INTERNATIONAL STANDARD

# ISO 24678-5

First edition
2023-06

# Fire safety engineering — Requirements governing algebraic formulae —

## Part 5: Vent flows

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

*Partie 5: Ecoulements au travers d'une ouverture*



Reference number
ISO 24678-5:2023(E)

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# Foreword

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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 document 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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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 16737:2012, which has been technically revised.

The main changes are as follows:

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

— the former Annexes A and B have been merged into a new Annex A;

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

— a new Annex B has been added to describe the examples of flow coefficient values.

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.

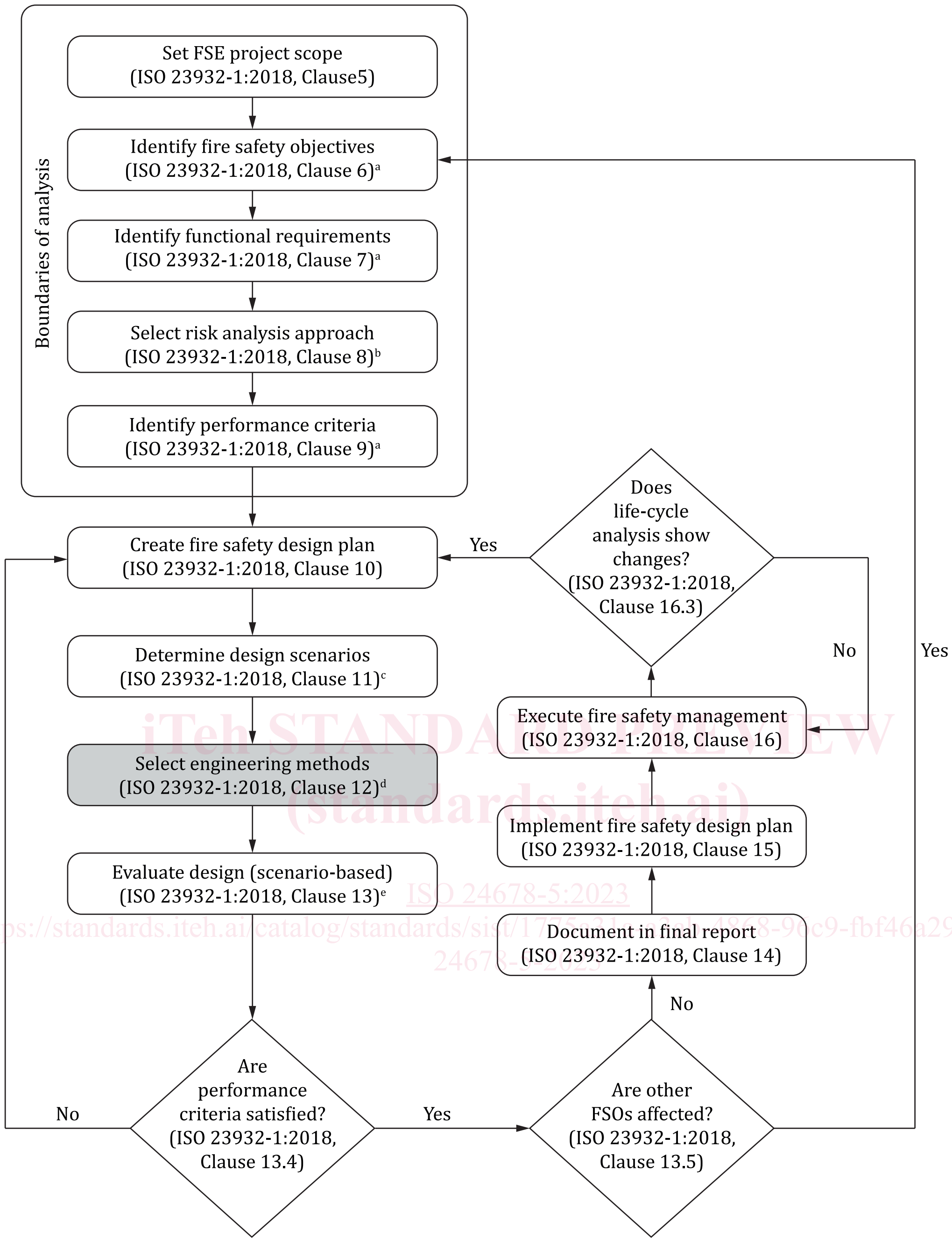
The algebraic formulae discussed in this document can be useful for estimating the consequences of design fire scenarios. Such formulae are valuable for allowing the practitioner to quickly determine how a proposed fire safety design needs to be modified to meet performance criteria and to compare among 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/TR 16738, ISO 24678-1, ISO 24679-1, ISO/TS 29761 and other supporting Technical Reports that provide examples of and information 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/TR 16738, ISO 24678-1, ISO 24678-2, ISO 24678-3, ISO 24678-4, ISO 24678-5 (this document), ISO 24678-6, ISO 24678-7 and ISO 24678-9.

