INTERNATIONAL STANDARD

ISO 24678-9

First edition
2022-08

Fire safety engineering — Requirements governing algebraic formulae —

Part 9:
Ejected flame from an opening

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

Partie 9: Panache de flamme sortant d'une ouverture

Reference number
ISO 24678-9:2022(E)

Contents

Page

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*.

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 in fire safety engineering calculation methods. 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 can 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 are met by a particular design and if not, how the design needs to be modified.

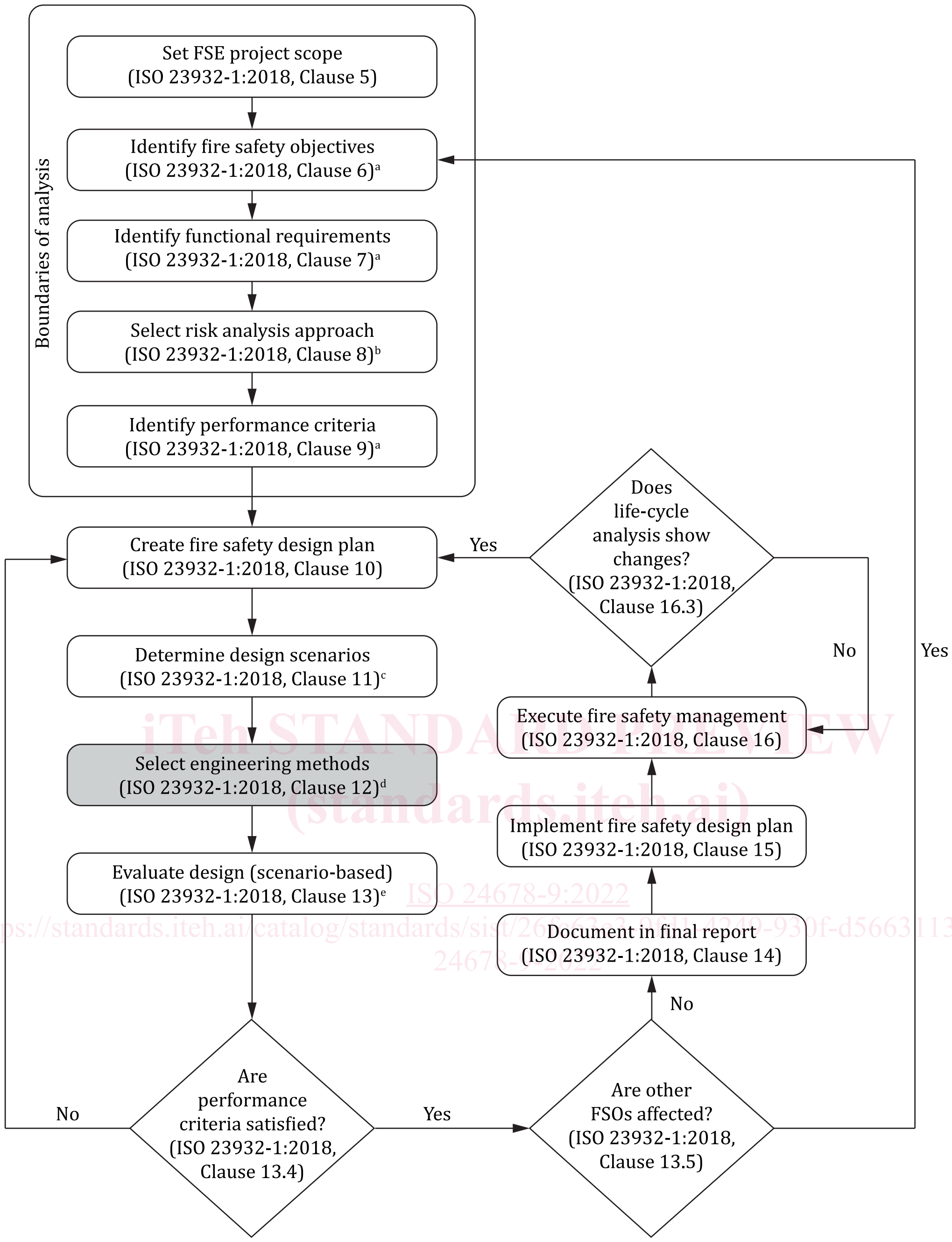
The subjects of engineering calculations include the fire-safe design of entirely new built environments, such as buildings, ships or vehicles as well as the assessment of the fire safety of existing built environments.

