INTERNATIONAL STANDARD

ISO 24678-2

First edition
2022-08

Fire safety engineering — Requirements governing algebraic formulae —

Part 2: Fire plume

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

Partie 2: Panaches de feu

Reference number
ISO 24678-2:2022(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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

For an explanation of the voluntary nature of standards, 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 www.iso.org/iso/foreword.html.

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

This first edition cancels and replaces ISO 16734:2006, which has been technically revised.

The main changes are as follows:

— the main body has been simplified by making reference to ISO 24678-1;

— comparisons with experimental data have been added in Annex A;

— Annex B has been added to describe input data on the fire source.

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

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

The ISO 24678 series is intended to be used by fire safety practitioners involved with fire safety engineering calculation methods. It is expected that the 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 a fire safety design. Such a 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 trial fire safety design is subject to specified design fire scenarios. Engineering calculation methods are used to determine if these performance criteria are met by a particular design and if not, how the design needs to be modified.

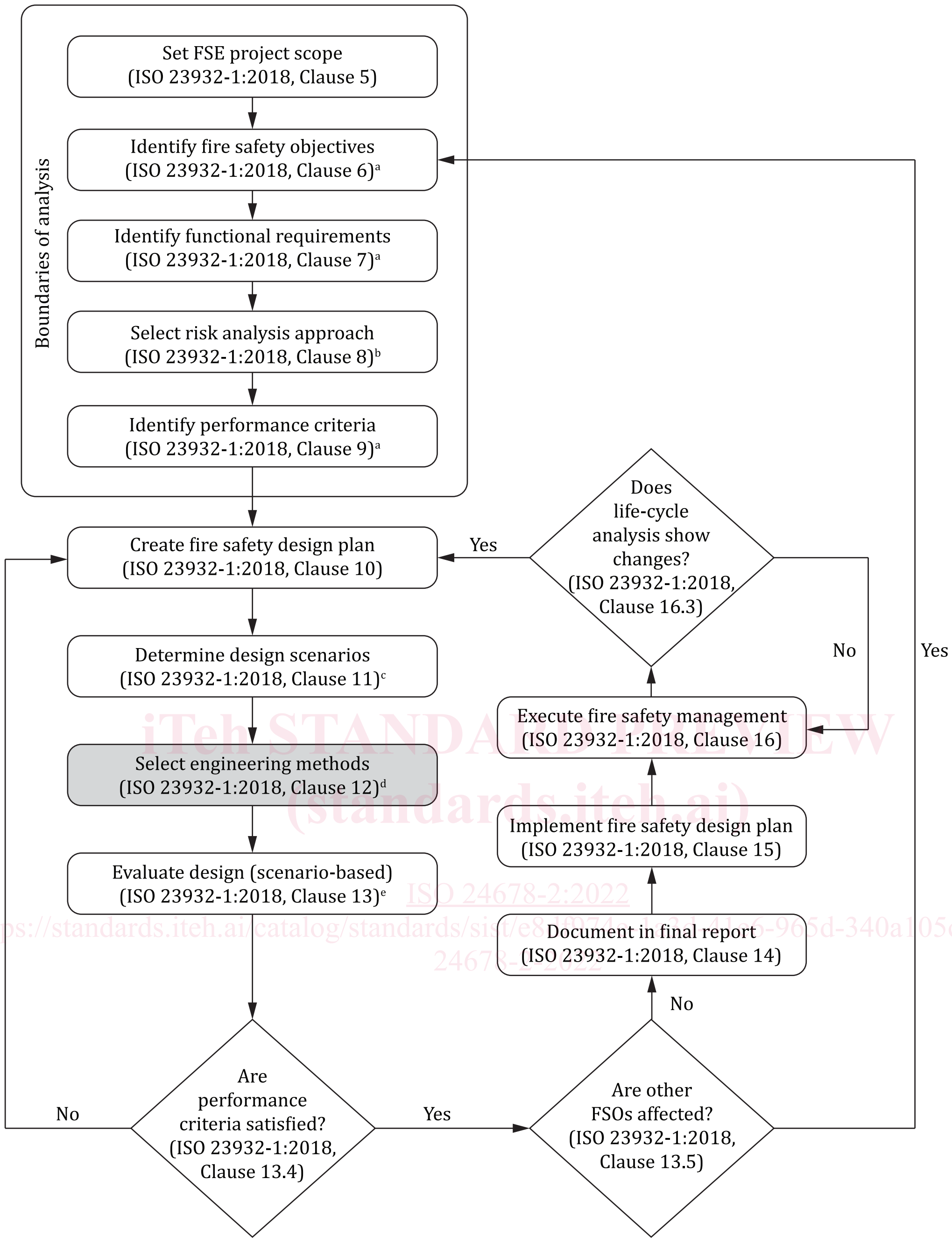
The subjects of engineering calculations include the fire-safe design of entirely new built environments, such as buildings, ships or vehicles, as well as the assessment of the fire safety of existing built environments.

