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Fire safety engineering — General principles

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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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ISO 23932 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

Introduction

The vast majority of fire safety designs rely on prescriptive specifications written into regional, national or local regulations. Currently, various engineering approaches are also allowed by these regulations, although information needed for an engineering approach is still generally obtained from conventional test methods. Fire Safety Engineering (FSE) is a discipline increasingly being used throughout the world in support of performance-based design, i.e. the reliance on engineering methods to determine whether a given design meets stated performance objectives. An example of such a concept already in use in the current regulatory environment is the "equivalency concept", where FSE supplements prescriptive design by being applied in a performance-based analysis to specific aspects of a design to obtain "equivalent" performance. The eight parts to ISO/TR 13387 developed by ISO/TC 92/SC 4 have already outlined the fundamental methodologies of FSE.

The difference between prescriptive and performance-based approaches to fire-safety design is highlighted in this International Standard by emphasizing the development of quantifiable fire-safety objectives as the first step in a performance-based analysis. Such objectives can be completely deterministic in nature or contain both deterministic and probabilistic aspects as used in a fire-risk assessment approach.

The new infrastructure of International Standards supporting performance-based fire-safety design consists of two basic types of fire-safety standards:

a) conceptual standards that describe the underlying concepts and contain general requirements for both engineering and test methods to support performance-based design; these correspond to principle and phenomenon standards in the ISO/TC 92 framework report;

b) standards that adapt the conceptual standards to specific configurations of the built environment, e.g. structural systems, transportation systems and manufacturing processes; these correspond to configuration standards in the ISO/TC 92 framework report. Conceptual standards have the advantage of broad applicability as guides for local/regional adoption and for new types of situations, while configuration standards are more specific and detailed.

This International Standard on general design principles and design philosophy for fire-safety engineering contains a comprehensive overview of the performance-based design process for fire safety and thus represents the type of principle standard discussed in the ISO/TC 92 framework report. As such, it is also a template guiding the development of other standards applicable to a wide range of generic and specific fire-safety design situations. Hence, it is important that this International Standard be viewed as an outline of the fire-safety engineering design process, not as a detailed design methodology.

Fire safety engineering — General principles

1 Scope

This International Standard provides general principles for 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 people and based on knowledge of the consequences of such behaviour on life safety, property and the environment.

This International Standard is not intended as a detailed technical design guide, but does contain the key elements needed by practicing fire safety engineers and peer reviewers (those entities who can be required to review the work of fire-safety engineers) for addressing the different steps and their linkages in a design process. The information contained in this International Standard is intended not only to be useful to engineers directly but also to serve as a template to guide the development of a consistent set of fire-safety engineering documents covering the role of engineering methods and test methods in performance-based design and assessment.

The basic principles of fire-safety design and related fire-safety objectives in this International Standard can be applied in any other document addressing phenomena associated with fire (e.g. fire growth, hot gases and effluents movement, structural and compartmentalization behaviour). Related fire-safety objectives include, for example,

- safety of life;
- conservation of property;
- continuity of operations;
- protection of the environment;
- preservation of heritage.

Furthermore, these basic principles can be applied to all configurations of the built environment (e.g. buildings, transportation systems and industrial installations).

Because prescriptive regulations covering fire-safety design will co-exist for some time with performance-based design, this International Standard takes into account that fire-safety designs conforming to prescriptive regulations can become the basis for comparison of engineered designs of new built environments.

2 Normative references

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

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

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

3.1
engineering judgement
process exercised by a professional or a team of professionals who is qualified by way of education, experience and recognized skills to complement, supplement, accept or reject elements of an engineering analysis

3.2
fire-safety manual
fire-safety information system
document or computer system detailing the fire-safety management procedures intended for implementation on a continuing basis

3.3
fire-safety strategy
specification of design functions used in achieving fire-safety objectives that, when fully elaborated and specified, forms the basis for a trial design

3.4
functional requirement
statement of the means to achieve specified fire-safety objectives, taking into account the features of a built environment

NOTE Mandatory functional requirements are required by building codes or national regulations; voluntary functional requirements are expressed by other interested/affected parties.

3.5
interested/affected party
party that is impacted by a fire safety design, including property owners and other property stakeholders, or authority having jurisdiction in charge of the public health and welfare

3.6
mandatory objective
fire-safety objective, such as life safety and protection of the environment, which is required by building codes or national regulations

3.7
performance criteria
quantitative engineering specifications that form an agreed basis for assessing the safety of a built-environment design

3.8
safety factor
multiplicative adjustment applied to calculated values to compensate for uncertainty in methods, calculations, input data and assumptions

3.9
trial design
design chosen for the purpose of making a fire-safety engineering analysis

3.10
uncertainty
quantification of the systematic and random error in data, variables, parameters or mathematical relationships, or of a failure to include a relevant element

3.11
validation

⟨fire calculation model⟩ process of determining the degree to which a calculation method is an accurate representation of the real world from the perspective of the intended uses of the calculation method, such as confirming the correct assumptions and governing equations implemented in a model when applied to the entire class of problems addressed by the model

3.12
verification

⟨fire calculation model⟩ process of determining that a calculation method implementation accurately represents the developer's conceptual description of the calculation method and the solution to the calculation method

NOTE The fundamental strategy of verification of computational models is the identification and quantification of error in the computational model and its solution.

