Technical Specification

ISO/TS 17886

First edition
2024-01

# Fire safety engineering — Design of evacuation experiments

*Ingénierie de la sécurité incendie — Conception des expériences d'évacuation*



Reference number
ISO/TS 17886:2024(en)

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# Foreword

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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 document 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).

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

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.

# 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

— 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

**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.]

**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 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.

**Table 1 — Potential parameters for measurement**

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

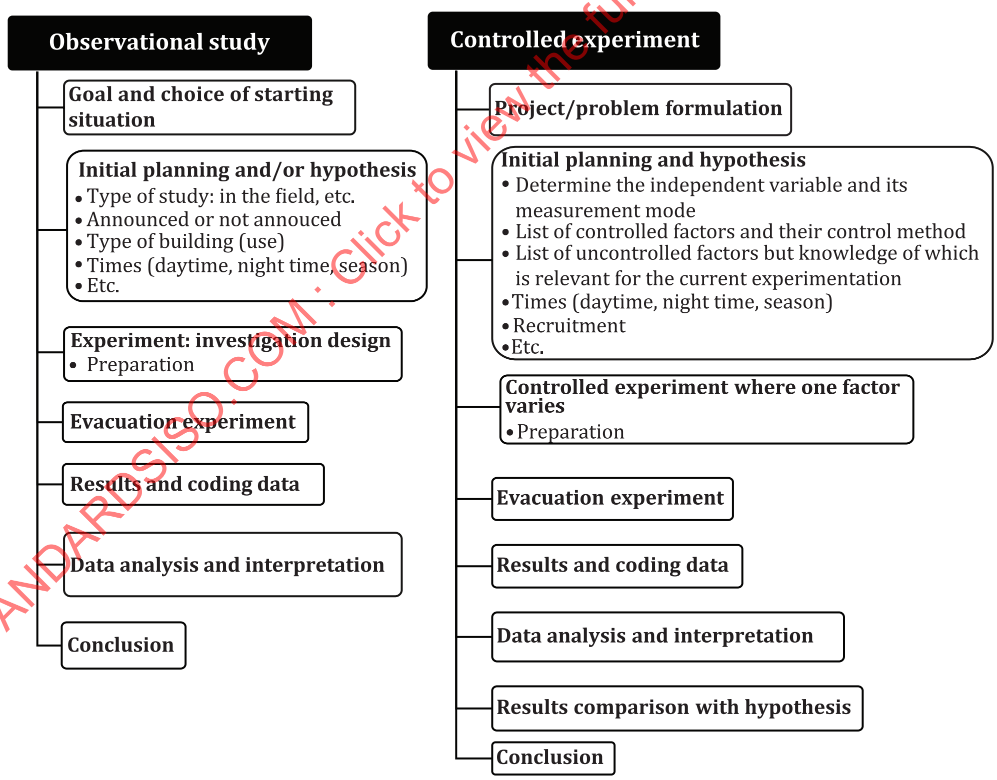



**Figure 1 — Flow chart of steps in designing observational studies and controlled experiments**



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 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 data treatment, ethical considerations and the production of useful results. The necessary statistical power required for data analysis shall be considered.

### 4.2.4 Data collection protocol

#### 4.2.4.1 General

The data collection protocol documents the details of the experiment, such as the data definition, the structure of the evacuation experiment, the method of data collection, and the type of analyses to be applied to the data.

All data collection methods can be described with regard to their objectivity (i.e. the degree to which data is independent of observer bias), reliability (i.e. the accuracy and consistency of the measuring method), and validity (i.e. the degree to which a measure represents what it is supposed to measure). The latter is particularly important for latent variables often queried in surveys (i.e. phenomena that cannot be directly observed but need to be inferred, such as emotional states of occupants). Data collection can be achieved by:[3]

— videos with stationary or moving cameras;

— still photographs;

— human observers (observations, interviews);

— measurements by human observers (e.g. using stop watches to time the evacuation process);

— use of sensors (automated data collection);

— survey questionnaires;

— virtual reality and/or augmented reality.

#### 4.2.4.2 Means to identify the persons

During the analysis of the video records, the recognition of each evacuee at different locations inside and outside the building and at diverse phases of the experiment is useful for calculating parameters and understanding behaviours.

Means to identify individuals depends of the type of experiment and the density of the persons.

For an announced experiment, persons (occupants, staff members actively involved in the experiment) can be equipped with ID badges with a colour and tag inside or a sticker with a number, a geo-localization device, RFID (Radio Frequency Identification), etc. For unannounced experiments or dense crowds, a system to identify persons on the videos, such as filming with overhead cameras with wide angle lenses, triangulation with two cameras, or distance measurement with a laser scanner[4] can be used.

#### 4.2.4.3 Considerations for measurements of walking speeds

Walking speed is often taken as the speed for a person to move from one location to another in the building. The minimum requirement for collecting this type of data is one camera per location. The location of the cameras shall allow accurate identification of each participant to allow tracking from the first to the second location. Cameras shall also be synched in time to enable accurate calculation of average walking speeds.

It is also possible to use video footage from two (or more) time-synched cameras filming the same person to derive the walking speed. If the same reference point on the person is seen by two (or more) cameras, triangulation can be used to determine the location of the person as a function of time. Triangulation is the estimation of the point of intersection of vectors originating at the cameras and pointing at the reference point on the person. The derived information can then be used to determine the local walking speed of the person rather than the average walking speed between two reference points as described above. There can potentially also be other ways to derive the local walking speed.

To compare and confirm the values, observers placed near each exit can note the time of the last person who left the location.

#### 4.2.4.4 Considerations for collection of movement path data

To extract the parameters from the video recordings, it is first necessary to define the areas of interest with virtual lines or counting lines in the video frame. Virtual lines can be used to create a 2D spatiotemporal matrix with two coordinates corresponding to the time and the position of the line.

The identification of these areas of interest then allows the quantification of specific parameters (e.g. flows of people, number of persons, tracks trajectories).

#### 4.2.4.5 Considerations for occupant density and interpersonal distance measurements

The density of occupant flow can be determined for a group of people or for each person in a group:

— ratio of the number of people in a group in an egress component divided by the total floor area occupied by the group (including the area between individuals);

— ratio of the floor area occupied by each individual person in the group divided by the total floor area occupied by the group (including the area between individuals).

### 4.2.5 Ethical considerations

Irrespective of jurisdiction, all experiments made with human subjects shall include an ethical analysis prior to data collection. Additional requirements can be applicable in certain jurisdictions. Independently of the professional qualification of the investigator and in addition to the deontology on scientific research, the experimenter/observer shall always address certain ethical issues and ensure the respect of the participant; see the Nuremberg Code,[5] Helsinki declaration,[6] Belmont Report,[7] and other sources.[2],[8],[9]

An ethical review is sometimes not mandatory before the experiment is conducted, but the experimenter shall still address certain ethical issues.