The algebraic formulae discussed in this document can be useful for estimating the consequences of design fire scenarios. Such formulae are valuable for allowing the practitioner to quickly determine how a proposed fire safety design needs to be modified to meet performance criteria and to compare among multiple trial designs. Detailed numerical calculations can be carried out up until the final design documentation. Examples of areas where algebraic formulae have been applicable include determination of convective and radiative heat transfer 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. However, the simple models often have stringent limitations and are less likely to include the effects of multiple phenomena occurring in the design scenarios.

The general principles of fire safety engineering are described in ISO 23932-1, which provides a performance-based methodology for engineers to assess the level of fire safety for new or existing built environments. Fire safety is evaluated through an engineered approach based on the quantification of the behaviour of fire and based on knowledge of the consequences of such behaviour on life safety, property and the environment. ISO 23932-1 provides the process (i.e. necessary steps) and essential elements for conducting a robust performance-based fire safety design.

ISO 23932-1 is supported by a set of fire safety engineering documents on the methods and data needed for all the steps in a fire safety engineering design as summarized in Figure 1 (taken from ISO 23932-1:2018, 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 standards provides an awareness of the interrelationships between fire evaluations when using the set of fire safety engineering documents. The set of documents includes ISO/TS 13447, ISO 16730-1, ISO 16732-1, ISO 16733-1, ISO/TS 16733-2, ISO 16735, ISO 16736, ISO 16737, ISO/TR 16738, ISO 24678-1, ISO 24679-1, 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 that document to the steps in the fire safety engineering design process outlined in ISO 23932-1. ISO 23932-1 requires that engineering methods be selected properly to predict the fire consequences of specific scenarios and scenario elements (ISO 23932:2018, Clause 12). Pursuant to the requirements of ISO 23932-1, this document provides the requirements 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 23932-1.



a See also ISO/TR 16576 (Examples).

b See also ISO 16732-1, ISO 16733-1, ISO/TS 16733-2, ISO/TS 29761.

c See also ISO 16732-1, ISO 16733-1, ISO/TS 16733-2, ISO/TS 29761.

d See also ISO/TS 13447, ISO 16730-1, ISO/TR 16730-2 to ISO/TR 16730-5 (Examples), ISO 16735, ISO 16736, ISO 16737, ISO/TR 16738, ISO 24678-1, ISO 24678-2 (this document), ISO 24678-6 and ISO 24678-7.

e See also ISO/TR 16738, ISO 16733-1, ISO/TS 16733-2.

NOTE Documents linked to large parts of the fire safety engineering process: ISO 16732-1, ISO 16733-1, ISO 24679-1, ISO/TS 29761, ISO/TR 16732-2 to ISO/TR 16732-3 (Examples), ISO/TR 24679-2 to ISO/TR 24679-4 and ISO/TR 24679-6 (Examples).

