 - 293^4]$$

Where:

α_c is the convective heat transfer coefficient as provided in EN1991-1-2;

ε_f is the emissivity of the fire;

ε_m is the surface emissivity of the member;

Φ is the configuration factor;

θ_m is the surface temperature of the member (°C);

σ is the Stephan Boltzmann constant.

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10.3 Parametric fires

One of the most popular post-flashover design fire models used in structural fire engineering is the EN1991-1-2 parametric fires based on the concept of heat balance inside a compartment and that the fire depended on the ratio of the opening factor to the thermal inertia of the compartment boundary.

The method assumes that a post-flashover fire will develop in a compartment (i.e. temperatures will be relatively uniform) and that the fire is ventilation controlled (instead of fuel controlled) and that the fire lasts as long as fuel is still available within the compartment (burnout). The parametric fire model takes into account the compartment size, fuel load, ventilation conditions and the thermal properties of compartment walls and ceilings.

As a result, the parametric curves are applicable when the flow of hot gases in and out of the enclosure is controlled by openings (vents) in the walls of the enclosure. Hence they are not applicable to enclosures with significant flow through horizontal openings in floors or ceilings.

EN1991-1-2 limits the application of the parametric fires to compartments with a floor area of up to 500m2, without openings in the roof, a maximum compartment height of 4m and compartments with mainly cellulosic type fire loads. There are also limits on the thermal absorptivity of the enclosure surface, opening factor and the fire load density. Additionally, the parametric fire curves are limited to compartments with cellulosic fuels

The EN1991-1-2 parametric fire curves have two distinct phases:

1) A heating phase where the gas temperature will rise with the increase of time.

2) A cooling phase. A linear slope is assumed for the cooling phase of the fire.

10.3.1 Heating phase

During the heating phase of a fire, the parametric fire curve is given by

$$\Theta_g = 20 + 1325\,(1 - 0.324e^{-0.2t'} - 0.204e^{-1.7t'} - 0.472e^{-19t'})$$

The parametric time (in hours) is given as:

$$t' = t\,\Gamma$$

With:

$$\Gamma = \frac{(O/b)^2}{(0.04/1160)^2}$$

In case of $\Gamma = 1$ the equation approximates the standard temperature-time curve.

The thermal inertia of linings (for an enclosure surface with single layer of material) can be given as:

$$b = \sqrt{\rho_b c \lambda}$$

with the following limits: $100 \le b \le 2200$ $J/m^2s^{1/2}K$

The density ρ_b, the specific heat c and the thermal conductivity λ of the boundary may be taken at ambient temperature.

When multiple materials are present in an enclosure, the thermal inertia of the enclosure is determined by considering the combined effect of different thermal inertia in walls, ceiling and floor (see BS EN 1991-1-2 for more details).

$$b = \frac{\Sigma b_j A_j}{A_t - A_v}$$

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The opening factor O, can be determined as:

$$O = \frac{A_v \sqrt{h_{eq}}}{A_t}$$

with the following limits: $0.02 \le O \le 0.20 m^{1/2}$. Note that National application documents of different countries in Europe may sometimes amend these values.

10.3.2 Heating duration and maximum temperature

The maximum temperature Θ_{max} in the heating phase happens for $t' = t'_{max}$

$$t'_{max} = t_{max}\, \Gamma$$

With $t_{max} = \max[(0.2\ 10^{-3} q_{t,d}/O); t_{lim}]$

$$q_{t,d} = q_{f,d}\, A_f\, /\, A_t$$

With the following limits $50 \le q_{t,d} \le 1\,000$ (MJ/m²).

Where $q_{f,d}$ is the design value of the fire load density related to the surface area of the floor, A_f, as provided in Annex E of BS EN 1991-1-2.

Where t_{lim} = 25 min in case of slow fire growth rate, 20min in case of medium fire growth rate and 15min in case of fast fire growth rate (note that t_{lim} need to be input in hours in the above equation).

The appropriate fire growth rate are given in Table E.5 in annex E of BS EN 1991-1-2.

When $t_{max} = t_{lim}$, the fire is fuel controlled and not ventilation controlled. In this case, instead of equation 6, the following expression needs to be used to calculate the time:

$$t' = t\, \Gamma_{lim}$$

Where:

$$\Gamma_{lim} = \frac{(O_{lim}/b)^2}{0.04/1160)^2}$$

$$O_{lim} = 0.1\ 10^{-3}\ \frac{q_{t,d}}{t_{lim}}$$

In case of ($O > 0.04$ and $q_{t,d} < 75$ and $b < 1160$), Γ_{lim} has to be multiplied by factor k given by the following expression:

$$k = 1 + \left(\frac{O - 0.04}{0.04}\right)\left(\frac{q_{t,d} - 75}{75}\right)\left(\frac{1160 - b}{1160}\right)$$

10.3.3 Cooling phase

EN1991-1-2 defines linear temperature-time curves for the cooling phase after the heating phase of parametric fire curves. Depending on the value of t'_{max} three different linear curves for gas temperature Θ_g are defined as follows:

$$\Theta_g = \Theta_{max} - 625(t' - t'_{max}x) \text{ for } t'_{max} \le 0.5$$

$$\Theta_g = \Theta_{max} - 250(3 - t'_{max})(t' - t'_{max}x) \text{ for } 0.5 < t'_{max} < 2$$

$$\Theta_g = \Theta_{max} - 250(t' - t'_{max}x) \text{ for } t'_{max} \ge 2$$

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Where:

$$t'_{max} = (0.2\ 10^{-3} q_{t,d}/O)\ \Gamma$$

With:

$x = 1.0$ if $t_{max} > t_{lim}$ or

$x = t_{lim}\ \Gamma/t'_{max}$ if $t_{max} = t_{lim}$

10.4 Travelling fires

less influenced by the ventilationoften more

. A recently proposed methodology for the characterisation of non-uniform fires in large compartments for structural fire design purposes is that knowniTFM T exposure is idealised for structural fire design purposes with the aim of removing complexities and simplifying its use but equally capturing the key phenomena by non-uniform fires. More experimental research in large compartments is still needed to advance y further and represent more realistic fire dynamics by fitting experimental data when it becomes available in the near future.

