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Fire safety engineering — Design of evacuation experiments

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Foreword

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

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Introduction

Performance-based engineering requires analyses of building design. Such analyses require a great deal of data on occupant response, movement and behaviour. Data is also collected for the development and validation of model calculations. Empirical data sets are rare and those that exist can be difficult to use in combination.

This document provides guidance in the conduct of evacuation experiments and the collection and coding of data, so that users can understand the context under which the data was collected, and in order to facilitate the use of data sets in combination with each other. Although the development of a repository of data is not part of the scope of this document, the use of a consistent process for collecting and distilling peer-reviewed reaction, response and movement data will allow the development of such a repository.

This document specifies the techniques used in the collection of evacuation data. It also provides guidance for documenting experiments, so as to provide context and background for the use of the data, as well as a methodology for the coding of those data.

The main criterion suggested in this document for evaluating an evacuation is total evacuation time (a parameter of "escape time" as defined in ISO/TR 16738). Evacuation time includes pre-travel activity time (often called "pre-movement time") and travel time. Escape time depends on a range of qualitative and quantitative parameters (see ISO/TR 16738). Other possible performance measurands include walking speeds on horizontal surfaces, stairs and ramps, occupant densities, flows through openings, delays before and during evacuation, exit choice, affiliation, altruism, scepticism, courtesy range, herding behaviour, space occupancy, risk perception, etc. Information on the influence of these parameters on total evacuation time and on understanding human behaviours is available in ISO/TR 16738, ISO/TS 29761 and SFPE Guide[1]).

Instrumentation for measuring walking speeds, densities, delays, etc. is discussed in this document, along with suggested locations for instrumentation. A minimum level of instrumentation is also suggested.

The safety of participants is strongly emphasized in this document.

The evacuation experiments carried out in accordance with this document will allow the comparison of the results of other experiments also realized with this document and thus, will contribute to increased epistemological knowledge. This will be useful for the development or modification of building regulatory requirements and could provide useful information for assisting in the development or testing of evacuation models.

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Fire safety engineering — Design of evacuation experiments

1 Scope

This document specifies a methodology for the design of experiments conducted in the built environment to collect data on evacuation for the following purposes:

— for use in fire safety engineering;

— for comparing different evacuation experiments realized in different jurisdictions and conditions;

— for studying one or more variables;

— for achieving a general overview of an evacuation or for testing one or more parameters;

— for design safety procedures and training;

— for assessing evacuation plan(s);

— for reducing uncertainty on the results;

— for verifying the relevance of preventive measures implemented before and after building design;

— for refining software input parameters and making them more realistic;

— for comparing the results obtained with different software;

— for verifying and validating evacuation models (for example ISO 16730-1).

This document provides guidance in several main areas: initial planning, preparation, the evacuation experiment itself, coding the collected data, data analysis and interpretation and documentation of results.

This document sets out the considerations for an evacuation experiment, including geometry of the space, lighting and environmental conditions, occupant characteristics, cue or alarm used, instrumentation and safety considerations. It discusses performance measurements for the evacuation experiment. The results of any experiment depend on all these factors and their interactions, if any. This document does not define a standard evacuation experiment.

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 23932-1, *Fire safety engineering — General principles — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943, ISO 23932 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

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— IEC Electropedia: available at https://www.electropedia.org/

3.1
built environment
building or other structure

EXAMPLE Off-shore platforms; civil engineering works, such as tunnels, bridges and mines; and means of transportation, such as motor vehicles and marine vessels.

Note 1 to entry: Some aspects of the building are of particular interest, for example, dimensions, occupancy type, etc. ISO 6707-1 contains several terms and definitions for concepts related to the built environment

3.2
controlled experiment
experiment where the researcher determines the composition of the participant population and is able to distinguish between participant groups and thus identify the independent variables

Note 1 to entry: The researcher checks all the factors likely to influence the experimentation. The researcher identifies all the factors and then varies them, one at a time.

3.3
escape time
interval between ignition and the time at which all occupants are able to reach a safe location

[SOURCE: ISO/TR 16738:2009, 3.3]

3.4
escape route
path forming that part of the means of escape from any point in a building to a final exit or other safe location

[SOURCE: ISO/TR 16738:2009, 3.2]

3.5
exit
doorway or other suitable opening giving access towards a place of relative safety

[SOURCE: ISO/TR 16738:2009, 3.4]

3.6
experiment
purposive investigation of a system through selective adjustment of controllable conditions and allocation of resources

Note 1 to entry: An experiment is a process or study that results in the collection of data or measurements with stated objectives.

