BRITISH STANDARD

BS 7346-4:2003

Components for smoke and heat control systems —

Part 4: Functional recommendations and calculation methods for smoke and heat exhaust ventilation systems, employing steady-state design fires — Code of practice

ICS 13.220.20

British Standards

Committees responsible for this British Standard

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BRE/LPC Laboratories
British Blind and Shutter Association
Building Services Research and Information
Consumer Policy Committee of BSI
Fire Resistant Glass and Glazing Federation
HEVAC Association
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Contents

Foreword

This part of BS 7346 has been prepared by Technical Committee FSH/25. The other parts comprising BS 7346 are:

- — *Part 1: Specification for natural smoke and heat exhaust ventilators*;
- — *Part 2: Specification for powered smoke and heat exhaust ventilators*;
- — *Part 3: Specification for smoke curtains*.

The above three standards are eventually to be replaced by EN 12101, *Smoke and heat control systems*, consisting of the following parts:

- — *Part 1: Specification for smoke barriers — Recommendations, test methods*;
- — *Part 2: Specification for natural smoke and heat exhaust ventilators*;
- — *Part 3: Specification for powered smoke and heat exhaust ventilators*;
- — *Part 4: Smoke and heat control installations — Kits*;
- — *Part 6: Functional requirements and calculation methods, components, installation and testing procedures for pressure differential smoke control systems*;
- — *Part 7: Smoke control ducts*;
- — *Part 8: Smoke control dampers*;
- — *Part 9: Power supply equipment*;
- — *Part 10: Control equipment*.

EN 12101 forms part of a series of European Standards, which are planned to cover:

- — CO_2 systems (EN 12094);
- — sprinkler systems (EN 12259);
- — powder systems (BS EN 12416);
- — explosion protection systems (BS EN 26184);
- — foam systems (pr EN 13565);
- — hydrant and hose reel systems (BS EN 671);
- — semi-rigid hose systems (EN 694).

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Summary of pages

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0 Introduction

0.1 General introduction

Smoke and heat exhaust ventilation systems (SHEVS) create a smoke free layer above a floor by removing smoke. They can, therefore, improve conditions to allow the safe escape and/or rescue of people and animals, to protect property and to permit a fire to be fought while still in its early stages. Ventilation systems for smoke removal also serve simultaneously for heat exhaust and can exhaust hot gases released by a fire in the developing stage.

The use of such systems to create smoke free areas beneath a buoyant smoke layer has become widespread. Their value in assisting in the evacuation of people from buildings, reducing fire damage and financial loss by preventing smoke logging, facilitating fire-fighting, reducing roof temperatures and retarding the lateral spread of fire is firmly established. For these benefits to be realised it is crucial that smoke and heat exhaust ventilators operate fully and reliably whenever called upon to do so during their installed life.

Components for a SHEVS need be installed as part of a properly designed smoke and heat exhaust system. Natural SHEVS operate on the basis of the thermal buoyancy of the gases produced by a fire.

The performance of these installations depends, for example, on:

- the temperature of the smoke;
- the fire size;
- the aerodynamic free area of the ventilators, or the volume of smoke exhausted by powered ventilators;
- the wind influence;
- the size, geometry and location of the inlet air openings;
- the size, geometry and location of smoke reservoirs;
- the time of actuation;
- the arrangements and dimensions of the building.

Ideally the design fire upon which calculations are based shows the physical size and heat output of the fire changing with time in a realistic manner, allowing the growing threat to occupants, property and fire-fighters to be calculated as time progresses. Such time-based calculations of the time-to-danger usually have to be compared with separate assessments of the time recommended for safe evacuation of occupants of the building or of the time recommended for initiation of successful fire-fighting. These latter assessment procedures fall outside the scope of this British Standard, although it is anticipated to supplement this standard with design procedures for time-dependant fires in the future. In these calculations fire growth curves are selected that are appropriate to the precise circumstances of the building occupancies, fuel arrangements and sprinkler performance, where appropriate. Where such information is available, these calculations are conducted on a case-by-case basis using recommended fire safety engineering procedures. Even where such an approach is adopted, appropriate performance recommendations, e.g. minimum clear height, external influences, can be drawn from this British Standard.

NOTE BS 7974 describes the application of fire safety engineering principles to the design of buildings.

Where such time-based calculations are not feasible, it is possible to use a simpler procedure based on the largest size a fire is reasonably likely to reach in the circumstances. This time-independent or steady-state design is not to be confused with steady fires, which achieve full size instantly and then burn steadily. Rather the procedure assumes that a SHEVS that is able to cope with the largest fire can also cope with the (usually earlier) smaller stages of the fire.