The experimenter shall:

— be aware of national laws and regulations on ethics and protection of privacy;

— ensure that physical or emotional harm to participants is restricted;

— ensure that the benefits of the experiment outweigh any risks, for the individual and for society as a whole;

— obtain the informed consent, in writing, of each participant before or after the experiment;

— obtain the consent of parents in the case of participants who are minors;

— respect the privacy, confidentiality and anonymity of the subjects;

— reflect upon the scientific use of personal data (information from questionnaires in particular);

— ensure data integrity (adequacy with what it represents) and ensure that data are not corrupted (degradation, unintentional modification, etc.) when collecting, capturing and processing data;

— include participants' right to terminate the experiment and withdraw their consent at any time without any negative consequences for the participant;

— pay close attention to the environment in which the experiment will be carried out (in order to minimize risk);

— de-identify data, i.e. the data collected for the experiment is separated from personal identifiers (e.g. names). Only de-identified data shall be processed and communicated for publication.

Two of these ethical principles can be difficult to meet in observational studies: informed consent and right to terminate the experiment. It is not possible to obtain informed consent before conducting an unannounced evacuation. However, consent can be obtained from building owners, and prior notice can be given without providing the exact time and date of the experiment. The researcher shall be aware, however, that prior notice of any sort can impact the evacuation exercise. National requirements can exist concerning how the participants shall be informed about the experiment.

A participant can potentially be unable to terminate an evacuation drill. In this case, some means can be implemented to enable his or her participation to be deleted from the collected data. Alternatively, an observer can intervene to terminate the experiment. An observer can be present in the space/room who can terminate the experiment if something goes wrong, or in case of suspicion that people are becoming worried or about to be injured.

Risks to the participants shall be minimized but can sometimes not be totally avoidable. The experimenter shall pay close attention to the environment in which the experiment will be done.

Privacy is protected in various ways, including limiting access to any video or film and destroying the video or film once the data is extracted, or masking the identities of the participants, either by coding their names or by blurring or pixelating their images. Any images or personal information shall be kept locked and confidential. No personal information shall be retained once the experiment and analysis are complete.

### 4.2.6 Site selection for observational studies

There are three main considerations in the selection of a site for an observational study:

a) attributes of the building,

b) fire protection features present including any emergency procedures, and

c) characteristics of the occupants.

These characteristics influence evacuation behaviours. It is assumed that the general purpose of the experiment has been determined, i.e. the experimenter has decided what built environment is being studied (apartment building, hotel, shopping mall, factory, ship, aircraft, etc.).

The attributes of the building include features such as number of floors, floor area, and number of stairwells and escalators. Fire protection features of interest include type of alarm and notification system, compartmentation, evacuation history of the building, signage, emergency procedures present, and training. Occupant characteristics include number of people, location throughout the structure, mobility issues, sensory issues, cognitive issues, interpersonal relationships, familiarity with the building and others. Details on these attributes are shown in Table 2.

**Table 2 — Considerations for site selection**

| Building attributes | Fire safety features | Occupant characteristics |
|---|---|---|
| # units | Central alarm (y/n) | # occupants |
| # floors | Local smoke alarm (y/n) (where) | # people who use a wheelchair |
| # elevators (location) | Pull-bar station (y/n) (where) | # people with other mobility impairment |
| # staircases (location) | Alarm control panel location | # people with visual impairment |
| # daily entrance-exit (location) | Alarm monitored (y/n) (by whom) | # people with hearing impairment |
| # fire exits (location) | P.A. system and speakers (y/n) | # people with intellectual impairment |
| Spatial organization (plan) | Smoke detectors (y/n) | # elderly |
| Complexity | Heat detectors (y/n) | # children |
| Balconies (y/n) (where) | Fire doors (y/n) (where) | Multi-cultural |
| SOURCE: Reference [2]. | | |

**Table 2** *(continued)*

| Building attributes | Fire safety features | Occupant characteristics |
|---|---|---|
| Basement (y/n) | Sprinklers (y/n) (where) | # occupants living alone |
| Parking (y/n) (where) | Pressurization (y/n) (where) | # family groups |
| Accessibility (y/n) (how-where) | Compartments (y/n) (where) | Socio-economic |
| Date of construction | Area of refuge (y/n) (where) | |
| Building code in effect (year) | Access to roof (y/n) (how) | |
| Pool/Gym/Party room (location) | Elevator back to 1st (y/n) | |
| Access to another building (how) | Master key (y/n) (where-who) | |
| Multi-occupancy | # false alarms per year | |
| | Previous drills (date) | |
| | Evacuation procedure (explain) | |
| | Fire-list (y/n, last update) | |
| | Provisions for occupants with disabilities (explain) | |
| SOURCE: Reference [2]. | | |

Besides the features of the structure that are relevant for the collection of useful data, the experimenter shall also consider the safety of the occupants. At least one visit to the site will be necessary to evaluate its appropriateness for the experiment.

EXAMPLE Is there a safe area for the occupants to move to during the drill? It would be inappropriate to evacuate occupants of a crowded nightclub onto a busy street.

### 4.2.7 Times

Experiment time is chosen depending on the response expected, the location and circumstances (daytime, night time, season, etc.). The moment at which the experiment takes place has an influence on the persons involved in the experiment. Human behaviours and, therefore, qualitative or quantitative responses are different. For example, people who are awake do not have the same reaction as people who are asleep; distances between persons can differ when people are wearing winter clothing compared to summer clothing.

### 4.2.8 Obtaining permission

Permission shall be obtained from the owners or management of any structure/building used in an evacuation experiment. It is often possible to use a regularly scheduled mandatory evacuation as an opportunity to collect data.

### 4.2.9 Fire department information/participation

In order for the experiment to take place under the best safety conditions, it can be useful to inform the fire department beforehand of the address, date, time of the experiment, etc. This would also help to avoid, for example, an alarmist call from a person who has noticed something unusual.

The fire department can also participate in the experiment. If the fire department is expected to participate in the evacuation experiment, then a liaison shall be set up with a fire department representative involved in the planning of the experiment. The role of the fire department shall be clearly defined in advance and included in evacuation scenarios. The involvement of the fire department can add realism to an evacuation exercise, such as their use of stairwells and control of elevators, as well as assistance in evacuating occupants with mobility, sensory or cognitive impairments. Fire department feedback can be useful to the interpretation of the results, the conclusion and perspectives.

#### 4.2.10 Recruitment

##### 4.2.10.1 General

Ideally, the participants in the study will be representative of the population of interest. Often, the recruitment of a fully representative group of participants is not possible, and this shall be documented as a limitation on the study results.

EXAMPLE When looking at the effect of alcohol on waking effectiveness of smoke alarms, the participants would include adults, male and female, of a wide range of ages. When looking at the time to evacuate a theatre, the participants would be representative of theatre audiences, and would best include all ages, male and female, and a wide range of mobility, sensory and cognitive abilities reasonably expected to be present in that environment.

Participants in an experiment can be people recruited specifically to participate in the exercise, or occupants using a public space who are unaware of the exercise, or occupants living or working in their usual environment, whether aware or not of the exercise.

In order to thank participants for their participation, they may be compensated or reimbursed after the experiment. This shall be noted in the experiment description. Appropriate reimbursement is a recruitment issue: how much participants are paid can influence who chooses to participate. People with jobs can potentially be less likely to participate. Details on compensation or reimbursement shall be part of the description of an experiment when used as an incentive to influence behaviour.

