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Life-threatening components of fire —

Part 2:
Methodology and examples of tenability assessment

Composants dangereux du feu —

Partie 2: Méthodologie et exemples d'analyse de tenabilité

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Foreword

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The committee responsible for this document is ISO/TC 92 *Fire Safety*, Subcommittee 3, *Fire threat to people and the environment*.

Introduction

Tenability of people in case of fire is an essential safety objective of regulations. Reasons that could lead to compromised tenability conditions are loss of visibility, thermal and toxic effects. ISO 13571 is a tool that has been developed to quantify the performance level related to these criteria in case of a fire.

This document presents application cases of ISO 13571. It is structured as follows:

- Clause 4 explains the principle of the application;
- Clause 5 presents the selection of performance criteria;
- Clause 6 presents the evaluation of the impact of fire to people according to ISO 13571;
- Clause 7 introduces the examples detailed in Annexes A, B, D and E.

Examples of application are presented in annexes. The first case of application concerns comparison of tenability in real-scale fire tests (Annex A and Annex B). The second case presents the methodology (Annex C) and two example cases (Annex D and Annex E) for application of ISO 13571 as performance criteria in Fire Safety Engineering studies according to ISO 23932. Annex F presents information on experimental production of input data.

Life-threatening components of fire —

Part 2:
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1 Scope

This document describes the practical application of ISO 13571 as a tool to evaluate effects of fire effluents on people. The method of application, performance criteria and evaluation of the impact are explained and illustrated by two families of examples: application to real-scale tests (Annex A and Annex B) and application to Fire Safety Engineering (Annex C, D and E).

2 Normative references

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

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and ISO 13571 apply. ISO and IEC maintain terminological databases for use in standardization at the following addresses:

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

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

4 Principle

Smoke toxicity, to a certain degree, is not a material property. Depending on the environment, availability of oxygen, thermal attack, flow conditions and surface areas available for combustion, the chemistry of the combustion of a given material can proceed along various routes and produce species in very different quantities.[1][2][3] It is then a systemic parameter, which need a systemic approach, as stated in ISO 19706.

It is also appropriate to keep the following points in mind:

— The production rates of various gaseous species change according to the combustion regime. In particular the influential parameters (not exhaustive) are:

  — Fuel nature

  — Oxygen availability

  — Temperature

  - Flows received and lost
- The species produced by the combustion are carried away from the initial fire source, and their effect is related to:
  - Sensitivity and activity of people
  - Concentrations (instantaneous)
  - Exposure times (accumulation)

Furthermore, the thermal effects related to the heat of the gases and smoke produced, along with the radiant fluxes, which they emit, play a role in the safety of people who are evacuating.

For a given design fire, it is therefore necessary to determine one or more exposure scenarios, which will make it possible to answer questions about the effects on people according to:

- The fire source and its development;
- The species produced by this fire source and their movement away from the original fire source;
- The evacuation of the people, their path and the toxic and thermal elements to which they are subject as a function of time.

Finally, it is useful to recall that toxic hazard in enclosures is mainly caused by the combustion of the contents and furnishings in the enclosure rather than the enclosure itself in the early phases of a fire. Furthermore, changes in regulations can lead to better insulation of the rooms, modification of the ventilation, and resistance of windows to bursting, all of which notably change the conditions for the accumulation of thermal energy and the generation of toxic species.

The following are the objectives of the application of ISO 13571:

- Assess effects of fire on people as a principal criterion for performance evaluation in Fire Safety Engineering studies, or in comparison of real-scale fire tests,
- Involve realistic fire sources in terms of:
  - Kinetics
  - Species produced, in particular by including data concerning the toxic species related to the burning of the contents and furnishings in building fires
- Be able to process all the materials present and not just certain ones
- Consider all potential toxic species, not only CO, as is often seen in practice
- Consider the aspects of production kinetics, movement of gases, and availability of oxygen
- Be able to process several scenarios and their possible variations:
  - “Typical” materials/”risky” materials
  - Risk in the room of fire origin room and outside the room of origin
  - Different fire regimes (smouldering, well ventilated, post-flashover)
  - Evacuation plans
- Consider the various risks for people and the associated sanction criteria as a function of thermal and toxic effects, both instantaneous and by accumulation.

5 Performance criteria

The selection of criteria to consider is conducted in early phases of a project, before any detailed study.

These criteria will make it possible to determine whether a given exposure scenario (i.e. a fire scenario combined with an evacuation scenario) is a success or failure. This concept depends above all on the susceptibility of the people to the fire effluent. In the application of ISO 13571, the objective that a person could realize his/her own evacuation without any assistance.