In practice, it is much easier to assess the largest reasonably likely size of fire than to assess the growth rate of that fire.

0.2 Smoke exhaust ventilation design philosophies

0.2.1 *Protection of means of escape (life safety)*

A common approach to protect a means of escape is to achieve a smoke-free height beneath a thermally buoyant smoke layer below a ceiling. A SHEVS uses this principle to allow the continued use of escape routes that are in the same space as the fire, e.g. within enclosed shopping malls and many atria. The rate of smoke exhaust (using either natural smoke exhaust ventilators or powered smoke exhaust ventilators) is calculated to keep the smoke at a safe height above the heads of people using the escape routes, and to keep the radiated heat from the smoke layer at a low enough value to allow the escape routes to be used freely, even while the fire is still burning.

0.2.2 *Temperature control*

Where the height of clear air beneath the thermally buoyant smoke layer is not a critical design parameter, it is possible to use the calculation procedures in **0.2.1** in a different way. The rate of smoke exhaust can be designed to achieve (for a specified size of fire) a particular value for the temperature of the gases in the buoyant layer. This allows the use of materials that would otherwise be damaged by the hot gases. A typical example is where an atrium façade has glazing that is not fire-resisting, but which is known to be able to survive gas temperatures up to a specified value. The use of a temperature control SHEVS in such a case could, for example, allow the adoption of a phased evacuation strategy from higher storeys separated from the atrium only by such glazing.

0.2.3 *Assisting the fire-fighting operation*

In order for fire-fighters to deal successfully with a fire in a building, it is first necessary for them to drive their fire appliances to entrances that give them access to the interior of the building. They then need to transport themselves and their equipment from this point to the scene of the fire.

In extensive and multi-storey complex buildings this can be a long process and involve travel to upper or lower levels. Even in single-storey buildings the fire-fighters within the building need, amongst other things, an adequate supply of water at sufficient pressure to enable them to deal with the fire. The presence of heat and smoke can seriously hamper and delay fire-fighters' efforts to effect rescues and carry out fire-fighting operations. The provision of SHEVS to assist means of escape or to protect property aids fire-fighting. It is possible to design a SHEVS similar to that described in **0.2.1** to provide fire-fighters with a clear air region below the buoyant smoke layer, to make it easier and quicker for them to find and to fight the fire. Temperature control designs are of less benefit.

This document does not include any functional recommendations for key design parameters where the primary purpose of the SHEVS is to assist fire-fighting. Such functional recommendations need to be agreed by the fire service responsible for the building in question. However, the calculation procedures set out in the annexes of this document can be used to design the SHEVS to meet whatever recommendations have been agreed.

0.2.4 *Property protection*

Smoke exhaust ventilation cannot by itself prevent fires growing larger but it does guarantee that a fire in a ventilated space has a continuing supply of oxygen to keep growing.

It follows that smoke exhaust ventilation can only protect property by allowing active intervention by the fire services to be quicker and more effective. Property protection is therefore regarded as a special case of **0.2.3**. Depending on the materials present, a property protection design philosophy can be based on the need to maintain the hot buoyant smoke layer above sensitive materials (similar in principle to **0.2.1**), or the need to maintain the smoke layer below a critical temperature (similar to **0.2.2**). In either case, the functional recommendations for key parameters on which the design is based need not be the same as where the primary purpose is life safety and will depend on the circumstances applying in each case. These key functional recommendations need to be agreed with all relevant interested parties. The calculation procedures in the annexes of this standard can be used to design the SHEVS.

0.2.5 *Depressurization*

Where a smoke layer is very deep, and storeys adjacent to the layer are linked to it by small openings, e.g. door cracks or small ventilation grilles in walls, it can be possible to prevent the passage of smoke through the small openings by reducing the pressure of the gases in the smoke layer. This approach is known as depressurization, and in the form described is mainly used for atrium buildings. The primary purpose of the technique is to prevent the entry of smoke into the spaces adjacent to the atrium, and not to provide protection to the atrium itself. The most common name given to the technique is atrium depressurization.

The design of atrium depressurization places additional recommendations on the design of the SHEVS installed in the atrium. These recommendations are given in **6.11**.