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 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 enclosure 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 (necessary steps) and essential elements to design a robust performance-based fire safety programme.

ISO 23932-1 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 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 includes ISO 16732-1, ISO 16733-1, ISO 16734, ISO 16735, ISO 16736, ISO 16737, the ISO 24678 series, the ISO 24679 series, ISO 16730-1, ISO/TS 29761, ISO/TS 13447, 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 29761.

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

d See also ISO/TS 13447, ISO 16730-1, ISO/TR 16730-2 to ISO/TR 16730-5 (Examples), ISO 16734, ISO 16735, ISO 16736, ISO 16737, ISO/TR 16738, ISO 24678-6.

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

NOTE Documents linked to large parts of the fire safety engineering design process: ISO 16732-1, ISO 16733-1, the ISO 24678 series, ISO 24679-1, ISO/TS 29761, ISO/TR 16732-2 and ISO/TR 16732-3 (Examples), ISO/TR 24679-2, ISO/TR 24679-4, ISO/TR 24679-5[1)] and ISO/TR 24679-6 (Examples).

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

1) Under development. Stage at the time of publication: ISO/DTR 24679-5:2022.

Fire safety engineering — Requirements governing algebraic formulae —

Part 9:
Ejected flame from an opening

1 Scope

This document specifies the requirements governing the application of explicit algebraic formula sets to the calculation of specific characteristics of ejected flame from an opening.

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
aspect ratio of an ejecting plane
ratio of the opening width to the height of ejecting plane, typically half of the opening height

3.2
ejected flame from an opening
flame ejected from an opening in a flashed enclosure

3.3
equivalent opening radius
equivalent radius for the ejecting plane, typically upper-half area of the opening

3.4
façade
products or constructions added to the external surface of an existing wall or frame

3.5
mass flow rate
<ejected flame> flow rate of fire effluent ejected from an opening

3.6
mean temperature rise
time-averaged gas temperature rise above the ambient value

3.7
neutral plane
location where the pressure difference across an opening is zero

3.8
trajectory of ejected flame
trace of the centreline of the ejected flame

3.9
unburnt gas
combustible gas generated in a fire enclosure but yet to burn outside of an opening as a part of ejected flame

4 Requirements governing the description of physical phenomena

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

4.2 The ejected flame from an opening is a complex, thermo-physical phenomenon that can be highly transient or nearly steady-state. It contains regions where there is usually flaming combustion and regions where there is no combustion taking place, but only a turbulent upward flow dominated by buoyancy forces. Regions of the ejected flame from an opening (whether or not flaming/combusting, influence of aspect ratio of opening, etc.) to which specific formulae apply shall be clearly identified.

4.3 The ejected flame from an opening can be significantly affected by many environmental parameters, e.g. property of enclosure and fire sources, aspect ratio of an opening, façade wall, external wind. The property of ejected flame shall be described taking these parameters into account.

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 domain of applicability apply.

9 Example of documentation

An example of documentation meeting the requirements in Clauses 4-8 is given in Annex A.

Annex A
(informative)

Formulae for heat flux from ejected flame from an opening

A.1 Scope

This annex provides a set of formulae for heat flux from ejected flame. As a simple case, a single rectangular opening in a flashed enclosure is considered.

