



BSI Standards Publication

Fire safety engineering — Verification and validation protocol for building fire evacuation models

National foreword

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Fire safety engineering — Verification and validation protocol for building fire evacuation models

*Ingénierie de la sécurité incendie — Protocole de vérification et
de validation de modèles d'évacuation dans un bâtiment en cas
d'incendie*





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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 04, *Fire safety engineering*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The objective of fire safety engineering is to assist in the achievement of an acceptable predicted level of fire safety. Part of this work involves the use of calculation methods and models to predict human behaviour in case of a fire. Evacuation analyses are performed to mitigate the adverse effects of a fire on people. The main principles that are necessary for establishing credibility of these evacuation models are verification and validation. This document addresses the procedures for verification and validation of evacuation models. The context of applications addressed in this document is building fires.

Evacuation models are applied to establish the time for an evacuating population to reach a place of safety. Evacuation models are also used to examine evacuation dynamics of different scenarios and to evaluate the effectiveness of procedural solutions.

Evacuation models present different levels of sophistication, ranging from simplified methods (such as capacity analysis or flow calculations) to complex computational agent-based models. Microscopic models represent evacuees in computer models as agents. Each evacuee is represented by an autonomous agent with certain properties, e.g. pre-evacuation time and walking speed. A crowd is built up of a group of agents acting together in a multi-agent-based evacuation model. Agents act according to behavioural rules defined in the model. These rules can represent agent-to-agent or agent-to-environment interactions. The macroscopic approach instead represents a crowd at an aggregate level, generally adopting analogies with other physical systems (e.g. hydraulic flows). In addition, in relation to their modelling assumptions in terms of space representation (coarse or fine network approach, continuous approach or hybrid), evacuation models are capable of representing geometries with a different level of accuracy.

Evacuation models operate at three main levels when they produce results, namely 1) Individual Level, 2) Aggregate Level and 3) Scenario level. The individual level deals with the simulation of the actions performed by each agent. The aggregate level concerns the interactions between agents or the interaction between agents and simulated objects which can influence the local conditions. The scenario level relates to the results that summarize the conditions at the end of the simulation, i.e. the final outcome of the model and the layout in which the evacuation takes place.

Potential users of evacuation models and those who are asked to accept the results need to be assured that these models provide sufficiently accurate predictions of human behaviour in fire. To provide this assurance, evacuation models being considered need to be verified for accuracy and validated for capability to reproduce the phenomena. A rigorous verification and validation process are a key element of quality assurance.

There is no fixed requirement of accuracy that is applicable to all possible applications of evacuation models. The accuracy level depends on the purposes for which an evacuation model is to be used. It is not necessary that all evacuation models demonstrate high accuracy in all their components as long as the error, uncertainty and limits of applicability of the models are known. The accuracy of the evacuation model predictions is also highly dependent on the competency of the user, e.g. model configuration, data input selection, results interpretation.

This document focuses on the predictive accuracy of evacuation models. However, other factors such as ease of use, relevance, completeness and status of development play an important role in the assessment of the use of the most appropriate model for a particular application. The assessment and suitability of evacuation models for the simulation of human behaviour in fire in several contexts of applications is supported by the use of a quality-assurance methodology to ensure that the requirements are being fulfilled. Tests and methods for measuring attributes of the relevant model characteristics are outlined in this document.

This document is complementary to ISO 16730-1, in which the procedures and requirements for verification and validation of calculation methods in fire safety engineering are addressed at a general level. This document should also be used in parallel with the relevant ISO documents in which design scenarios are discussed (ISO 16733-1 and ISO/TS 29761).

This document is intended to have the following users:

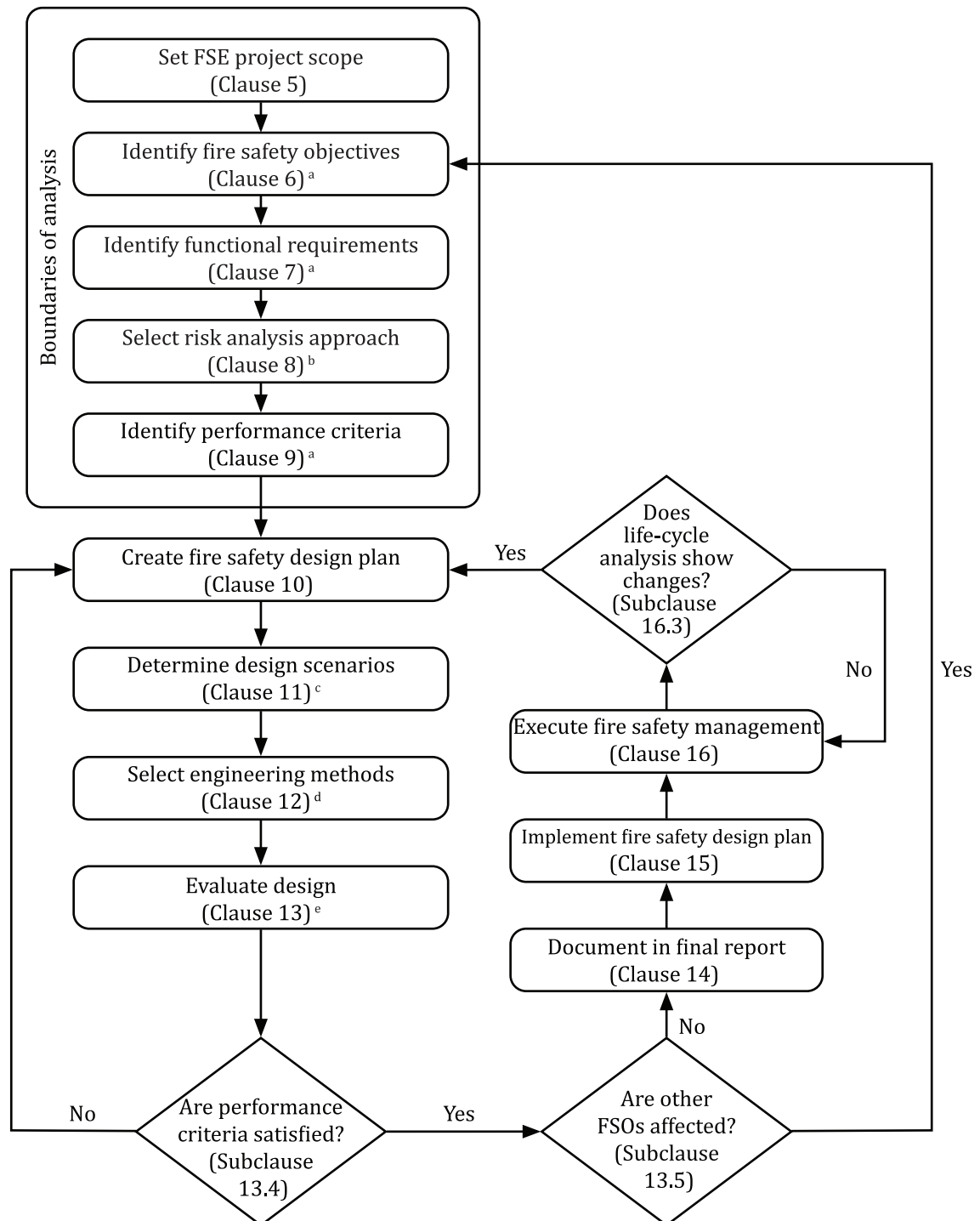
- a) Conceptual model developers (individuals or organizations that perform development activities, including requirements analysis, design and testing of components): These users can use this document to document the usefulness of a particular fire evacuation model for building applications. Part of the model development process includes the identification of precision and limitations of applicability, and independent testing.

NOTE Model developers generally have access to more model components than a user, given their work in the model development phase.

- b) Software model developers (individuals or organizations that maintain computer models, supply computer models, and those who evaluate computer model quality as part of quality assurance and quality control): These users can use this document to document the software features and capabilities and to assure users that an appropriate testing protocol is followed to ensure quality of the application tools by documenting the verification and validation of the model pursuant to this document,
- c) Model users (individuals or organizations that use evacuation models to perform a fire safety analysis): These users can use models verified and validated pursuant to this document to assure themselves that they are using an appropriate model for a particular application and that it provides adequate accuracy.
- d) Developers of performance codes and standards: These users can use this document to specify the verification and validation procedure for evacuation models used in fire safety designs for a given set of applications.
- e) Approving bodies/officials (individuals or organizations that review or approve the use of evacuation models): These users can use this document as a basis to ensure that the results submitted show clearly that the evacuation model is used within its applicability limits and has an acceptable level of accuracy.
- f) Educators: These users can use this document to demonstrate the application and acceptability of evacuation models being taught.

General principles are described in ISO 23932-1, which 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 knowledge of the consequences of such behaviour on life safety, property and the environment. ISO 23932-1 provides the process (necessary steps) and essential elements to design a robust performance-based fire safety programme.

ISO 23932-1 is supported by a set of fire safety engineering International Standards on the methods and data required to undertake the steps in a fire safety engineering design as summarized in ISO 23932-1 and shown in [Figure 1](#) (taken from ISO 23932-1). This set of International Standards is referred to as the Global fire safety engineering analysis and information system. This global approach and system of standards provides an awareness of the interrelationships between fire evaluations when using the set of fire safety engineering International Standards.

**Key**

^a See also ISO/TR 16576 (Examples).

^b See also ISO 16732-1, ISO 16733-1, ISO/TS 29761.

^c See also ISO 16732-1, ISO 16733-1, ISO/TS 29761.

^d See also ISO/TS 13447, ISO 16730-1, ISO/TR 16730-2 to 5 (Examples), ISO 16734, ISO 16735, ISO 16736, ISO 16737, ISO/TR 16738, ISO 24678-6.

^e See also ISO/TR 16738, ISO 16733-1.

Figure 1 — Flow chart of the fire safety engineering process

Fire safety engineering — Verification and validation protocol for building fire evacuation models

1 Scope

This document describes a protocol for the verification and validation of building fire evacuation models. This document mostly addresses evacuation model components as they are in microscopic (agent-based) models. Nevertheless, it can be adopted (entirely or partially) for macroscopic models if the model is able to represent the components under consideration.

The area of application of the evacuation models discussed in this document includes performance-based design of buildings and the review of the effectiveness of evacuation planning and procedures. The evacuation process is represented with evacuation models in which people's movement and their interaction with the environment make use of human behaviour in fire theories and empirical observations^[5]. The simulation of evacuation is represented using mathematical models and/or agent-to-agent and agent-to-environment rules.

The area of application of this document relates to buildings. This document is not intended to cover aspects of transportation systems in motion (e.g. trains, ships) since specific ad-hoc additional tests may be required for addressing the simulation of human behaviour during evacuation in these types of systems^[6].