In fact, each person is different and according to their constitution, age, gender, possible underlying conditions, etc. the FEC and FED which they can endure before being incapacitated varies. There is, however, no feedback from experience which can be used in statistical terms. Due to the lack of precise knowledge in this field, approximating the distribution of individual susceptibilities by a log-normal distribution with a median value of one as thresholds for the FED and FEC is proposed. Half the population is therefore considered as being able to tolerate FED and FEC each having a value of one, and the other half is more sensitive and cannot tolerate values of FED and FEC equal to or above one.

As an example of a safety criterion that provides protection for a larger fraction of the population, ISO 13571:2012, A.5.2 shows that a value 0,3 protects a significant portion of the more sensitive people. At this value, 11,4 % of the population remains vulnerable to incapacitation by exposure to the fire effluent. It should be kept in mind that one of the consequences of the distribution described by the ISO 13571:2012 standard for the sensitivity of individuals (log-normal law) is that there is no value for the criterion which is low enough to guarantee protection of all occupants in an evacuation situation. Designing a facility such that the FED and FEC values are kept to extremely low values is likely to require immediate detection and suppression or to preclude otherwise desirable construction and furnishing products. It is the regulator's role to weigh these considerations.

6 Evaluation of the impact

6.1 Effects of fire on people

The impact of fire effluent on a person depends on two interacting components. The first is the location of a person and how that location might change during the course of the fire. The second is the evolving concentrations of the effluent constituents where the person is located.

A fire safety assessment could be made considering the evolution of tenability for a person who is stationary at one position in a room. This would apply to people who are asleep or medically confined. Such an application in real-scale fire tests is presented in Annex A. Assessment could also consider the exposure of a person moving along an egress path with its travel path in real-scale fire tests (Annex B) or included in a Fire Safety Engineering approach (Annexes C to E).

The exposure models used are those described in ISO 13571:2012. In particular, they cover the toxic and thermal models, but do so independently. For the toxic models, the effects of the asphyxiating and irritating gases are considered separately. See ISO 19706 for more details on the relevance of these models.

6.2 Models for toxic impact

Toxic effluents can have two principal mechanisms of action on people when considering acute exposure. Depending on their nature, they are classified into two categories:

- asphyxiating gases (CO, HCN, etc.)
- irritating gases (HCl, HBr, etc.)

There are also indirect effects like those of the low oxygen concentration (hypoxia) or high CO_2 concentration (hyperventilation). Other effects exist, like clogging of the respiratory tracts because of the presence of soot.

The evaluation of the effects related to exposure to smoke requires knowledge of the central concepts. The References [4] and [5] present a review of the art of these concepts.

Because of the complexity of the problem, there are various models incorporating toxic effects. Although all of them can be used, a first consensus was established on the models given in ISO 13571. In the ISO 13571 models, the asphyxiating gases, incorporated using the calculation of a Fractional Effective Dose (FED), and the irritating gases, incorporated using the calculation of Fractional Effective Concentration (FEC), are considered separately.

Thus, the asphyxiating gases (mainly CO, and HCN) are considered from the perspective of an accumulation mechanism, and the irritants (mainly HCl, HBr, HF, SO_2, NO, NO_2, acrolein, and formaldehyde) from that of their instantaneous effect. These assumptions are only valid when considering short-term acute effects at an incapacitating level of exposure. For irritants, other, dose-related aspects need to be included when considering long exposures or lethality levels.

One of the limits of the ISO 13571 asphyxiant gas model is that it does not incorporate the rarefaction of oxygen, O_2, which also has an asphyxiating effect. However, in many situations this effect can be considered to be minor compared with the effects of CO and HCN. CO_2 is considered as producing a hyperventilation factor in ISO 13571.

6.3 Models for thermal impact

Three mechanisms are considered: hyperthermia linked to exceeding the body's thermal regulation capacity, skin burns, and burns in the bronchial tubes. In most cases, bronchial tube burns take place at higher exposure levels than skin burns.

There are two models proposed in ISO 13571 one for radiant flux exposure and one for exposure to convective heat exchange – and they are synthesized in the form of an FED making it possible to calculate the cumulative dose.

6.3.1 Radiant flux exposure model

Two formulas are proposed in ISO 13571. The first makes it possible to calculate the time to get second-degree burns on the skin; the second makes it possible to calculate the time to reach the pain threshold.