0.3 Applications of smoke and heat exhaust ventilation

SHEVS can create and maintain a clear layer beneath the smoke to:

a) keep the escape and access routes free;

b) facilitate fire-fighting operations;

c) reduce the potential for flashover and thus full development of the fire;

d) protect equipment and furnishings;

e) reduce thermal effects on structural components during a fire;

f) reduce damage caused by thermal decomposition products and hot gases.

SHEVS are used in buildings where the particular (large) dimensions, shape or configuration make smoke control necessary.

Typical examples are:

— single and multi-storey shopping malls;
— large retail units;
— single and multi-storey industrial buildings and sprinklered warehouses;
— atria and complex buildings;
— enclosed car parks;
— stairways;
— tunnels;
— theatres.

The choice of either a powered or natural SHEVS depends on aspects of the building’s design and sitting in relation to its surroundings.

Special conditions apply where gaseous extinguishing systems, e.g. systems conforming to EN 12094 or BS ISO 14520, are used. Usually, gaseous extinguishing systems are not compatible with a SHEVS.

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1 Scope

This part of BS 7346 gives recommendations and guidance on functional and calculation methods for smoke and heat exhaust ventilation systems for steady-state design fires. It is intended for a variety of building types and applications, including single-storey buildings, mezzanine floors, warehouses with palletized or racked storage, shopping malls, atria and complex buildings, car parks, places of entertainment and public assembly and uncompartmented space within multi-storey buildings.

This standard does not include any functional recommendations for design parameters where the primary purpose of the SHEVS is to assist fire-fighting.

NOTE Such functional recommendations need to be agreed with the fire service responsible for the building in question. The calculation procedures set out in the annexes of this document can be used to design the SHEVS to meet whatever recommendations have been agreed.

This standard does not cover the following:

- smoke clearance, where smoke is exhausted from a building after the fire has been suppressed;
- cross-ventilation, where wind-induced or fan-induced air currents sweep smoke through and out of the building, usually as part of fire-fighting operational procedures;
- ventilation of stairwells, which usually represents a special application of smoke clearance and which does not necessarily protect the continued use of the stairwell;
- fully-involved fires.

2 Normative references

The following referenced documents are indispensable for the application 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.

BS 5306-2, *Fire extinguishing installations and equipment on premises — Part 2: Specification for sprinkler systems.*

BS 5588-4, *Fire precautions in the design, construction and use of buildings — Part 4: Code of practice for smoke control using pressure differentials.*

BS 5588-6, *Fire precautions in the design, construction and use of buildings — Part 6: Code of practice for places of assembly.*

BS 5588-7, *Fire precautions in the design, construction and use of buildings — Part 7: Code of practice for the incorporation of atria in buildings.*

BS 5588-10, *Fire precautions in the design, construction and use of buildings — Part 10: Code of practice for shopping complexes.*

BS 5588-11, *Fire precautions in the design, construction and use of buildings — Part 11: Code of practice for shops, offices, industrial, storage and other similar buildings.*

BS 5839-1, *Fire detection and alarm systems for buildings — Part 1: Code of practice for system design, installation and servicing.*

BS 7346-1, *Components for smoke and heat control systems — Part 1: Specification for natural smoke and heat exhaust ventilators.*

BS 7346-2, *Components for smoke and heat control systems — Part 2: Specification for powered smoke and heat exhaust ventilators.*

BS 7346-3, *Components for smoke and heat control systems — Part 3: Specification for smoke curtains.*

BS EN 12259-1, *Fixed fire-fighting systems — Components for sprinkler and water spray systems — Part 1: Sprinklers.*

DD ENV 1991-2-3, *Eurocode 1: Basis of design and actions on structures — Part 2.3: Actions on structures — Snow loads.*

DD ENV 1991-2-4, *Eurocode 1: Basis of design and actions on structures — Part 2.4: Actions on structures — Wind actions (together with United Kingdom National Application Document).*

ENV 1991-2-5, *Eurocode 1: Basis of design and actions on structures — Part 2.5: Actions on structures — Thermal actions.*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1.1
adhered plume
spill plume rising against a vertical surface and into which air entrains on one side, although there may be free ends

NOTE This is sometimes referred to as a single-sided plume.

3.1.2
aerodynamic free area
product of the geometric area and the coefficient of discharge

3.1.3
ambient
property of the surroundings

3.1.4
atrium
enclosed space, not necessarily vertically aligned, passing through two or more storeys in a building

NOTE Lift wells, escalator shafts, building services ducts and protected stairways are not classified as atria.