Figure 1 — Flow chart illustrating the fire safety engineering design process (from ISO 23932-1:2018)

Fire safety engineering — Requirements governing algebraic formulae —

Part 2: Fire plume

1 Scope

This document specifies the requirements governing the application of a set of explicit algebraic formulae for the calculation of specific characteristics of fire plume.

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 24678-1, *Fire safety engineering — Requirements governing algebraic formulae — Part 1: General requirements*

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
axisymmetric
in a state in which mean motion and properties, such as mean temperature rise, are symmetric with respect to a vertical centreline

3.2
characteristic plume radius
radius at which the time-average plume temperature rise above the ambient value is one half the centreline value

3.3
convective fraction of heat release rate
ratio of the convective heat release rate to the total heat release rate

3.4
convective heat release rate
component of the heat release rate carried upward by the fire plume motion

Note 1 to entry: Above the mean flame height, this component is considered invariant with height.

3.5
entrained mass flow rate
air drawn in from the surroundings into the fire plume

Note 1 to entry: The mass flow rate in the plume at a given level can be considered equal to the mass flow rate of air entrained below that level into the plume. The fire source contributes an insignificant mass to the plume flow, typically less than 1 % of the total at the mean flame height.[28]

3.6
fire source diameter
effective diameter of the fire source, equal to the actual diameter for a circular source or the diameter of a circle having an area equal to the plan area of a non-circular source

3.7
fuel mass burning rate
mass generation rate of fuel vapours

3.8
mean flame height
time-average height of flames above the base of a fire, defined as the elevation where the probability of finding flames is 50 %

3.9
mean temperature rise
time-average gas temperature rise above the ambient value

3.10
mean vertical gas velocity
time-average velocity of vertical gas motion on the plume centreline

3.11
quasi-steady state
state in which it is assumed that the full effects of heat release rate changes at the fire source are felt everywhere in the flow field immediately

3.12
radiant energy release factor
ratio of the combustion heat released in a fire as thermal radiation to the net heat of combustion

3.13
virtual origin
point source from which the fire plume above the flames appears to originate

Note 1 to entry: The location of the virtual origin is likely to be above the fire source for the case of flammable liquid pool fires having a diameter of approximately 10 m or less and below the fire source for pool diameters larger than 10 m to 20 m.

4 Requirements governing the description of physical phenomena

4.1 The requirements governing the description of physical phenomena apply as specified in ISO 24678-1 in addition to the following.

4.2 The fire plume resulting from a fire source is a complex, thermo-physical phenomenon that can be highly transient or nearly steady-state. It contains regions closer to the fire source where there is usually flaming combustion (unless the source is a smouldering fire) and regions farther from the source where there is no combustion taking place, but a turbulent upward flow dominated by buoyancy forces. Regions of the fire plume (whether or not flaming/combusting, degree of fire source influence, etc.) to which specific formulae apply shall be clearly identified.

4.3 The fire plume can be significantly affected by many environmental parameters, e.g. the nature and arrangement of the burning materials that act as a fire source; whether there is flaming or smouldering combustion; degree of air restriction or vitiation; wind flows or compartment air motion; etc. For a liquid hydrocarbon fire burning in the open under calm (windless) conditions, the problem of describing the fire plume by algebraic formulae is simplified since most of these environmental parameters have a negligible influence. General types of source fires, flow-boundary (including symmetry) conditions and other scenario elements to which the analysis is applicable shall be described with the aid of diagrams.

5 Requirements governing the calculation process

The requirements specified in ISO 24678-1 governing the calculation process apply.

6 Requirements governing limitations

The requirements specified in ISO 24678-1 governing limitations apply.

7 Requirements governing input parameters

The requirements specified in ISO 24678-1 governing input parameters apply.

8 Requirements governing the domain of applicability

The requirements specified in ISO 24678-1 governing the domain of applicability apply.

