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Fire safety engineering — Estimating the reduction in movement speed based on visibility and irritant species concentration

Ingénierie de la sécurité incendie — Estimation de la réduction de la vitesse de déplacement basée sur la visibilité et la concentration en espèces irritantes

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Foreword

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

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

In performance-based fire safety design, the designer can need to consider that people will move through an environment containing fire smoke. For these types of conditions, the movement speed of occupants is expected to be influenced by the smoke. For example, speed can potentially be reduced due to visibility and the presence of irritant species affecting vision. The precise influence will depend on the smoke characteristics (e.g. soot content and species concentration) as well as on the characteristics of the occupants and the built environment.

This document provides guidance on how visibility, irritant species, occupant characteristics and the built environment influence movement speed in fire smoke. In addition, the document provides correlation between movement speed and selected smoke characteristics, namely visibility and irritant species concentration. Performance criteria related to visibility and irritant species are not specified in this document. Additionally, this document does not consider other sub-incapacitating effects of fire species, (e.g. influence on cognition from asphyxiant or irritant species), nor does is consider the effects of smoke on way-finding or behaviour.

Fire safety engineering — Estimating the reduction in movement speed based on visibility and irritant species concentration

1 Scope

The aim of this document is to provide designers with correlations that can be used in performance-based fire safety design to represent the reduction of movement speed of building occupants when walking in an environment with low visibility, which also contains irritants. Different correlations are provided for deterministic analysis and probabilistic analysis.

It is recognized that values for visibility and irritant species concentration can be used as performance criteria in performance-based fire safety design. Performance criteria related to visibility and irritant species are not specified in this document. However, it is always necessary to take into account relevant performance criteria when applying this document. For example, an occupant cannot be assumed to continue moving if a performance criterion related to visibility or irritant species concentration is violated in the design calculations.

It is also recognized that fire smoke can have an influence on the cognitive processes of occupants during evacuation. This type of influence on cognition is not covered in this document but can be considered if deemed to have a major impact.

Fire smoke can also influence behaviour (e.g. occupants changing their movement path if moving into worsening smoke conditions). This type of behaviour change is not included in this document but can be considered if deemed to have a major impact.

In some jurisdictions, it is not permitted to include fire smoke in escape routes as part of the fire safety design; this document is not applicable in such situations.

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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 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
extinction coefficient
C_s
natural logarithm of the ratio of incident light intensity to transmitted light intensity, per unit light path length

Note 1 to entry: The typical unit is m^{-1}.

3.2
movement speed
v
speed of an individual occupant

Note 1 to entry: Movement speed is calculated by dividing the length of the movement path followed by the occupant to get from the start position (A) to the end position (B) by the time taken for the occupant to get from A to B. Any major stops or pauses along the movement path are omitted from the time used in the calculation of movement speed.

3.3
unimpeded movement speed
v_u
movement speed without interference

Note 1 to entry: An example of interference is fire smoke.

3.4
visibility distance
V
distance at which an object with defined characteristics can be seen in fire smoke

Note 1 to entry: Characteristics can include whether the object is light-reflecting or light-emitting.

3.5
visibility-impacted movement speed
v_{vis}
movement speed when movement is influenced by reduced visibility

4 Movement in fire smoke

4.1 General

Occupants moving in fire smoke during evacuation will reduce their movement speed due to a variety of different factors. As far as possible, a built environment shall be designed to allow evacuation using paths not affected by fire smoke. However, there can be cases where evacuation through fire smoke cannot be avoided. When including such cases in a performance-based fire safety design, the movement speed shall be reduced as a function of the smoke characteristics, i.e. visibility and irritant species concentration. In addition, characteristics of occupants and the built environment shall be considered.

The presence of fire smoke can cause people to walk faster or slower, depending on conditions. While the presence of a limited amount of fire smoke during evacuation, i.e. high-visibility and low-irritant species concentration, can influence people to temporarily walk faster than their unimpeded walking speed, this increase of movement speed shall not be considered in performance-based fire safety design. Instead, only the negative impact of fire smoke on movement speed shall be considered, i.e. the reduction of movement speed as a function of the smoke characteristics.

Movement speed can be measured in different ways. For example, the speed can be taken as the shortest distance from start position (A) to end position (B) divided by the time to get from A to B. Alternatively, the distance of the actual movement path from A to B, including any deviation from the shortest path, can be divided by the time taken to get from A to B. Also, pauses or stops along the way from A to B can optionally be included in the calculations.