3.1.5
attendance time
time taken for the arrival of the fire services at a fire scene after receipt of the initial call at the fire brigade control room

3.1.6
authority
organization, officer or individual responsible for approving SHEVS and/or sprinkler systems, equipment and procedures

NOTE An authority might be a fire and building control authority, a fire insurer, or another appropriate public authority.

3.1.7
automatic activation
initiation of an operation without direct human intervention

3.1.8
backdraft
sudden deflagration caused by admitting fresh air into a room or compartment containing vitiated air, unburnt fuel gases and a source of ignition

3.1.9
ceiling jet
flow of smoke under a ceiling, extending outwards from the point of fire plume impingement on the ceiling

NOTE The temperature of a ceiling jet is usually greater than the adjacent smoke layer.

3.1.10
channelling screen
smoke barrier installed beneath a balcony or projecting canopy to direct the flow of smoke and hot gases from a room opening to the spill edge

3.1.11

coefficient of discharge

ratio of actual flow rate, measured under specified conditions, to the theoretical flow rate through the ventilator (C_v) or through an inlet opening (C_i)

NOTE 1 This is sometimes referred to as aerodynamic efficiency.

NOTE 2 BS 7346-1 defines the coefficient of discharge in terms of the theoretical flow rate through the ventilator only. The coefficient of discharge takes into account any obstructions in the ventilator, such as controls, louvres or vanes and the effect of external side-winds.

3.1.12

convective heat flux

total heat energy carried by the gases crossing a specified boundary per unit time

3.1.13

depressurization

control of smoke using pressure differentials whereby the air pressure in the fire zone or adjacent accommodation is reduced to below that in the protected space

3.1.14

design fire

hypothetical fire having characteristics that are sufficiently severe for it to serve as the basis of the design of a smoke and heat exhaust ventilation system

3.1.15

exhaust ventilator

device used to move gases out of a building

3.1.16

fire compartment

enclosed space, comprising one or more separate spaces, bounded by elements of construction having a specified fire resistance and intended to prevent the spread of fire (in either direction) for a given period of time

NOTE The term is not to be confused with room of origin or fire cell.

3.1.17

fire operational position

position or configuration of a component specified by the design of the system during a fire

3.1.18

flashover

rapid transition from a fuel-bed controlled fire to a state of total surface involvement of combustible materials in a fire within an enclosure

3.1.19

free plume

spill plume into which air can be freely entrained into both long sides of the plume

NOTE The plume can also have free ends. Free plumes are sometimes referred to as double-sided plumes.

3.1.20

free-hanging smoke barrier

smoke barrier fixed only along its top edge

3.1.21

fuel-bed controlled fire

fire in which the rate of combustion, heat output and fire growth are primarily dependent on the fuel being burned

3.1.22

fully-involved fire

fire in which all surfaces of the combustible materials are totally involved

NOTE This is also referred to as a fully-developed fire.

3.1.23
geometric area
area of the opening through a ventilator, measured in the plane defined by the surface of the building, where it contacts the structure of the ventilator

NOTE Geometric area is expressed as A_v. No reduction is made for controls, louvres or other obstructions.

3.1.24
heat flux
total heat energy crossing a specified boundary per unit time

3.1.25
heat release rate
calorific energy released by a material, product or assemblage of fuels during combustion under specified conditions per unit time

3.1.26
manual operation
initiation of the operation of a smoke and heat exhaust ventilation system by a human action

NOTE This initiation might be performed, for example, by pressing a button or pulling a handle. A sequence of automatic actions started by an initial human action is regarded as a manual operation for the purposes of this standard.

3.1.27
mass flux
total mass of gases crossing a specified boundary per unit time

3.1.28
mezzanine floor
intermediate floor level between any two storeys, or between the floor and roof of a building having a smaller area than the floor below

3.1.29
natural ventilation
ventilation caused by buoyancy forces resulting from differences in density between smoky and ambient air gases due to temperature differences

3.1.30
neutral pressure plane
height within a building where the internal air pressure is equal to the air pressure outside the building at the same height

3.1.31
powered ventilation
ventilation that is caused by the application of external energy to displace gases through a ventilator

NOTE Fans are usually used to produce powered ventilation.

3.1.32
pressure differential system
system of fans, ducts, vents and other features provided for the purpose of creating a lower pressure in a fire zone than in a protected space

3.1.33
quick response sprinkler
sprinkler that has a response time index of less than 50 $m^{\frac{1}{2}}s^{\frac{1}{2}}$ and therefore responds at an early stage of fire development

NOTE BS EN 12259-1 specifies requirements for the construction and performance of quick response sprinklers in fire-fighting systems.