9 Example of documentation

An example of sets of algebraic formulae meeting the requirements in Clauses 4-8 is provided in annexes. Annex A contains a set of algebraic formulae for a fire plume from a circular or near-circular fire source in a quiescent environment. Annex B contains information on input data on fire source properties.

Annex A
(informative)

Formulae for quasi-steady, axisymmetric fire plumes from a circular or near-circular fire source

A.1 General

This annex describes a set of formulae for axisymmetric fire plume. Properties such as flame height, mass flow rates, temperature distribution are calculated. The fire source can be circular or near-circular shape.

A.2 Symbols used in Annex A

A_s	plan area of fire source (m^2)
$b_{\Delta T}$	characteristic plume radius where the mean temperature rise is one-half the centreline value (m)
c_p	specific heat of air at constant pressure (kJ/kg·K)
D	fire source diameter (m)
g	acceleration due to gravity (m/s^2)
ΔH_c	net heat of combustion of fire source material (kJ/kg)
L	mean flame height above base of fire source (m)
$\dot{m}_{ent}$	entrained mass flow rate (kg/s)
$\dot{m}_{ent,L}$	entrained mass flow rate at the mean flame height (kg/s)
$\dot{m}_f$	fuel mass burning rate (kg/s)
N	non-dimensional parameter, as defined in A.4.2
$\dot{Q}$	heat release rate from fire source (kW)
$\dot{Q}_c$	convective heat release rate from fire source (kW)
s	stoichiometric mass ratio of air to fuel
T_0	mean temperature on plume centreline (K)
T_{0L}	mean temperature on plume centreline at mean flame height (K)
T_a	ambient temperature (K)
u_0	mean vertical gas velocity on plume centreline (m/s)
z	height above base of fire source (m)
z_v	height of virtual origin above base of fire source (m)

ΔT_0 mean temperature rise above ambient on plume centreline (K)

ΔT_{0L} mean temperature rise on plume centreline at mean flame height (K), typically 500 K

ΔT_{ave} spatial-average plume temperature rise at or above mean flame height (K)

α convective fraction of heat release rate, $1-\chi_R / \chi_a$, typically 0,6 to 0,7

ρ_a density of ambient air (kg/m^3)

χ_a combustion efficiency factor

χ_R radiant energy release factor

A.3 Description of physical phenomena addressed by the formula set

A.3.1 General description of the calculation method

A.3.1.1 Calculation procedure

Estimating the fire plume properties involves the following steps:

— determination of characteristics of the fire source (burning fuel surface, mass burning rate, etc.);

— determination of flame height;

— calculation of centreline temperature and mass flow rate at and above mean flame height.

A.3.1.2 Fire plume characteristics to be calculated

The formula set provides gas temperatures and velocities for locations along the plume vertical centreline (symmetry axis). Mean flame height, plume entrained mass flow rate and characteristic radius based on the rise in gas temperature and average plume temperature rise are also calculated.

A.3.1.3 Fire plume regions to which formulae apply

A distinction is made between regions above the mean flame height and regions below the mean flame height in the fire plume, with formulae applicable to the region above only.

A.3.2 Scenario elements to which the formula set is applicable

The formula set is applicable to plumes rising above quasi-steady state fire sources that are approximately circular or square in plan area in a quiescent environment (i.e. burning is without interference from active protection measures, wind, etc.). The fire source is a horizontal, upward-facing burning fuel surface or a three-dimensional burning array for which the mean flame height is greater than the array height. Applicable fire sources include those outside of enclosed spaces, those inside of enclosed spaces (when the fire source itself and its flames are remote from the boundaries of the enclosed space). An applicable fire source can also consist of a built environment fully involved in fire, when the mean flame height due to flames burning through the top of the built environment (e.g. a collapsed roof) is greater than the height of the built environment. See Clause A.6 for quantitative limitations on these scenario elements.