In this document, movement speed is calculated by dividing the length of the movement path followed by the occupant to get from A to B divided by the time taken for the occupant to get from A to B. Any major stops or pauses along the movement path are omitted when calculating the movement speed.

The following subclauses identify factors influencing movement speed in fire smoke (see 4.2 to 4.5). The following subclauses provide guidance only and, if available for the specific case, data shall be consulted.

Examples of data can be found in References [1-35]. In Clause 6, a methodology for representing the influence of visibility and irritant species concentration on movement speed in fire smoke is presented.

4.2 Visibility

Visibility in fire smoke is related to the proportion of light obscured. Light obscuration by fire smoke, i.e. a measure of smoke density, is often expressed as the extinction coefficient. For the purpose of this document, the extinction coefficient is expressed according to Formula (1):[36]

$$C_s = \frac{1}{L} \cdot \ln \frac{I}{I_0} \tag{1}$$

where

C_s is the extinction coefficient (m^{-1});

L is the distance travelled by light (m);

I/I_0 is the fraction between intensity of light after travelling the distance L and initial intensity of the light (-).

It shall be noted that the measured extinction coefficient of fire smoke in experiments will differ depending on the relationship between the wavelength distribution of the light used in an experiment and the characteristics of the smoke aerosols. Such aspects as the size, shape and colour of the aerosols can influence the measurements. In particular, there is a strong correlation between the wavelength of the light and the size of the aerosols contributing to the measured value of the extinction coefficient. Care shall therefore be taken to make sure an adequate experimental method is employed. For example, extinction coefficients calculated based on obscured intensity of infra-red light are not suitable for estimating the visibility of exit signs emitting visible light.

Visibility can be expressed in terms of the visibility distance, which is the maximum distance at which an object can be seen in fire smoke. The visibility distance can be estimated based on the extinction coefficient according to Formula (2). The constant K assumes different values for light-reflecting objects versus light-emitting objects. Formula (2) simplifies the physical phenomenon of visibility and is therefore only strictly valid for cases where no ambient light sources are present along the viewing path from the observer and the object. As a design tool, Formula (2) yields acceptable outcomes, but the designer is free to apply more accurate correlations if warranted.

$$V = \frac{K}{C_s} \tag{2}$$

where

V is the visibility distance (m);

K is a constant which equals 2 for light-reflecting objects and 8 for light-emitting object (based on the range of values from Reference [36]);

C_s is the extinction coefficient (m^{-1}).

When estimating the visibility distance in fire smoke, it is important to distinguish between the two cases of movement towards a light-reflecting object versus a light-emitting object. When moving towards a light-emitting object (e.g. lights at human height on the wall), the visibility distance of the lights (light-emitting object) will be longer than the visibility distance of the adjacent walls (light-reflecting object). If people move towards the lights on the wall, they will also be able to see any obstacles between them and the light source. In this case, the correlation for light-emitting objects is most relevant for estimating the visibility distance, which will in turn determine the reduction of movement speed. For other cases, i.e. when people are not moving towards light-emitting objects, the correlation for light-reflecting objects is most relevant for estimating the visibility distance.

As people walk in fire smoke, they will typically reduce their movement speed as a function of decreasing visibility to avoid potentially dangerous collisions with obstacles (e.g. building features or other people) or to reduce the risk of falling. The movement speed starts to reduce once low visibility prohibits free movement, i.e. when people are no longer able to move at their unimpeded speed without risking injury due to a collision or fall. In theory, this means that there is an upper limit, i.e. an upper visibility distance, where a specific occupant moving at their preferred speed will start to reduce their movement speed.

At lower visibility, the movement speed reduces as the visibility becomes lower, until a lower limit, i.e. a lower visibility distance, is reached. The lower visibility distance typically corresponds to smoke-logged conditions, which create a situation similar to movement in complete darkness. Below the lower visibility distance, people move at a constant low movement speed, which is expected to be a speed at which collisions or falls lead to limited injuries.

4.3 Irritant species

Movement speed in smoke is affected by irritant species, which can cause acute eye/respiratory tract irritation and subsequent tear generation. In addition to being painful, these irritant effects will reduce people's ability to move without risking collision or falls, i.e. people will not be able to see the surrounding environment. Although the irritant effects can increase gradually as a function of irritant species concentration, it is expected that a major reduction of movement speed occurs when it becomes difficult for people to keep their eyes open. At this level of irritant species concentration, a situation similar to movement in complete darkness occurs. This means that people move at a constant low movement speed, which is typically a speed at which collisions or falls lead to limited injuries.