A major concept behind the TFM is that the fire induced field is split for a compartment (over the longest direction into two regions), into the near-field (flames) and the far-field (smoke). This results in the generation of spatially non-uniform and transient temperature curves for the whole floor as shown in XXX. The near-field represents the burning region of the fire where the flames directly impinge on the ceiling. The far-field represents the region remote from the burning area where the structure is mainly heated by hot smoke moving away from the fire source. The travelling fire methodology assumes that for larger enclosures the importance of the thermal inertia of the linings is lower and as a result the growth and decay phases will be faster [REF].

TFM considers a range of possible fire dynamics instead of selected design fires. It covers a wide range of fire sizes – a family of possible fires depending on the fire coverage (A_f) of the total floor area. The TFM typicallyes a rectangular shape of the floor plate/compartment and therefore a fire can be characterised in a non-dimensionless form, F_{size}, as:

$$F_{size} = \frac{L_f}{L}\ or\ \frac{A_F}{A}$$

The size of fire is a major variable in the TFM, which directly affects the far-field temperatures and the total burning time.

TFM aes a uniform fuel load across the fire path, $q_{f,d}$ (kJ/m^2), and a constant heat release rate $\dot{Q}''$ (kW/m^2. B on a given burn area, A_f (m^2), the total heat release can then be calculated as:

$$\dot{Q} = A_f \dot{Q}''$$

A the fire spreads, each fire area would have a constant burning time of:

$$t_b = \frac{q_{f,d}}{\dot{Q}''}$$

T compartment area that the fire has travelled across is considered to be burnt out. F is assumed to spread at a constant fire spread rate, s along a linear fire path (other fire paths are possible and can be expressed in similar ways) and is given by:

$$s = \frac{L_f}{t_b}$$

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Given that for the same fuel load, the burning time would be the same, it can be observed that larger fires would travel faster compared to smaller fires. In the work by inghave been introduced to reduce the family of fires passed to structural analysis and neglect unrealistic results.

For a linearly travelling fire, the total burning time can then be calculated from the following expression:

$$t_{total} = t_b \left(\frac{1}{F_{size}} + 1 \right)$$

As a result smaller fires experience longer burning duration compared to larger fires. The total burning time has a major influence in protected steel and concrete structures in comparison to maximum temperature reached.

In the TFM, the near-field represents the flames directly impinging on the ceiling and assumes the peak flame temperatures. T [21]In the TFM, the near-field represents the flames directly impinging on the ceiling and assumes the peak flame temperatures. has been introduced which assumes that structural members will actually experience lower average gas temperatures rather than the peak flame temperatures observed in fires. Based on this work, the flapping length can be determined as follows:

$$f = L_f + 2\,H \tan\left(f_{angle} \frac{\pi}{180} \right)$$

The reduced average near-field temperature can then be determined as:

$$T_f = T_a + \frac{T_{nf}\left(2r_{x1} + L_f\right) - 2T_a \cdot r_{x2}}{f} + \frac{32.28\dot{Q}^{2/3}}{H \cdot f}\left(r_2^{1/3} - r_{x2}^{1/3}\right)$$

where:

$$r_2 = f/2$$

$$r_{x1} = \max[0, r_0 - L_f/2]$$

$$r_{x2} = \max[L_f/2, r_0]$$

$$T_{nf} = 1200°C$$

$$r_0 = \dot{Q}\left(\frac{5.38}{H(T_{nf} - T_a)}\right)^{3/2}$$

In the TFM the flapping angle of ±6.5° is assumed. For a flapping angle of 0°, the resulting reduced average near-field temperature will be the same as the near-field temperature (i.e. typically 1200^{0}C).

In TFM the far-field model represents cooler smoke temperatures which decrease with distance away from the fire. TFM is flexible in stating that any available temperature-distance correlation could be used to describe the far-field temperature depending on the accuracy required.TFM is flexible in stating that any available temperature-distance correlation could be used to describe the far-field temperature depending on the accuracy required. In the latest versions of TFM Alpert's correlation has been recommended to determine the temperatures in the far-field. Compared with other available solutions Alpert's correlation provides results within the acceptable limits of accuracy and, therefore, was chosen for its' simplicity . The equation considers the temperatures at ceiling level and as a result is more appropriate for structural members near the ceiling level (commonly the steel beams and the concrete slab).

It should be noted that the Alpert correlation uses the total heat release rate, rather than its convective portion which is related to buoyancy as it has been derived based on pool fires [REF]. In addition, Alpert's correlation assumes an unconfined ceiling with no accumulated smoke layer. For the purposes of the TFM this assumption has been neglected since the aim was to provide an approximate input for the structural fire design purposes [REF].

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have developed a can be determined $T_{max}(x,t) = T_{\infty} + \frac{5.38}{H}\left(\frac{L\,L_t^*\,W\,\dot{Q}''}{|x+0.5\,L\,L_t^*-\dot{x}_t|}\right)^{2/3}$

$$T_{max}(x,t) = T_{nf,}\ if\ \begin{cases} T_{ff} > T_{nf}; \\ |x + 0.5\,L\,L_t^* - \dot{x}_t| \leq 0.5L_f. \end{cases}$$

$$for\ \dot{x} \leq L\ \rightarrow\ \dot{x}_t = s \cdot t;\ L_t^* = \min[L^*, (s \cdot t)/L]$$

$$\dot{x} > L\ \rightarrow\ \dot{x}_t = \mathrm{L};\quad L_t^* = 1 + (L_f - s \cdot t)/L$$

It should be noted that this solution neglects the presence of a core in the floor plate (which is assumed to be conservative).

10.5 External flaming

Any of the fires that could occur in a compartment such as post-flashover fires, travelling fires or localised fires could lead to external flaming through an opening (typically windows or doors) that could directly impact external steel. As a result, this is a different thermal exposure rather than a different design fire.

External design fires are covered in detail in section 11.

11 Other equation-based design fires

11.1 General

To be edited and added to.