3.13
voluntary objective

fire safety objectives that are requirements expressed by interested/affected parties beyond mandatory objectives

4 Overview of the fire-safety engineering process

Fire is a complex phenomenon that imposes fluid-dynamic, thermal, mechanical and chemical actions (loads) on a built environment, on occupants or users of a built environment and on fire services. Therefore, it is essential that the fire-safety design process outlined in this International Standard be an integral part of all construction projects involving aspects that cannot be adequately accommodated by prescriptive requirements. The fact that fire actions (loads) can lead to changes that alter subsequent fire behaviour, with a resulting modification of the fire action (load), makes the interaction of fire-safety design with all other component design features essential during the life of a project. For example, boundaries can rupture in response to a fire, which can allow the introduction of additional ventilation causing an increase in fire intensity. The actions of building occupants can also influence the fire development by opening or closing doors/windows or by attempting to fight the fire.

The chart in Figure 1 is an outline of the fire-safety engineering process (design, implementation and maintenance) of a built environment, with reference to clause numbers where the process is explained in more detail.

Figure 1 shows the various steps required for the development of a fire-safety engineering process that fully meets the objectives of all interested/affected parties. After having defined accurately the scope of the project (Clause 5), the first step (Clause 6) involves the development of fire-safety objectives, related functional requirements and quantitative performance criteria for the various design functions (e.g. fire protection) that are required to achieve the fire-safety objectives. A specific fire-safety design plan is then developed (Clause 8), containing trial design elements that can potentially satisfy the quantitative performance criteria according to a preliminary hazards identification (Clause 7). It is necessary to agree on a set of design fire scenarios that can be used to challenge the performance of these design functions (Clause 9). Whether the performance criteria are, in fact, satisfied is determined by an engineering analysis of the trial design, as described in Clause 11, making use of engineering methods selected as indicated in Clause 10. If the performance criteria are not satisfied by the trial design, modifications are required until a final design plan in line with requirements is achieved. The final project report, including the necessary documentation, is produced and validated (Clause 12). The implementation of this final design plan leading to the erection of the built environment is discussed in Clause 13. Even after implementation is complete, the fire-safety engineering process continues with periodic inspections and ongoing fire-safety management procedures as described in Clause 14.