3.1.34
replacement air
clean air entering a building, below the smoke layer, to replace smoky gases being removed by the smoke and heat exhaust ventilation system

NOTE This is sometimes referred to as inlet air.

3.1.35

safety management staff

staff designated for, and trained in, safety management procedures, who are familiar with the smoke control design philosophy, evacuation procedures and related matters

3.1.36

slot extract

physically extensive vent designed to prevent the passage of thermally buoyant smoky gases from one side of the vent to the other

NOTE This is sometimes referred to as slit extract or slit extraction. This could be, for example, a long intake grill in a ceiling, leading to a powered ventilator used to prevent any outflow of smoke from a shop into a mall.

3.1.37

smoke and heat control system

arrangement of components installed in a building to limit the effects of smoke and heat from a fire

3.1.38

smoke and heat exhaust system

smoke control system that exhausts smoke and heat from a fire in a building or part of a building

3.1.39

smoke and heat exhaust ventilation system

system in which components are jointly selected to exhaust smoke and heat in order to establish a buoyant layer of warm gases above cooler, cleaner air

NOTE 1 This is sometimes referred to as throughflow ventilation.

NOTE 2 For the purposes of this document, smoke and heat exhaust ventilation is abbreviated to SHEVS. SHEVS is used in both the singular and plural sense.

3.1.40

smoke and heat exhaust ventilator

device designed to move smoke and hot gases out of a building under conditions of fire

3.1.41

smoke barrier

device used to channel, contain and/or prevent the migration of smoke

NOTE Smoke barriers are also referred to as smoke curtains, smoke blinds or smoke screens.

3.1.42

smoke control damper

device that can be opened or closed to control the flow of smoke and hot gases

NOTE In the fire operational position, the smoke control damper can be open (to exhaust smoke from the fire compartment) or closed (to avoid smoke spreading to other zones).

3.1.43

smoke reservoir

region within a building limited or bordered by smoke barriers or structural elements in order to retain a thermally buoyant smoke layer in the event of a fire

3.1.44

spill edge

edge of a soffit beneath which a smoke layer is flowing, and adjacent to a void or the top edge of a window through which smoke is flowing out of a room

NOTE This is sometimes referred to as a rotation point. The soffit, for example, might be a balcony or canopy.

3.1.45

spill plume

vertically rising plume resulting from the rotation of an initially horizontally-flowing smoke layer around a spill edge

NOTE Where the spill plume is longer parallel to the spill edge than it is broad, i.e. in a horizontal direction at a right angle to the spill edge, the plume is also often known as a line plume or a two-dimensional plume.

3.1.46

stagnant region

region within or below a smoke reservoir where the gases do not move after the thermally buoyant smoke layer has been established

3.1.47

standard response sprinkler

sprinkler with a response time index of between 100 $m^{½}s^{½}$ and 200 $m^{½}s^{½}$

NOTE BS EN 12259-1 specifies requirements for the construction and performance of standard response sprinklers in fire-fighting systems.

3.1.48

steady-state design fire

design fire based on the largest fire with which a smoke and heat exhaust ventilation system is expected to cope

NOTE This type of design fire is usually assumed to be either square or circular.

3.1.49

stratification

formation of distinct layers of clear and smoky gases within the height of the space

3.1.50

temperature control system

smoke and heat exhaust ventilation system designed to cool a potentially hot smoke layer by the deliberate entrainment of ambient air into the rising plume

NOTE A temperature control system can enable the use of façade materials that cannot withstand high temperatures.

3.1.51

transfer duct

duct and associated fan that moves smoky gases from a potentially stagnant region of a smoke reservoir to another region of the same smoke reservoir from where those smoky gases are exhausted from the building

3.1.52

ventilator

device for moving gases into or out of a building

3.1.53

void edge screen

smoke barrier deployed beneath the edge of a balcony or projecting canopy

NOTE Void edge screens can either be used to create a smoke reservoir beneath the balcony or canopy, or to restrict the length of spill edge in order to create a more compact spill plume.

3.1.54

wind pressure coefficient

ratio of the wind-induced pressure rise at a specified location on the exterior of the building to the dynamic pressure due to the wind speed at the highest part of the building

3.2 Symbols and units

For the purposes of this British Standard, the following mathematical and physical quantities, represented by symbols and expressed in units, apply.