This document includes a list of components for verification and validation testing as well as a methodology for the analysis and assessment of accuracy associated with evacuation models. The procedure for the analysis of acceptance criteria is also included.

A comprehensive list of components for testing is presented in this document, since the scope of the testing has not been artificially restricted to a set of straightforward applications. Nevertheless, the application of evacuation models as a design tool can be affected by the numbers of variables affecting human behaviour under consideration. A high number of influences can hamper the acceptance of the results obtained given the level of complexity associated with the results. Simpler calculation methods, such as macroscopic models, capacity analyses or flow calculations, are affected to a lower extent by the need to aim at high fidelity modelling. In contrast, more sophisticated calculation methods (i.e. agent-based models) rely more on the ability to demonstrate that the simulation is able to represent different emergent behaviours. For this reason, the components for testing are divided into different categories, enabling the evacuation model tester to test an evacuation model both in relation to the degree of sophistication embedded in the model as well as the specific scope of the model application.

In [Annex A](#), a reporting template is provided to provide guidance to users regarding a format for presenting test results and exemplary application of verification and validation tests are presented in [Annex B](#).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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*

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

ISO/IEC 25000, *Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — Guide to SQuaRE*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and ISO 16730-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 acceptance criteria

criteria that form the basis for assessing the acceptability of the safety of a design of a *building* (3.8)

Note 1 to entry: The criteria can be qualitative, quantitative or a combination of both.

[SOURCE: ISO 13943:2017, 3.3 — modified]

3.2 accuracy

degree of exactness actually possessed by an approximation, measurement, etc.

Note 1 to entry: Accuracy includes *error* (3.19) and uncertainty.

3.3 agent

simulated *occupants* in an *agent-based model* (3.4)

3.4 agent-based model

computational model for simulating the actions and interactions of autonomous *agents* (3.3) using a set of rules

3.5 arrival time

time interval between the time of a warning of fire being transmitted to each occupant and the time at which each individual occupant of a specified part of a *building* (3.8) or all of the building is able to enter a place of safety

3.6 assessment

process of determining the degree to which an *evacuation model* (3.20) is an accurate representation of the real world from the perspective of the intended uses of the model and the degree to which the model implementation accurately represents the developer's conceptual description of the model and the solution to the modelling approach

Note 1 to entry: Key processes in the assessment of suitability of a calculation method are *verification* (3.37) and *validation* (3.36).

3.7 behavioural uncertainty

uncertainty in evacuation scenarios associated with the impact of *human behaviour in fire* (3.24) during evacuation

3.8 building

structure or edifice intended for different uses

Note 1 to entry: Examples of uses include residential, offices, hotels, shopping malls, industrial premises, hospitals, arenas, theatres, exhibition halls, train stations, etc.

3.9**calibration**

process of adjusting modelling parameters in a computational model for the purpose of improving agreement with experimental data

[SOURCE: ISO 13943:2017, 3.42 — modified]

3.10**component testing**

process of checking that the components of a model work as intended

3.11**computer model**

operational computer programme that implements a conceptual model

3.12**crowd**

occupants or *agents* (3.3) whose behaviour, in conjunction with the *environment* (3.18), influences those around them

3.13**default value**

standard setting or state to be taken by the programme if no alternate setting or state is initiated by the system or the user

3.14**default setting**

an initial condition or algorithm provided by a developer as part of the model software

3.15**density**

the number of occupants divided by the available area pertinent to the space where the occupants are located

3.16**deterministic model**

model that uses science-based mathematical expressions or rules to produce the same result each time the method is used with the same set of input data values

[SOURCE: ISO 13943:2017, 3.80 — modified]

3.17**emergent behaviour**

behaviour which occurs due to the interactions among smaller or simpler entities which do not exhibit such properties themselves, e.g. *agents* (3.3)

3.18**environment**

conditions and surroundings that can influence the behaviour of an item or persons when exposed to fire

[SOURCE: ISO 13943:2017, 3.95 — modified]

3.19**error**

recognizable deficiency in any phase or activity of calculation that is not due to lack of knowledge

[SOURCE: ISO 13943:2017, 3.98 — modified]

3.20**evacuation model**

computer model (3.11) for the representation of *evacuation behaviour* (3.21)

3.21

evacuation behaviour

behaviour of the occupants (in the real world) or *agents* (3.3) (in a model) meant to directly or indirectly influence them to reach a place of safety

[SOURCE: ISO 13943:2017, 3.100 — modified]

3.22

evacuation time

time interval between the time of a warning of fire being transmitted to the occupants and the time at which the *occupant* population of a specified part of a *building* (3.8) or all of the building are able to enter a place of safety

[SOURCE: ISO 13943:2017, 3.101 — modified]

3.23

fire safety engineering

application of engineering methods based on scientific principles to the development or *assessment* (3.6) of designs in *buildings* (3.8) through the analysis of specific fire scenarios or through the quantification of risk for a group of fire scenarios

3.24

human behaviour in fire

actions performed in the event of a fire as a result of a behavioural or decision-making process (i.e. recognition of fire, way-finding, pre-evacuation, etc.)