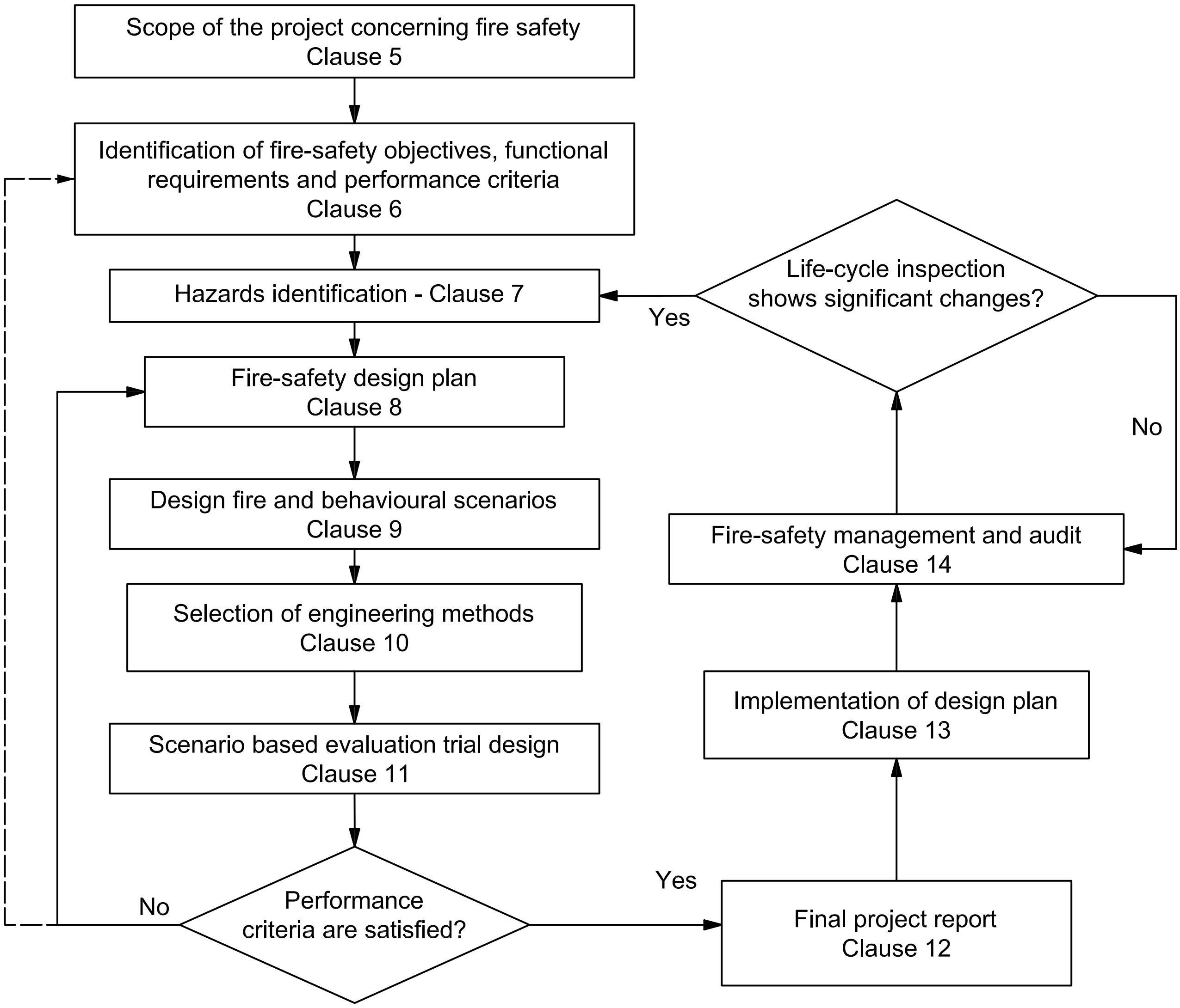

Figure 1 — Flowchart illustrating the fire-safety engineering process — Design, implementation and maintenance

5 Scope of the project concerning fire-safety engineering process

The fire-safety engineering process should be initiated at the earliest stage of a project (that may include, for example, architectural concept design, structural, ventilation, plumbing, electrical designs) for a new built environment, to modify or refurbish an existing built environment or to evaluate compliance with updated regulations. Fire-safety design should be integrated fully with all other engineering design specialties throughout such a project. The requirement for this type of integration is obvious when considering, for example, how the result of acoustic or thermal engineering (introduction of flammable sound/heat absorbing materials) or enhancement of security (limitation of methods of egress) can introduce unintended fire-safety design problems.

To facilitate the determination of actions (loads) on a new built environment due to a fire, it is necessary for a preliminary design plan to be made available to fire-safety designers. This preliminary plan should contain information about the purpose/function of each part of the design, dimensions of each part of the design (including openings) and a description of the anticipated location of all fixtures, furnishings, decorations, equipment and combustible products planned for installation, stored or used in the new built environment, as well as the description and analysis of processes for industrial installations. When dealing with the refurbishment of an existing built environment, it is necessary to provide the same kinds of information. In this case, it is not a preliminary plan but the description of the existing components that provides the basis.

At this stage, it is necessary that the contractual and organizational context of the design work be clearly defined, including the extent to which an FSE approach will be applied (for the whole built environment or part of it) and the functions and duties of each member of the design team.

6 Identification of fire-safety objectives, functional requirements and performance criteria

6.1 General description

Through a process of discussion, negotiation and/or compromise by all interested/affected parties, fire-safety objectives should be identified (including those stated in mandatory regulations), functional requirements that translate these objectives into the required functionality (e.g. fire-protection systems) of the fire-safety design should be developed and quantitative performance criteria should be established for determining whether this functionality results in the achievement of the fire safety objectives.

This process provide answers to the following questions; see 6.3 to 6.5.

- Regarding objectives: What are the required/desired outcomes of all foreseeable fires?
- Regarding functional requirements: How will these outcomes be achieved by design functionality?
- Regarding performance criteria: How will the adequacy of the design be measured in engineering terms?

6.2 Compatibility with prescriptive regulations

Prescriptive regulations generally provide “acceptable solutions” for fire-safety design elements or specific fire-safety design features that are “deemed to satisfy” regulatory requirements. Such regulations may, in some cases, also provide explicit mandatory objectives and/or functional statements concerning the intent of the regulations. When this is the case, additional regulatory information should be used to help prepare the objective statements and to list the functional requirements discussed in 6.3 to 6.5. In the absence of information on the intent of regulations, it is necessary that sets of objectives and functional requirements be developed independently to identify how the impact of fire scenarios is measured by performance criteria.

In addition, when developing an alternative to a prescriptive acceptable solution, it is not necessary that performance criteria be absolute; they can be relative to the performance reached by the acceptable solution. When relative performance criteria are used, it is necessary that the comparison basis be clearly and completely explained.

6.3 Fire safety objectives of interested/affected parties

6.3.1 General

When dealing with performance-based codes or regulations, it is necessary to identify a set of broad objective statements (e.g. desired outcomes) specific to fire safety and in terms understandable to all interested/affected parties. Interested/affected parties can include authorities having jurisdiction, owners, developers, employees and other prospective occupants, emergency responders, insurers and neighbours. Interested parties other than the owner can be represented by authorities having jurisdictions or by third-party professionals.

Since fire safety is a regulatory matter in most countries, there is generally limited scope for modifying these requirements, and it is necessary to provide evidence that the required regulatory objectives are fulfilled. On the other hand, there can be some other objectives that are voluntary, such as minimizing of business interruption or providing a higher level of safety than required by regulatory requirements. In this case, engineering analysis can lead to the modification of objectives, e.g. to the achievement of a balance of safety and cost that is more acceptable to the interested/affected parties.

Objective statements typically address one or more of the areas in 6.3.2 to 6.3.6.