##### 4.2.10.2 Participants recruited to participate in an experiment

Participants can be recruited for a study through a variety of means. A study can seek participants who meet specific demographic categories (e.g. college-age students willing to participate in an experiment studying the effect of alcohol on wakening, or older adults with a range of hearing or vision impairments, etc.) or participants can be sought from the general public if the experiment is collecting data that applies to a broad section of the public. Participants recruited for an experiment may be aware that they are taking part in an evacuation experiment, but they are not necessarily informed of all the scenarios. For example, they can be not told that some of the exits will be unavailable during the experiment. In other cases, the audience might be told they were recruited for another purpose, for example, to watch and comment on a movie, when in reality they will be participating in an evacuation experiment.

##### 4.2.10.3 Participants involved in observational studies

###### 4.2.10.3.1 Participants using public spaces

For unannounced observational studies that take place in public-use spaces, such as cinemas, shopping centres and transit systems, it will not be possible to notify participants of the experiment beforehand. In this case, it is possible that participants will never be aware that they were involved in a research project and will not therefore be able to sign the informed consent as mentioned in 4.2.5.

###### 4.2.10.3.2 Occupants in their usual environment

It can sometimes be necessary to notify occupants before an evacuation experiment in a structure where they live or work. If the goal is to observe an unannounced evacuation, a notice can simply explain that an evacuation drill will take place within a fairly short period of time, without being specific. This notice can be reassuring to people who might become anxious when the alarm sounds. However, it can also give warning that will result in non-evacuation (knowing that it is a drill) or other non-routine behaviour.

If, according to the scenario, the alarm is to be initiated by a building occupant, his or her role in the experiment shall be thoroughly planned out.

If there are concerns about the safety of people with limitations or health issues among the participants, the experiment can be discussed with them in advance, especially if there is no plan in place for how they are expected to respond in an evacuation. Often people with difficulties want to participate in drills to assess their own and others' performance. They can be given the option to opt out, but if they do opt out, they shall be given guidance for the best procedure to follow in the event of an alarm or actual incident. Limiting participation of people with disabilities, however, can cause different results in the experiment than would occur in an actual evacuation, as other occupants may respond, react and behave differently in a situation with and without people with difficulties around them.

## 4.3 Preparation

### 4.3.1 Determine necessary equipment

Once permission is obtained, on-site preparations can be made a few days before the experiment. An inventory of equipment required in the experiment shall be compiled. The size of the structure used in the experiment will impact the amount of equipment required. For a field experiment, an inventory of existing equipment before the experiment is necessary, so that the amount of supplemental equipment (e.g. cameras) can be determined. For observational studies, the occupants' familiarity with the structure's evacuation plan and routine can use help in predicting occupant movements, which will determine equipment placement.

The necessary equipment can include cameras, meters, area markings and microphones for sound sampling. If crowd density has to be calculated from measurements, it can be necessary to mark out the coverage areas to be monitored. The number of video cameras and their locations depend on the layout of the building and the goal of the experiment. Passages, corridors, staircases and doors are some typical points of interest.

Particular attention is paid to the equipment because the success of the experiment depends on it for both quantitative data (speeds, times, flows, etc.) and qualitative data (behaviours, etc.). It is therefore important to check that all instruments are reliable and calibrated.

Cameras can need power sources and battery backup.

A system for communication among the organizers, the video control centre, and all persons involved in the experiment shall be provided.

If the scenario includes the use of a smoke generator during the experiment, precautions shall be taken and provisions made to remove the smoke after the experiment.

### 4.3.2 Determine and train necessary staff

Observers, camera and sound team, evacuation-trained occupants if any, fire department representatives if invited to participate, and fire security personnel if present in the considered building, shall all be informed of their roles in the experiment. Care shall be taken to prevent the actions of researchers and their team from impacting the results.

Depending on the scenarios, the roles and responsibilities of each stakeholder involved in the experiment shall be defined and formulated with precision.

The number of staff shall be adapted to the measurements to be taken and the means used (video or observers with meters).

All stakeholders/staff shall to be familiar with the building, so a visit before the experiment could be useful.

### 4.3.3 Document characteristics of the space

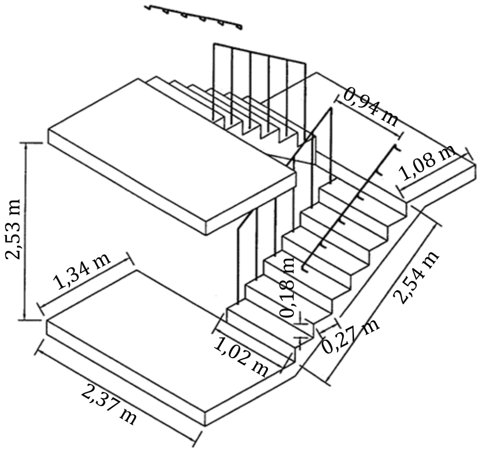
#### 4.3.3.1 General

The characteristics of the space shall be documented so that the initial conditions faced by the participants can be recorded. They can be taken a few days before or even after the experiment, as long as they will accurately reflect the conditions during the experiment.

#### 4.3.3.2 Physical description of the space

The physical measurements of the space are useful for drawing plans and elevations of the building. They are also useful for indicating the initial locations of occupants and staff and for some calculations (speed, flow, etc.) and behaviours observed. These measurements also depend on the type of experiment, observational or controlled.

Important measurements include travel paths (length and width of travel segments), stairwell dimensions, including dimension of steps (tread, riser and nosing), and number of steps in each flight. See Figure 2 for the dimensions of interest in a stairwell. Table 3 gives escalator attributes.




SOURCE Reference [2], used with the permission of the author.

**Figure 2 — Stairwell measurements**

**Table 3 — Escalator attributes**

| Factor | Attributes | Questions |
|---|---|---|
| Label | | |
| Type | | Scissor/enclosed, etc. |
| Connecting floors | | |
| Location | | Internal location, external, etc. |
| Speed | | |
| Direction | | |
| Angle | | |
| Clear Width | | |
| Steps | | |
| | Length of approach | Distance from start of escalator to first step |
| | Length of run-off | Distance from last step to end of escalator |
| | # steps | |
| | Rise height/tread depth | |
| | Nosing | |
| | Edge of steps | |
| | Consistency | |
| | Condition | Debris/damage/etc. |
| | Material | |
| | Diagonal length | |
| | Occupiable area | |
| | End notification | |
| Handrail | | |
| SOURCE: Reference [5]. | | |

**Table 3** *(continued)*

| Factor | Attributes | Questions |
|---|---|---|
| | Projection | |
| | Material used | |
| | Height from the step | |
| Clear head room | | Step to the bottom of stair above |
| Condition | | |
| Lighting | | |
| | Normal | |
| | Emergency levels | |
| Access | | |
| Sign/guidance | | Presence/illumination levels, etc. |
| SOURCE: Reference [5]. | | |

#### 4.3.3.3 Alarm measurements

In order to verify that the participants are well informed about the hazard, samples of ambient sound levels shall be taken before or after the experiment in public areas, corridors and stairwells, as well as restrooms and offices (in office building) and hotel rooms. Samples shall also be taken in several rooms in apartments. Samples shall be taken in travel paths during the evacuation while the alarm is sounding, and if possible, in offices, hotel rooms and apartments if this can be done without interfering with the evacuation. Sound samples shall be taken with open/closed door and open/closed windows. The two sets of sound samples are taken at the same place.