A.3.3 Self-consistency of the formula set

The formula set provided in this annex has been derived and reviewed by G. Heskestad[29] (see Clause A.5) to ensure that calculations resulting from different formulae in the set are consistent (i.e. do not produce conflicts).

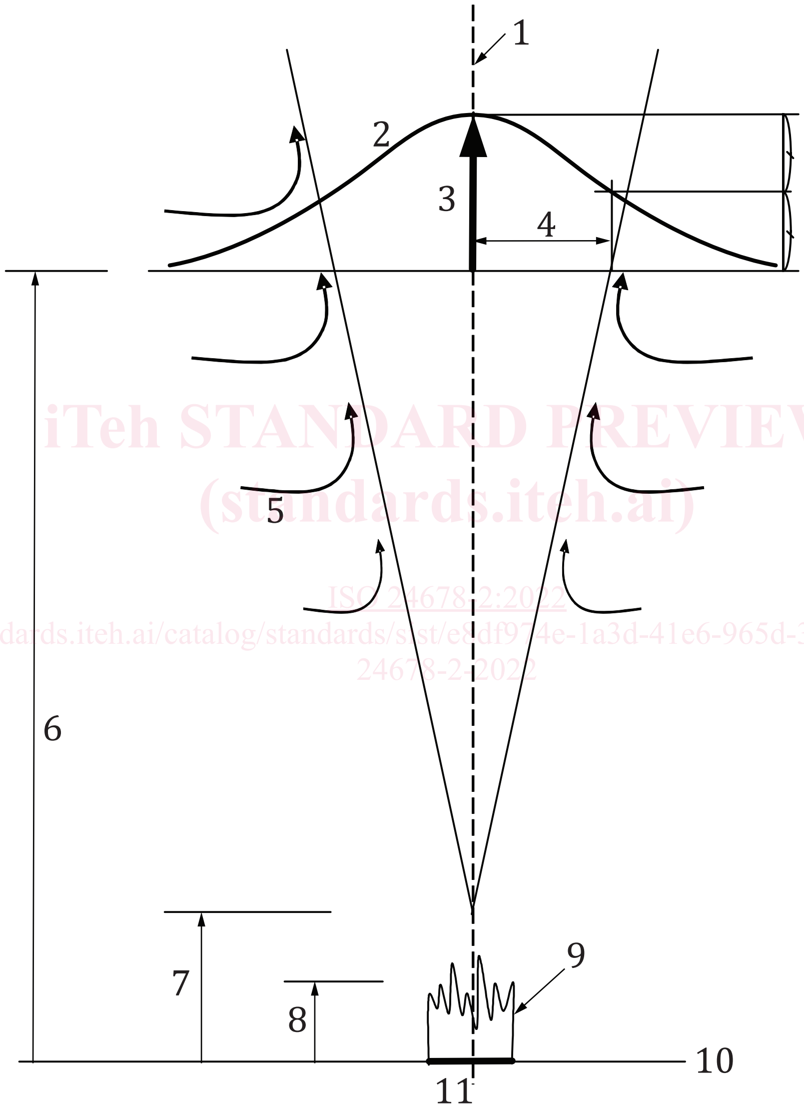
A.3.4 International Standards and other documents where the formula set is used

Formulae (A.4), (A.9) and (A.18) are used in NFPA 204[30] for smoke and heat venting.

A.4 Formula set: documentation of calculation process

A.4.1 General description of axisymmetric plumes

Properties of axisymmetric, quasi-steady state fire plume as shown in Figure A.1 are considered. Mean flame height, centreline velocity and temperature rise at and above mean flame height are calculated.



Key

1 centreline
2 velocity profile
3 centreline velocity
4 characteristic plume radius
5 air entrainment
6 height above base of fire source
7 height of virtual origin
8 mean flame height
9 flame
10 base of fire source
11 plan area of fire source

Figure A.1 — Illustration of parameters describing the plume flow