It should be noted that the skin temperature depends on the applied flux density at the surface and the ease with which the blood carries away the energy reaching under the skin. Because of this there is a threshold located around 2,5 kW.m^{-2}, below which exposure to the flux does not cause a significant temperature increase of the skin and above which the temperature increase occurs quickly. A greater exposure can however be acceptable with the exposure time is short, especially when considering passing before an opening leading to an area on fire. Further details can be found in ISO 13571.

6.3.2 Temperature exposure model

Two formulas are included in ISO 13571, according to whether the subject is dressed normally or lightly dressed (even naked) for calculating the time necessary to become incapacitated (for an air environment at less than 10 % relative humidity).

6.3.3 Dose calculation model

The dose effect linked to the accumulation of the temperature is calculated using the thermal model FED equation of ISO 13571.

7 Examples of application

Annex A presents an example of application of ISO 13571 to a series of real-scale fire tests performed on houses with different designs of floors between the basement and the rest of the house, in two different basement fire scenarios. The objective of the study was to better understand the impact of basement fires on the ability of occupants on the upper storeys to escape. ISO 13571 models are used to monitor tenability conditions at various locations in the upper storeys. The example gives a relative comparison between different designs, using FED as the comparison criterion, without considering any specific evacuation scenario.

Annex B presents the application of ISO 13571 to different real-scale fire scenarios on a single sleeping room. Analysis is based on the time to reach compromised tenability conditions using thermal and toxic models of ISO 13571 and different evacuation strategies. The results identify the main factor comprising tenability for each scenario, according to occupant’s behaviour.

Annex C presents a methodology to apply ISO 13571 to Fire Safety Engineering studies. It refers to ISO 23932 and proposes a mathematical approach that allows obtaining tenability data as performance criteria. This methodology is based on a construction of a source term of toxic gases in addition to a source term of heat release in the Design Fire Scenario studied. It proposes ways to obtain data for each fire stage and presents the input data in a matricial shape.

Annex D is a first application of methodology proposed in Annex C. The situation is a fire in a hotel room connected to a corridor equipped with mechanical smoke control devices. Tenability assessment in the corridor is studied according to the ISO 13571 models. Various scenarios of occupant behaviour are tested, such as different departure times, a travel trough the corridor or turn back depending on the conditions. The different evacuation strategies and occupant behaviour lead to contrasted results: in some scenarios, tenability is driven by thermal effects, and in some other, toxic effects prevails.

Annex E is a second application of the methodology proposed in Annex C. The situation is a fire in a restaurant equipped with natural smoke control openings and an operating heating, ventilating, and air conditioning (HVAC) system. The fire starts in a hidden technical room (dishwashing room). Tenability assessment is performed along two escape routes, considering various pre-movement delays. The different evacuation strategies and occupant behaviour lead to contrasted results: depending on route chosen and pre-movement delay, tenability is driven by either thermal effects or toxic effects. Results are also expressed as success (FED, FEC < 0,3) versus pre-movement delay.

Annex A
(informative)

Example of application to real-scale fire scenarios - FED and ASET calculations for fire experiments conducted in a full-scale test house under two basement fire scenarios

A.1 General

An experimental program was undertaken to study the fire performance of various engineered floor systems used in single-family houses as construction moves away from the traditional solid sawn wood joists[6]. The experimental program was conducted using a test facility representing a two-storey detached single-family house with a basement (referred to as the test house hereafter). It involved full-scale fire experiments with unprotected floor assemblies located over the basement (unsheathed on the basement side) using two specific basement fire scenarios. The objective of the study was to better understand, from the perspective of tenability and structural integrity of the floor assemblies as egress routes, the impact of basement fires on the ability of occupants on the upper storeys to escape.

The experimental program used a timeline approach to establish the sequence that affects the life safety and egress of occupants under two specific basement fire scenarios. This sequence included fire initiation, smoke alarm activation, onset of untenable conditions on upper storeys, and structural failure of the test floor assembly as a viable egress route on the first storey. The experimental approach was designed to determine how long egress routes would remain viable from the perspective of both tenability and structural integrity of the test floor assembly. With the use of engineered joists and trusses in floor construction, it is desirable that the time to incapacitation of occupants should not be adversely affected. Structural failure of the floors constructed with alternative engineered products should not occur prior to the time taken to reach incapacitating levels of smoke, gases and heat. This involved FED and ASET calculations using experimental data and comparison between ASET and the floor failure time.

A.2 Experiments

Brief descriptions of the experiments are provided in the following sections. Further details of the experimental setup can be found in reference[6].