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

NOTE Documents linked to large parts of the fire safety engineering design process: ISO 16732-1, ISO 16733-1, ISO 24678-1, ISO 24679-1, ISO/TS 29761, ISO/TR 16732-2 and ISO/TR 16732-3 (Examples), ISO/TR 24679-2 to ISO/TR 24679-4, ISO/TR 24679-6, ISO/TR 24679-8 (Examples).

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

# Fire safety engineering — Requirements governing algebraic formulae —

## Part 5:
## Vent 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 vent 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**
**boundary**
surface that defines the extent of an enclosure

**3.2**
**datum**
elevation used as the reference elevation for evaluation of hydrostatic pressure profiles

Note 1 to entry: This is typically the lowest boundary of the enclosure.

**3.3**
**effective flow area**
flow area effective to air and smoke movement

**3.4**
**flow coefficient**
fraction of effective flow area over total area of a vent

**3.5**
**hydrostatic pressure**
atmospheric pressure profile associated with height

**3.6**
**neutral plane height**
elevation at which the pressure inside an enclosure is the same as the pressure outside the enclosure

**3.7**
**pressure difference**
difference between the pressure inside an enclosure and outside the enclosure at a specified elevation

**3.8**
**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

**3.9**
**smoke layer height**
interface position
interface height
elevation of the smoke layer interface relative to a reference elevation

**3.10**
**vent**
opening in an enclosure boundary through which air and smoke can flow as a result of naturally- or mechanically-induced forces

**3.11**
**vent flow**
flow of smoke or air through a vent in an enclosure boundary



## 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 buoyant flow through a vent is a complex thermo-physical phenomenon that can be highly transient or nearly steady-state. Vent flows may contain regions involved in flaming combustion and regions where there is no combustion taking place. In addition to buoyancy, vent flows can be influenced by dynamic forces due to external wind or mechanical fans.

**4.3** Physical phenomena (e.g. natural vent flow, mechanical smoke exhaust, pressurization smoke control) 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

An example of documentation meeting the requirements in Clauses 4 to 8 is provided in Annex A. Annex B contains examples of flow coefficient values to be used as input to calculations of vent flow.

# Annex A
(informative)

# Formulae for vent flows

## A.1 Scope

This annex is intended to document the methods to calculate mass flow rate through vents. The formula set covers the flow through vents connecting two enclosures with the same temperature, with uniform but different temperatures, or with two-layered temperature profiles.