A.2 Symbols and abbreviated terms used in Annex A

a	coefficient for axial distance calculation
a'	coefficient for horizontal distance calculation
A	opening area (m^2)
A_T	internal surface area of an enclosure (m^2)
B	width of the opening (m)
c_p	specific heat of air at a constant pressure (kJ/kg·K)
C	coefficient for axial distance calculation
C'	coefficient for horizontal distance calculation
$f_{\text{rect-h}}$	configuration factor of a rectangular plane to a horizontal target (-)
$f_{\text{rect-v}}$	configuration factor of a rectangular plane to a vertical target (-)
F	configuration factor (-)
$F_{\text{h,cont}}$	configuration factor of continuous flame region seen from a horizontal target (-)
$F_{\text{h,int}}$	configuration factor of intermittent flame region seen from a horizontal target (-)
$F_{\text{h,opening}}$	configuration factor of opening area seen from a horizontal target (-)
$F_{\text{v,cont}}$	configuration factor of continuous flame region seen from a vertical target (-)
$F_{\text{v,int}}$	configuration factor of intermittent flame region seen from a vertical target (-)
$F_{\text{v,opening}}$	configuration factor of opening area seen from a vertical target (-)
g	gravitational acceleration (m/s^2)
h	heat transfer coefficient ($kW/m^2 \cdot K$)
H	opening height (m)
ΔH	heat of combustion (kJ/kg)
L_e	length of radiating plane (m)

m	exponent for axial distance calculation
m'	exponent for horizontal distance calculation
m_b	mass burning rate of fuel
m_{in}	mass flow rate of inflow fresh air into an opening (kg/s)
m_{out}	mass flow rate of outflow gas out of an opening (kg/s)
n	aspect ratio of the ejecting plane of an opening (–)
q_{conv}	convective heat flux (kW/m^2)
q_{rad}	radiative heat flux (kW/m^2)
q_{total}	total heat flux (kW/m^2)
Q	heat release rate from combustibles in an enclosure (kW)
Q_e	enthalpy flow rate of the gas ejected from an opening (kW)
Q_f	heat release rate from unburnt gas (kW)
Q_{ef}	total heat release rate from ejected flame (kW)
Q_{ef}^*	dimensionless heat release rate from ejected flame for aspect ratio ≤ 5
$Q_{l,ef}^*$	dimensionless heat release rate from ejected flame for aspect ratio > 5
$Q_{v,crit}$	critical heat release rate for onset of ejected flame (kW)
r_0	equivalent opening radius (m)
S	separation distance between an opening and a target (m)
T_e	mean temperature of ejected flame (K)
$T_{e,cont}$	mean temperature of continuous flame region (1 093 K)
$T_{e,int}$	mean temperature of intermittent flame region (977 K)
T_f	fire enclosure temperature (K)
T_s	surface temperature of a target (K)
T_∞	ambient temperature (K)
ΔT_e	mean temperature rise of ejected flame above ambient (K)
ΔT_f	temperature rise in a fire enclosure above ambient (K)
x	horizontal distance in an outward direction from the top of the opening (m)
z	height above the top of the opening (m)
z'	height of ejected flame along the trajectory (m)
Z_n	height of the neutral plane (m)
Δz	height of a virtual origin for aspect ratio ≤ 5 (m)

Δz_l height of a virtual origin for aspect ratio > 5 (m)

α flow coefficient (–)

β volume expansion ratio (K^{-1})

ε emissive power of ejected flame (kW/m^2)

λ ratio of height of radiating plane to width of radiating plane (-)

θ flame tilt angle (rad.)

Θ dimensionless temperature for aspect ratio ≤ 5 (-)

Θ_l dimensionless temperature for aspect ratio > 5 (-)

ρ_∞ density of ambient air (1,2 kg/m^3)

ρ_e density of ejected flame gas (kg/m^3)

σ Stefan-Boltzmann constant ($5{,}67\times10^{-11}$ $kW/m^2 \cdot K^4$)

ξ ratio of normal distance to radiation plane to width of radiating plane (-)

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 heat flux received by a target from an ejected flame involves the three following steps:

— determination of characteristics of the ejected flame from an opening;

— determination of heat flux characteristics of ejected flame from an opening;

— calculation of heat flux received by a target (configuration factor of a flame to a target, atmospheric transmissivity along radiation path).