Sound measurement locations shall be clearly identified on the building map. A comparison with the evacuation path could give also information.

### 4.3.4 Technical preparation

Several devices can be used in an evacuation experiment. Numbers and choices of technical devices depend on the objectives and hypothesis of the experiment and on the characteristics of the site/building.

Each device has its own technical considerations to be taken into account.

As cameras are used to monitor experiments and to estimate quantitative and qualitative parameters, some technical aspects are specified here to achieve these objectives.

All equipment shall be numbered for reference and each device shall be tested before the drill. If cameras have automatic shutoffs when no movement is detected for some period of time, that option shall be deactivated. The consistency and traceability of the numbering shall also be checked before the drill. Cameras shall be synched in time because post resynchronization is difficult and not always possible.

Specific brands of cameras and other equipment and data processing software are not discussed in this document.

### 4.3.5 Camera placement

Observations are useful for collecting both quantitative data (speeds, times) and qualitative data (paths adopted, types of behaviours, etc.). The location of camera is very important for minimizing errors in the exploration of videos.

The location of people in a building is typically assumed to be the place they are standing, which can generally be taken as the point on the floor located between their feet. If the camera can capture the feet of the participants, their position can be relatively easy to determine. However, due to such aspects as high person densities or obstructions, it is not always possible to capture the location participant's feet. In such cases, the experimenter then needs to monitor the location of another part of the body (e.g. upper body, neck or head) and infer the participant's location from this data.

A common strategy for determining participant's location is to place cameras filming downwards from the ceiling of the building. This location often makes it possible to distinguish participants' upper body in spite of high person densities.

As the location of participants is often taken to be the location of their feet, the reference mesh is typically at floor level. This reference mesh can be marked before the experiment and filmed by cameras in order to be used in the subsequent analysis.

The cameras and other measurement devices shall be placed in optimal positions, based on expected occupant movement, performance and behaviours. In an evacuation of an apartment building or hotel, appropriately-placed cameras will capture the moment at which occupants step into the corridor. As it is essential to capture the end point of an evacuation, cameras shall be placed on all final exit points. If occupants have the possibility of terminating their evacuation on outside balconies, cameras shall be mounted outside to capture that action. The precise location of each numbered piece of equipment shall be noted.

Cameras already installed in the building can be used for the experiment with the agreement of the owner. Surveillance cameras can be used if already strategically placed, provided this does not violate local ethical considerations. If such cameras are used, their settings and resolution shall be considered for the analysis, in order to protect privacy. Additional cameras installed for an unannounced evacuation shall be unobtrusive and installed in such a way that their view of the area is unobstructed and they do not influence evacuee behaviour.

Mobile cameras can be used along with fixed cameras in order to cover the entire space or to follow the last person during the evacuation.

The location of cameras and other identification devices shall be determined based on the hypothesis (scenarios) or objectives being studied in the experiment. In some cases (e.g. when the aim is to collect data on people density) many cameras and careful consideration of their placement can be necessary. In other cases (e.g. when determining average walking speed between two locations) fewer cameras can be needed.

In order to track people through the building, the film footage needs to be time synched. This synching can be achieved by starting all cameras at the same time, synchronizing the internal clock of the cameras, filming the same watch with cameras, using a sound signal to find a common time in all films, etc.

Numbers of cameras depends on the scenarios and the means of identification of the persons. Camera rapidness, suppression of blind spots and camera position in height are parameters to be considered.

Human behaviour can be observed with zenith cameras, frontal cameras or their combinations. For zenith cameras, the placement of the cameras is done in order to limit perspective distortion and angle distortion.

To facilitate image processing and to extract information, it is necessary to know/consider the following points in the positioning of cameras.

— Geometrical parameters: distribution of cameras, inclination/orientation of cameras relative to observed surfaces, visibility/absence of obstacles in the area to be monitored.

— Technical parameters related to the devices: cameras operating mode, type of connection needed to connect camera to the recorder system, recorder capacity (recording on a computer or in a video recorder), proximity of the power sources.

— Camera-related settings: image quality, sound quality, brightness, ambient lighting, angle of incidence.

— Environmental conditions: lighting conditions, use of a smoke generator.

To verify that the surveillance zone is satisfactory and to reach the best angle for focusing and video quality, the height of the cameras' positioning is also to be tested before the experiment to limit perspective and angle distortions.

Perspective distortion and angle inclination distortion corrections are described in Annex A.

#### 4.3.6 Preparation of occupants

The necessary preparation of occupants will depend to some degree on the scenario being tested. The general scenarios discussed here include:

a) occupants in the usual work or living environment;

b) participants recruited to participate in an experiment; and

c) participants who are using public spaces and are unaware of the experiment.

For experiments that take place where the participants live or work and for experiments where participants are recruited, material explaining the experiment shall be prepared and distributed. It shall explain the experiment and provide contact information so that an occupant can discuss the experiment with someone on the research team who will tell occupants what they are expected to do during the evacuation.

To avoid confusion and misunderstanding, to build trust, and to contribute to exploring/comparing results, ideally, each participant will sign a form including "organization" and "participant" components.

The “organization form” shall specify, in particular, the following information:

— the organizer/researcher of the experiment;

— the objectives of the experiment;

— the date, time and location of the experiment;

— an explanation of the risks;

— notification that the information is anonymous;

— notification that data collected by the researchers will remain strictly confidential and for the exclusive use of the investigators concerned. The identity of participants will not appear in any report or publication and any information about them will be treated confidentially;

  NOTE Some jurisdictions or ethical bodies will require that the data be destroyed after some period of time after use.

— whether or not the experience is remunerated or compensated (movie ticket, etc.).

The "participant form" shall specify, in particular, the following information:

— age;

— gender;

— agreement/consent to participate.

In all cases, note the number of building occupants, the population characteristics, and the presence or not of people with impairments/disabilities (number of people with disabilities, type of disabilities, etc.).

#### 4.3.7 Preparation of data collection instruments

##### 4.3.7.1 General

If a questionnaire is to be distributed to the participants in a study after the event, it shall be developed prior to the experiment, to be handed out immediately after the evacuation.

In cases where participants in public places will not be informed prior to the experiment, informed consent shall be obtained from the building owner or manager, or other responsible person before the event, and from the participants after the event.

#### 4.3.7.2 Preparation of questionnaire

For each experiment a questionnaire can be developed to complete the observations and to collect more details.

Questionnaires are developed in accordance with ethical considerations.

Questionnaires shall be carefully thought out and tested. They include an introduction with a description of the purpose, an explanation of what people need to do, a statement that the data collected is confidential, etc. and a conclusion with thanks. Questionnaires shall be tested to validate the questions, to verify the coherence of the questions, to have an idea of the time needed to complete them, etc.