6.3.2 Safety of life

Life safety objectives are typically stated in terms of requirements to reduce or avoid a certain level of harm for occupants and other affected people within and outside the built environment. For safety from injuries that can occur before an occupant can reasonably react to fire and begin evacuation, the objective is typically stated in terms of requirements on equipment or other products to reduce the likelihood of fire occurrence.

An example of a safety-of-life objective is “occupants not intimate with the fire are not injured by smoke or flames”. Fire-service operations involve higher risk and the objective of safety of life for such personnel is typically stated in terms of limiting their risk of injury.

6.3.3 Conservation of property

The property-conservation objectives typically seek to reduce or avoid both damage to the built environment and damage to contents, such as equipment.

An example of a property-conservation objective is “property losses should not be a significant fraction of the total value of the built environment and its contents”.

6.3.4 Continuity of operations

The business- or operations-continuity objectives typically seek to reduce the length of time that operations are interrupted but can also be stated in terms of

- the economic cost of such interruptions, including market share and lost employment opportunities;
- the functional continuity required for the safety of a specific process.

An example of a business-continuity objective is “normal business operations should not be interrupted for a significant period”. An example of an operation-continuity objective not limited to business is “transportation, power, information, health care and other infrastructure necessary for the functioning of the community/region/country should not be interrupted for a significant period”.

6.3.5 Protection of the environment

The environmental-protection objectives typically seek to reduce or avoid the immediate and long-term effects of a fire on the quality of the natural environment. Fires that cause serious long-term effects on the natural environment are rare, but an example is an oil tanker or offshore fire that causes extensive ocean pollution. If there are governmental requirements for environmental quality, it is possible to state the minimum environment protection objectives in terms of compliance with those requirements.

An example of an environment-protection objective is “in the event of a fire, the amount of toxic effluents released to the atmosphere shall be limited”.

6.3.6 Preservation of heritage

The heritage protection objectives typically seek to avoid the loss or alteration of objects for which the value at stake is not primarily economic. These irreplaceable objects are generally both old and unique, having cultural or other symbolic significance. However, heritage protection can also be an economic issue depending upon the cost of its protection.

An example of a heritage protection objective is “the risk of damage to the objects in the museum, in the event of fire, shall be minimized”.

6.4 Functional requirements

Each fire-safety objective should be associated with one or more functional requirements that it is necessary to satisfy by the fire-safety design. A functional requirement is a statement of a condition necessary to achieve the fire-safety objective. That is, the means to achieve an objective are specified as the requirements for the functions, which are elements subject to control through fire safety design, such as the structure, compartments or other defined spaces, materials and products used in the construction of the built environment or fire-protection systems. The specification of functions that have requirements provides the first level of detail of the fire-safety design strategy. The requirements themselves provide a second level of detail on the fire-safety design strategy. While objectives are stated in terms of non-quantifiable outcomes of fires, functional requirements are stated in terms of the function of the fire-safety design that is deemed necessary to achieve the stated objectives. Functional requirements are still qualitative, but they apply at the level of the design elements and so are more meaningful and directly useable for engineering. For example, for a high rise building, a safety-of-life objective typically is developed into functional requirements both to avoid failure of the structure and to protect the paths of egress from harmful fire effects until evacuation is completed. The first is a functional requirement in terms of structural stability and the second is a functional requirement in terms of life safety.

Examples of two such functional requirements are “no design fire scenario should result in permanent structural damage before evacuation of occupants and work by the fire service are completed” and “no design fire scenario should result in harmful fire effects in spaces used for evacuation before evacuation therein is completed”.

6.5 Performance criteria

6.5.1 General

Performance criteria are engineering metrics that are expressed in deterministic or probabilistic (e.g. measures of fire risk) form to determine whether each functional requirement has been satisfied by the fire-safety design. Performance criteria are quantitative engineering measures that can be stated either explicitly or implicitly and should consider reliability and effectiveness.

6.5.2 Explicit performance criteria

Explicit performance criteria should be developed for each functional requirement. For example, a functional requirement that “no design fire scenario should result in unacceptable structural deformation before evacuation of occupants and work of the fire service are completed” typically is developed into quantitative criteria for structural fire resistance until the predicted or probable evacuation of occupants and the necessary operation of fire service. Furthermore, a functional requirement that “no design fire scenario should result in harmful fire effects in spaces used for evacuation before evacuation is completed” typically is developed into quantitative criteria for visibility and concentrations of narcotic (e.g. carbon monoxide) and irritant gases during the period of occupant evacuation and fire service activities.

6.5.3 Implicit performance criteria

When either it is not possible to agree on explicit performance criteria or the assessment is made on a deemed-to-satisfy basis, it is possible to compare, using specific elements of FSE, the performance of an alternative design plan with the predicted or known or probable performance of a design plan that follows the requirements of prescriptive regulations. In this case, the criteria for the performance of individual design functions are implicit and can be obtained only from calculations (predictions) or from reference-scale tests (known behaviour) or from statistical surveys (established probability) on the performance of a reference design plan in which major design elements are prescribed.