3.25

macroscopic model

computer model (3.11) in which *occupant* movement is represented only at an aggregate level, based on computer-assisted algorithms

3.26

microscopic model

computer model (3.11) in which *agents* (3.3) perform autonomous movement based on individual parameters, capabilities and behavioural attitudes based on computer-assisted algorithms

3.27

model component

part which constitutes a model (i.e. a sub-model, algorithm or behavioural rule)

3.28

modelling

process of construction or modification of a model movement behaviour which enables occupants of a *building* (3.8) to reach a place of safety or safe refuge once they have begun to evacuate

3.29

occupant

person whose main physical characteristics are *walking speeds* (3.38) and body size

Note 1 to entry: *Evacuation models* (3.20) generally account for gender implicitly, i.e. as a consequence of the assumed body size and walking speeds. For this reason, gender is not explicitly mentioned in this document when referring to occupants.

3.30

performance-based design

design that is engineered to achieve specified objectives and *acceptance criteria* (3.1)

[SOURCE: ISO 13943:2017, 3.295 — modified]

3.31**pre-evacuation time**

time period after an alarm or fire cue is transmitted and before occupants first move (or travel) towards an exit

3.32**probabilistic model**

model that treats phenomena as a series of sequential events or states, with mathematical equations or rules to govern the transition from one event to another

Note 1 to entry: For example, from ignition to established burning, and probabilities assigned to each transfer point.

[SOURCE: ISO 13943:2017, 3.314 — modified]

3.33**route availability**

escape routes available to the occupants

3.34**simulation**

exercise or use of a calculation method to represent components of a system, their interaction and their progression over time

3.35**simulation model**

computer model ([3.11](#)) that treats the dynamic relationships that are assumed to exist in the real situation as a series of elementary operations on the appropriate variables

3.36**validation**

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

[SOURCE: ISO 13943:2017, 3.416 — modified]

3.37**verification**

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 1 to entry: The fundamental strategy of verification of computational models is the identification and quantification of *error* ([3.19](#)) in the modelling approach and its implementation.

[SOURCE: ISO 13943:2017, 3.419 — modified]

3.38**walking speed**

maximum uncongested speed at which individual evacuees move towards a place of safety

4 Documentation**4.1 General**

The technical documentation relating to testing should be sufficiently detailed so that all calculation results can be reproduced within the stated accuracy by an appropriately qualified independent individual or group. Sufficient documentation of calculation methods, including computer software, is essential for assessing the adequacy of the scientific and technical basis of the calculation methods, and the accuracy of computational procedures. Also, adequate documentation can assist in preventing the unintentional misuse of calculation methods. Reports on any verification and validation of a specific calculation method should become part of the documentation. The validity of a calculation method

includes comparing results to data from real fire incidents, or from statistical surveys, tests and experiments, and shall be stated by applying quality assurance methodology. These give a measure or a set of measures that shall be compared to previously defined criteria to demonstrate whether agreed quality requirements are met.

Documentation shall include:

- technical documentation that explains the scientific basis of the calculation method, see [4.2](#); and
- a user's manual, in the case of a computer programme, see [4.3](#).

The following clauses describe necessary requirements for technical documentation and a user's manual. The list is not intended to exclude other forms of information that can assist the user in assessing the applicability and usability of the calculation method.

4.2 Technical documentation

Technical documentation is needed to assess the scientific basis of the calculation method. The provision of technical documentation of a calculation method is a task to be performed by model developers. Technical documentation must thoroughly describe the calculation method and its basis, demonstrate its ability to perform adequately, and provide users with the information they need to apply the calculation method correctly. In case of calculations that make use of algebraic formulae derived from experimental results by regression or when analytical solutions are applied, the user shall rely on relevant documentation from standards or similar material, like scientific literature. When standards are developed that contain calculation methods to be used together with technical documentation as described below shall be given, where applicable.

a) The description of the calculation method shall include complete details on:

1) Purpose:

- define the problem solved or function performed;
- describe the results of the calculation method;
- include any feasibility studies and justification statements.

2) Theory:

- describe the underlying conceptual model (governing phenomena), if applicable;
- describe the theoretical basis of the phenomena and physical laws on which the calculation method is based, if applicable.

3) Implementation of Theory, if applicable:

- present the governing equations;
- describe the mathematical techniques, procedures, and computational algorithms employed and provide references to them;
- identify all the assumptions embedded in the logic; take into account limitations on the input parameters that are caused by the range of applicability of the calculation method;
- discuss the precision (error) of the results obtained by important algorithms, and, in the case of computer models, any dependence on particular computer capabilities;
- describe results of the sensitivity analyses.

4) Input:

- describe the input required;

- provide information on the source of the data required;
 - for computer models, list any auxiliary programmes or external data files required;
 - provide information on the source, contents and use of data libraries for computer models.
- b) The verification and validation of the calculation method must be completely described, with details on:
- the results of any efforts to evaluate the predictive capabilities of the calculation method. This should be presented in a quantitative manner;
 - references to reviews, analytical tests, comparison tests, experimental validation and code checking already performed. If, in the case of computer models, the verification of the calculation method is based on beta testing, the documentation should include a profile of those involved in the testing (e.g. were they involved to any degree in the development of the calculation method or were they naive users);
 - were testers given any extra instruction that would not be available to the intended users of the final product, etc.); and
 - the extent to which the calculation method meets this document.

The technical documents shall be collected in one document such as a manual as far as computer models are concerned. Whenever explicit algebraic formulae are used to solve a fire safety engineering problem, relevant technical documentation may be cited from sources as indicated above.