They include general questions on the participant, the building, etc. and questions requesting feedback on the experiment. Questionnaires include closed-ended questions (predefined options, answers limited) and open questions (free answers, own answers) and an empty part for participants' comments.

Specific questionnaires shall be provided for all people (participants public members, staff members, firefighters, observers, etc.) present in the experiment.

Questionnaires can be distributed after the experiments and collected immediately or sent back a few days later, with the return address indicated on the questionnaire if they are to be returned later.

Questionnaires can also be online on a website, which affords the opportunity to record responses automatically into a database.

#### 4.3.7.3 Preparation of interviews

Oral questions are developed in accordance with ethical considerations. Interviews can be structured (lists of questions), semi-structured (with a framework of themes) or unstructured (no prearranged questions) or a combination.

## 4.4 Evacuation experiment

### 4.4.1 General

In order to calculate the diverse parameters and compare the data, there are three key elements to the actual execution of the exercise: set-up for the experiment, the evacuation event or experiment itself, and post-event procedures. These are described in the following subclauses. In some studies, only a single evacuation will be conducted. In others, the participants can carry out repeated evacuations under varying scenarios, in which case the steps below are repeated.

### 4.4.2 Set-up for the experiment

— Prior to the experiment, all equipment shall be tested.

— All equipment shall be calibrated and synchronized. For example, the internal clocks of cameras shall be synchronized so that occupant movements between camera locations can be tracked accurately. Similarly, sound equipment if used shall be synchronized. Cameras shall be installed and their views adjusted to be sure that they are capturing the correct element of the egress path (door, corridor, etc.).

— If sounds are part of the experiment, ambient noise samples shall be collected and the location of the samples recorded.

— Grids for data post-treatment, if used, shall be put in place.

— Signage, if used, shall be installed.

— If the alarm will be activated by a building occupant, the procedure shall be planned beforehand. For example, the occupant might pull a building alarm or might telephone the fire department at the appointed time, before evacuating the building.

— When the experiment involves subjects who are participating with knowledge of the event, for ease of identification in the video record, they can be assigned numbers that they can wear affixed to their clothing or on headgear or they can wear colour-coded clothing. (When the participants are not aware of the experiment ahead of time, researchers will have to rely on identification based on individual features, including identification of clothing).

— Participants shall sign the informed consent prior to start the experiment.

— Materials shall be provided to compile data collected to assure data traceability (e.g. computer supports).

#### 4.4.3 Evacuation event

When everything is ready, the experiment can begin according to the pre-established plan.

For observational studies, in many cases the sequence of events is as follows:

— Cameras are started and observers, if any, take their positions before the alarm sounds. The team who will take sound measurements shall be waiting at their first location. Observers and the audio team shall be careful not to interfere with the evacuation in any way.

— According to the plan, the alarm is sounded. This can be done at the alarm panel, an occupant who has been trained in advance can manually pull the alarm, or the alarm could be activated by smoke.

— When everyone has reached a location of safety, the 'all-clear' announcement can be made, allowing occupants to return to the building.

#### 4.4.4 Post-event procedures

— The cameras and other devices are turned off, dismantled and any physical damage to walls, etc. shall be repaired.

— Letters and questionnaires, if used, are distributed to the occupants, with instructions on how to return completed forms (questionnaires can also be completed at the end of the experiment).

— Questionnaires shall be marked with unit numbers or some other identifying detail that will allow matching the occupant's starting location with their subsequent actions and observations. Informed consent forms are collected from participants if the consent was obtained after the experiment.

— Interviews, if any, are conducted.

### 4.5 Coding data

Coding is used to format data, facilitate analysis and draw conclusions. The first step is to organize the data.

In order to facilitate the use of the data obtained by questionnaires and video recordings, the elaboration of an observation grid or a rating scale can be useful. These observation/evaluation grids contain variables that can be used for data analysis. For example, similar examples of data analysis can be examined in order to identify types of behaviour that can be expected, or a data scan can be performed in order to develop a first-pass list of actions and associated metrics to quantify them. This makes it possible to obtain a chronology of the actions/events to be monitored (see an example in Reference [10]).

The method for coding and storing the data collected in the experiment depends on the medium used. Each medium will be discussed separately below.

— Questionnaire data is coded and stored. Responses to questions can be recorded in a spreadsheet or other database. Each questionnaire represents a single case, and each question or every subpart of a question represents a variable. Each case shall have a unique identifier and demographic data such as age, initial location, etc. shall be included on the data collection form and recorded in the database. Closed-ended questions, such as multiple-choice questions or questions with simple answers, such as age or floor of origin, do not require coding. Open-ended questions with narrative answers will require some interpretation. The coding shall be done in stages. First, all responses to a question are recorded (listed). Then, the individual responses can be aggregated in a logical fashion that groups similar responses.

EXAMPLE 1 Individual descriptions of preparation actions (“got coat,” “grabbed purse,” “picked up briefcase”) could all be grouped in a category of answers labelled “gathered belongings.” Then various grouped responses can then be ordered in categories (e.g. “preparation,” “warning,” “investigation,” etc.).

— Videotapes shall be carefully reviewed in order to extract information that can be entered into a spreadsheet or other database. For consistency, it is important that the researcher(s) analyse videotapes in the same way. Before the actual analysis of the video data, it shall be verified that they will analyse videotapes in the same way. For this purpose, it is advisable for people to analyse a video extract over a short period of time and then compare their coding. Any discrepancies shall then be resolved.

  The review of the videotape will involve uniquely identifying each evacuee, from their first appearance on camera, and then time stamping each pertinent benchmark or point of reference as it is reached. It is essential for the benchmarks to be precisely defined before the analysis of the videotape begins. Variables such as gender, age (or age category) and presence of obvious movement limitation can be assessed and recorded for each evacuee. Other details can be noted when they occur, such as attempts to use the elevator, turning back behaviour, etc.

  EXAMPLE 2 “Entering the stairwell” can be defined as the time when a person’s foot touches the landing.

  Similarly, rules shall be defined for formation of groups or traveling ‘alone.’ Movement limitations can include mobility impairments (disabilities) as well as assisting another person with a movement impairment, helping small children, carrying pets, children or objects, etc. Many limitations will not be readily available unless the researcher has been made aware of them outside of the experiment.

Quantitative measurements from videos recordings can be made manually or post-processed.

There are different methods for treating data from videos: statistical methods, counting system, localization, estimation of movement, and use of some specific algorithms for human movement in crowd for example.

When multiple media are used (for example, video and questionnaires), it is extremely helpful if it is possible to match questionnaire responses and videotaped observations for the same person. Comparisons will help to validate the questionnaire responses and to verify details on the videotape such as age and presence of mobility limitations.

## 4.6 Data analysis

### 4.6.1 General

After coding, data analysis involves converting the raw information into a format where it can be further analysed and the various elements comprising evacuation (travel speed, delay times, occupant densities, etc.) can be summarized and studied. For evaluating behaviour and movement of people, the researcher can find technical information in ISO/TR 16738.

The initial conditions for the experiment shall be recorded, such as the number of participants, their initial locations, the demographics (age, gender, mobility and cognitive abilities, etc.), mobility characteristics (population physical size, presence of disability, etc.), the presence of smoke, congestion levels, or merging flows, etc.