Note 2 to entry: An empiric procedure carried out under controlled conditions in order to discover an unknown effect or law, to test or establish a hypothesis, or to illustrate a known law. A situation that will test a causal hypothesis, used to test independent variables effects on dependents variables

Note 3 to entry: A scientific approach to obtain qualitative and qualitative results based on observation and measurements

Note 4 to entry: Set of actions and objective observations carried out to solve a problem, answer a question or confirm/refute a hypothesis on a phenomenon

[SOURCE: ISO/TR 13195:2015, 2.1, modified — Notes to entry added.]

3.7
evacuation time
interval between the time of a warning of fire being transmitted to the occupants and the time at which all of the occupants are able to reach a place of safety

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3.8
fire scenario
qualitative description of the course of a fire with respect to time, identifying key events that characterize the studied fire and differentiate it from other possible fires

[SOURCE: ISO 16733-1:2015, 3.3, modified — Notes to entry removed.]

3.9
flow time
time required for a group of occupants to pass through a specific exit or set of exits from an enclosure or building

[SOURCE: ISO/TR 16738:2009, 3.5]

3.10
interpersonal distance
physical distance between people

3.11
measurand
particular quantity subject to measurement

3.12
measure
variable to which a value is assigned as the result of measurement

[SOURCE: ISO 16730-1:2015, 3.12]

3.13
measurement
set of operations having the object of determining a value of a measure

[SOURCE: ISO 16730-1:2015, 3.13]

3.14
observational study
study where the researcher observes participants and measures variables of interest without control of independent variables

Note 1 to entry: An independent variable is a variable that is intentionally changed to observe its effect on the dependent variable and includes any experimental factor whose variations are under the control of the experimenter. Independent variable fluctuations result in changes in the response of a dependent variable.

Note 2 to entry: A dependent variable is the studied variable expected to change when the independent variable is changed. A variable is called dependent if its variations are linked to the fluctuations of one or several independent variables. It represents the response (effect) of the experimental subject to the experimental conditions set by the experimenter.

3.15
pre-travel activity time
for an individual occupant, interval between the time at which a warning of a fire is given and the time at which the first move is made by that occupant towards an exit

Note 1 to entry: This consists of two components: *recognition time* (3.16) and *response time* (3.18).

Note 2 to entry: For groups of occupants, two phases can be recognized:

— pre-travel activity time of the first occupants to move;

— pre-travel activity time distribution between the first and last occupants to move.

[SOURCE: ISO/TR 16738:2009, 3.9, modified — "for an individual occupant" added at the beginning of the definition and "an occupant" changed to "that occupant" in the definition.]

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3.16
recognition time
interval between the time at which a warning of a fire is given and the first response to the warning

[SOURCE: ISO/TR 16738:2009, 3.10]

3.17
recruitment
assembly of a group of participants/persons who are involved or participate in an experiment, such as occupants, observers, camera crew, persons in charge of timing, etc.

Note 1 to entry: Sample specifications outline all characteristics used for defining participants (age, gender, numbers of persons, etc.). Localization information for the persons involved in the experimental trial is also included.

3.18
response time
interval between the time at which the first response to the event occurs and the time at which travel begins to a safe location

[SOURCE: ISO/TR 16738:2009, 3.11]

3.19
travel time
time needed, once movement towards an exit has begun, for an occupant of a specified part of a building to reach a safe location

[SOURCE: ISO/TR 16738:2009, 3.14]

3.20
uncertainty
quantification of the systematic and random error in data, variables, parameters or mathematical relationships, or of a failure to include a relevant element

[SOURCE: ISO 23932-1:2009, 3.14]

3.21
validation
process of determining the degree to which a calculation method is an accurate representation of the real word from the perspective of the intended uses of the calculation method

[SOURCE: ISO 16730-1:2015, 3.24]

3.22
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

[SOURCE: ISO 16730-1:2015, 3.25, modified — Note 1 to entry removed.]

3.23
walking speed
unrestricted speed of movement of a person

[SOURCE: ISO/TR 16738:2009, 3.15]

4 Design of evacuation experiments

4.1 General

This document specifies a methodology for the design of experiments related to evacuation. These experiments can be conducted in the field or in laboratories to collect data for use in fire safety engineering

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in the built environment, as well as for the design of safety procedures and training and to improve calculation models and code developments. Documents exist that provide extremely detailed steps to take in collecting human performance data and the user is referred to such documents for additional detail and advice.[2],[3] The steps detailed in the following subclauses assume that some preliminary decisions have been made about the purpose of the evacuation experiment, e.g. the purpose for which the data will be used, who the stakeholders and other interested parties are, and how the data will be stored and presented.