Quality assurance methods shall be used to determine the suitability of the software for its intended purposes. This process is further defined later in this document and is supported by the definition and use of relevant quality assurance methods to arrive at a measurement or a set of (derived) measurements that allow scaling of the quality of a calculation method and whether a calculation method is accurate enough to meet the requirements of the intended user (see, for example, concept on internal and external metrics and on quality in use from the ISO/IEC JTC1 series of Software Quality Requirements and Evaluation [SquaRE]). For further information see the ISO/IEC 25000 series (and following) documents. The purpose of a calculation method's evaluation, in general, is to compare the quality of a calculation method against quality requirements that express user needs, or even to select a calculation method by comparing different calculation methods.

- c) The technical documentation shall include at least one (or more) worked example(s). Worked examples may be required both for explicit algebraic formulae and for mathematical models. The latter is addressed in [4.3 h](#)). The purpose of a worked example is to demonstrate what the required input data are and their limitations, and the range of applicability of the result(s) of the calculation method being considered. Examples for required input data and their intended range or limitations within which the calculation has been validated are, for example, geometry, material properties, and boundary conditions. The range of applicability and accuracy of the calculation method shall be clearly stated in the documentation.

NOTE Significant errors in safety decisions and fire protection measures implemented can result from the use of the calculation method outside the range of stated scenarios determined through the validation process (see [5.4](#) for requirements for identifying the range of applicability established by a validation process).

Standards on calculation methods shall include worked example(s) in an informative annex. By specifying the required components of a worked example in a standard on calculation methods (e.g. ISO 16734 through ISO 16737) guidance is thus given on how to apply the standard correctly, together with information in the standard itself on requirements on limitations and input parameters. Examples taken from real world problems can be (development of) temperature of a steel member, or a fire insult to a cable in a nuclear power plant. Since there are examples available in open literature, the requirement of demonstration of worked examples in an informative annex to a standard on calculation methods may also be met by reference to e.g. textbooks that include such examples.

4.3 User's manual

A user's manual is required only in case of computer models. The user's manual for a computer model should enable users to understand the model application and methodology, reproduce the computer operating environment and the results of sample problems included in the manual, modify data inputs, and run the programme for specified ranges of parameters and extreme cases. The manual should be concise enough to serve as a reference document for the preparation of input data and the interpretation of results. Installation, maintenance, and programming documentation should be included in the user's manual or be provided separately. There should be sufficient information for installing the programme on a computer. All forms of documentation should include the name and sufficient information for defining the specific version of the calculation method and identifying the organization responsible for maintenance of the calculation method and for providing further assistance.

In case of computer models, the user's manual shall provide all the information necessary for a user to apply a computer model correctly. It should include:

- a) Programme description:
 - a self-contained description of the model;
 - a description of the basic processing tasks performed, and the calculation methods and procedures employed (a flow chart can be useful);
 - a description of the types of skills required to execute typical runs.
- b) Installation and operating instructions:
 - identify the minimum hardware configuration required;
 - identify the computer(s) on which the programme has been executed successfully;
 - identify the programming languages and software operating systems and version in use;
 - provide instructions for installing the programme;
 - provide the typical personnel time and setup time for performing a typical run;
 - provide the information necessary for estimating the computer execution time on applicable computer systems for typical applications.
- c) Programme considerations
 - describe the functions of each major option available for solving various problems with guidance for choosing these options;
 - identify the limits of applicability (e.g. the range of scenarios over which the underlying theory is known or believed to be valid or the range of input data over which the calculation method was tested);
 - list the restrictions and/or limitations of the software, including appropriate data ranges and the programme's behaviour when the ranges are exceeded, where this information should be derived from and be consistent with that contained in the technical documentation.
- d) Input data description:
 - name and describe each input variable, its dimensional units, the default value (if any) and the source (if not widely available);
 - describe any special input techniques;
 - identify limits on input based on stability, accuracy and practicality of the data and the applicability of the model, as well as their resulting limitations to output;

- describe any default variables and the process for setting those variables to user-defined values;
 - if handling of consecutive cases is possible, explain the conditions of data retention or re-initialization from case to case.
- e) External data files:
- describe the contents and organization of any external data files;
 - provide references to any auxiliary programmes that create, modify or edit these files.
- f) System control requirements:
- detail the procedure required to set up and run the programme;
 - list the operating system control commands;
 - list the programme's prompts, with the ranges of appropriate responses;
 - if possible to do so, describe how to halt the programme during execution, how to resume or exit, and the status of the files and data after the interruption.
- g) Output information:
- describe the programme output and any graphics display and plot routines;
 - provide instructions on judging whether the programme has converged to a good solution, where appropriate.
- h) Sample problems/worked examples:
- provide sample data files with associated outputs to allow the user to verify the correct operation of the programme. These sample problems should exercise a large portion of the available programmed options. For comparison, see [4.2 c\)](#).
- i) Error handling:
- list error messages that can be generated by the programme;
 - provide a list of instructions for appropriate actions when error messages occur;
 - describe the programme's behaviour when restrictions are violated;
 - describe recovery procedures.

5 Verification

5.1 General

Verification is the process of determining that the implementation of a calculation method accurately represents the developer's conceptual description of the calculation method and of the solution to the calculation method. This does not imply that the governing equations or rules are appropriate, only that they are being implemented and solved correctly and that the implementation accurately represents the developer's conceptual description of the calculation method and of the solution to the calculation method.