7 Hazard identification

Hazard identification comprises both internal and external hazards, as follows, that can have an impact on the built environment, hazards unique to the use of the property and hazards common to many properties, combustible materials or products, equipment and other heat sources, natural hazards, and activities.

a) Internal hazards should consider at least the following:

  - construction products and goods;
  - equipment for normal use and fire safety;
  - occupancy type and associated utilization of the built environment;
  - type of activities or uses.

b) External hazards should consider at least the following:

  - neighbouring activities;
  - natural environmental hazards.

In this identification, fire-incident data applying to similar types of built environment or environmental conditions may be used.

8 Fire-safety design plan

The trial fire-safety design plan (whether derived from a deterministic fire-risk analysis or obtained by other means) is an elaboration of the fire-safety strategy and consists of a set of fire-safety design elements.

This plan should be described and documented in a fire-design report presenting enough detailed information to allow its evaluation in terms of meeting the fire-safety objectives when assessed against the design fire scenarios (Clause 11), which should also be documented in the fire-design report. The design plan can define all functions of the built environment in accordance with a fire-safety strategy or can define some functions as fulfilling deem-to-satisfy solutions. Nevertheless, whatever the situation, it is necessary to take into account in the analysis the interaction between all parts.

A useful organization of functions and design elements into sub-systems (SS) is provided in ISO/TR 13387:

- SS1: initiation of fire and effluent production;
- SS2: spread of fire and propagation of effluents;
- SS3: compartmentalization and structural stability;
- SS4: detection, activation and suppression;
- SS5: human behaviour and evacuation;
- (SS6: fire-fighter intervention).

9 Fire and behavioural scenarios

9.1 General

A scenario typically involves the description of a hazard as an important first step. It is necessary that hazard identification (Clause 7) be conducted in a methodical and organized manner (using existing techniques) to ensure that there are no omissions.

According to this hazard identification, two kinds of scenarios can be elaborated:

- fire scenarios (for fire behaviour);
- behavioural scenarios (for human behaviour) addressing both health and life safety and possible impact on the fire development related to some aspects of fire scenarios.

9.2 Fire scenarios

9.2.1 Identification of potential fire scenarios

The first step in developing a fire scenario is a description of events associated with the hazard that leads to fire initiation. Following fire initiation, there may be events associated with the effectiveness of fire- or smoke-protection measures to limit the impact of the fire. Finally, the scenario is characterized in terms of the consequences of the fire and the likelihood or frequency of those consequences.

In some instances, the failure of one part of a protection measure can have an adverse effect on the effectiveness of another fire protection measure, e.g. an open fire door not only is an ineffective barrier to fire spread but also can lead to the failure of a gaseous extinguishing system due to loss of agent. Another example is an earthquake that contributes to fire initiation at many locations while also causing the failure of sprinkler piping and loss of compartmentalization for protecting against these fires. It is necessary to take particular care to ensure that any such multiple failures from a single event or accident due to interdependencies are identified and accounted for when formulating fire scenarios.

9.2.2 Selection of design fire scenarios

9.2.2.1 General

A standardized method should be used to identify a manageable group of design fire scenarios for analysis. Consultation with interested/affected parties is necessary to ensure that all relevant scenarios are considered. When performance criteria are in a probabilistic form, the design fire scenarios should be chosen so that calculations based on them suffice to produce an acceptably accurate estimate of the required measures of fire risk. When the performance criteria are in a deterministic form, the design fire scenarios should be chosen so that a design shown to deliver acceptable safety for these scenarios can be depended upon to deliver acceptable safety for all the scenarios that were not analysed as well.

The selection of design fire scenarios can be carried out by a qualitative (or a quantitative) risk analysis.

9.2.2.2 Use of qualitative fire risk assessment to select design fire scenarios

A qualitative fire risk assessment process is appropriate to identify and select a group of design fire scenarios that pose a challenge to all formulated functional requirements, when

- major elements of design plans, including such elements as passive and active fire protection, are already decided (whether by owners or other interested/affected parties);
- the potential impacts of fires involving the built environment are agreed by all interested/affected parties to involve only losses that are acceptable (e.g. due to regulations on the number of occupants endangered, on the value of property endangered, etc.)

The qualitative analysis should use likelihood and consequence to characterize each fire scenario in this selection process.

9.2.2.3 Use of quantitative fire risk assessment to select design fire scenarios and design elements

A quantitative fire risk assessment is appropriate as a method to select design fire scenarios and even design elements when

- decisions about major elements of design plans, including passive and active fire protection, have not been made (whether by owners or other interested/affected parties);
- the potential impacts of fires involving the built environment are agreed not to be manageable through regulation.

In such a fire risk assessment, a wide range of potential fire scenarios is analysed quantitatively to establish measures of overall fire risk. The quantitative fire risk assessment allows the selection of the major design elements (active, such as sprinkler protection, or passive, such as compartmentalization or other elements) that are necessary to minimize overall fire risk. As a direct result of the quantitative fire risk assessment, design fire scenarios that are critical contributors to overall fire risk can be identified from the group of all fire scenarios analysed.

9.3 Selection of behavioural scenarios

When life safety is the objective being considered, the evaluation of an engineered design requires an assessment as to whether occupants are protected for the period of time from after fire ignition until they reach a place of safety.

The location of occupants within a building at any one time and the way occupant location changes with time during normal use and emergency situations depends on the interaction of a variety of parameters related to the characteristics of the building and the occupants, the fire-safety management system proposed for the building and the developing fire scenario.