This document is intended as a guide for the design of experiments, in a laboratory setting or in the field, to establish pre-evacuation time and the key movement factors that then influence overall movement time in order to determine the total evacuation time (e.g. walking speeds, delay times, waiting and resting times, occupant densities during evacuation, inter-personal distances, behaviours during evacuation, rate of descent in the stairs, flow through openings, exit choice) and psychological or social factors (e.g. affiliation, altruism, scepticism, courtesy range, social influence/social interaction, space occupancy, influence of the presence of staff, risk perception, etc.). These key factors can be useful for describing or predicting occupant movement under actual emergency conditions. The results of experiments conducted in accordance with this document will also be useful elements for making regulatory decisions regarding fire safety requirements.

Evacuation experiments are a means of generating input data for computer evacuation models and for providing output data with which to compare modelling results. Data obtained are also useful for engineering calculations and for contributing to the development of models and regulatory code. Another principal reason for conducting experiments is as a means of assessing the potential hazard and/or validating an evacuation or fire safety plan associated with the use of building elements in a particular application.

This document is used to design experiments intended to measure and describe the actions and behaviours of occupants under controlled or non-controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of people under actual emergency conditions.

This document does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this document to establish appropriate safety, health and ethical practices.

For the purposes of this document, evacuation experiments are considered in two categories: observational studies and controlled experiments. These experiments can be carried out in a laboratory or in the field. Observational studies allow influential factors to be identified; controlled approaches focus on specific factors of interest, typically excluding other factors in the process. The two approaches are compared in the two flowcharts in Figure 1.

Observational studies are those where the researcher does not control the independent variable, such as post-fire investigations or observations of evacuation drills or occupant movement where the researcher does not influence the composition of the participant population. Data recorded here has high ecological validity, and absolute values (e.g. movement speeds) can be transferred to other similar contexts. However, this method does not allow for hypotheses testing and no causal inference on behavioural phenomena is possible.

Controlled experiments in this case are those where the researcher determines the composition of the participant population (through recruitment) and distinguishes between participant groups and thus identifies the independent variables. Data recorded here has lower ecological validity compared to observational studies. However, causal inferences on behavioural phenomena are possible.

4.2 Initial planning

4.2.1 Purpose of experiment

The first step in planning the experiment is to determine what aspect of evacuation is to be measured, given the planned objective or application of results. This will guide the choice of building (or other built environment) to be used, the equipment needed to make the measurements, the placement of measurement equipment and the analysis that will be possible. Possible elements that can be measured include, but are not limited to the lists shown in Table 1.

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Table 1 — Potential parameters for measurement

Measurands and calculations parameters	Behavioural parameters

— Total evacuation time or specific evacuation time (floor, area, sub-population).
— Time required to evacuate the population of a location to areas of safety).
— Pre-evacuation activity time.
— Travel times.
— Delay times.
— Walking speed in corridors or stairs.
— Flow rates through doors or along corridors.
— Resting time during evacuation.
— Route loading.
— Other
	— Emerging behaviour:
	  — merging behaviour,
	  — congestion.
	— Individual responses:
	  — exit/route choice.
	— Individual performances:
	  — fatigue,
	  — body sway,
	  — ease in use of latching devices.
	— Collective responses:
	  — interpersonal distance,
	  — counter flow,
	— Other.