Regulatory authorities or the qualitative design review team can prescribe other design fire characteristics to be used in the analysis. Typically the temperature/heat flux versus time is prescribed.

11.2 External design fires

11.2.1 General

There are two types of fires that can harm the external surface (or façade) of a built environment: fires originating within the built environment and those originating outside it. An example of the former is when flames from a fully developed internal fire issue from an opening and thereafter transfer heat to an external surface (or façade). An example of the latter is when flames from a fire in miscellaneous storage or waste adjacent to the built environment transfer heat to the external surface. In both cases, flame heat transfer can lead to ignition of combustible content in the external surface and subsequent sustained flame spread. This can cause considerable damage to the external surface or propagation of fire to the interior via openings in the external surface at locations and distances remote from the original source fire.

Generally, the highest imposed total heat transfer from flames to external surfaces, and, therefore, the greatest risk of damage or sustained flame spread, occurs as the result of fire sources outside and adjacent to the external surface. It is important to select an external design fire that accurately reproduces the maximum heat-flux exposure to be expected from the design fire scenario of concern.

11.2.2 Flames issuing from an opening

To be edited and added to.

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Flames issuing from an opening in the external surface of a built environment can be characterized by a heat flux profile on the external surface along the length of the flame. The jet of flame issuing from a window of a compartment fully involved in fire may be characterized by the flame length and the temperature along the jet. Expressions have been derived for both of these variables and are in use in some national codes.

11.2.3 Fire from a burning object adjacent to an external surface

To be edited and added to.

Flames from a burning object near the external surface of a built environment shall be characterized by a heat-flux profile along the length of the flame.

12 Fire Tests

In some cases, engineering calculation methods are not available, e.g. for estimating fire growth in complex material systems or for estimating the response of a given fire to proposed protection systems, such as sprinklers, because of the complexity of the interactions involved. For such cases, the only way to predict the outcome of a given scenario is to make use of one or more reference-scale test methods or ad hoc test methods developed for the purpose. This type of test method is intended to represent a possible "real" fire situation by exhibiting a wide range of "real" fire phenomena in a full-scale geometry while maintaining a well-defined, well documented and well controlled test environment.

Reference-scale test methods are used either directly, to evaluate specific trial design strategies, or indirectly, to evaluate the accuracy of a particular engineering calculation method that, if found to be suitable, are then used to evaluate a range of design strategies. In all cases, proper interpretation of results from reference-scale test methods is particularly important to ensure validity for the particular design application. For example, if a reference-scale test environment is used to evaluate a trial sprinkler protection strategy in a warehouse, it is important that the test results must be analysed to verify that the success of fire protection is not influenced by factors, such as oxygen depletion, that might not be present during an actual fire.

In some cases, it is necessary to employ a combination of test results and calculations. Generally, the efficiency of the calculation method is determined by assessing the results of the test, and a calculation is performed for the real-case scenario, taking into account some safety factor to deal with the accuracy of the method obtained in the comparison with the test results.

Given the inherent randomness of fire starts and initial conditions and the nature of some of the factors affecting the development and severity of fire, a probabilistic analysis should always be considered. This section provides an overview of selected probabilistic analysis methods, relating to design fires. More detailed guidance on fire risk assessment and probabilistic analysis is provided in ISO 16732.

In general, probabilistic approaches treat selected design fire input and output parameters as ranges of statistically distributed values, instead of the single fixed values typically used in deterministic approaches. In addition, the impact of fire protection measures (e.g. a sprinkler system) can be accounted for based on the probability of their successful operation (reliability) and efficacy. The objective for the use of such an approach in performance-based design is typically to account for the variability and / or uncertainty in the input parameters and to investigate their impact on fire severity, smoke production and other important characteristics of fire development.

The approaches by which design fires can be incorporated into probabilistic analysis include:

Inclusion of statistical representativeness/distribution characteristics to important input parameters;

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1)

Stochastic models and

12.1 Inclusion of statistical representativeness/distribution characteristics

Inclusion of statistical representativeness characteristics to important input parameters, is a relatively simple way of explicit probability treatment, however, in majority of cases only partial. This approach is similar to the worst credible scenario approach, however, an explicit quantification of parameter representativeness is provided. It should be pointed out that the statistical representativeness relates only to the parameter(s) in question rather than the design fire as a whole. For example the assumed fire load density may be taken as representative of 90% cases (90th percentile) for the occupancy in question. However, even if one of the input parameters is selected as the upper 90th percentile value, the design fire as such does not necessarily represent 90% of the fires in the given occupancy type, as the fire is affected by further parameters, such as fuel configuration and ventilation, etc. The value for these other parameters can also be selected from a representative statistical distribution. On the other hand, selecting most or all input parameters from upper extreme intervals, may result in an overly severe fire with a very low probability of occurrence.

12.2 sampling

Subsequently results are aggregated and their respective distributions analysed.In relation to design fires can be used to account for variability and/or uncertainty of input parameters, e.g. fire growth rate, or the random nature of certain input parameters, e.g. spatial configuration of fuel items. The higher number of runs, each with uniquely sampled input variables, the higher the accuracy/representativeness of the simulation results Due to the high number of repetitions required software tools are used to carry out simulations.

Monte Carlo employs repeated random sampling from predefined input variable sets or distributions which are then used in calculation algorithms. An example use of such is shown in Figure 4. enclosure is populated with fuel items from a predefined database. The location of the items can be random or user-defined and the number of the items depends on their respective masses and the actual value of the fuel load density sampled from the specified distribution for the given run. Each of these runs with randomly sampled input produces a different HRR curve. For subsequent analyses (evacuation, structural) a representative envelope curve or the individual curves can be used, depending on the modelling tools employed.