In order to account for the likelihood and consequence of potential fire scenarios, it is necessary to define the classes of occupants who can be present in the building. The response of occupants to a fire condition is influenced by a whole range of variables related to the characterization of the occupants in terms of their number, their distribution within the building at different times, their familiarity with the building, their abilities and disabilities, their reaction to smoke and any physiological effects the fire effluent can have on them; behaviours and other attributes; the characterization of the building, including its use, layout and services; the provision for warnings, means of escape and emergency-management strategy; the interaction of all these features with the developing fire scenario and provisions for emergency intervention (fire brigade and rescue facilities).

These attributes make up the occupant behavioural scenarios for consideration in evaluating the design. Design behavioural scenarios can represent the conditions in a single enclosure or a group of similar enclosures within a built environment. Any structure can contain a variety of different behavioural scenarios to consider during a fire evacuation. A small number of design behavioural scenarios may be used to represent the conditions in different enclosures in a wide variety of structures, although the individual scenarios can vary somewhat in particular cases.

It is impossible to analyse all scenarios, even with the aid of the most sophisticated computing resources. It is necessary to reduce this infinite set of possibilities to a manageably small set of scenarios that are amenable to analysis and that collectively represent the range of combinations of occupant characteristics that can be present.

10 Selection of engineering methods and preliminary report

10.1 Engineering methods to be used

It is necessary to select engineering methods to assess whether a proposed or existing design plan meets fire-safety objectives. This selection process involves the determination of which engineering method(s), as mentioned below, have acceptable accuracy and efficiency in demonstrating that performance criteria are satisfied as the result of one or more design fire scenarios.

10.1.1 Calculation methods

10.1.1.1 Deterministic methods

A deterministic approach is normally based on the evaluation of the seriousness of consequences of each design fire scenario and is compared with threshold figures expressing performance criteria. The relative likelihood of the scenarios is not explicitly considered, but other probabilistic considerations, such as reliability, may be evaluated separately.

10.1.1.2 Fire-risk assessment

Fire-risk assessment of a fire-safety design plan consists of an analysis of the risks and a quantified combination of the probability and severity of harm that are predicted to result if the design is implemented, combined with an evaluation of the acceptability of those risks.

10.1.1.3 Validation and verification

It is necessary to follow detailed guidance for validation and verification of calculation methods and for assessing whether a given calculation method is appropriate.

Fire can have multiple impacts on the built environment, its occupants and the environment. It is necessary to validate the equations and models used to predict these impacts.

For those calculation methods that consist of algebraic equations and computer models applicable to specific fire phenomena (e.g. fire plume, ceiling jet, smoke layer, vent flow or fire growth), a distinction can be made between equations developed for which validation is needed and equations/models that have already been validated, particularly those that have been published as International Standards or Technical Specifications. It is necessary that any equation or model be used only within its field of validity, otherwise it is necessary to provide justifications.

10.1.2 Data from test methods and surveys

Data from test methods or experiments and surveys are typically used as input to various types of engineering methods to determine probabilities for fire risk assessment.

It should be shown that the data from a test method or survey meet the specific requirements of the relevant engineering method or fire-risk assessment technique used and are suitable and adequate for the design under consideration.

It should be shown that the data from a test method or survey meet specific reliability (e.g. as measured by repeatability and reproducibility) and accuracy requirements that are documented in the test method or survey standards.

10.1.3 Analysis of results from reference fire scenario test

Where calculation methods are not available or are not valid due to the complexity of the phenomena involved, a design may be evaluated through the analysis of results from fire tests having a characteristic scale comparable (based on engineering judgement) to the largest dimension of the built environment that can influence the outcomes. It is necessary that such tests that are designed to reproduce all important features of fire behaviour for the situation of interest be denoted as reference-fire scenario tests. Results from this type of fire test should be analysed to show that the conclusions drawn are applicable to the relevant design situation and that such conclusions do not represent an unwarranted extrapolation from test data. Such a test is limited to simple configurations of the built environment or parts thereof.

10.1.4 Engineering judgement

When calculation methods and/or data are not available (or not fully appropriate) and the performance of reference-scale tests is not possible due to limited resources, it can be necessary to utilize engineering judgement to agree on the data being used or to determine if certain parts of a fire-safety design meet objectives by satisfying performance criteria. It is desirable that this be a team effort involving individuals with the relevant areas of expertise and experience.

10.2 Preliminary qualitative report

At this stage of an assessment, it is necessary that the selection of design scenarios and the selection of engineering methods being used for evaluation document the information included in a preliminary qualitative report. It should also include the scope of the project, fire-safety objectives, functional requirements and performance criteria selected.

The preliminary report should receive the agreement of the interested/affected parties, especially the authorities having jurisdiction when dealing with regulatory objectives.

Following comments received by these interested/affected parties, it can be necessary to change one or more of the items contained in the preliminary report.

11 Scenario-based evaluation of trial design

The trial fire-safety design plan should be evaluated by carrying out an engineering analysis using engineering methods to determine whether the quantitative performance criteria are achieved for each design fire scenario.

