INTERNATIONAL STANDARD

# ISO 24678-6

First edition
2016-08-01

# Fire safety engineering — Requirements governing algebraic formulae —

## Part 6: Flashover related phenomena

*Ingénierie de la sécurité incendie — Exigences régissant les formules algébriques —*

*Partie 6: Phénomènes liés à l'embrasement généralisé*



Reference number
ISO 24678-6:2016(E)

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# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

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

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



The committee responsible for this document is ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.



A list of all parts in the ISO 24678 series can be found on the ISO website.



# Introduction

This document is intended to be used by fire safety practitioners involved with fire safety engineering calculation methods. Examples include fire safety engineers; authorities having jurisdiction such as: territorial authority officials, fire service personnel, code enforcers and code developers. It is expected that users of this document are appropriately qualified and competent in the field of fire safety engineering. It is particularly important that users understand the parameters within which particular methodologies may be used.

Algebraic formulae conforming to the requirements of this document are used with other engineering calculation methods during fire safety design. Such design is preceded by the establishment of a context, including the fire safety goals and objectives to be met, as well as performance criteria when a tentative fire safety design is subject to specified design fire scenarios. Engineering calculation methods are used to determine if these performance criteria will be met by a particular design and if not, how the design must be modified.

The subjects of engineering calculations include the fire-safe design of entirely new built environments, such as buildings, ships or vehicles as well as the assessment of the fire safety of existing built environments.

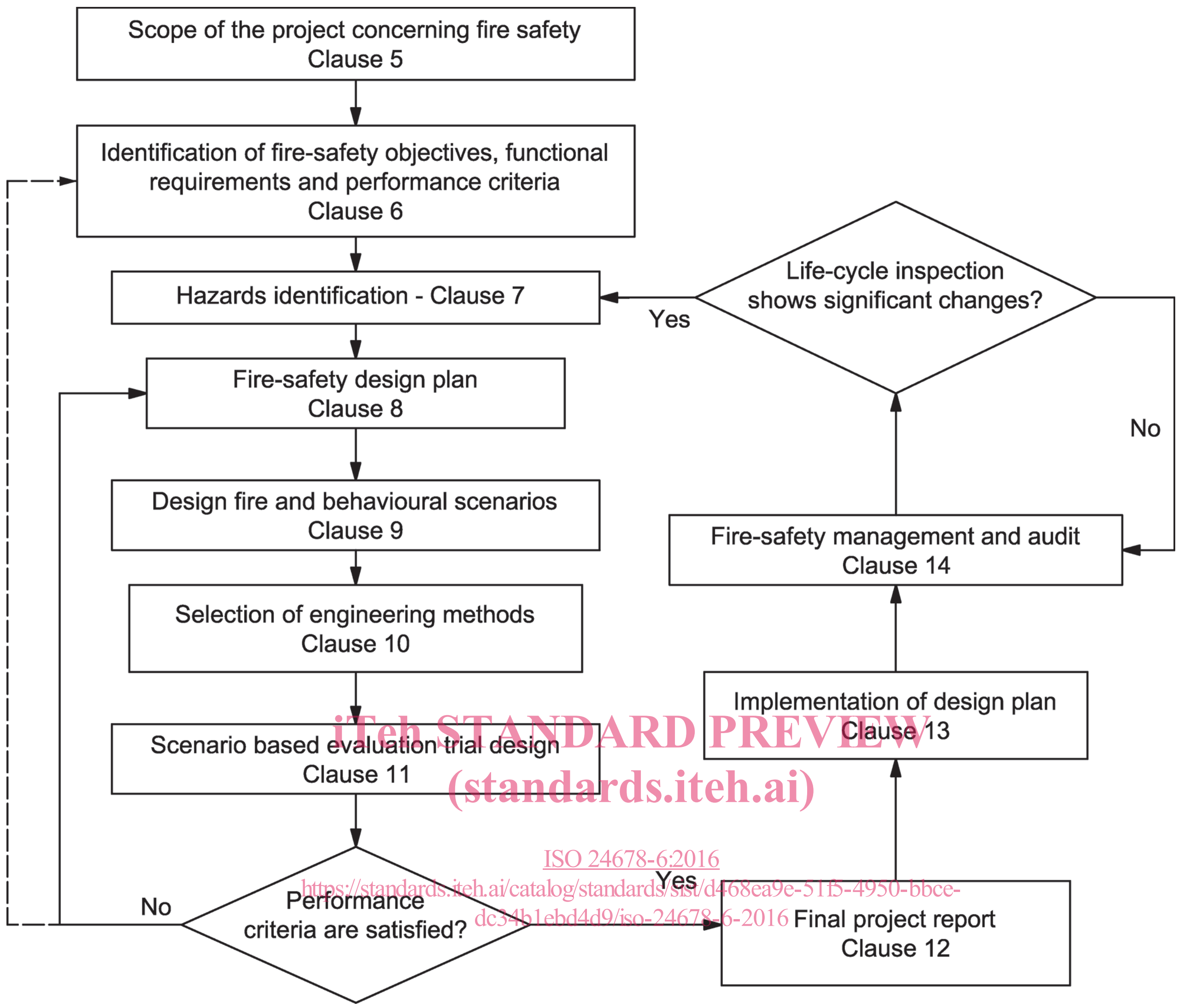
The algebraic formulae discussed in this document are very useful for estimating the consequences of design fire scenarios. Such formulae are particularly valuable for allowing the practitioner to quickly determine how a proposed fire safety design should be modified to meet performance criteria. Thus, detailed numerical calculations can be delayed until final design documentation. Examples of areas where algebraic formulae have been applicable include determination of heat transfer, both convective and radiant, from fire plumes, prediction of ceiling jet flow properties governing detector response times, calculation of smoke transport through vent openings and analysis of compartment fire hazards such as smoke filling and flashover.