This section presents a list of components for the verification of evacuation models for the study of human behaviour in building fires. The components subjected to verification are divided into different categories. The first category relates to the basic components that shall be verified in order to have a model able to represent basic evacuation scenarios. Some of these basic components have been defined in line with the work conducted by the International Maritime Organization in the context of the verification of evacuation models for passenger ships^[9]. If one of these components is not present in the model, the associated verification test is not conducted, but the model testers shall clearly state

that this component is missing. The second category relates to the behavioural components that a model may include in relation to its predictive behavioural capabilities. The third category refers to fire-people interaction components. These components deal with the representation of the interactions between people and the effects of fire (e.g. reduced visibility, toxicity). The last category refers to the components that a model may include in relation to the specific building/application in consideration. Evacuation models may include further components in addition to the list presented in this section. If additional components are available in an evacuation model, this shall be included in the verification testing procedure.

The basic components of all evacuation models shall be verified. Evacuation model testers may further verify the behavioural components, the fire/people interaction components and the building-specific components in relation to the stated field of applicability of the model under consideration.

Components can be categorized in different manners^[10]. Core components relate to different functionalities, namely Pre-evacuation (P), Movement (M), Navigation/Route selection (N&R) and Flow conditions/constraints (F). The levels which are addressed in the components can be 1) Individual, 2) Aggregate or 3) Scenario level.

This document presents the components, as well as a list of possible tests that can be used for the verification of them. Different tests can be used by model testers if they are able to verify the components under consideration in a satisfactory manner (i.e. the tester shall provide an equivalent proof that the component has been verified). In some instances, evacuation models can require different test methods for the analysis of their results regarding the input variables required for their calibration. In these instances, a justification of the different test method shall be provided by the model tester.

The basic and additional components are listed in this document in accordance with the following structure:

- a) *Test name*: name of the test;
- b) *Objective*: the purpose of the test conducted;
- c) *Geometry*: the configuration/layout of the test;
- d) *Scenario(s)*: the evacuation scenario that is going to be simulated;
- e) *Expected result*: the result (qualitative or quantitative) that the evacuation model is supposed to produce;
- f) *Test method*: different approaches can be used to assess model performance. These are generally either qualitative or quantitative. A qualitative evaluation is a judgement-based comparison between simulated and expected results (e.g. an expected behaviour based upon the current behavioural theory, a descriptive/graphic narrative, a timeline graphic, a histogram, a behaviour diagram, data trace, boxplots or a subject matter expert test). Quantitative testing involves numerical or statistical comparisons between the simulated and expected results (e.g. expressed as quantitative differences in terms of event frequency, correlation analysis, functional analysis, confidence intervals or inferential statistics of performance measures); and
- g) *User's actions*: the actions required of the tester while performing and presenting the tests.

Models may adopt two approaches when representing an emergent behaviour. This can be the result of a deterministic user-defined assumption for the outcome or the result of a predictive sub-model. On one hand, models employing a deterministic approach can be tested for verification only, i.e. no validation studies can be made since the simulated outcome is based on an *a priori* assumption. On the other hand, models including predictive sub-models can be tested using both verification and validation testing. For this reason, the model tester shall document what type of sub-model is being tested (deterministic user-defined or predictive).

In this document, verification of emergent behaviours is deliberately distinguished from validation. This is because those tests evaluate if model results are in line with ideal cases based on current behavioural theories rather than making a direct quantitative use of experimental (or real) evacuation data. If

experimental data are used as benchmark for the assessment of the component under consideration, a test should be intended as a validation test.

In some instances, the testing of a component may require that a sufficient number of simulation runs is performed in order to evaluate the results of evacuation simulations in relation to multiple simulations. This is due to the fact that evacuation simulations may make use of stochastic variables and/or random sampling. The need for the analysis of this issue is specified in this document for each relevant component and the model tester should report the methods adopted to address this issue.

An example application of a verification test is presented in [Annex B](#).

5.2 Basic components

A list of basic components that shall be verified in evacuation models is presented in [Table 1](#). Each component is briefly described and an associate test that can be used for its testing is presented. It should be noted that some of the tests recommended for the basic components are based on largely arbitrary geometric layouts. This means that similar tests can be conducted provided that the tests are able to verify the described basic component under consideration.

Table 1 — List of basic components in evacuation models that should be verified

Test [#]	Title	Level ^a	Core component ^b
1	Pre-evacuation time assignment	A	P
2	Walking speed in a corridor	I	M
3	Walking speed on stairs	I	M
4	Movement around a corner	A-S	M
5	Assigned demographics	A	M
6	Horizontal counter-flows (rooms)	A	M
7	Overtaking people with movement disabilities	A	M
8	Exit route allocation	I-S	N&R
9	Dynamic availability of exit	S	N&R
10	Congestion in front of a flight of stairs	A	F
11	Maximum flow rates at an opening/exit	A	F
12	Stair flow rates	A	F
13	Relationship between flow rate, density and walking speeds in a corridor	A	F
^a Individual level (I), Aggregate level (A), Scenario level (S).			
^b Pre-evacuation (P), Movement (M), Navigation and Route Selection (N&R), Flow conditions/constraints (F).			

Test 1 — Pre-evacuation time assignment

The ability of evacuation models to assign distributions of pre-evacuation times to occupants shall be verified. Model testers shall demonstrate quantitatively that the model is able to represent the pre-evacuation time assignment of a population corresponding to the assigned values. A possible test is presented in [Table 2](#).

