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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

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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).

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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 second edition cancels and replaces the first edition (ISO 16737:2006), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the main body was simplified by referring to Part 1 of this standard;

— the former Annexes A and B were merged into new Annex A;

— comaprisons with experimental data were added in Annex A;

— new Annex B was 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

This document 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 the users understand the parameters within which particular methodologies can be used.

Algebraic formulae conforming to the requirements of this standard 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.

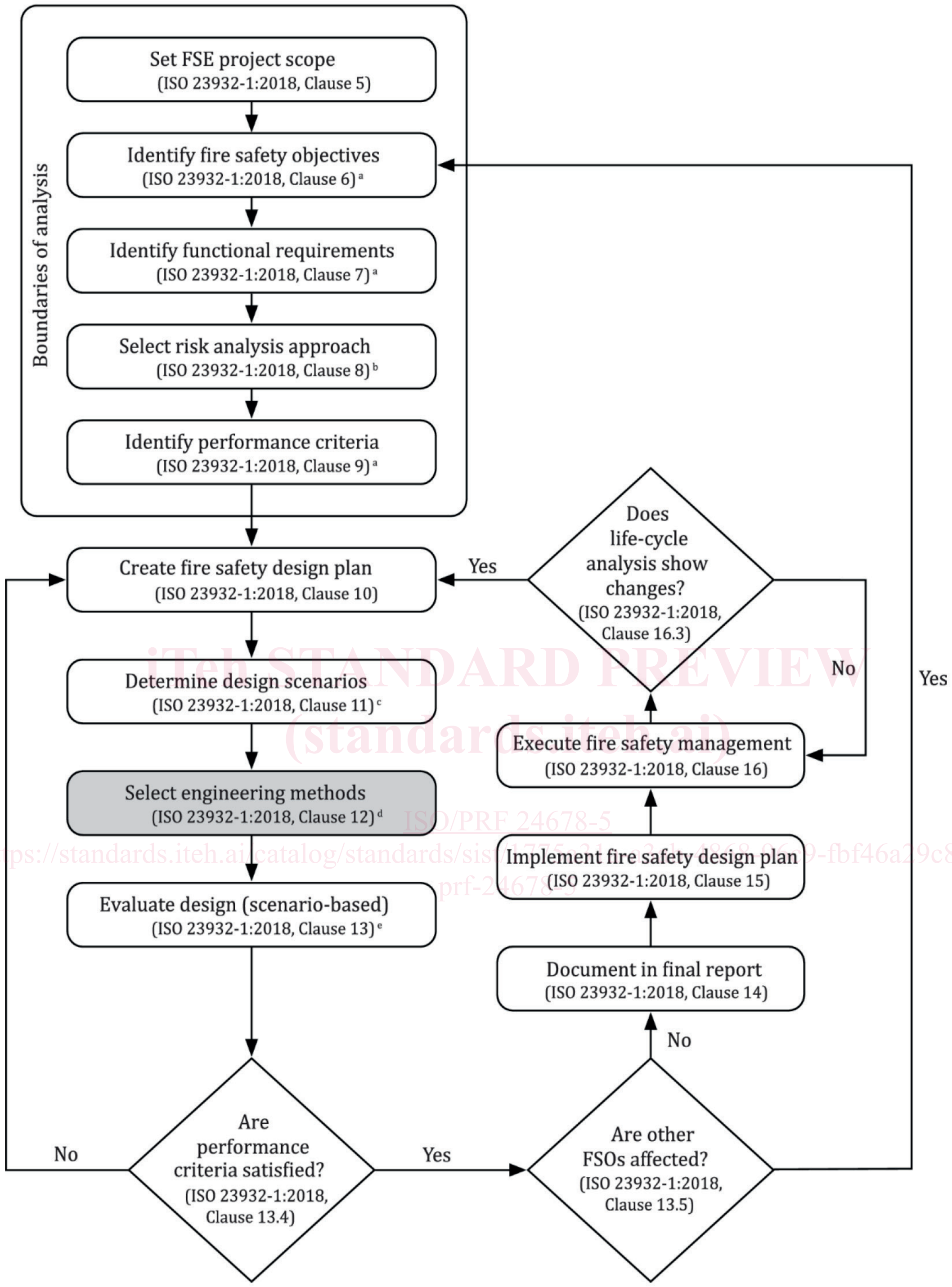
The subjects of engineering calculations include the fire safety design of entirely new built environments, such as buildings, ships or vehicles as well as the assessment of the fire safety of existing built environments.

The algebraic formulae discussed in this standard 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 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 fire scenarios.

The general principles 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 to conduct a robust performance-based fire safety design.