With respect to flashover phenomena, algebraic formulae are often used to estimate the threshold (minimum) heat release rate required to produce flashover in the space under consideration. These estimates can suggest restrictions on flammable contents or an appropriate fire detection and suppression package to limit the maximum expected heat release rate to below that expected to produce flashover. These formulae are empirically developed from experiments done in relatively small rectilinear enclosures of similar size and with walls and ceilings of similar thermal properties. Thus, the calculated threshold flashover heat release rates do not incorporate the many variables that complicate enclosure fires. Consequently, these calculated values should be considered as preliminary estimates. Ultimately, these estimates can be useful for checking the results of zone and the more comprehensive numerical models that calculate fire growth and its consequences.

ISO 23932 is supported by a set of fire safety engineering documents available on the methods and data needed for the steps in a fire safety engineering design summarized in ISO 23932:2009, Clause 4 and shown in Figure 1 (taken from ISO 23932:2009, Clause 4). This set of documents is referred to as the Global Fire Safety Engineering Analysis and Information System. This global approach and system of documents provides an awareness of the interrelationships between fire evaluations when using the set of fire safety engineering documents. The set includes ISO 16730-1, ISO 16732-1, ISO 16733-1, ISO 16734, ISO 16735, ISO 16736, ISO 16737, ISO/TS 13447, ISO/TS 24679, ISO/TS 29761 and other supporting technical reports that provide examples of and guidance on the application of these documents.

Each document supporting the Global Fire Safety Engineering Analysis and Information System includes language in the introduction to tie said document to the steps in the fire safety engineering design process outlined in ISO 23932. ISO 23932 requires that engineering methods are selected properly to predict the fire consequences of specific scenarios and scenario elements (ISO 23932:2009, Clause 10). Pursuant to the requirements of ISO 23932, this document provides the requirement governing algebraic formulae for fire safety engineering. This step in the fire safety engineering process is shown as a highlighted box in Figure 1 and described in ISO 23932.






NOTE From ISO 23932:2009, Clause 4.

**Figure 1 — Fire-safety engineering process: Design, implementation and maintenance flowchart**

# Fire safety engineering — Requirements governing algebraic formulae —

# Part 6: Flashover related phenomena

## 1 Scope

This document provides requirements to govern the application of explicit algebraic formula sets to the calculation of flashover-related phenomena.

This document is an implementation of the general requirements provided in ISO 16730-1 for the case of fire dynamics calculations involving sets of explicit algebraic formulae.

This document is arranged in the form of a template, where specific information relevant to algebraic flashover formulae are provided to satisfy the following types of general requirements:

a) description of physical phenomena addressed by the calculation method;

b) documentation of the calculation procedure and its scientific basis;

c) limitations of the calculation method;

d) input parameters for the calculation method;

e) domain of applicability of the calculation method.



Annex A contains a set of algebraic formulae each of which calculate the minimum heat release rate to cause flashover in residential size enclosures.

## 2 Normative references

The following documents are referred to in 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 16730-1, *Fire safety engineering — Procedures and requirements for verification and validation of calculation methods — Part 1: General*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and the following shall 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

**3.1**
**critical heat release rate for flashover**
minimum heat release rate of a fire in an enclosure to cause flashover in that enclosure

## 4 Symbols

Symbols for the calculations used to predict flashover onset in Annex A are listed in A.2.