Table 2 — Example of Pre-evacuation time assignment verification test

Test name	Pre-evacuation time assignment
Objective	Assess consistency between user pre-evacuation time assignment and model representation.
Geometry	A room of size 8 m by 5 m with a 1 m exit.
Scenario(s)	Ten occupants are randomly located in the room. Check the types of distributions used by the evacuation model to represent pre-evacuation times. Impose a pre-defined distribution (e.g. uniform, normal, log-normal, etc.) of pre-evacuation times in accordance with the input distributions provided within the evacuation model. Repeat the test for each distribution of pre-evacuation time embedded in the model.
Expected result	Verify that each occupant starts moving at the appropriate time and that the pre-evacuation of the population fall within the specified range.
Test method	The test method is a quantitative verification of the model assignment expressed in terms of pre-evacuation time. In relation to the type of distribution under consideration, the model tester should identify a suitable quantitative method to evaluate the differences among the simulated and assigned distributions.
User's actions	This test should be repeated several times (i.e. multiple runs of the same scenario should be performed) in order to verify the simulation of the expected pre-evacuation time assignment over multiple runs. The requirements for the number of runs may vary over different distributions. Different tests may be employed to demonstrate that the values belong to certain distributions. Model testers should demonstrate this with a suitable test in relation to the distribution(s) under consideration.

Test 2 — Walking speed in a corridor

The ability of evacuation models to simulate an occupant maintaining an assigned walking speed over time shall be verified. An occupant shall cover a distance on a horizontal plane in a time corresponding to an assigned walking speed. Some models adopt a network approach to simulate space, hence they may not allow the representation of an exact speed or an exact length. In those cases, results can be verified in a given range rather than exact results. This component testing is not directly applicable to macroscopic models, where only the aggregate level of movement is taken into consideration. Current models do not generally permit a direct representation of the impact of fatigue on walking speeds on stairs. If this feature is implemented in a model, an additional test shall be conducted. A possible test is presented in [Table 3](#).

Table 3 — Example of walking speed in a corridor verification test

Test name	Walking speed in a corridor
Objective	Assess consistency between user walking speed assignment in a corridor and model representation.
Geometry	A corridor 2 m wide and 40 m long.
Scenario(s)	One occupant with an assigned walking speed of 1 m/s walking along the corridor.
Expected result	The occupant should cover the distance of the corridor in 40 s.
Test method	The test method is a quantitative verification of model results, i.e. the difference between the expected result and the simulation results.
User's actions	The effectiveness of this test can be improved by setting additional prescriptions in relation to the type of model under consideration. For example, in the case of models that use a network approach, results may be dependent on the configuration of the grid adopted. In the case of models using a fine grid, results may be affected by the rotation of the corridor in relation to the grid in use. The test should be performed using at least two different rotations of the geometry (e.g. 0° and 45°). Considerations should also be made by the tester on the necessity (or not) of performing this test with different grid configurations (e.g. simulating the default cell size and a set of both reduced and increased cell sizes) in order to test the sensitivity of the results to cell size. The method for setting up the destination should be reported. The model tester should also report if the agents exhibit acceleration/deceleration to the specific walking speed.

Test 3 — Walking speed on stairs

The ability of evacuation models to represent occupant movement up and down stairs shall be verified. An occupant shall cover a distance on a stair in a time corresponding to an assigned walking speed. Some models adopt a network approach to simulate space, hence they may not allow the representation of an exact speed or an exact length. In those cases, results can be verified in a given range rather than exact results. This component testing is not directly applicable to macroscopic models, where only the aggregate level of movement is taken into consideration.

Occupant movement on unconventional stairs (e.g. spiral stairs, curved stairs) shall be considered if the stated applicability of the evacuation model under consideration involves these building components for evacuation. Evacuation models do not generally permit a direct representation of the impact of fatigue on walking speeds on stairs. If this feature is implemented in a model, it shall be tested as well. A possible test is presented in [Table 4](#).

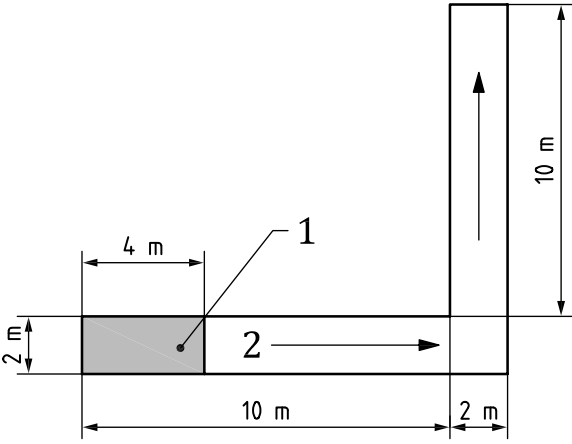
Table 4 — Example of walking speed on stairs verification test

Test name	Walking speed on stairs
Objective	Assess consistency between user walking speed assignment on stairs and model representation.
Geometry	A stair 2 m wide and with a length of 10 m, measured along the incline.
Scenario(s)	One occupant with a walking speed of 1 m/s (upwards or downwards) is walking along the stair incline.
Expected result	The occupant is expected to cover the distance in 10 s (upwards or downwards).
Test method	The test method is a quantitative verification of model results, i.e. the difference between the expected result and the simulation results.
User's actions	Evacuation models may use the same input to modify people's movement on the stairs (either upward or downward movement). For example, the user defines a speed factor (either manually or by inserting certain parameters such as stair tread and width). The method for setting up the destination should be reported. The method for representing occupant movement on stairs should be documented.