This evaluation quantifies the performance of the trial design. Depending on whether the performance criteria are expressed in a deterministic or a probabilistic manner, the evaluation can involve specific calculations for each design fire scenario or a probabilistic representation of calculations applying to a range of design fire scenarios.

11.1 Quantification of design fire scenarios

11.1.1 Input data

Data are required to determine, with sufficient accuracy, the design fire to use for each design fire scenario and to quantify the effects of these design fire scenarios. Data can be obtained from tests and/or surveys, or from literature.

It is necessary to check carefully the data derived from tests and surveys regarding

- the validity of the methodology by which data were obtained;
- the range of application of the testing and survey results;
- the uncertainty attached to them.

In the majority of cases, it is recommended to control the set of data by using them when comparing the results of a calculation method with valid experimental or statistical results.

For data taken from the literature, the same verification as for data from tests and surveys is necessary.

11.1.2 Evaluation of consequences

It is necessary to determine the consequences of each design fire scenario taking into account the performance (such as effectiveness, level of confidence, response time) of the fire-protection systems and any interactions between the fire-protection systems and the fire severity.

When dealing with health and life safety, behavioural scenarios have to be taken into account.

These analyses will consider

a) determination of fire behaviour. The evaluation of design fire scenarios through a deterministic analysis or the evaluation of all representative fire scenarios in a fire risk assessment should include the following aspects of fire behaviour:

    — design fire growth in the built environment,

    — movement of effluents caused by the design fire in the built environment,

    — functioning and reliability of active fire-protection systems,

    — functioning and reliability of passive fire systems,

    — effects of the fire-safety management;

b) determination of fire impact. The evaluation of fire behaviour, considering the relevant objectives, should be made identifying the impacts of fire on the following:

    — life safety,

    — property,

    — continuity of operations,

    — protection of the environment,

    — preservation of heritage.

11.1.3 Evaluation of frequency of events

For each design fire scenario considered, it is necessary to undertake an appropriate, detailed evaluation of its probability of occurrence.

11.1.4 Safety factors and uncertainty

In evaluating a fire safety design plan, as with any engineering evaluation, there are many sources of uncertainty. These can include uncertainties associated with

a) the choice and definition of the scenario(s);

b) the functioning of fire protection measures;

c) the selection of appropriate engineering methods for a chosen scenario;

d) the validity of the selected engineering method;

e) the value of input data and chosen parameters;

f) assumptions made as part of the analysis.

The magnitude of uncertainty associated with each component of the evaluation should be quantified and then combined to establish an overall level of uncertainty. This overall level provides the basis for the choice of safety factors (or safety margins) for application.

Many uncertainties are explicitly quantified in probabilistic analysis.

It is not yet possible to quantify levels of uncertainty for all stages of the design process, nor is there yet a generally accepted methodology for combining them.

Any safety factors incorporated in a proposed solution involve a degree of expert judgement by the design engineer and, consequently, also by those responsible for assessing and approving the solution. Wherever possible, this judgement should be informed by an understanding of the basis and limitations of the chosen scenarios, models and data, and should be made explicit in the reporting and presentation of the final design.

For the important practical case where a design is based on a single analytical expression, methods have been developed in structural and other engineering areas to derive safety factors (partial coefficients) corresponding to a pre-determined level of risk or failure. The method is usually termed “reliability-based design” and assumes that relevant uncertainties are quantified in statistical terms. A general description of the methodology is given in ISO/TR 13387-1:1999, Annex E.

11.2 Comparison with performance criteria

It is necessary to compare the results of the evaluations of the fire-safety design for each design fire scenario for both consequence and frequency, as well as with the performance criteria for the relevant fire-safety objectives. If the comparison is unsatisfactory for one or several of the objectives/design scenarios, the following responses are possible.

- The trial design should be modified, to meet any performance criteria that are not met by the original trial design. Any changes made in the fire-safety design plan due to actions from Clause 11 should result in a repeat of the procedures outlined in Clauses 7 through 11.
- When the objective under consideration is voluntary, it can be possible to change the objective or performance criteria with the informed agreement of the interested/affected parties.
- For some situations, it can be necessary to review the scope of the project. In this case, the process should return to Clause 5.

12 Final project report

12.1 Project documentation

12.1.1 General

Three different kinds of documentation should be issued:

- a report for the conditions of use of the built environment;
- a report on the fire-safety engineering assessment performed, in line with the conditions of the built environment;
- a manual of inspection and maintenance procedures for application during the life of the built environment.

12.1.2 Fire-safety engineering assessment report

This report shall clearly and completely explain the basis of the assessment (including all assumptions) and shall include at least the following:

- project scope;
- contents of the final preliminary qualitative report (see 10.2) or a reference to it;
- presentation of the fire-safety strategy;
- presentation of the engineering methods and input data used for the assessments and justification for the choices made;
- various steps of the evaluation of the trial design for the design fire scenarios and results;
- comparison of the results with performance criteria;
- summary conclusion.