## A.2 Symbols and abbreviated terms used in this annex

| | |
|---|---|
| $A_{eq}$ | equivalent area of multiple seral vents ($m^2$) |
| $A_{ij}$ | area of vent connecting enclosures *i* and *j* ($m^2$) |
| $B$ | width of a vent (m) |
| $B_{eq}$ | equivalent width of multiple seral vents (m) |
| $B_{ij}$ | width of vent connecting enclosures *i* and *j* (m) |
| $c_p$ | specific heat of air and smoke (kJ/kg·K) |
| $C_D$ | flow coefficient (-) |
| $g$ | gravity acceleration ($m/s^2$) |
| $h$ | height above the datum (m) |
| $h_{ij}$ | height of vent connecting enclosures *i* and *j* (m) |
| $h_l$ | height of lower edge of vent above the datum (m) |
| $h_m$ | height of the bottom of middle segment above the datum (m) |
| $h_n$ | neutral plane height above the datum (m) |
| $h_t$ | height of the bottom of top segment above the datum (m) |
| $h_u$ | height of upper edge of vent above the datum (m) |
| $\dot{H}_{ij}$ | enthalpy flux from enclosure *i* to enclosure *j* (kW) |
| $\max(x_1,x_2)$ | maximum of $x_1$ and $x_2$ |
| $\min(x_1, x_2)$ | minimum of $x_1$ and $x_2$ |
| $p_i(h)$ | pressure in enclosure *i* at height *h* above the datum (Pa) |
| $p_j(h)$ | pressure in enclosure *j* at height *h* above the datum (Pa) |
| $q_{m,ij}$ | mass flow rate of smoke or air from enclosure *i* to *j* (kg/s) |

| | |
|---|---|
| $q_{m,ij,b}$ | mass flow rate of smoke or air from enclosure *i* to *j* through bottom segment (kg/s) |
| $q_{m,ij,m}$ | mass flow rate of smoke or air from enclosure *i* to *j* through middle segment (kg/s) |
| $q_{m,ij,t}$ | mass flow rate of smoke or air from enclosure *i* to *j* through top segment (kg/s) |
| $q_{w,ij}$ | mass flux of chemical species from enclosure *i* to enclosure *j* (kg/s) |
| $T_{a,i}$ | air layer temperature in enclosure *i* (K) |
| $T_i$ | temperature of enclosure *i* (K) |
| $T_j$ | temperature of enclosure *j* or outside (K) |
| $T_{s,i}$ | smoke layer temperature in enclosure *i* (K) |
| $T_0$ | reference temperature, typically the outside temperature (K) |
| $u_{ij}$ | flow velocity from enclosure *i* to enclosure *j* (m/s) |
| $Y_i$ | mass fraction of chemical species in enclosure *i* (kg/kg) |
| $z_i$ | smoke layer height in enclosure *i* (m) |
| $\rho_{a,i}$ | gas density of air layer in enclosure *i* (kg/m) |
| $\rho_i$ | gas density of smoke (or air) in enclosure *i* (kg/m$^3$) |
| $\rho_j$ | gas density of smoke (or air) in enclosure *j* (kg/m$^3$) |
| $\rho_{s,i}$ | gas density of smoke layer in enclosure *i* (kg/m$^3$) |
| $\rho_0$ | gas density of smoke (or air) at reference temperature (kg/m$^3$) |
| $\Delta p_{ij}(h)$ | pressure difference between enclosure *i* and *j* at height *h*; that is, $p_i(h)$-$p_j(h)$ (Pa) |
| $\Delta p_{flood}$ | minimum pressure difference to cause uni-directional flow (Pa) |
| $\zeta$ | height used as an integration variable (m) |



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

### A.3.1 General descriptions of calculation method

#### A.3.1.1 Calculation procedure

The methods permit calculation of flows through vents in enclosure boundaries arising from pressure differences that develop between an enclosure and adjacent spaces as a result of temperature differences. Pressure differences may also result from fire gas expansion, mechanical ventilation, wind or other forces acting on the enclosure boundaries and vents, but these forces are not addressed in this document. Given a pressure difference across a vent and the temperatures of the enclosures that the vent connects, mass flow rate is calculated by using orifice flow theory.

The properties of an enclosure, such as smoke layer height, temperature, and other properties are calculated by the principle of heat and mass conservation for the smoke layer as described in ISO 24678-4.