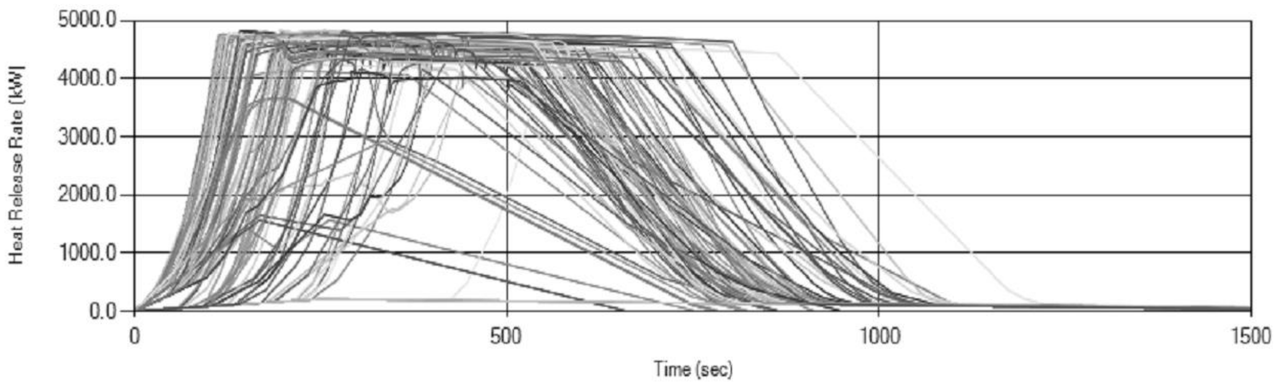

Figure 4 Example of Monte Carlo simulation output – HRR curves [reference]

Provide example based on Wade et. Al. *Developing probabilistic design fires for performance-based fire safety engineering* re use of Monte Carlo for design fire.

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12.3 Stochastic models

is a stochastic model treating the stages of fire growth as phases or realms. transition the fire the the transition probability probability of another state is

six states defined as realms for residential occupancies: no-fire state, sustained burning, vigorous burning, interactive burning, remote burning and full room involvement. The realms were defined by critical events characterized by heat release rate, flame height and upper room gas temperature.

Network models are more advanced stochastic which takes into account the time-dependence of state transition probabilities and spread of fire within the built environment. Examples of such network approximations are shown in Figure 3 [SFPE reference s3ch14].

Probably not going to include example here such as the below, but reference to new FRA standards suite.

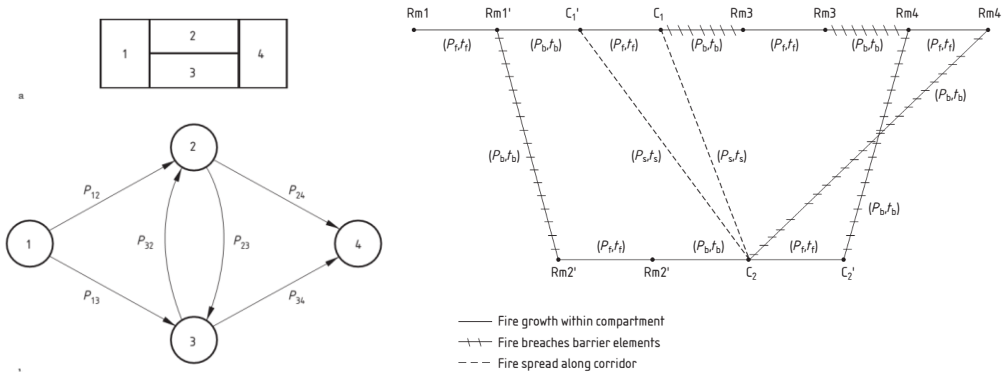

Figure 3 Network fire spread model interpretation examples of built environment [PD 7974-7+SFPE]

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Annex A
(informative)

Data for Development of Design Fires

A.1 Introduction

The following table is intended to guide the user as to the type and source of data typically required in applying this International Standard. Sometimes data required for a specific scenario is not available requiring users to apply engineering judgement. In this case, alternative sources of data could be from individuals with field observation knowledge based on lengthy work experience. Delphi panels comprising groups of experts are also sometimes used to try and eliminate bias in the grouping of opinions into an expert estimate. Also see ISO 16732-1 for further guidance on use of engineering judgment and in estimating frequency and probability.

A.2 Data for Development of Design Fires

Table A.1

Data Element	Units	Value and/or Source	Reference

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Heat release rate rate of thermal energy production generated by combustion (4.46) [1]	W	Often the only reliable way to estimate the heat release rate for flaming fires is to use experimental data. Oxygen consumption calorimeters have been used to measure the burning rates of large-scale objects with rates of heat release of up to tens of megawatts [**Erreur ! Source du renvoi introuvable.**]. Small-scale systems exist to measure the mass loss and heat release rates per unit area of specimens under well-defined conditions. Heat release rate is usually expressed as a time-varying function of time. Collated sources of data for classes or type of product involved, with variability analysed (e.g. upper 90 percentile) would be desirable. By applying modelling techniques, it may be possible in some cases for simple geometries (eg walls/ceilings [**Erreur ! Source du renvoi introuvable.**]) to make reasonable estimates of the burning rates of larger objects/elements, including conditions differing from the conditions under which the input data was obtained. Ideally HRR, mass loss rate and effective heat of combustion for a fire scenario should be obtained from the same data set to ensure internal consistency of data. The following lists a number of test methods designed to measure rate of heat release and related parameters under well-defined conditions. ISO 5660-1 specifies a method for assessing the heat release rate of a specimen exposed in the horizontal orientation to controlled levels of irradiance with an external igniter. The heat release rate is determined by measurement of the oxygen consumption derived from the oxygen concentration and the flow rate in the combustion product stream. [**Erreur ! Source du renvoi introuvable.**] ISO TR 5660-3 Reaction-to-fire tests -- Heat release, smoke production and mass loss rate -- Part 3: Guidance on measurement gives some guidance on the conditions for the testing and relevant data obtained. [**Erreur ! Source du renvoi introuvable.**] ISO 14696 provides a method for measuring the response of materials, products and assemblies exposed in vertical orientation to controlled levels of radiant heating with a piloted ignition source. The test method is used to determine the ignitability, heat release rates, mass loss rates and visible smoke development of materials, products and assemblies under well-ventilated conditions. [**Erreur ! Source du renvoi introuvable.**] ISO 24473 specifies a series of test methods that simulate a real scale fire on a test object or group of objects under well-ventilated conditions. A range of different fire sizes can be studied according to the scale of the equipment available. [**Erreur ! Source du renvoi introuvable.**] Useful sets of collated information on the burning rates of materials and products can be found in [**Erreur ! Source du renvoi introuvable.**,**Erreur ! Source du renvoi introuvable.**,**Erreur ! Source du renvoi introuvable.**,**Erreur ! Source du renvoi introuvable.**], Data sources for specific applications also include: office workstations [**Erreur ! Source du renvoi introuvable.**,**Erreur ! Source du renvoi introuvable.**,**Erreur ! Source du renvoi introuvable.**,**Erreur ! Source du renvoi introuvable.**] shopping centres [**Erreur ! Source du renvoi introuvable.**].	Subclause