Employed data collection methods shall also be specified.

Both quantitative and qualitative aspects are analysed. Depending on the experiment’s purpose, data are analysed at the individual or aggregate level. Parameters can be calculated for an individual or for a group or both. Interaction between data shall also be considered when interpreting qualitative or quantitative responses.

Note that each parameter/indicator has a relative error which can also be calculated. To complete the analysis of the data, it is sometimes necessary to make a statistical analysis of the experimental data in order to limit the errors of interpretation of quantitative or qualitative data. Data that is then used for building relationships for human flow parameters (e.g. flow time) or for studying observed behaviours.

The quantitative indicators covered in the following subclauses are not exhaustive.

### 4.6.2 Calculation of evacuation times in observational studies

The three main elements of evacuation time to be determined are:

a) starting time;

b) movement time; and

c) total evacuation time.

Starting time is the time between the sounding of the alarm or the presentation of the first cue and the participant's commencement of evacuation. In case of a residential fire drill, this can be the time the person appears (on camera) at the door of his or her apartment. In a cinema evacuation, it can be the time a person stands and begins their attempt to leave.

Movement time is the time that elapses from the start time, until the participant reaches the location of safety (often outside the building). This is the person's travel time, from start to finish.

Total evacuation time is the time from the sounding of the alarm until the person reaches the location of safety. It can also be the time interval between the sounding of the alarm and the last person who left the place.

These times are calculated for each participant. They can be reported as averages for all occupants or can be reported in time intervals. The times shall be reported in such a way as to show the distribution of times, for example, minimum and maximum times, means, standard deviation and quartiles.

### 4.6.3 Calculation of travel speeds

#### 4.6.3.1 General

The ability to calculate travel speeds for participants will be highly dependent on camera location and ease of identifying the individual participants. Methods for calculating travel speeds on horizontal surfaces and on stairs are described in this subclause. Other techniques for calculating travel speeds include the use mobile devices with sensors.

#### 4.6.3.2 Calculating travel speeds on horizontal surfaces

The travel speed calculation on horizontal surfaces can be made by simply establishing two points along the travel route and dividing the time it takes an occupant to move from one to another by the distance between the two points. If the distance is long, and portions are not covered by cameras or observers, there is uncertainty in the actual travel time. The elapsed time can include rest stops or other delays, for example while seeking information or waiting for firefighters to pass in the stairs.

Alternatively, individual occupants can be observed for a fixed interval of time, allowing the observer to obtain the distribution of path lengths travelled in that certain time interval.[11] By this method, it is possible to determine the true law of distribution of random value argument: travel speed. The result is that the experimenter obtains the distribution of the random variable of path length that different people passed through for the same time interval. This random variable is a linear function of a random argument, i.e. it reflects the true law of distribution of the random variable speed circulation.[11]

This second method is an effective way to calculate instantaneous walking speeds when the time interval is short. However, it is important for this time interval not to be too short. For example, with a time interval as short as 0,1 s, body sway or a small error could influence the calculation more than the participant's actual location change.

Another method is to calculate the travel speed with mobile cameras which follow the last person who left the place (in individual value).

#### 4.6.3.3 Calculating travel speeds on stairs

Travel speed on stairs can be calculated similarly, in terms of observing the participant's presence at defined starting and end points for the travel time or during a fixed interval of time. The travel distance on the stairs shall be calculated and reported based on the diagonal distance along the stair treads and an arced path along the landings.

It can be interesting to note the effective space used by the evacuee on stairs, which will consequently impact other parameters.[12],[13]

Movement on landings is included in the calculation of movement on stairs. However, as with travel on horizontal surfaces, some elapsed time can include rest stops. People taking a break on stairs often do so on the landing where there is more space for other people to pass them. Rest stops shall not be included in the travel speed calculations but shall be recorded and reported separately.

For the comparison, it can be interesting to specify the speed on the stairs and the time spent in landings in relation to the dimension of the staircases and the crowdedness in the staircase. It can also be interesting to note the behaviour before entering the stairs. Depending on the case, it can be interesting to evaluate the impact on the travel speed on stairs following the entrance of other people coming from the lower floors in the staircase, merging flows.[14],[15]

NOTE There can also be people in refuge areas on stairs which can affect the travel distances for people moving in the stairs.

### 4.6.4 Establishing values of evacuation flows

Flows of persons through restrictions such as corridors, stairs and doorways, etc. can be established with stopwatches and video cameras.

Flow rate of doorways or stairs is the number of evacuated people within a certain time interval.

### 4.6.5 Establishing values of flow intensity (specific flow)

Flow intensity of persons can be established with stopwatches and video cameras.

Specific flow is the flow rate divided by the width of an egress component (doorway width, exit/opening space width). It is also calculated as the speed multiplied by the occupant/persons density.

### 4.6.6 Calculation of occupant density

Occupant density can be determined for a group of people or for each person in a group.

Occupant density can be calculated by marking corridor sections with a grid, or overlaying a grid on the video. Observations of the number of evacuees within the grid will provide the occupant density (i.e. persons per $m^2$ or $m^2$ per person). Density can also be obtained by dividing the number of individuals in the group by the total floor area occupied by the group. When looking at occupant density in stairwells, it shall be clearly documented how the grid space is defined. For example, if only part of the landing is used in the evacuation, the occupant density may include or not include the generally unoccupied space. This shall be clearly reported so that data from different sources can be compared.

Density can be measured globally (from the beginning line to ending line) or locally (cell/grid by cell/grid). The size of the cell can be expressed as a percentage of anthropomorphic data (i.e. body depth, shoulder breadth).

#### 4.6.7 Calculation of interpersonal space

In a walking situation, some parameters (speed walking, flow, etc.) depend on interpersonal distance and other constraints (dimensions, obstacles, etc.). This can produce different spatial arrangement of crowd flow/group proximity patterns. This reflects the social force.[16]

The calculation of interpersonal space and body sway are made similarly. Both require an overhead camera to record the space and the sway, and a grid that will allow measurement of the distance. The grid can be placed on the floor beforehand or can be overlaid on the video.

When the camera is fixed vertically, each human head is represented in the form of a sphere and each body in the form of a cylinder. The interpersonal distance can be calculated with the projection on the defined grid/cell. When the camera is not fixed vertically, some corrections shall be made, as shown in Annex A.

#### 4.6.8 Calculation of body sway

Body sway (slight postural movements made by an individual in order to maintain a balanced position) can be measured by the total displacement of the centre of mass relative to the base of support over time. Body sway influence variation movements in walking pattern and by consequence space occupied by each person. This latter parameter is useful for calculating other parameters, like flow.

For each person, sway amplitude can be calculated as the distance from each body centroid position to a line of progression.

#### 4.6.9 Calculating flow at a doorway

Restriction of the overall flow can be the consequence of movement through elements which restrict the space, like a doorway. Width, design of the doorway and its use by occupants (fully open, partially open, etc.) are parameters to consider.

Quantitative measures (speed movement, specific flow, etc.) and qualitative parameters (characteristic of door mechanism, how the door is open, etc.) shall be included. The fluctuation in the opening and closing of the door influences egress time.