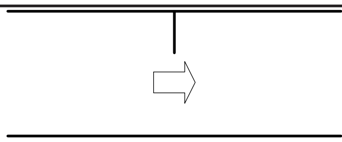
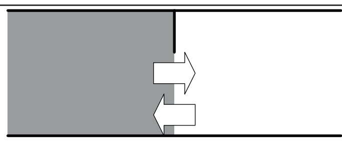
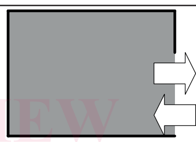
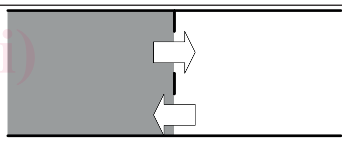
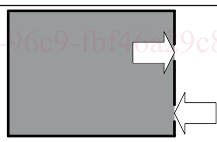
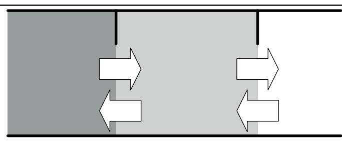
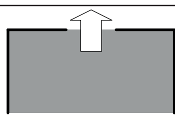
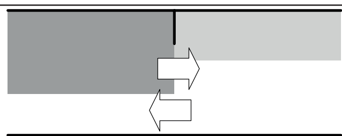
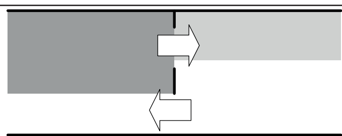
#### A.3.1.2 Vent flow properties to be calculated

The formula set provides the mass, enthalpy and chemical species flow rates.

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

The set of formulae is applicable to quasi-steady state vent flows driven by buoyancy caused by fire. Dynamic pressure effects, such as wind, are not considered. Methods to calculate vent flow conditions are developed for two types of temperature profiles: one is a uniform temperature profile while the other is a two-layered profile as calculated by ISO 24678-4. The calculation conditions are summarized in Table A.1.

**Table A.1 — Summary of calculation conditions of vent flows**

| Temperature profile | Arrangement of vent(s) | flow patterns |
|---|---|---|
| Uniform | a) Single vent |  |
| Single layer | b) Single vertical vent (general case, flow may be either uni-directional or bi-directional) |  |
| | c) Single vertical vent (special case, flow is bi-directional) |  |
| | d) Multiple vertical vents (general case, flow may be either uni-directional or bi-directional) |  |
| | e) Multiple vertical vents (special case of two small vents in one enclosure, flow is bi-directional) |  |
| | f) Multiple serial vertical vents (combination of multiple serial vents into equivalent single vent) |  |
| | g) Single horizontal vent (stable uni-directional flow only) |  |
| Two layers | h) Single vertical vent (general case, flow may be either uni-directional or bi-directional) |  |
| | i) Multiple vertical vents (general case, flow may be either uni-directional or bi-directional) |  |



### A.3.3 Self-consistency of the formula set

The formula set provided in this annex has been derived and reviewed by many researchers (see Clause A.5) to ensure that calculation results from different formulae in the set are consistent (i.e. do not produce conflicts).

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

ISO 24678-4 uses vent flow formulae to calculate smoke layer properties.