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Heat release rate per unit (HRRPUA)	kW/m^2	ISO 5660-1 specifies a method for assessing the heat release rate of a specimen exposed in the horizontal orientation to controlled levels of irradiance with an external igniter. The heat release rate is determined by measurement of the oxygen consumption derived from the oxygen concentration and the flow rate in the combustion product stream. [**Erreur ! Source du renvoi introuvable.**] ISO 5660-3 Reaction-to-fire tests -- Heat release, smoke production and mass loss rate -- Part 3: Guidance on measurement gives some guidance on the conditions for the testing and relevant data obtained. [21] **Limitations** Caution is needed in selecting an appropriate value for HRRPUA depending on the application. ISO 5660-1 allows determination of a time-varying HRRPUA for a specific level of externally applied irradiance. The data may be summarised as averages over defined periods from ignition, Peak HRR or maximum values may also be identified.	
Heat of Gasification thermal energy required to change a unit mass of material from the condensed phase to the vapour phase at a given temperature (4.175)	kJ/g	There are various techniques for determining heat of gasification including thermal analysis techniques such as differential scanning calorimetry or by calculation using specific heats and heats of vaporization. Data for a range of materials and techniques are given in [**Erreur ! Source du renvoi introuvable.**].	
Heat of combustion thermal energy produced by combustion (4.46) of unit mass of a given substance [1]	kJ/g	The gross heat of combustion of products at constant volume can be determined in a bomb calorimeter using ISO 1716 [**Erreur ! Source du renvoi introuvable.**]. See also ISO 1928 [**Erreur ! Source du renvoi introuvable.**]. Multiplying the mass of fuel by the gross heat of combustion enables the theoretical rate of heat release to be calculated assuming complete combustion of all the fuel. For more representative and realistic calculations for fire scenarios the chemical or effective heat of combustion is generally a more appropriate parameter to be used (see effective heat of combustion). The net heat of complete combustion is the calorific energy generated in chemical reactions leading to complete combustion per unit mass of the fuel consumed. Heat of combustion values for typical fuels are compiled in Table 1 [**Erreur ! Source du renvoi introuvable.**].	

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Effective heat of combustion heat released (4.176) from a burning test specimen (4.322) in a given time interval divided by the mass lost from the test specimen in the same time period [1] also known as chemical heat of combustion	kJ/g	Effective heat of combustion may also be referred to as chemical heat of combustion, see Tewarson [**Erreur ! Source du renvoi introuvable.**]. The chemical heat of combustion is the calorific energy generated in chemical reactions leading to varying degrees of incomplete combustion per unit mass of the fuel consumed. In fires, combustion is never complete therefore the chemical heat of combustion will always be less than the net heat of complete combustion. The ratio between the two is known as the combustion efficiency. The chemical heat of combustion can also be split into convective and radiative components. Values of chemical, convective and radiative heats of combustion for a range of materials are given in [**Erreur ! Source du renvoi introuvable.**]. The effective (chemical) heat of combustion differs from the gross heat of combustion by a factor that takes into account incomplete combustion. Typically the effective (chemical) heat of combustion is about 80% of the gross heat of combustion [**Erreur ! Source du renvoi introuvable.**]. The effective heat of combustion is required where the rate of heat release is to be calculated given knowledge of the mass loss rate of the fuel, rather than by full scale testing and measurement of the heat release rate of burning items. The effective heat of combustion can be determined by oxygen consumption calorimeter data where the heat release and the mass loss have been measured. See ISO 5660-1 [**Erreur ! Source du renvoi introuvable.**]. Oxygen consumption calorimeters are the most practical means of determining time-dependent effective heat of combustion for fuel items containing a mixture of materials. See also [**Erreur ! Source du renvoi introuvable.**]. Effective heat of combustion is reduced with an increase in moisture content in the fuel. Therefore, the moisture content of the fuel should be noted when selecting values for effective heat of combustion. A gross effective heat of combustion can be determined by burning the full item and then burning specimens of each of the components in an oxygen bomb calorimeter. However, this does not provide time-dependent effective heat of combustion values.	
Fire load quantity of heat which can be released by the complete combustion (4.50) of all the combustible (4.43) materials in a volume, including the facings of all bounding surfaces [**Erreur ! Source du renvoi introuvable.**].	kJ	Fire load is determined by multiplying the mass of each material by its heat of combustion, and summing for all materials. Fire load may be based on effective heat of combustion (4.74), gross heat of combustion (4.170), or net heat of combustion (4.237) as required by the specifier. Fire load is commonly expressed for different occupancy type as a floor area density (see fire load density),	