An effective width can be calculated for a uniform period of time by the comparison between the exact width of the doorway and the width used.[17] Then, the specific flow through a doorway is calculated with the effective width.

#### 4.6.10 Setting parameter values of human flows in case of merging/merging process

The merging process occurs at the floor-stair interface, in a junction in a corridor, or at a corner (bi-directional flows). For example, in the staircase, confluence of a flow occurs between the evacuees descending from upper floors and ones entering the staircase at lower floor levels.[18],[19] Merging can have an impact on escape time, flow rate, density, etc.

The merge ratio is defined in ISO/TR 16738 as:

— the ratio of the number of lanes of flow upstream and the number of lanes of flow downstream after flows have reached a merge point or shared space; or

— the proportional share of downstream flow accounted for by flows that have met at merge points.

The merging ratio is the flow mergers divided by the total occupant flow.

#### 4.6.11 Number of occupants on each floor

The number of occupants on each floor is necessary for calculating quantitative indicators (time to enter in a staircase, etc.) or explaining qualitative parameters. The number of occupants can be established with stopwatches and video cameras floors to floor.

#### 4.6.12 Congested situations

Congestion and queuing in front of bottlenecks are correlated with the number of persons. This relates to walking speed and population density.

#### 4.6.13 Questionnaires and interviews

Statistical data obtained from the questionnaires and comparison of the data can be completed by the results of the qualitative analysis method used to explore interviews.

#### 4.6.14 Behaviours

Qualitative and quantitative human behaviours or decision-making process analysis are obtained from the video analysis coupled with questionnaires and interviews.

#### 4.6.15 Sound measurements

Intelligibility can be reached from sound samples. The loss of acoustic transmission in the diverse locations can be calculated.

### 4.7 Interpretation and documentation of results

After the analysis of the qualitative and quantitative data, the next steps involve interpretation.

### 4.8 Examples

The steps taken to design evacuation experiments are shown in several examples in Annex B. In some examples, not all steps were reported. In these cases, the missing steps are noted.

# Annex A
(informative)

# Perspective distortion and angle distortion corrections

## A.1 Perspective distortion and angle distortion

The importance of perspective distortion and angle distortion depends on the degree of precision required when establishing a location and the data in which the observer is interested.

## A.2 Perspective distortion

Due to short distances between cameras and the participants, wide-angle lenses can be necessary. Wide-angle lenses have the advantage of widening the field view of the camera, but will also distort the image (see Figure A.1).

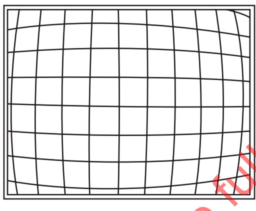


**Figure A.1 — Distortion of a mesh with square cells when filmed with a camera with a wide-angle lens**

It is possible to quantify the distortion effects by filming a mesh of known dimensions. By matching the physical dimensions of the mesh with the distorted dimension in the camera image, a distortion matrix can be calculated. This matrix can then be used to achieve an undistorted image. This matrix can serve as a calibration pattern.

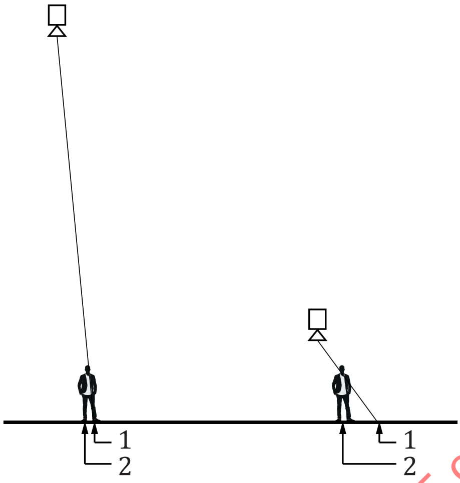
It is also possible to correct the perspective with a compromise between the distance between cameras and participants. Lens-opening, acquisition of time and lighting is necessary. It is also possible to use a software package.

## A.3 Angle distortion

If the distance between overhead cameras and the participants is long enough, i.e. if the height of the ceiling is sufficient, a mesh on the floor can be used even if a part of the upper body is used as a reference point for the position of the person. However, if the distance is short this type of approximation can give rise to systematic measurement errors due to the angle distortion (see Figure A.2). Similar errors occur if the cameras are not placed directly overhead, but instead film participants at an angle.

There are several ways to compensate for angle distortion when a part of the upper body is used as a reference point and cameras cannot be placed directly overhead at a sufficiently large distance. One approach is to use a mesh at the approximate height of the body part being observed, e.g. at head level. Key points of the mesh can be marked on walls or a mesh can be created at the desired height before the experiment and filmed by the cameras. This mesh can then be used in the subsequent analysis. One limitation of this approach is that an approximate height of the body part needs to be assumed when the height of the mesh is decided. This can in turn give rise to angle distortions due to varying height of the participants, i.e. that fact that the observed body part is not at the same height for all participants. The angle distortion can be removed more accurately when the actual body heights of each participant can be obtained. Using markers with an identifier, such as two-dimensional barcodes, each participant can be identified by computer image detection and then the trajectory data can be connected to their body height data to remove the angle distortion.

An alternative approach for avoiding angle distortion is to use triangulation with two cameras. This approach requires two cameras placed in different locations filming the same body part of the participant. By identifying the body part in the two video images and determining where the vectors from the two cameras to the body part intersect, it is possible to determine the location of the participant.[4] This approach eliminates the problem of angle distortion.




**Key**

1 estimated location

2 exact location

**Figure A.2 — Angle distortion for long (left) and short (right) distances for a mesh located at floor level when the upper body is used as a reference point for participants' location**

# Annex B
(informative)

# Example exercises

## B.1 General

This annex will describe the steps taken to design experiments that have been described in the literature. Although all steps were not reported in all cases, missing information will be noted.

## B.2 French cinema experiment[20]

### B.2.1 What is measured/purpose of study

The purpose of this study[20] was to collect data on pre-movement times, travel times, walking speeds down stairs and flow rates through doorways, and to observe and analyse behaviours that influence evacuation in a cinema theatre.

### B.2.2 Type of study

This was a controlled experiment, as the researchers were able to determine the composition of the participant population and were able to manipulate the independent variable (in this case, the availability of exits within the theatre).

### B.2.3 Recruitment

The 122 participants in the study were volunteers. The public was made up of 30 women and 92 men, between 19 and 63 years old, averaging 32,6 years and coming from various socio-professional categories (executives, engineers, students, technicians, and administration staff). The audience consists of people aware of safety in the broad sense and not only fire safety. (56 participants were police constable students). Participants were recruited from either private organizations or public institutions such as École de Police, Paris Fire Brigade.

A cinema ticket was given as compensation.

The participants were informed that they were participating in evacuation drills but did not know the details of the experimental design.

### B.2.4 Site selection and description

The experiment was conducted in one of 13 cinema theatres built in compliance with French regulations. The whole of the complex can accommodate 2 800 people. The cinema room used in the experiment was on the third (uppermost) level of the building and could hold almost 200 people with five spaces available for wheelchairs. There were three exit doors in the cinema room and in the hallway outside the cinema room there were doors leading to stairs down to ground level.