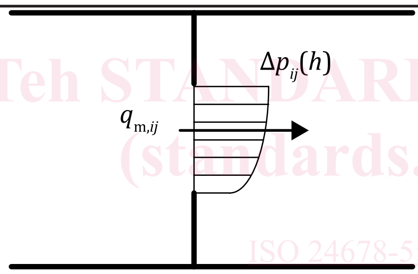
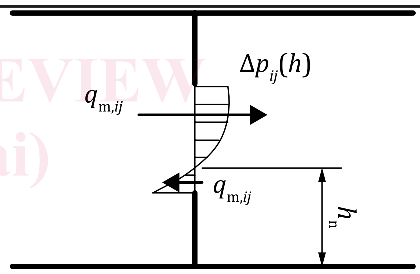
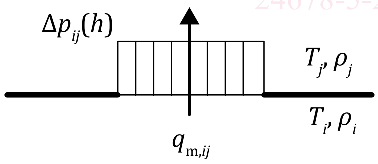
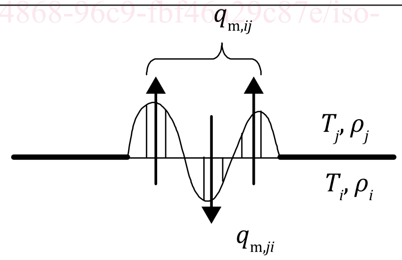
## A.4 Formula-set documentation of calculation procedure

### A.4.1 General aspects of vent flow

#### A.4.1.1 Classifications of vent flows

The velocity of flow through a vent is calculated according to the orifice flow theory based on application of Bernoulli's theory. Methods to calculate vent flows are developed for the conditions shown in Table A.2. For the case of vertical and horizontal vents, flow may be uni-directional or bi-directional. Explicit formulae presented in this annex are applicable to bi-directional and uni-directional flows through vertical vents and uni-directional flow through horizontal vents. For horizontal vents, bi-directional flow takes place when the pressure difference is small. No general formula is available in this annex because the flow is unstable.

**Table A.2 — Classifications of vent flows**

| | Uni-directional flows | Bi-directional flows |
|---|---|---|
| **Vertical vent** |  |  |
| **Horizontal vent** |  |  |



#### A.4.1.2 Orifice flow formula — uniform pressure difference over vent area

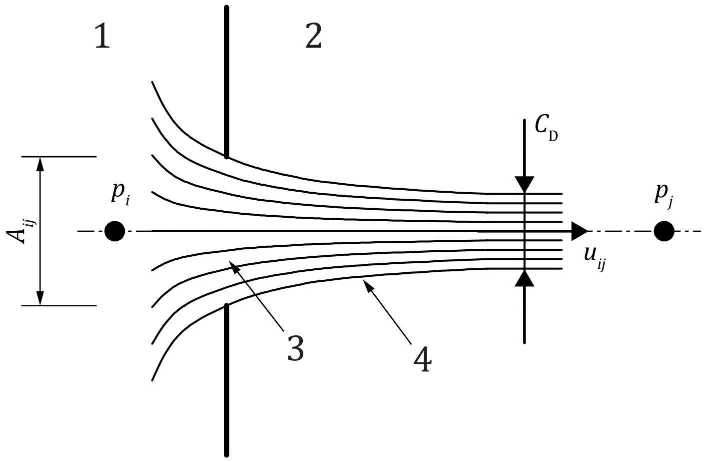
When uniform pressure difference is created by actions such as mechanical fans, the mass flow rate through the vent is given by Formula (A.1):

$$q_{m,ij} = C_D A_{ij} u_{ij} = C_D A_{ij} \sqrt{2\rho_i \Delta p_{ij}} \qquad (A.1)$$

where $\Delta p_{ij}$ is calculated using Formula (A.2):

$$\Delta p_{ij} = p_i - p_j \qquad (A.2)$$

It is assumed that the pressure difference across the vent is uniform over the entire vent area as shown in Figure A.1.




**Key**

1 enclosure *i*

2 enclosure *j*

3 vent

4 stream lines

**Figure A.1 — Streamlines and flow coefficient for isothermal orifice flow**



### A.4.1.3 General flow formula – non-uniform pressure difference over vent area

When a vertical temperature profile $T_i(h)$ exists in enclosure *i* as shown in Figure A.2, the gas density, $\rho_i$, at height *h* above the datum is calculated by Formula (A.3):



$$\rho_i(h) = \frac{\rho_0 T_0}{T_i(h)} \approx \frac{353}{T_i(h)} \quad \text{(A.3)}$$

NOTE Smoke is approximated by an ideal gas whose property is identical to air at normal atmospheric pressure.