The influence of irritant species on movement speed is not relevant if people are wearing certain types of personal protective equipment. For example, fire fighters wearing breathing apparatus would typically not be influenced by irritant species, but can still reduce their walking speed due to decreasing visibility.

4.4 Occupant characteristics

The ability to move through fire smoke depends on occupant characteristics. For example, such aspects as visual acuity and night vision ability are expected to influence how the movement speed is reduced. Similarly, people have different susceptibility to irritant species. In addition, the unimpeded movement speed varies within a population. This unimpeded speed is expected to influence the visibility distance at which speed reduction starts, i.e. occupants initially moving slowly will only start to reduce their movement speed when the smoke becomes very dense.

The variability of characteristics within a population can, to a large extent, be handled by choosing an appropriate risk analysis approach. However, the designer shall pay careful attention to any systematic trends that are to be expected for a specific situation. For example, adjustments of the correlation between movement speed and visibility distance or irritant species concentration shall be made in case of a population with, on average, reduced visual acuity and increased sensitivity to irritants, e.g., elderly or children. It is also possible that fear of falling and subsequent injury can influence some populations (e.g. elderly and people with specific medical conditions such as arthritis, multiple sclerosis, etc.) to further reduce their movement speed as a function of visibility distance or irritant species concentration. Designs for buildings in which the occupant characteristics can be expected to change with time shall consider the expected population over the lifetime of the building.

4.5 Built environment

Certain features of the built environment influence movement speed in fire smoke. The influence of many of these features have not yet been quantified and are therefore not explicitly included in this document. However, the designer can modify the provided correlations based on data, making sure the suggested modifications are properly justified. Justification of modifications shall always be documented.

Examples of important features of the built environment and their potential influence on movement in fire smoke are listed below.

- — Uneven or coarse floor surfaces: lower unimpeded movement speed and a more rapid reduction of movement speed in fire smoke.
- — Uneven wall surfaces and obstacles: more rapid reduction of movement speed in fire smoke.
- — Handrail along wall: higher minimum movement speed in fire smoke.
- — Continuous visual way-guidance system (e.g. light strip): higher minimum movement speed in fire smoke.
- — Geometry requiring decision making (e.g. way-finding choices) along the evacuation path: lower unimpeded movement speed and a more rapid reduction of movement speed in fire smoke.

The designer can consult available data (e.g. movement experiments in smoke filled environments) in order to quantify the influence of identified features (see examples in 4.1). The features listed above are only examples and there can potentially be other aspects of the built environment that also influence movement speed in fire smoke.

5 Risk analysis approach

As discussed in ISO 23932-1, all fire safety engineering analyses are risk analyses, with the differentiation between levels being reflected in terms of the level of treatment of uncertainty in the analysis. The lowest level of treatment of uncertainty is achieved by the qualitative analysis, in which deviations from the tolerable risk, often taken as the deviations from regulatory provisions, are identified and addressed. The intermediate level of treatment of uncertainty is achieved by the deterministic analysis, in which the trial fire safety design is evaluated using a set of worst credible case scenarios. The highest level of treatment of uncertainty is achieved by the probabilistic analysis, in which the full range of representative scenarios are identified and evaluated. Probabilistic analysis represents the most explicit treatment of uncertainty, in that the full range of representative scenarios are identified and evaluated, either as specific scenarios or distributions, including uncertainty and variability in the input parameters.

Both deterministic and probabilistic analysis for the fire safety objective of life safety usually involves the selection and evaluation of both evacuation and fire scenarios. In cases where movement through fire smoke cannot be avoided, account shall be taken of the influence of fire smoke on the movement of people. The requirements in this document are therefore mainly applicable to deterministic and probabilistic analysis.

In the deterministic analysis, a worst credible scenario approach is used to address uncertainty. In the context of movement through fire smoke, this means that a conservative estimate of unimpeded movement speed and a conservative estimate of the reduction of movement speed in smoke shall be applied.

In the probabilistic analysis, the designer shall attempt to represent the full range of scenarios. In the context of movement thought fire smoke, this means that a representative distribution of unimpeded movement speed and a representative reduction of movement speed in smoke shall be applied.

6 Correlations for design

6.1 General

The representation of movement speed in fire smoke in performance-based fire safety design is a process in which first the reduction caused by visibility is addressed, followed by consideration of