A.2.1 Facility

Each storey of the test house had a floor area of 95 m^2 and a ceiling height of 2,4 m. The basement was partitioned to create a fire compartment representing a 27,6 m^2 basement living area; the remaining area was not used during the experiments. The fire compartment had a rectangular exterior opening (2,0 m wide by 0,5 m high) covered with a removable non-combustible panel. The walls of the fire compartment were lined with 12,7 mm thick regular gypsum board. The gypsum board met ASTM C1396 and CAN/CSA-A82.27 material standards and consisted of a solid set gypsum core enclosed in face paper and liner back paper with a weight of 7,8 kg/m^2, a Flame Spread rating of 15 and Smoke Developed rating of 0 in accordance with ASTM E84 (UL 723, UBC 8-1,NFPA 255, CAN/ULC-S102). An enclosed stairwell connected the fire compartment to the first storey. At the top of this stairwell, a 0,81 m wide by 2,05 m high doorway led to the first storey. This doorway either had a door in the closed position (closed basement doorway) or had no door at all (open basement doorway), depending on the scenario being studied.

The first storey had an open-plan layout with no partitions. A test floor assembly was constructed on the first storey directly above the basement fire compartment for each experiment. A range of engineered floor systems, including wood I-joist, steel C-joist, metal plate wood truss and metal web wood truss assemblies as well as solid wood joist assemblies were used in the full-scale fire experiments. A 0,89 m wide by 2,07 m high doorway led to the exterior. The staircase to the second storey was not enclosed.

The second storey had a corridor (measuring 4,45 m long by 1,10 m wide) and bedrooms. Two bedrooms (each having a floor area of 16,8 m^2) were used as target bedrooms in the experiments. The door to one of the bedrooms was kept open whereas the door to the other bedroom remained closed. Each bedroom doorway was 0,81 m wide by 2,05 m high.

A.2.2 Fire scenarios

Two fire scenarios were used in the full-scale fire experiments:

- the doorway from the first storey to the basement had no door (referred to as the open basement doorway scenario);
- a hollow-core interior door was used in the doorway in the closed position (referred to as the closed basement doorway scenario).

A simple and repeatable fuel package was developed for use in full-scale experiments to fuel a fire that simulated a basement living area fire. This fuel package consisted of a mock-up sofa constructed with 9 kg of flexible polyurethane foam without any upholstery fabric, and 190 kg of wood cribs beside and underneath the mock-up sofa. The polyurethane blocks used were furniture grade flexible foam with a chemical formula of $CH_{1,91}\ O_{0,263}\ N_{0,055}$ and a density of 32,8 kg/m^3. The fuel package was located at the centre of the fire compartment in order to provide a greater challenge to the unprotected floor assemblies above. The mock-up sofa was ignited in accordance with the ASTM 1537 test protocol [7] and the wood cribs provided the remaining fire load to sustain the fire for a desired period of time.

To provide the ventilation necessary for combustion and to simulate the fire-induced breakage and complete fall-out of the window glass, the non-combustible panel that initially covered the exterior window opening of the fire compartment was manually removed when the temperature reached 300 °C at the opening. This condition was normally reached within 90 s to 120 s after ignition in the experiments. The exterior door on the first storey was opened at 180 s after ignition and left open to simulate some occupants evacuating the test house.

A.2.3 Measurements

Various measurement devices were used and data was collected at 5 s intervals in the experiments. Extensive thermocouple arrays were installed throughout the test house to measure temperatures. Flame-sensing devices and floor deflection devices were installed on the test floor assemblies. Residential ionization and photoelectric smoke alarms were installed on each level and in each bedroom.

Measurements of smoke density and gas concentrations were focused on upper storeys. On the first storey, smoke and gas sampling ports were located at a quarter point at 0,9 m and 1,5 m above the floor. On the second storey, smoke and gas sampling ports were located at the centre of the corridor at 0,9 m and 1,5 m above the floor. Smoke and gas samples from these sampling locations were connected to nondispersive infrared CO/CO_2 gas analyzers, O_2 gas analyzers and smoke density meters. Detailed gas analysis using Fourier Transform Infrared (FTIR) spectrometers was only conducted in a limited number of experiments.

A.2.4 Fire development in the basement fire compartment

Figure A.1 and Figure A.2 show the temperature profiles measured at the centre of the four quadrants of the basement fire room at the ceiling height for all of the tests. The polyurethane foam used for the mock-up sofa dominated the initial fire growth. The fast development of the fire from ignition to attainment of the first temperature peak was consistent for all of the tests. The temperatures at the ceiling height exceeded 600 °C at approximately 120 s in all of the tests, indicating that the basement fire compartment reached flashover conditions. Following this initial stage, the effects of ventilation became more pronounced and the fire became wood-crib-dominated and also involved the unprotected