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

The formula set is applicable to heat flux from quasi-steady-state ejected flames from a rectangular opening equipped in a wall. Heat flux to a wall above an opening and to a wall facing an opening are calculated.

A.3.3 Self-consistency of the formula set

The formula set provided in this annex has been derived and reviewed 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

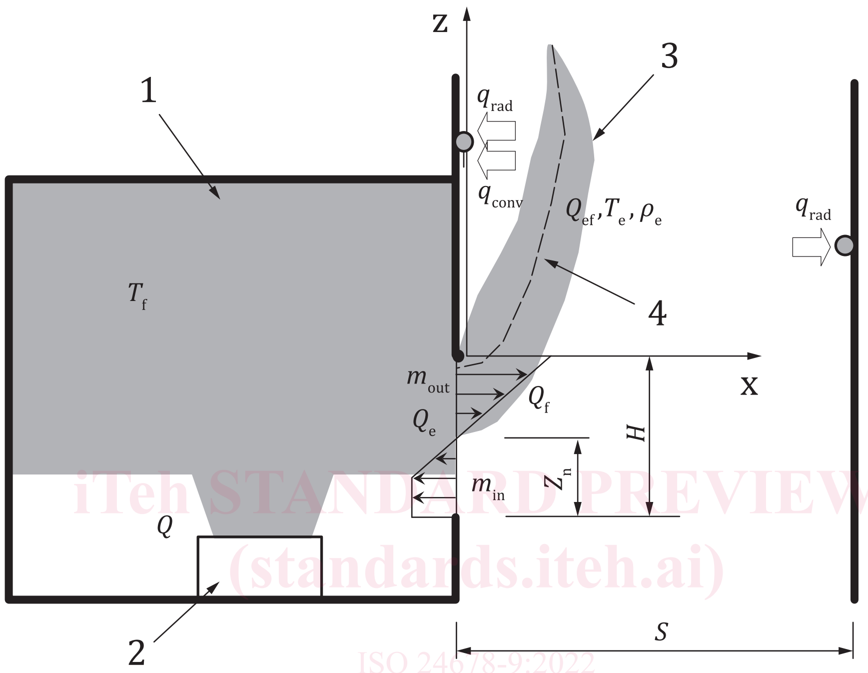
None specified.

A.4 Formula set: documentation of calculation process

A.4.1 General description of the calculation process

As shown in Figure A.1, heat flux is emitted by a flame and received by a target surface. The heat flux received by a target from ejected flame can be calculated by Formula (A.1):

$$q_{\text{total}} = q_{\text{rad}} + q_{\text{conv}} \tag{A.1}$$



Key

1 enclosure
2 fire source
3 ejected flame
4 central axis

Figure A.1 — Heat flux from an ejected flame to a target

Figure A.2 depicts the successive steps for estimating the heat flux received by a target from an ejected flame. As presented in Figure A.2, the model is composed of different interdependent sub-models. the heat release rate and temperature in the room are determined from the specified burning object characteristics. Then the heat release rate from the ejected flame from an opening is calculated considering the unburnt gas. Using this value, a trajectory of the ejected flame and the central axis temperature are determined. The geometry of the ejected flame is determined by the aspect ratio of the opening and is calculated using the height from the top of the opening and the horizontal distance from the top of the opening. The effect of blockage by participation medium such as soot, water vapour and dipole gases is considered where necessary as atmospheric transmissivity.

The target is considered as an infinitesimally small plane element, which is assumed to be located at the minimum distance between the ejected flame and the target. As configuration factors are also considered in the calculations of the physical phenomena, the point is associated with an element surface. In the rest of this document, the target is seen as a unit surface of a target.