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Fire load density fire load (4.114) per unit area [**Erreur ! Source du renvoi introuvable.**]	kJ/m^2	Fire load density is usually expressed on a floor area basis and allows the typical fire load for a given room to be easily determined. Statistical distributions of fire load density from the literature are very useful for design purposes. An upper percentile value will typically be selected for use in deterministic design. Data collated from surveys is typically for defined property uses and may be assumed to be representative of similar types of rooms or occupancies. Care should be taken to try and use the most appropriate data for the part of the building under consideration. For example, for a large store, use the published data for such stores to describe fire load density in showrooms or storage rooms or receiving/shipping areas, but describe fire load density in office rooms by reference to published data on offices. See references for examples of published data for office buildings [12], commercial premises [13], dwellings [**Erreur ! Source du renvoi introuvable.**, 17]. A more general discussion and collation of data sources is provided in [**Erreur ! Source du renvoi introuvable.**]. If statistical data for a specific property use is not available in the literature then the engineer can either select data for a property that has similar characteristics in terms of the quantities and types of materials present. Alternatively, a first principles analysis identifying the expected room contents, including the mass and materials of construction, could be carried out. The product of the mass and heat of combustion summed over all contents will provide an estimate of the total fire load in the room. **Limitations** Care may be needed in using data from another country due to potential differences in building size and style, culture etc. Individual surveys may have limitations that should be noted. Note: be aware of whether data is presented with unit area on floor area basis or a surface area basis.	
Area burning rate area of material burned (4.28) per unit time under specified conditions [**Erreur ! Source du renvoi introuvable.**]	m^2/s	See discussion on rate of heat release. ISO 5660-1. It is desirable that all related parameter estimates be obtained under common conditions, and preferably from the same experiments. **Limitations** Note: be aware of whether data is presented with unit area on floor area basis or a surface area basis.	

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Mass burning rate mass of material burned (4.28) per unit time under specified conditions [**Erreur ! Source du renvoi introuvable.**]	kg/s	The mass burning rate is useful for both flaming and smoldering fire types. The mass burning rate can be determined using the same test methods used for rate of heat release providing a load cell has been fitted. E.g. ISO 5660-1:2002 [**Erreur ! Source du renvoi introuvable.**]. It is desirable that all related parameter estimates (e.g HRR, mass loss rate, effective heat of combustion) be obtained under common conditions, and preferably from the same experiments. ISO 17554:2005 [**Erreur ! Source du renvoi introuvable.**] specifies a small-scale method for assessing the mass loss rate of essentially flat specimens exposed in the horizontal orientation to controlled levels of radiant heating with an external igniter under well-ventilated conditions. The mass loss rate is determined by measurement of the specimen mass and is derived numerically. The time to ignition (sustained flaming) is also measured in this test. Mass loss rate can be used as an indirect measure of heat release rate for many products. **Limitations** Regarding the calculation of species concentrations in the smoke layer, the product of the mass loss rate and yield is the challenging quantity for a calculation, not mass loss rate alone.	

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Yield mass of a combustion product (4.48) generated during combustion (4.46) divided by the mass loss of the test specimen (4.322) [**Erreur ! Source du renvoi introuvable.**]	g/g	Typically combustion products of interest include CO, CO2, C (soot/smoke), HCN and H2O. The yield can be measured using apparatus including oxygen consumption calorimeters (eg. cone, furniture or room calorimeter). CO, CO2, HCN and H20 concentrations in the exhaust flow can be measured with an appropriate gas analyser. C (soot) yield may be determined using a soot mass filter to collect and weigh deposits or may be estimated based on smoke optical measurements in the exhaust duct. The yield measurement may be presented as an average over the period of the test or as an instantaneous value as a function of time. ISO 19703 [**Erreur ! Source du renvoi introuvable.**] provides definitions and equations for the calculation of toxic product yields and the fire conditions under which they have been derived in terms of equivalence ratio and combustion efficiency. Sample calculations for practical cases are provided. The methods can be used to produce either instantaneous or averaged values for those experimental fires in which time-resolved data are available. See ISO 16312-1 for guidance on the properties of a good combustion product generator and ISO/TR 16312-2 for an evaluation of 12 such combustors. See also ISO/TS 19700 to indicate the degree of accuracy with which they can generate yield data. **Limitations** Measurements and range of combustion products are strongly dependent on the chemical composition of the fuel and the local equivalence ratio and burning regime (flaming or smouldering, well-ventilated or under-ventilated). The product of the mass loss rate and yield is the challenging quantity for a calculation, not yield alone.	

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Smoke production rate product of the volumetric flow rate of smoke and the extinction coefficient of the smoke at the point of measurement	m^2/s	In laboratory experiments, the production of smoke and its optical properties are often measured simultaneously with other fire properties as heat release rate and flame spread. The measurements are usually dynamic in full-scale testing, i.e. they are performed in a flow-through system. In small-scale testing, they may be either dynamic, as in the cone calorimeter, or static, i.e. the smoke is accumulated in a closed box. Small-scale tests are necessary as practical tools. Full-scale tests are generally considered to be more reliable and are needed to establish the utility of the small-scale tests. ISO 5660-2 [**Erreur ! Source du renvoi introuvable.**] specifies a small-scale method for assessing the dynamic smoke production rate of essentially flat specimens exposed to controlled levels of radiant heating under well-ventilated conditions with or without an external igniter. The rate of smoke production is calculated from measurement of the attenuation of a laser light beam by the combustion product stream. **Limitations** Measurements and range of combustion products are strongly dependent on the chemical composition of the fuel and the local equivalence ratio and burning regime (flaming or smouldering, well-ventilated or under-ventilated). The rate of smoke production has not been validated against any fire scenario.	
Specific extinction area the ratio of the extinction area of smoke to the mass loss of the specimen that is associated with the production of that smoke	m^2/kg	For the application of smoke data to fire models, it is sometimes desirable to report the data in terms of the yield of smoke per unit mass loss of specimen, independent of the apparatus flow conditions and specimen mass. See ISO 5660-2:2002 Annex A [**Erreur ! Source du renvoi introuvable.**].	
Surface Temperature for Ignition	K	Useful for ignition of secondary targets. **Limitations** Temperature may not be sufficient if the item is spatially extensive.	
Criticial Heat Flux (CHF) for Ignition	kW/ m^2	Useful for ignition of secondary targets. Minimum heat flux for ignition can be estimated from ISO 5660-1 [**Erreur ! Source du renvoi introuvable.**] or other apparatus (eg OSU, FPA), by repeated testing, sequentially reducing the irradiance, until ignition does not occur. Testing may be done with/without a spark igniter applicable for piloted and auto ignition behaviour. Critical heat flux values for a range of materials can be found in Table 3-4.2 of [**Erreur ! Source du renvoi introuvable.**].	