### B.2.5 Equipment/instruments

Fixed cameras and mobile cameras were used to collect data on pre-movement times, exit choices and other behaviours and to record crowd density. The recording equipment included existing surveillance cameras on the outside exits and the hallway and two hand-held cameras in the theatre. These mobile cameras also follow the last person who left the place. Times were measured by observers using mobile cameras and stopwatches. A questionnaire was developed to report details about the individuals (age, etc.) and to report their movements and decisions.

### B.2.6 Experiment

The participants participated in four different theatre evacuation scenarios:

a) all exits available;

b) only one exit available from the cinema room and that exit leading to downward stairs;

c) all exits from the cinema room available but one hallway exit blocked; and

d) one cinema room exit and one hallway exit blocked, but staff assisting with instructions.

The participants' movements were recorded on video in the cinema room, in the hallway and at the outside exits. Observers recorded times at various locations along the exit routes. The questionnaire was administered after the four drills were completed.

### B.2.7 Analysis

Time to evacuate the cinema room was calculated as the time from the sounding of the alarm until the time at which the last person left the cinema room. The total evacuation time was calculated as the time at which the last person left the building. Pre-movement time was reported as the time from alarm recognition (defined here as the time when the cinema room lights were turned back on) until the time at which the majority of the participants were standing. The flows through doorways were based on the time between the first and last person leaving the area.

### B.2.8 Results

The experiments allowed the quantification of some characteristic values of evacuation in a cinema and the qualification of some human behaviours.

## B.3 North America mid-rise administrative building pre-evacuation[21]

### B.3.1 What is measured/purpose of study

The purpose of this study[21] was to collect pre-evacuation data and evacuation times during an unannounced evacuation exercise from a mid-rise administrative building. Pre-evacuation is defined as the time between the alarm sounding and the arrival at a stair entrance.

### B.3.2 Type of study

This was an observational study of an unannounced experiment. It was part of a project to evaluate different notification systems and emergency procedures.

### B.3.3 Recruitment

The participants were the resident population from a mid-rise office building. 825 people were present in the complex at the time of the experiment.

### B.3.4 Site selection and description

The experiment was conducted in an administrative office complex consisting of a 14-floor tower and three-floor low-rise structure.

### B.3.5 Equipment/instruments

Video, manuals and survey techniques were used.

People were counted via video camera and manual counting by observers and stopwatches. The position of observers and cameras were chosen in such a way as to not influence the evacuation. Video cameras were installed in such a way as to preserve anonymity.

Data from the exits of the building were collected with the security cameras outside of the building.

### B.3.6 Experiment

During an emergency fire and earthquake exercise, the time taken to arrive at the stairs entrance after receiving notification from a voice notification system was measured.

### B.3.7 Analysis

Analysis involved the development of a simple set of guidelines for data collection and a scheme to estimate time of groups of evacuees.

A post-event survey was completed. The responses were collected via email or on a hardcopy 24 hours after the experiment.

### B.3.8 Results

The experiment allowed the presentation of numerical (pre-evacuation times, overall evacuation times, survey responses) and descriptive results following the phases of the evacuation.

It provided an evaluation of average pre-evacuation time for each group of evacuees.

Numerical and descriptive data collected are connected through a graphical scheme.



## B.4 Swedish cinema experiment[22]

### B.4.1 What is measured/purpose of study

The purpose of this study[22] was to collect data on pre-movement times and to observe and analyse behaviours that influence evacuation in a cinema theatre when one of six different types of alarm systems is used. The objective was to see which type of alarm would be most effective in reducing delays in evacuation.

### B.4.2 Type of study

This was an observational study, as the researchers used members of the general public who were unaware that an experiment was taking place. Although they were able to manipulate the independent variable (in this case, the type of alarm) they were not able to control the participant population.

### B.4.3 Recruitment

There was no recruitment for these experiments. The participants were members of the general public who were in the theatre to see a movie.

### B.4.4 Site selection and description

The cinema theatre was located in a city in the south of Sweden. A cinema complex comprising of multiple cinema theatres was chosen. A cinema in a large metropolitan area was chosen in order to reduce the risk of rumours of the experiments spreading to a large proportion of potential cinema visitors.

### B.4.5 Equipment/instruments

Cameras were used to collect data on pre-movement times and other behaviours. A questionnaire was developed to report the individuals' behaviours and attitudes.

### B.4.6 Experiment

The movie theatre was evacuated 18 separate times, with six different alarm systems tested three times each. The participants' behaviours were recorded on video in the cinema theatre. The questionnaire was administered after the experiment.

### B.4.7 Analysis

The time taken for participants to respond (pre-movement time) was derived for all 18 experiments using the recorded video footage. In addition, replies to questionnaires were reviewed to determine participant demographics, behaviour and associations with the different alarms.

### B.4.8 Results

The results of the study revealed that an acoustic alarm combined with an information sign was a good, simple and cost-effective way to improve evacuation safety for places like cinema theatres. Furthermore, a voice alarm is often effective as it makes people determined to evacuate. However, it is important to carefully choose appropriate voice messages. For example, the experiments showed that a message recorded with a female voice with south Swedish accent was interpreted more accurately than a message recorded in a male voice with a Stockholm dialect.



## B.5 Swedish road tunnel experiment[23]

### B.5.1 What is measured/purpose of study

The purpose of this study[23] was to observe how motorists respond in an emergency and how they perceive available information, and to investigate if flashing green lights can influence exit choice in a road tunnel.

### B.5.2 Type of study

This was a controlled experiment, as the researchers were able to determine the composition of the participant population and were able to manipulate the independent variables (in this case, the design of the emergency exits and their exposure to voice messages).

### B.5.3 Recruitment

Employees of a road administration agency were recruited through announcements on posters, in emails and at a meeting. They were employees of the agency but were not involved in that road tunnel or in the planning of the experiment. They were screened for anxiety and depression. They were told that they were participating in an experiment involving driving and understanding road signs but were not told the true purpose of the study. There were 29 participants and they were reimbursed for their participation.

### B.5.4 Site selection and description

The site was a road tunnel under the city. There were emergency exits in the tunnel and signs at 20-m intervals that indicated the distance back to the tunnel entrance. There was a fire alarm system consisting of signs at the ceiling with flashing amber lights and static amber text and a voice message in Swedish, English and German over the public address system, preceded by an alarm tone.

### B.5.5 Equipment/instruments

This study involved the use of cameras, questionnaires, surveys, interviews and focus groups. Fifteen video cameras were installed to cover the entire area (exits, vehicles and the participants as they moved in the tunnel on foot). Smoke machines were used to generate non-irritant theatrical smoke. Green flashing lights were installed at two of the three exits. The participants attached identifying numbers to their clothing and their vehicle.

Questionnaires were prepared. For the interviews, a set of 24 open-ended questions were prepared. For the focus groups, a checklist covering the same issues as the interviews was prepared. The interviews and focus groups were recorded.

### B.5.6 Experiment

The participants met and were given instructions for the study they thought they were involved in and then drove their cars to the tunnel entrance where they completed a first questionnaire. As they drove their