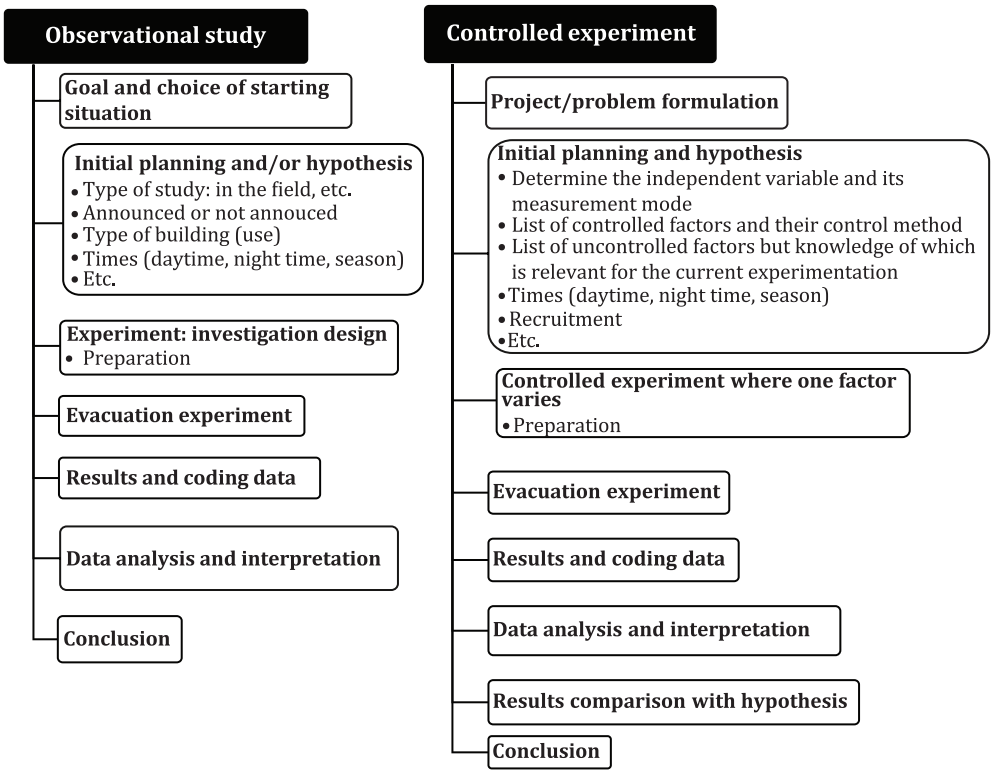

Figure 1 — Flow chart of steps in designing observational studies and controlled experiments

Some additional decisions about the focus of the experiment are also specified in this step.

For example, will the participants involved in the experiment be the regular users of the building (people who live or work in the building)? If so, will the occupants be notified about the experiment or will it be unannounced? In some studies, participants are brought into the test environment (for example, people

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invited to participate in a cinema evacuation). If an evacuation drill is to be studied, will it be a full building evacuation or a phased evacuation or something specially arranged for the experiment, such as a partial evacuation? Will there be people with disabilities in the building? How much of the building population will be monitored during the evacuation?

If evacuation drills are carried out during the normal use of the building and people are in a part of the building where they could interfere with evacuation, what effect would this have? For example, in the case of an evacuation drill in a cinema, how would people waiting in the hallway to enter the auditorium interfere with movement of people trying to escape?

4.2.2 Types of experiments

Once the objectives are chosen, the following elements need to be identified:

— type of studies (observational evacuation or controlled evacuation, announced or unannounced experiments, in-field or in-lab experiment);

— influential factors and outcomes;

— level of granularity of the data collection (individual/collective, macroscopic data/microscopic data);

— operationalization of data collection (e.g. objective vs. subjective data; precision and accuracy of chosen measuring method).

Experiments give qualitative data and quantitative data.

The choice of experiment type has implications for the data collected. It can also influence the occupants' performances, the decision-making or their movement characteristics.

For experiments undertaken in a laboratory, this is not an issue. But for experiments in the field, there is a need to establish how to conduct the experiment, i.e. announced vs. unannounced evacuation. This is an important factor because it impacts the hypothesis.

In a laboratory, experiments are announced experiments with controlled evacuation.

In the field, three possibilities are offered for an experiment.

— Case 1: Unannounced experiment.

— Case 2: Announced experiment where date and time are known by the participants.

— Case 3: Announced experiment where the exact date and time are unknown by the participants.

For announced experiment, sub-cases can exist which include the parameter "regular users" vs. "recruited evacuees". Recruitment is presented in 4.2.10.

4.2.3 Development of fire/evacuation scenarios and experimental design

4.2.3.1 General

A clear definition of the details of the experiment helps to make the data analysis possible, improves the usefulness of the results, and reduces the likelihood of the data being misinterpreted and misapplied. The overall data collection and analysis plan considers how the experimental factors, both controlled and uncontrolled, will meet the specific objectives of the experiment and will satisfy the practical constraints (time, site availability, availability of recruited participants, etc.).

To develop evacuation scenarios, the researcher may refer to ISO/TS 29761 and ISO 16733-1.

4.2.3.2 Sample size

The sample size depends on type of experiment (controlled or observational study), the goals and variables of interest, whether or not there are statistical considerations, the time available for data collection and

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