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Thermal Response Parameter (TRP) for Ignition	kW.s$^{1/2}$/ m^2	The thermal response parameter accounts for the combined effect of the ignition temperature, ambient temperature, thermal conductivity, specific heat and density for a material, and can be used to estimate the ignition time given knowledge of the incident heat flux and critical heat flux (see reference [**Erreur ! Source du renvoi introuvable.**]). TRP depends on chemical as well as physical properties of the material. TRP may be determined by linear regression of ignition data from the cone calorimeter ISO5660-1 or other apparatus (eg OSU, FPA), Thermal response parameter values for a range of materials can be found in Table 3-4.2 of [**Erreur ! Source du renvoi introuvable.**].	
Thermal Inertia the product of the thermal conductivity, the density and the specific heat capacity, given by kρc	J2/(m4.K 2.s)	Useful for ignition of secondary targets.	
Radiative Fraction fraction of energy released from the fire as thermal radiation	(-)		

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Annex B
(informative)

Examples of probability-based design fires

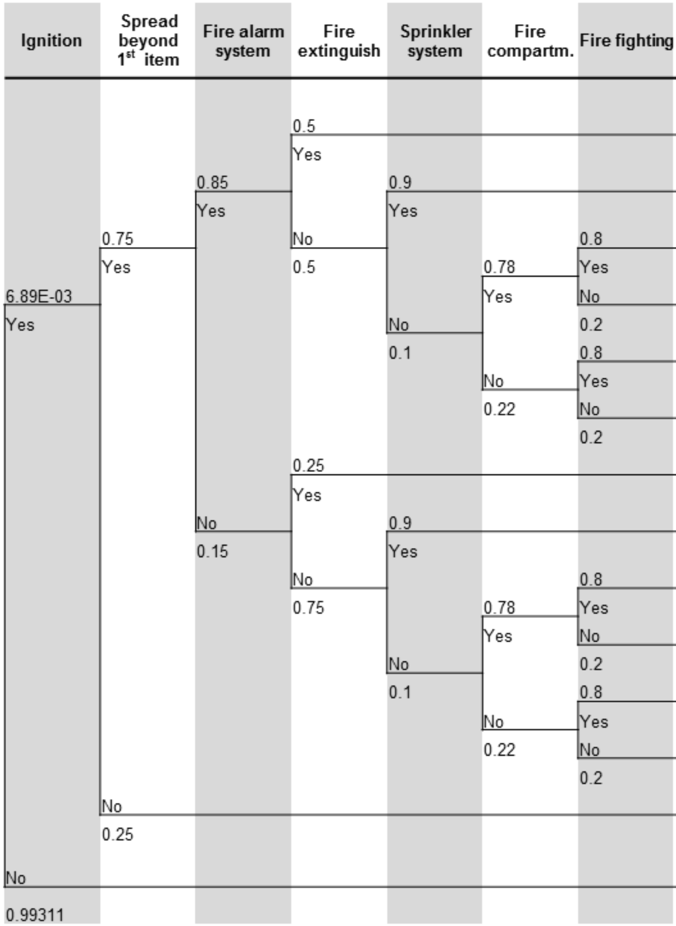
B.1 An example of intended content – Event tree analysis

The following example is a fabricated building representing a single-storey shopping centre with a total floor area of 3600 m². It is divided into four retail units, each with a floor area of 900 m².

The impact of the following fire protection measures is assumed:

- Fire detection and alarm system;
- Portable fire extinguishers – first-aid firefighting;
- Sprinkler system;
- Fire partitioning;
- Fire service intervention.

The expected fire damage is established from the fire damage statistics for the given occupancy. Further details and references to be added once the content is agreed in principle.



Fire damage	Scenario ID	Probability	Frequency [years]	Expected yearly damage
2.5 m²	2	2.20E-03	4.55E+02	5.49E-03 m²
10 m²	3	1.98E-03	5.06E+02	1.98E-02 m²
270 m²	4	1.37E-04	7.30E+03	3.70E-02 m²
900 m²	5	3.43E-05	2.92E+04	3.08E-02 m²
270 m²	6	3.87E-05	2.59E+04	1.04E-02 m²
1800 m²	7	9.66E-06	1.03E+05	1.74E-02 m²
2.5 m²	8	1.94E-04	5.16E+03	4.84E-04 m²
10 m²	9	5.23E-04	1.91E+03	5.23E-03 m²
600 m²	10	3.63E-05	2.76E+04	2.18E-02 m²
900 m²	11	9.07E-06	1.10E+05	8.16E-03 m²
600 m²	12	1.02E-05	9.77E+04	6.14E-03 m²
3600 m²	13	2.56E-06	3.91E+05	9.21E-03 m²
1 m²	1	1.72E-03	5.81E+02	1.72E-03 m²
0 m²	0	9.93E-01	0.00E+00	0.00E+00 m²
		Overall expected fire damage:		0.17 m²/year

A similar example below, relating to scenario occurrence probability so perhaps more relevant to ISO 16733-1.

