INTERNATIONAL STANDARD

ISO 24678-3

First edition
2022-08

Fire safety engineering — Requirements governing algebraic formulae —

Part 3: Ceiling jet flows

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

Partie 3: Écoulements en jet sous plafond

Reference number
ISO 24678-3:2022(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 16736:2006, which has been technically revised.

The main changes are as follows:

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

— a formula for time-mean temperature rise of a ceiling jet in a smoke layer, Formula (A.8), has been added in Annex A;

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

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.

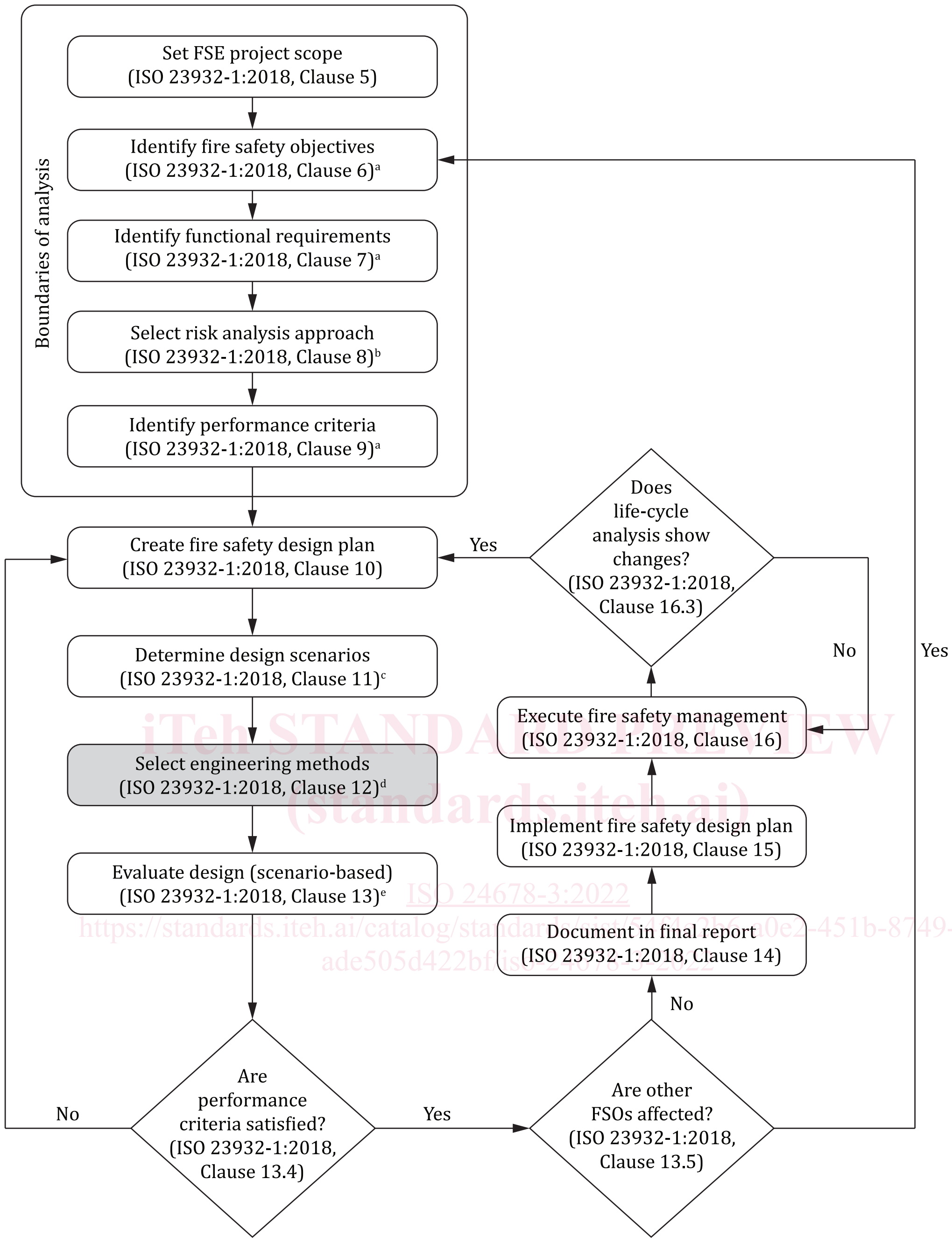
The subjects of engineering calculations include the fire-safe design of entirely new built environments, such as buildings, ships or vehicles, as well as the assessment of the fire safety of existing built environments.

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 16734, ISO 16735, 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 23932-1:2018, 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, 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 3: Ceiling jet flows

1 Scope

This document specifies the requirements governing the application of a set of explicit algebraic formulae for the calculation of specific characteristics of ceiling jet flows.