## 5 Requirements governing description of physical phenomena

**5.1** The onset of flashover is a complex thermo-physical phenomenon that can be highly transient. As a result of burning in an enclosure, hot smoke layer develops in the upper part as stated in ISO 16735. Heat and mass transfer in enclosure takes place. Radiative and convective heat transfer to fuel surface may increase the heat release rate. To calculate the onset of flashover, interactions between phenomena should be considered.

**5.2** Flashover phenomena to be calculated and their useful ranges shall be clearly identified, including those characteristics inferred by association with calculated quantities.

**5.3** Scenario elements (e.g. two-layer environment) to which specific formulae apply shall be clearly identified.

**5.4** Because different formulae describe different flashover characteristics (5.2) or apply to different scenarios (5.3), it shall be shown that if there is more than one method to calculate a given quantity, guidance shall be given on the selection of appropriate methods. A descriptive example is given in Annex A.



## 6 Requirements governing documentation

**6.1** The procedure to be followed in performing calculations shall be described through a set of algebraic formulae.

**6.2** Each formula shall be presented in a separate clause containing a phrase that describes the output of the formula, as well as explanatory notes and limitations unique to the formula being presented.

**6.3** Each variable in the formula set shall be clearly defined, along with appropriate SI units, although formula versions with dimensionless coefficients are preferred.

**6.4** The scientific basis for the formula set shall be provided through reference to recognized handbooks, the peer-reviewed scientific literature or through derivations, as appropriate.

**6.5** Examples shall demonstrate how the formula set is evaluated using values for all input parameters consistent with the requirements in Clause 6.

## 7 Requirements governing limitations

**7.1** Quantitative limits on direct application of the algebraic-formula set to calculate output parameters, consistent with the scenarios described in Clause 6, shall be provided.

**7.2** Cautions on the use of the algebraic-formula set within a more general calculation method shall be provided, which shall include checking of consistency with the other relations used in the calculation method and the numerical procedures employed.

## 8 Requirements governing input parameters

**8.1** Input parameters for the set of algebraic-formulae shall be identified clearly, such as; geometric dimensions of enclosure surfaces and vents, special location of vents, special location of fire source, physical properties of boundaries, combustion properties and so on.

**8.2** Sources of data for input parameters shall be identified or provided explicitly within the document.

**8.3** The valid ranges for input parameters shall be listed as specified in ISO 16730-1.

## 9 Requirements governing domain of applicability

**9.1** One or more collections of measurement data shall be identified to establish the domain of applicability of the formula-set. These data shall have certain level of quality [e.g. repeatability and reproducibility; see ISO 5725 (all parts)] assessed through a documented/standardized procedure.

**9.2** The domain of applicability of the algebraic formulae shall be determined through comparison with the measurement data of 9.1.

**9.3** Potential sources of error that limit the set of algebraic formulae to the specific scenarios given in Clause 6 shall be identified, for example, the assumption of uniform gas layers in an enclosed space.

# Annex A
(informative)

# Algebraic formulae for calculating the minimum heat release rate to cause flashover in residential size enclosures

## A.1 Description of physical phenomena addressed by the formula set

### A.1.1 General

The formula sets discussed in Annex A were all empirically derived using temperature and heat flux measurements from tests where different fuels were burned in enclosures of similar size and construction. The tests were generally done to study enclosure fire behaviour including the phenomenon of flashover. Because combustion products from fires have substantially higher temperature than the ambient air, the enclosure gases stratify with the less dense hot combustion products forming a growing hot layer in the ceiling volume of the enclosure. The consensus threshold heat release rate for flashover ($Q_{fo}$) is reached when the measured temperature of hot layer exceeds certain values such as 500 °C to 600 °C (approximately 770 K to 870 K) and radiation heat flux to floor surface exceeds 20 kW/m$^2$ which is enough to ignite common combustible materials in a short time.[12]



The range of application is limited by the range in size of the tests from which these formulae were derived; namely, enclosures that have moderate volume. All of these formulae were empirically derived based on small- and residential-sized enclosures. The data sets[12][13] analysed show wide variations because they are collected from similar experimental enclosures but using different fuel packages and enclosure lining materials. Note that the majority of algebraic relationships discussed in the following subclauses have been derived from experiments in naturally ventilated enclosures. Only one of the formulae was developed for forced ventilation conditions. To assess uncertainty, it will be necessary to do it for each test article individually.