Symbol	Unit	Quantity
A_f	m^2	Plan area of fire
A_i	m^2	Total geometric free area of all air inlets
A_v	m^2	Geometric area of smoke exhaust ventilator, measured in square metres
A_vn	m^2	Geometric free area of the n'th individual ventilator
A_vtot	m^2	Total geometric free area of all smoke exhaust ventilators in one smoke reservoir
b_f	m	Length of wind-impacted façade of the building
$C_\mathrm{ci}A_\mathrm{ci}$	m^2	Aerodynamic free area of an individual opening through a suspended ceiling to a plenum chamber above
C_d	—	Effective coefficient of discharge for an opening in a room's wall
C_e	$\mathrm{kg\cdot m^{-5/2}\cdot s^{-1}}$	Entrainment coefficient for a large fire plume
$C_\mathrm{equivalent}$	—	Equivalent coefficient of discharge applied to the total geometric free area of natural smoke and heat exhaust ventilators exhausting smoke from a plenum above a suspended ceiling, to include the flow restrictive effects of the openings in the suspended ceiling as well as of the ventilators
C_i	—	Coefficient of discharge, i.e. coefficient of performance, of an opening supplying inlet air
C_pi	—	Wind pressure coefficient at the exterior of the dominant inlet
C_pl	—	Wind pressure coefficient at the topmost leeward storey of the building
C_pv	—	Wind pressure coefficient at the exterior of the ventilators
C_v	—	Coefficient of discharge, i.e. coefficient of performance, of a natural ventilator
C_vn	—	Coefficient of discharge of the n'th individual ventilator
c	$\mathrm{kJ\cdot kg^{-1}\cdot K^{-1}}$	Specific heat of air at constant pressure
D	m	Effective diameter of the fire
D_d	m	Depth of downstand above the opening in a room's wall, measured from the underside of any balcony or projecting canopy outside that opening; or the height of rise of the plume above the top edge of the opening
D_op	m	Width of a wind-induced overpressure zone surrounding an outstanding structure on a roof
D_st	m	Maximum horizontal dimension of an outstanding structure above the roof where smoke exhaust ventilators are fitted
D_su	m	Horizontal extent of a zone of wind-induced suction, i.e. negative wind pressure coefficients
D_v	m	Characteristic linear dimension of a smoke exhaust ventilator
D_w	m	Depth of flowing smoky gas layer in the opening in a room's wall
d_B	m	Depth of buoyant layer of smoky gases beneath a balcony or projecting canopy
d_c	m	Horizontal deflection away from the vertical of the bottom bar of a free-hanging smoke barrier
d_h	m	Length of smoke barrier measured downwards along the fabric
d_l	m	Depth of buoyant smoke layer in a smoke reservoir, measured from the ceiling to the visible base of the smoke layer