12.1.3 Conditions of use of the built environment

The conditions of use of the built environment, consistent with assumptions made in the design, shall be documented in a report. This serves as information by the owner-manager of the built environment throughout its lifetime. This report should include

a) a description of the built environment and its activity, such as the following for the case of a building:
   - number of stories and floor area of each story,
   - location of the building relative to property lines and streets,
   - use of the built environment,
   - purpose/function and dimensions of each part of the built environment,
   - description of the location of all fixtures, furnishings, decorations, equipment and combustible products,
   - for industrial installations, a description and analysis of the processes,
   - occupancy of each space,
   - access of fire service intervention,
   - location and features of the final refuge,
   - evacuation routes to the final refuge; and

b) a list of assumptions made in the assessment which need to be followed, such as:
   - upper limit and location of fire load,
   - upper limit and location of occupants,
   - active fire protection measures (including in-house fire-fighters),
   - passive fire protection measures,

- egress trials,
- inspection and maintenance.

12.1.4 Inspection and maintenance procedures

The report shall list

- whether the initial design input data are fulfilled (e.g. change or evolution of the initial activity, increase of fuel quantity, etc.);
- which protection systems require periodic inspection and maintenance and how and when it is necessary that this be done.

12.2 Global project review

It is necessary for the three reports mentioned in 12.1 to receive full agreement from interested/affected parties to ensure that all the requirements were taken into account and that the final project plan fulfils all the fire safety objectives.

12.3 Agreement of authorities having jurisdiction

When dealing with regulatory fire-safety objectives, the agreement of authorities having jurisdiction is generally necessary. In this respect, the final assessment report shall be provided with, if necessary, the two other reports. The authority having jurisdiction may provide their comments directly or request a peer review of the final design by a third party. This third-party peer review can lead to additional evaluation and/or modification to the final design. If so, the process should be repeated for the modified parts.

13 Implementation of fire-safety design plan

13.1 Identification and treatment of changes

A construction/manufacturing verification report should be prepared.

When deviations from the final design plan are necessary, they shall be documented and, depending on their effect on fire safety, agreement of interested/affected parties or the authority having jurisdiction can be necessary.

In any case, when there is doubt about the significance of a deviation, the fire-safety engineer involved in the fire-safety assessment should be consulted.

13.2 Validation of built environment conformity

Confirmation or evidence that products used in construction or components used in manufacturing are in accordance with the assumptions made in the fire-safety assessment should be available and, where applicable, properly certified.

In some specific uses, when *in situ* tests have been specified to confirm the expected operation of, for instance, active protection or detection devices, those tests shall be performed and reported.

Confirmation or evidence should be available that construction and manufacturing have been accomplished according to the documented design.

13.3 Update of project documentation

When deviations are made in the construction of the built environment, it is necessary to update the three final reports mentioned in Clause 12.

14 Fire-safety management and inspection

14.1 General

Once a fire-safety design is implemented in the built environment, both fire-safety management and independent inspection should be exercised during the built environment's life cycle. The management and inspection processes ensure that the design fire scenarios used by fire safety engineers are always relevant.

14.2 Fire-safety management

14.2.1 Requirement for fire-safety management

Fire-safety management procedures have a vital role to play in the prevention and control of fires, the evacuation of occupants to protected areas and the maintenance of fire safety systems. In certain types of locations, particularly those occupied by large numbers of people, effective management procedures are crucial to a speedy and orderly evacuation. The measures of effective fire-safety management are evidence that the probability of starting a fire has been reduced and evidence that the likelihood of successful evacuation has been enhanced.

14.2.2 Fire-safety manual or information system

The possibility of failures in management procedures and fire protection systems should be considered. This is particularly important as it is often difficult to be certain that effective fire-safety management procedures can be maintained over the lifetime of the built environment. To accomplish this, a fire-safety manual or fire-safety information system can be an effective means of keeping a record of maintenance of fire-protection systems and a checklist of procedures to follow in emergency situations. In-house inspection procedures should also be implemented.

14.2.3 Liaison with fire service

An important element for a successful fire-safety management is effective liaison with fire-service personnel over the life cycle of the built environment. Such liaison should include pre-fire planning that is relevant to current conditions, for example, that fire-service personnel be familiar with the location of fire hazards and with the operation of fire protection systems.

14.3 Independent inspection

14.3.1 Inspection procedures

Where an independent inspection of fire protection and management procedures is carried out regularly, e.g. at least once a year, it is reasonable to assume that fire-protection systems and evacuation procedures are more likely to work effectively than where there are no regular, independent audits. In a built environment that is not subject to independent audit, additional fire protection measures can be necessary to achieve an acceptable level of safety.

14.3.2 Changes

When changes in use, occupancy or fuel load or when renovation or modification of the built environment is identified as significant by independent inspection or other means, the fire-safety design process should be repeated or reviewed, beginning with Clause 6 or Clause 7, at the option of all interested/affected parties. It is preferable to incorporate in a fire-safety design elements or devices that prevent improper use or occupancy of a facility without due notice to all interested/affected parties.

Bibliography

[1] ISO/TR 13387 (all parts), *Fire safety engineering*

[2] ISO/TR 13387-1:1999, *Fire safety engineering — Part 1: Application of fire performance concepts to design objectives*

[3] ISO/TS 16732, *Fire safety engineering — Guidance on fire risk assessment*

[4] ISO/TS 16733, *Fire safety engineering — Selection of design fire scenarios and design fires*

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