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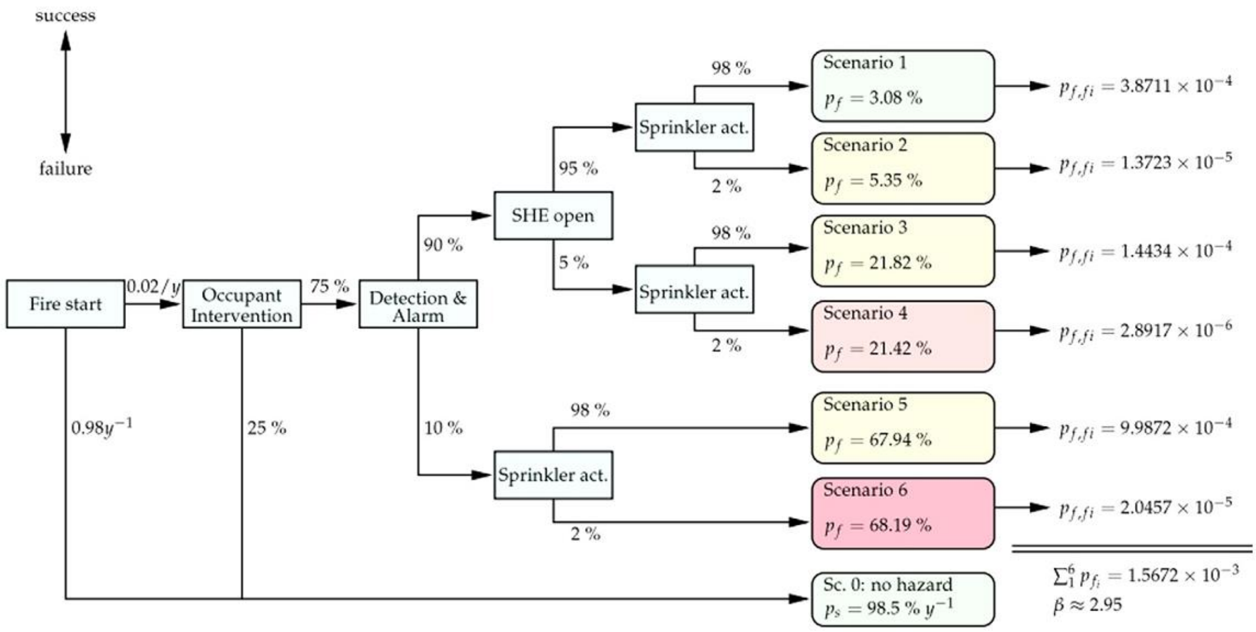

Fig. 4. The complete event tree considering all fire protection systems.

Taken from C. Albrecht / Fire Safety Journal 64 (2014) 81–86

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Travelling fire section:

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13 Stray text (to be moved or deleted)

However, design fire characteristics can be subsequently modified based upon the outcome of the analysis. For example, if the single-item fire grows sufficiently intense that flashover in an enclosure is likely, it is necessary to modify the design fire to reflect the characteristics of a ventilation-controlled or fuel-bed-controlled fully-developed fire. Similarly, events such as sprinkler activation and window breakage impact on the design fire. It is necessary to ensure, however, that the design fire is appropriate to the objectives of the fire-safety engineering analysis and results in a design solution that is conservative.

An example where more than one design fire can be required for a particular design fire scenario is when fire spreads beyond the room of fire origin to another enclosure. A new design fire can be required to represent the fire in the second enclosure.

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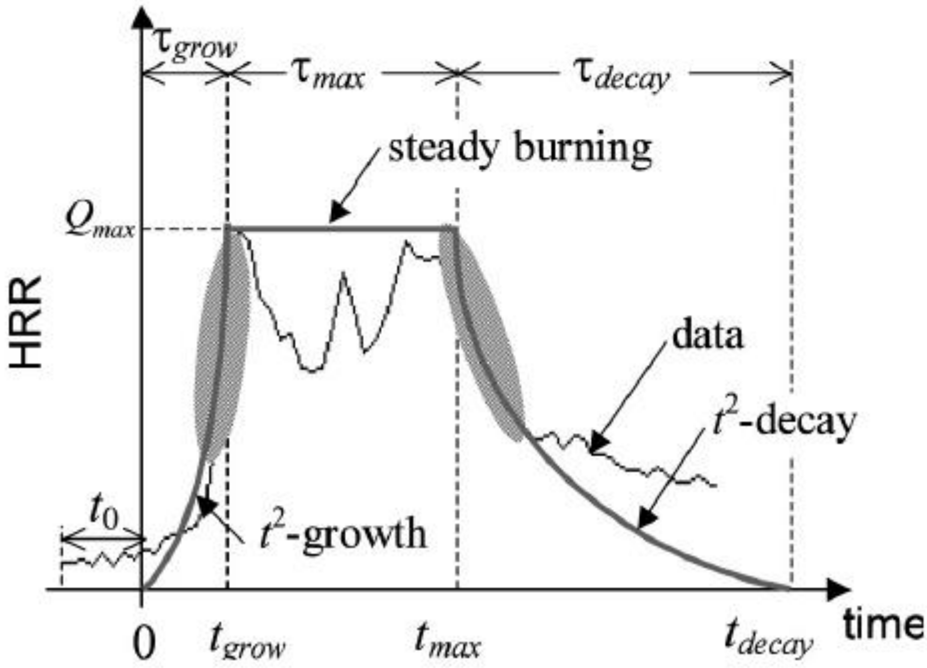
13.1 Design Fire Variables

[Two approaches – firstly where a specific fuel package is the basis of the design fire, and secondly where the fire growth is described using a generic power law curve. If using the former, it is important to consider potential compartment effects on the mass loss rate when free burning test data is utilised.]

13.1.1 Generalised heat release rate description of a design fire



t_0 =	time at which the incipient (pre-growth) stage ends (s)
t_{grow} =	time at which the heat release rate of the growing fire reaches a maximum value (s)
t_{max} =	time at which the steady burning stage ends (s)
t_{decay} =	time at which the decay stage ends (s)
τ_{grow} =	duration of the growing fire stage (s)
τ_{max} =	duration of the steady burning stage (s)
τ_{decay} =	duration of the decay stage (s)
$\dot{Q}_{max}$ =	maximum heat release rate (kW)
α =	fire growth coefficient (kW/s^n)
α_d =	fire decay coefficient (kW/s^m)
n =	power law coefficient for growing fire (-)
m =	power law coefficient for decaying fire (-)

The heat release rate is given by:

$$\dot{Q}(t) = \begin{cases} \alpha t^n, & 0 \le t < t_{grow} \\ \dot{Q}_{max}, & t_{grow} \le t < t_{max} \\ \alpha_d (t_{decay} - t)^m, & t_{max} \le t < t_{decay} \end{cases} \quad \text{(C.2)}$$

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The power law coefficient for the fire growth stage is typically taken as $n = 2$ and for the decay stage as $m = 2$.

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