Symbol	**Unit**	**Quantity**
d_{ls}	m	Depth of smoke layer below the top edge of a free-hanging smoke barrier
d_{lv}	m	Depth of the buoyant smoke layer beneath the centre of the smoke and heat exhaust ventilator
d_n	m	Depth of buoyant smoke layer beneath the n'th individual ventilator or smoke intake
d_o	m	Depth of an opening connecting a storey and a deeper space such as an atrium
d_{slot}	m	Depth of a smoke layer beneath the top edge of an exhaust slot, facing the direction of flow
G_1	$kg\cdot m^2\cdot s^{-2}$	Turning moment per horizontal metre of smoke barrier deflecting that barrier away from the vertical due to buoyant pressure
G_2	$kg\cdot m^2\cdot s^{-2}$	Turning moment per horizontal metre of smoke barrier returning that barrier toward the vertical due to the weight of the bottom bar and of the fabric
g	$m\cdot s^{-2}$	Acceleration due to gravity
H	m	Height of ceiling above floor
h	m	Height of top of vertical opening in a room's wall above the floor
h_f	m	Height of fuel array measured from lowest part of the fuel to the highest
h_{st}	m	Height of an outstanding structure above the roof in which smoke exhaust ventilators are fitted
h_b	m	Height of building from ground to roof, assumed flat, or to top of a parapet if present
L	m	Horizontal separation between channelling screens measured along the (assumed straight) spill edge
L_i	m	Minimum length of a linear smoke exhaust intake needed to avoid plugholing
L_s	m	Length of an exhaust slot
M_B	$kg\cdot s^{-1}$	Mass flow rate of smoky gases flowing beneath a balcony or projecting canopy outside the opening from a fire-room
M_{crit}	$kg\cdot s^{-1}$	Maximum smoke exhaust rate possible through an individual ventilator without causing plugholing
M_f	$kg\cdot s^{-1}$	Mass flow rate of smoky gases rising through a specified height above the fire
M_l	$kg\cdot s^{-1}$	Mass flow rate of smoky gases entering the smoke reservoir's buoyant layer
M_n	$kg\cdot s^{-1}$	Mass exhaust rate through the n'th ventilator
M_s	$kg\cdot s^{-1}$	Mass flow rate exhausted from a layer by all other fans except the slot extract
M_{slot}	$kg\cdot s^{-1}$	Mass flow rate of a buoyant layer approaching a slot extract
$M_{slot\ exhaust}$	$kg\cdot s^{-1}$	Mass exhaust rate through a slot extract needed to prevent a buoyant layer of smoky gases flowing past the slot
M_w	$kg\cdot s^{-1}$	Mass flow rate of smoky gases passing through a vertical opening
M_X	$kg\cdot s^{-1}$	Total mass flow rate of smoky gases in a spill plume rising past height X
m	$kg\cdot m^{-1}$	Mass per metre length of bottom bar of a hanging smoke barrier
m_c	$kg\cdot m^{-2}$	Mass per square metre of fabric constituting a hanging smoke barrier
N	—	Minimum number of natural smoke exhaust ventilators or smoke intakes leading to powered smoke exhaust ventilators required for a smoke reservoir
P	m	Perimeter of fire, measured horizontally
Q_B	kW	Convective heat flux in the smoky gases beneath the balcony or projecting canopy
Q_f	kW	Convective heat flux in the smoky gases leaving the flames above the fire
Q_l	kW	Convective heat flux in the smoky gases in the smoke reservoir's buoyant layer

Symbol	**Unit**	**Quantity**
Q_w	kW	Convective heat flux in the smoky gases flowing through the opening in one or more walls of a fire-room
q_f	$kW \cdot m^{-2}$	Heat release rate per square metre from the fire
$q_{f,(low)}$	$kW \cdot m^{-2}$	Low value of q_f assumed as a default value
$q_{f,(high)}$	$kW \cdot m^{-2}$	High value of q_f assumed as a default value
T_{amb}	K	Absolute ambient temperature
T_B	K	Average absolute temperature of gases beneath a balcony or projecting canopy
T_l	K	Absolute average temperature in a smoke reservoir's buoyant layer
$t_{ambient}$	°C	Ambient air temperature
t_w	°C	Average temperature of buoyant layer at the opening in a room's wall
V_{ci}	$m^3 \cdot s^{-1}$	Volume flow rate of smoky gases through an individual opening in a suspended ceiling into a plenum chamber above
V_l	$m^3 \cdot s^{-1}$	Total volumetric exhaust rate from the smoke reservoir
v_{wind}	$m \cdot s^{-1}$	Wind speed at the same height as the top of the building assumed to be the maximum for design of an atrium depressurization system
W	m	Width of vertical opening in a room's wall
W_B	m	The distance between the opening from a fire-room and a transverse barrier (e.g. where the transverse barrier is a smoke barrier at the void edge, this is the breadth of the balcony)
W_l	m	The width of a smoke reservoir measured at a right angle to the direction of smoke flow
X	m	Effective height of rise of a spill plume above the spill edge, used when calculating the entrainment of air into the spill plume
Y	m	Height of clear air beneath the smoke reservoir's buoyant smoke layer, i.e. height from the base of the fire to the smoke layer
y	m	Height above the neutral pressure plane within a layer
Z	m^2	Height above the top of the burning fuel
z_0	m	Height of the virtual origin of the point-source plume measured above the top of the burning fuel
β	°	Angle of deflection of a hanging smoke barrier
γ	$kg \cdot K^{1/2} \cdot L^{-5/2}$	Downstand factor expressing the dependence of the mass flow rate and layer depth on the effects of a downstand at right angles to the direction of flow
Δd_B	m	Additional local deepening of a layer against a transverse barrier
Δd_h	m	Additional hanging length of a smoke barrier to provide a safety margin to allow for the bowing of that barrier
Δp_{ci}	Pa	Pressure difference across an individual opening in a suspended ceiling as gases flow through that opening
Δp_{fan}	Pa	Pressure drop produced by a powered smoke and heat exhaust ventilator at its intake
Δp_y	Pa	Buoyant pressure excess, at a height y above the neutral pressure plane, above the ambient atmospheric pressure at the same height
Θ_f	°C	Average smoky gas temperature, measured above ambient temperature, 1 m above the top of the burning fuel materials
θ_B	°C	Average temperature above ambient temperature of the gases in a buoyant smoke layer beneath a balcony or projecting canopy
θ_1	°C	Average temperature above ambient temperature of the gases in a buoyant smoke layer in a smoke reservoir
θ_w	°C	Average layer temperature above ambient temperature of gases flowing through the opening in a room's wall