The formula sets; all normalized by the opening factor $A\sqrt{H}$, relate $\dot{Q}_{fo}$ to the total interior area of the enclosure and a factor proportional to the thermal inertia of the enclosure surfaces. The formula set found to best represent data is identified using the available data and calculations of $\dot{Q}_{fo}$ using a CFD fire model.[14]

### A.1.2 General description of calculation method

Consider a growing fire in a compartment such as a mattress in a bedroom that has just been ignited by a carelessly discarded cigarette. Sufficient quantities of air are available for combustion in the early stages of fire growth. The burning is said to be fuel-controlled because the combustion, including the resultant heat release rate, is primarily influenced by fuel factors such as fuel type (the mattress) and its configuration (horizontal). Combustion products tend to collect in a layer under the ceiling because they are hotter and therefore less dense than the ambient environment. There is often a fairly sharp demarcation between a hot upper smoke layer and a relatively cool lower layer. As burning continues, the hot layer increases in depth and temperature. This augments the radiative and convective heat transfer to burning items below, which in turn increases their HRR resulting in an increase in the upper layer temperature, further enhancing heat transfer rates to burning items and enclosure surfaces. If sufficient fuel is present and arranged in such a way that the fire does continues to grow, the fire can enter a transitional phase known as flashover.

Flashover is defined as “the rapid transition to a state of total surface involvement in a fire of combustible material within an enclosure”. Essentially, almost all exposed combustible surfaces ignite and burn during flashover. This results in a fully-developed fire. Flashover often represents the transition from fuel-controlled burning to ventilation-controlled burning where the heat release rate is limited by oxygen availability, which is provided by the flow of fresh air into the compartment. After flashover, there is typically no longer any separation between a hot upper layer and a cool lower layer. Rather, a single well-mixed zone of hot gases exists. The heat release rate has reached a maximum and remains relatively constant until a large fraction of the fuel in the compartment has been consumed. Post-flashover burning represents the most hazardous stage of a compartment fire, and it is therefore of great practical interest to be able to estimate the critical heat release rate at which a fire will show transition to its flashover stage.

While the phenomenon of flashover is universally accepted, the critical conditions defining the threshold for flashover are not. Hot layer temperature between 500 °C and 600 °C, radiative heat flux to the floor of 20 kW/m$^2$ and appearance of flames exiting vents are all used to signal the event of enclosure flashover. Flashover shall be considered to have occurred when any two of the conditions have been met.[15] Because most enclosure fire tests involve extensive temperature measurements, models are designed to predict vertical temperature gradients and the attainment of upper layer temperatures in the above range is most often used to indicate when flashover occurs. Particularly, the algebraic formulae for flashover always use this criterion.

Roughly speaking, the onset of flashover in an enclosure occurs when the radiant heat flux to the floor averages 20 kW/m$^2$. This heat flux level corresponds, more or less, to an upper layer temperature of around 500 °C to 600 °C, noting that the radiant flux emitted by a 600 °C black body is about 20 kW/m$^2$.

### A.1.3 Scenario elements to which the formula set is applicable

The set of formulae is relevant to the prediction of the minimum heat release rate necessary to cause flashover in a compartment. Except where noted, these formulae apply to naturally ventilated fires, i.e. those where the effect of forced ventilation due to HVAC systems is negligible. In addition, the effect of wind is neglected.



### A.1.4 Self-consistency of the formula sets



The formula set is developed in self-consistent manner.

### A.1.5 Standards and other documents where the formula set is used

None specified.

## A.2 Symbols

| | |
|---|---|
| $A$ | area of ventilation opening (m$^2$) |
| $A_f$ | area of floor (m$^2$) |
| $A_T$ | total interior area of the enclosure excluding opening area (m$^2$) |
| $A_{wc}$ | area of walls and ceiling (m$^2$) |
| $h_T$ | effective heat transfer coefficient (kW·m$^{-2}$·K$^{-1}$) |
| $(k\rho c)_f$ | thermal inertia of floor lining (kJ$^2$·m$^{-4}$·K$^{-2}$·s$^{-1}$) |
| $(k\rho c)_{wc}$ | thermal inertia of wall and ceiling linings (kJ$^2$·m$^{-4}$·K$^{-2}$·s$^{-1}$) |
| $H$ | height of ventilation opening (m) |
| $\dot{m}$ | mechanical ventilation rate (kg·s$^{-1}$) |
| $\dot{Q}_{fo}$ | critical (minimum) heat release rate to cause flashover (kW) |