Test 4 — Movement around a corner

The ability of evacuation models to represent occupant movement within scenario boundaries shall be verified. Occupants should be able to navigate around a corner without penetrating walls. A test is necessary in order to make sure that the space representation is correct and that occupants move only in the simulated space. Current tests of movement around a corner should be intended only as a verification of the boundaries available in the scenario, i.e. no evaluation of the expected occupant trajectories in the corner is made (i.e. the current testing is not a verification of emergent behaviours). Nevertheless, once a sufficient body of benchmark experiments on occupant trajectories is available for comparison, testing can be expanded in order to include the analysis of occupant trajectories (i.e. it can become a validation test). A possible verification test is presented in [Table 5](#).

Table 5 — Example of movement around a corner verification test

Test name	Movement around a corner
Objective	Assess consistency between space usage in a corner and model representation.
Geometry	A corner is represented in accordance with Figure 2.  Key 1 20 persons, uniformly distributed 2 direction of movement Figure 2 — Schematic geometric layout of the test (top view)
Scenario(s)	Twenty occupants are uniformly distributed in one end of the hallway (in a space measured 2 m by 4 m). They have pre-evacuation time equal to 0 and a walking speed of 1 m/s.
Expected result	The occupants are expected to successfully navigate around the corner without penetrating the boundaries.
Test method	The test method is a qualitative or quantitative verification of occupant movement (or a quantitative validation of occupant trajectories if experimental data are available). The analysis is performed by observing the travel path walked by the occupants (qualitative evaluation) and/or tracking the coordinates of the paths of the occupants (quantitative evaluation).
User's actions	The test should include measurements of the flow rates entering and exiting the corner. These flow rates are compared, and differences are measured. The tester should document if changes in flow rates occur and if the corner causes a bottleneck. The method for setting up the destination should be reported. Further testing can be carried out to consider corners of different angles (e.g. 180°).

Test 5 — Assigned demographics

The ability of evacuation models to assign population demographics characteristics shall be verified. A possible verification test concerning the consistency of walking speed distributions is presented in [Table 6](#).

Table 6 — Example of assigned occupant demographics verification test

Test name	Assigned occupant demographics
Objective	Assess consistency between occupant demographics assignment and model representation.
Geometry	A square room of size 100 m by 100 m.
Scenario(s)	Choose a crowd consisting of a population with pre-defined characteristics. Those should be selected in the same range of the expected building(s) occupancy. Assign the walking speeds over a population of 100 occupants evenly distributed in the room.
Expected result	Show that the assigned walking speed distribution is consistent with the distribution specified in the scenario.
Test method	The test method is a quantitative verification of model assignments, i.e. the analysis of the walking speeds simulated by the evacuation model. In relation to the type of distribution under consideration, the model tester should identify a suitable quantitative method to evaluate the differences among the simulated and assigned distributions.
User's actions	Values to be used for the characterization of occupant demographics are dependent on several factors, such as building use, nationality, etc. Refer to Lord et al. (2005) ^[11] for examples of actual distributions. The data used for the characterization of occupant demographics shall be clearly documented. Model testers should demonstrate that the simulation of occupant demographic distributions is verified over multiple runs, i.e. the test should be repeated several times.

Test 6 — Horizontal counter-flows

The ability of evacuation models to simulate horizontal counter-flows shall be verified. Current testing should be intended only as a verification of the qualitative abilities of models to represent counter-flows, i.e. no evaluation of the expected occupant trajectories is included. Nevertheless, once a sufficient body of benchmark experiments on occupant trajectories is available for comparison, testing can be expanded in order to include the analysis of occupant trajectories (i.e. it can become a validation test). A possible verification test is presented in [Table 7](#).

Table 7 — Example of horizontal counter-flows verification test

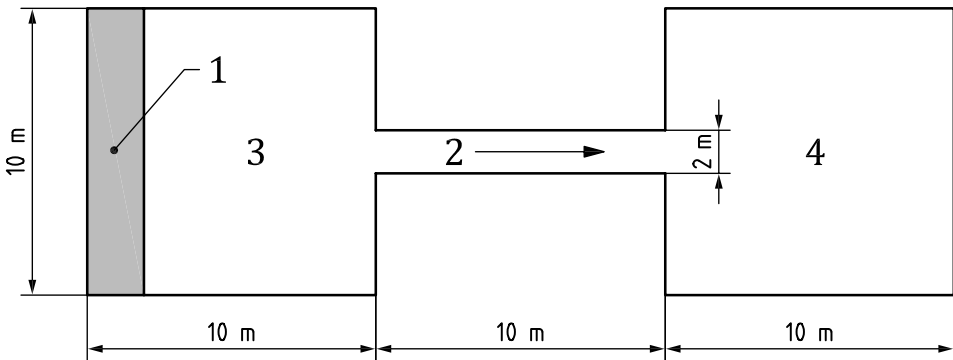
Test name	Horizontal counter-flows								
Objective	Assess the qualitative abilities of models to represent horizontal counter-flows.								
Geometry	Two rooms 10 m (wide and long) connected via a corridor 10 m long and 2 m wide starting and ending at the centre of one side of each room (see Figure 3).  Key <table><tr><td>1</td><td>100 persons</td><td>3</td><td>room 1</td></tr><tr><td>2</td><td>direction of movement</td><td>4</td><td>room 2</td></tr></table>	1	100 persons	3	room 1	2	direction of movement	4	room 2
1	100 persons	3	room 1						
2	direction of movement	4	room 2						

Figure 3 — Schematic geometric layout of the test (top view)

Figure 3 — Schematic geometric layout of the test (top view)