The hydrostatic pressure in enclosure $i$ is calculated by integrating gas density over height, using Formula (A.4):

$$p_i(h)=p_i(0)-\int_0^h \rho_i(\zeta)g\,\mathrm{d}\zeta \tag{A.4}$$

Hydrostatic pressure difference between enclosures i and j at height $h$ is calculated using Formula (A.5):

$$\begin{aligned}\Delta p_{ij}(h)&=p_i(h)-p_j(h)\\ &=\{p_i(0)-p_j(0)\}-\int_0^h\{\rho_i(\zeta)-\rho_j(\zeta)\}g\,\mathrm{d}\zeta\\ &=\Delta p_{ij}(0)-\int_0^h\{\rho_i(\zeta)-\rho_j(\zeta)\}g\,\mathrm{d}\zeta\end{aligned} \tag{A.5}$$

where the pressure difference at the datum is determined by Formula (A.6):

$$\Delta p_{ij}(0)=p_i(0)-p_j(0) \tag{A.6}$$

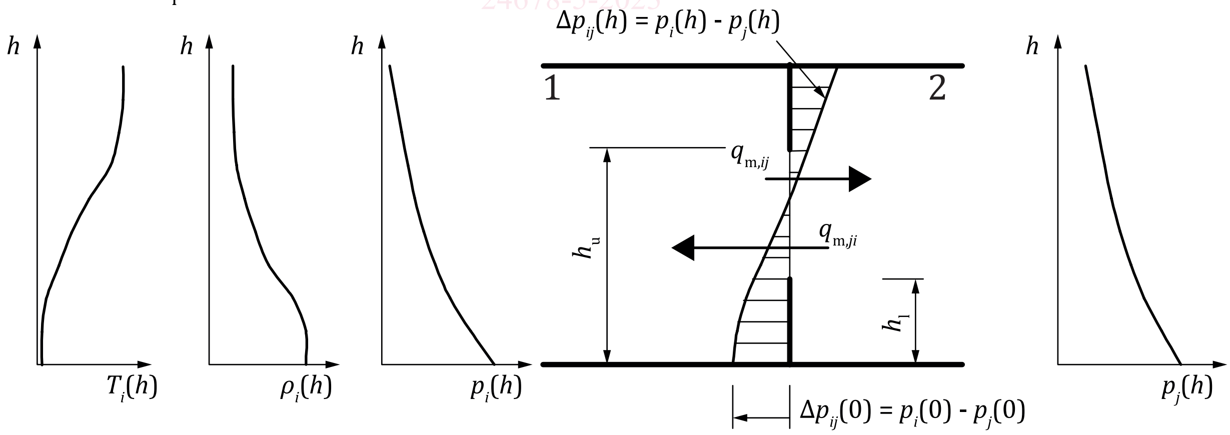
Flow through a vertical vent is calculated by applying the orifice flow theory to each vertical segment of the vent. Given the hydrostatic pressure difference calculated using Formula (A.5), mass flow rates between enclosures are calculated using Formulae (A.7) and (A.8):



$$q_{\mathrm{m},ij}=C_\mathrm{D}B\int_{h_\mathrm{l}}^{h_\mathrm{u}}\sqrt{2\rho_i(\varsigma)\max(\Delta p_{ij}(\varsigma),0)}\,\mathrm{d}\varsigma \tag{A.7}$$



$$q_{\mathrm{m},ji}=C_\mathrm{D}B\int_{h_\mathrm{l}}^{h_\mathrm{u}}\sqrt{2\rho_\mathrm{j}(\zeta)\max(-\Delta p_{ij}(\zeta),0)}\,\mathrm{d}\zeta \tag{A.8}$$




**Key**

1 enclosure $i$

2 enclosure $j$

**Figure A.2 — Hydrostatic pressure difference between two adjacent enclosures**