ISO 23932-1 is supported by a set of fire safety engineering International Standards and Technical Specifications 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, ISO 24678, ISO/TS 24679, 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 23932:2018, 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 5 (Examples), ISO 16735, ISO 16736, ISO 16737, ISO/TR 16738, ISO 24678.

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, ISO 24678, ISO/TS 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 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 5:
Vent flows

1 Scope

This document specifies the requirements governing the application of explicit algebraic formula sets to 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 13943:2017, *Fire safety — Vocabulary*

ISO 24678-1:2019, *Fire safety engineering — Requirements governing algebraic formulae — Part 1: General requirements*

3 Terms and Definitions

For the purpose of this document, the terms and definitions given in ISO 13943 and the following applies.

ISO and IEC maintain terminological 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
vent
an opening in an enclosure boundary through which air and smoke can flow as a result of naturally- or mechanically-induced forces

3.2
vent flows
the flows of smoke or air through a vent in an enclosure boundary

4 Requirements governing 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 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 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 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, with two-layered temperature profiles.

A.2 Terms and definitions used in this Annex

The terms and definitions defined in the main body apply in addition to the followings:

A.2.1
boundary
A surface that defines the extent of an enclosure

A.2.2
datum
the elevation used as the reference elevation for evaluation of hydrostatic pressure profiles

A.2.3
enclosure
a room, space or volume that is bounded by surfaces

A.2.4
flow coefficient
an empirical efficiency factor that accounts for the difference between the actual and the theoretical flow rate through a vent

A.2.5
hydrostatic pressure
the atmospheric pressure profile associated with height

A.2.6
neutral plane height
the elevation at which the pressure inside an enclosure is the same as the pressure outside the enclosure

A.2.7
pressure difference
the difference between the pressure inside an enclosure and outside the enclosure at a specified elevation

A.2.8
quasi-steady state
the assumption that the full effects of heat release rate changes at the fire source are felt everywhere in the flow field immediately

A.2.9
smoke
the airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass

A.2.10
smoke layer
the relatively homogeneous volume of smoke that forms and accumulates beneath the boundary having the highest elevation in an enclosure as a result of a fire, also referred to as the hot upper layer and the hot gas layer

A.2.11
Smoke layer height
the elevation of the smoke layer interface relative to a reference elevation, typically the lowest boundary of the enclosure. Also referred to as the interface position

A.3 Symbols and abbreviated terms used in this Annex

A_{eq}	equivalent area of muitiple seral vents (m)
A_{ij}	area of vent connecting enclosures i and j (m^2)
B_{eq}	equivalent width of muitiple 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
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)
$q_{m,ij}$	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_0 reference temperature, typicall the outside temperature (K)

T_i temperature of enclosure i (K)

$T_{\mathbf{a,i}}$ air layer temperature in enclosure i (K)

$T_{\mathbf{s,i}}$ smoke layer temperature in enclosure i (K)

u_{ij} flow velocity from enclosure i to enclosure j (m/s)

$w_{\mathbf{i}}$ mass fraction of chemical species in enclosure i (kg/kg)

$\rho_{a,i}$ gas density of air layer in enclosure i (kg/m)

ρ_i gas density of smoke (or air) in enclosure i (kg/m^3)

ρ_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)

ρ_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)

Δp_{flood} minimum pressure difference to cause uni-directional flow (Pa)

ζ height used as an integration variable (m)

A.4 Description of physical phenomena addressed by the formula set

A.4.1 General descriptions of calculation method

A.4.1.1 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[1].

A.4.1.2 Vent flow properties to be calculated

Formulae provide the mass, enthalpy and chemical species flow rates.

A.4.2 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 24687-4.[1] The calculation conditions are summarized in Figure A.1.