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
ceiling
highest elevation boundary of the enclosed space in any built environment, such as a room in a building or a cabin in a vehicle

3.3
characteristic depth of ceiling jet temperature profile
depth below the ceiling surface, at a given radius, at which the time-mean temperature rise above ambient in the ceiling jet flow becomes a factor of e^{-1} times the time-mean maximum temperature rise at that radius

3.4
characteristic depth of ceiling jet velocity profile
depth below the ceiling surface, at a given radius, at which the time-mean gas velocity in the ceiling jet flow becomes a factor of e^{-1} times the time-mean maximum gas velocity at that radius

3.5
convective fraction of heat release rate
ratio of the convective heat release rate to the net heat release rate

3.6
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.

3.7
fire plume turning region
flow area in which there is a transition from a plume flow to a ceiling jet flow, defined by a ratio of radial distance to effective ceiling height equal to 0,15 to 0,2

3.8
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

3.9
fuel mass burning rate
mass generation rate of fuel vapours

3.10
jet flame
flame that is dominated by momentum, rather than buoyancy forces

3.11
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 %

3.12
mean gas velocity
time-average gas velocity in the ceiling jet flow at a given radial distance

3.13
mean temperature rise
time-average gas temperature rise above the ambient temperature value in the ceiling jet flow, at a given radial distance

3.14
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

3.15
radiant energy release factor
ratio of the combustion heat released in a fire as thermal radiation to the net heat of combustion

3.16
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 surface of the burning fuel for the case of flammable liquid pool fires having a diameter of about 10 m or less and below the burning fuel surface 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 Ceiling jet flow characteristics to be calculated and their useful ranges shall be clearly identified, including those characteristics inferred by association with calculated quantities, e.g. the association of hot smoke layer under ceiling and radiant heat transfer to targets remote from the ceiling jet flow, if applicable.

4.3 Regions of the ceiling jet flow (whether or not in the fire plume turning region, degree of fire-source influence, etc.) to which specific formulae apply shall be clearly identified.

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

A set of algebraic formulae meeting the requirements of this document is provided in Annex A.

Annex A
(informative)

Formulae for quasi-steady state, axisymmetric ceiling jet flows from a circular or near-circular fire source under unobstructed ceiling

A.1 Scope

This annex provides a formula set for axisymmetric ceiling jet flows. Properties such as ceiling jet velocity and temperature are calculated. The fire source may be circular or near circular shaped.

A.2 Symbols used in Annex A

A_s	fire source plan area (m^2)
D	fire source diameter (m)
e	base of natural logarithms
g	acceleration due to gravity (m/s^2)
h	convective heat transfer coefficient [$kW/(m^2 \cdot K)$]
L	mean flame height above base of fire source (m)
l_T	characteristic depth of ceiling jet temperature profile (m)
l_V	characteristic depth of ceiling jet velocity profile (m)
$\dot{m}_f$	fuel mass burning rate (kg/s)
p	absolute air pressure (101,3 kPa)
$\dot{q}_c''$	convective heat flux (kW/m^2)
$\dot{Q}$	heat release rate actually measured or specified (kW)
$\dot{Q}_c$	convective heat release rate (kW)
Ra	plume Rayleigh number (–)
r	radial distance from plume centreline (m)
T_a	ambient temperature (K)
V	time-mean gas velocity (m/s^1)
V_{max}	time-mean maximum gas velocity (m/s^1)
y	vertical distance below ceiling (m)
z_H	height of ceiling above base of fire source (m)

z_v height of virtual origin above base of fire source (m)

α convective fraction of heat release rate, $1\text{-}\chi_R/\chi_a$ (−)

ΔH_c net heat of combustion (kJ/kg)

ΔT time-mean temperature rise above the ambient value (K)

ΔT_c ceiling temperature rise above the ambient value at a given radial position (K)

ΔT_{max} time-mean maximum temperature rise above the ambient value (K)

ν kinematic viscosity of air (m^2/s)

θ maximum slope angle of the ceiling surface (rad)

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 descriptions of the calculation method

A.3.1.1 Calculation procedure

Estimating the ceiling jet properties involves the following steps:

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

— determination of flame height;

— calculation of axial temperature and velocity along a ceiling jet flow.

A.3.1.2 Ceiling jet flow characteristics to be calculated

The formula set provides maximum gas temperatures and maximum gas velocities for locations at a radius from the plume vertical centreline (symmetry axis). Characteristic ceiling jet flow depth and rates of convective heat transfer to the ceiling are also calculated.

A.3.1.3 Ceiling jet flow regions to which formulae apply

A distinction is made between the flow within or at the exit of the plume turning region and the flow outside of the plume-turning region, with different formulae applicable within and outside of this region.

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

The set of formulae is applicable to the impingement on flat, unobstructed ceilings of fire plumes from quasi-steady state fire sources that are approximately circular or square in plan area. The fire source is a horizontal, upward-facing burning surface or a three-dimensional burning array for which the mean flame height, L, is more than 110 % of the array height yet less than 10 % of the total ceiling height above the base of the fire source.

A.3.3 Self-consistency of the formula set

The set of formulae provided in this annex have been derived and reviewed by R. L. Alpert[28] (see Clause A.5) to ensure that calculation results from different formulae in the set are consistent (i.e. do not produce conflicts).