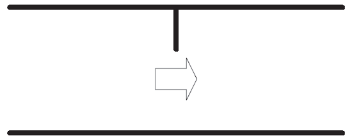
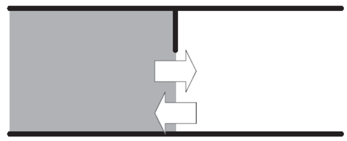
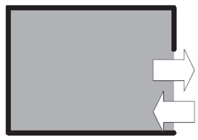
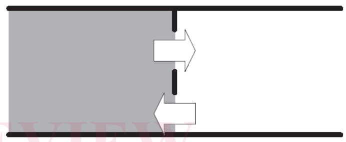
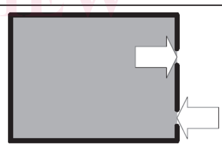
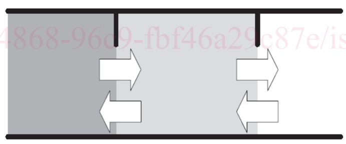
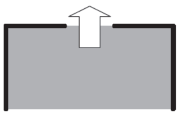
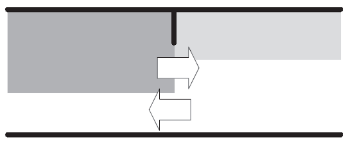
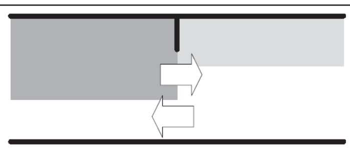
Temperature profile	Arrangement of vent(s)	flow patterns
Uniform	(a) Single vent	
Single layer	(b) Single vertical vent (general case, flow may be either uni-directional or bi-directional)	
	(c) Single vertical vent (special case, flow is bi-directional)	
	(d) Multiple vertical vents (general case, flow may be either uni-directional or bi-directional)	
	(e) Multiple vertical vents (special case of two small vertical 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 layered	(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)	

Figure A.1 — Summary of calculation conditions of vent flows

A.4.3 Self-consistency of the formula set

The set of formulae provided in this Annex have been derived and reviewed by many researhers (see clause A.6) to ensure that calculation results from different formulae in the set are consistent (i.e., do not produce conflicts).

A.4.4 Standards and other documents where the formula set is used

ISO 24678-4[1] uses vent flow formulae to calculate smoke layer properties.

A.5 Formula-set documentation of calculation process

A.5.1 General aspects of vent flow

A.5.1.1 Classifications of vent flows

The velocity of flow through a vent is calculated according to the orifice flow theory based on application of the Bernoulli's theory. Methods to calculate vent flows are developed for the conditions shown in Figure 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.

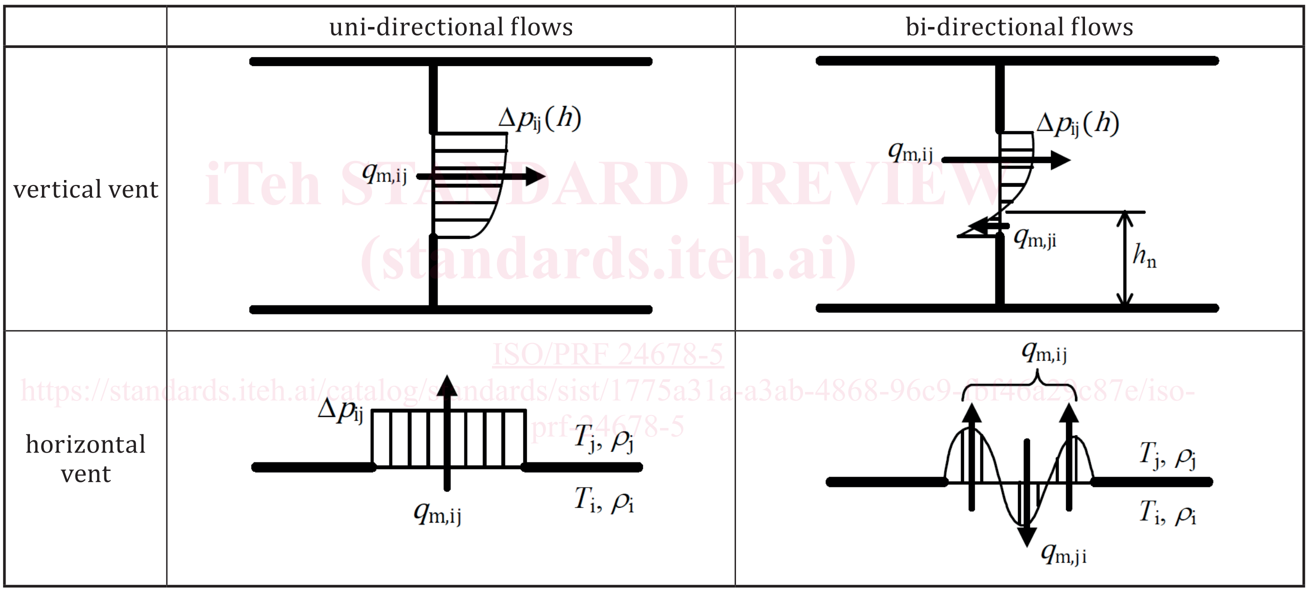


Figure A.2 — Classifications of vent flows

A.5.1.2 Orifice flow formula – uniform pressure difference over vent area

When uniform pressure difference is created by some actions such as mechanical fans, the mass flow rate through the vent is given by:

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

where

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

It is assumed that the pressure difference across the vent is uniform over the entire vent area as shown in Figure A.3.