Symbol	Unit	Quantity
ρ_{amb}	$\mathrm{kg \cdot m^{-3}}$	Density of air at ambient temperature
Ψ	m	Height from the base of the buoyant smoke layer to the neutral pressure plane within that layer, relative to the exterior of the building
Ω	—	Function defined by Equation (J.3)

4 General recommendations

4.1 Design objectives

4.1.1 *Commentary*

The flow of thermally buoyant smoky gases through a building depends on the properties of those gases, on the flow path, i.e. the internal shape of the building, on the external pressure field of the building, i.e. the external shape and the situation of the building, and heat losses from smoky gases. The external pressure field is dominated by the wind. It follows that if any smoke and heat exhaust ventilation system (SHEVS) is to meet the specified level of designed performance inside and outside the building, the design of that system needs to take account of the internal and external geometric features of the building that influence the flow of, and the entrainment of, air into the smoke plume, as well as external influences (wind), using the appropriate calculation procedures recommended in Clause ***5****, Clause* ***6*** *and Clause* ***7****.*

4.1.2 *Recommendations*

SHEVS should be designed in accordance with the following recommendations.

a) The purpose for which a SHEVS is designed should be clearly defined. The designer should indicate whether the SHEVS will serve as:

1) a means of protecting escape routes (keeping the escape and access routes free from smoke and radiant heat); or

2) a means of protecting of property (protecting equipment and furnishings by reducing the damage caused by thermal decomposition products, hot gases and heat radiation); or

3) a means of controlling the temperature of hot smoky gases affecting, for example, the building's structure, façades or glazing; or

4) a means of facilitating fire-fighting operations by creating a smoke-free layer; or

5) a combination of any of these.

Documentation indicating that the design philosophy and calculations meet one, or a combination, of the design objectives given in this subclause should be provided in accordance with **4.7.1**.

b) If an existing building with an existing SHEVS is altered structurally or if the usage of the building where the SHEVS is installed is changed, the designer should reassess the whole system, including any changes to the external environment using the documentation from previous designs (see **4.7.1**), where available.

c) Compatibility with other safety and/or building systems inside the same building should be incorporated into the design of the system (see Clause **7**).

d) A SHEVS should interact with other safety and/or building systems in accordance with Clause **7**.

4.2 Reliability

4.2.1 *Selection of components*

All selected components should conform to the reliability tests given in BS 7346-1, BS 7346-2 and BS 7346-3.

NOTE 1 It is anticipated that BS 7346-1, BS 7346-2 and BS7346 -3 will be replaced by EN 12101 at a future date.

NOTE 2 Further information and additional advice can be found in NFPA 92B [1] and BRE Report BR 368 [2].

4.2.2 *Activation of the SHEVS*

In order to meet the design objectives of **4.1**, the operation of the SHEVS should be in accordance with the following recommendations.

a) A SHEVS for the protection of Means of Escape (life safety) should be activated by smoke detection systems conforming to BS 5839-1. Provision should be made to ensure that activating the different components of the SHEVS cannot be overruled by manual control except in the case of **4.2.3**.

b) A SHEVS for property protection should be activated by a water flow device conforming to BS EN 12259-1 and BS 5306-2, operating at a pressure flow equivalent to that of the lowest flow through a single sprinkler, or by manual release or by both methods.

c) A SHEVS to facilitate fire-fighting operations should be activated by a fire detection system conforming to BS 5839-1, or by a water flow device operating at a pressure flow characteristic equivalent to that of the lowest flow through a single sprinkler conforming to BS 5306-2, or by manual release or by a combination of these methods.

4.2.3 *Manual activation of a SHEVS*

Where a SHEVS that is normally activated by a fire or smoke detection system is able to be overridden by a manual control, technical provisions, e.g. a code or special key, should be in place to ensure that this manual control can only be executed by authorized persons who are familiar with the SHEVS, e.g. safety management staff as described in **4.8.2** or the fire-fighting service.

If there is no automatic activation of the SHEVS, the manual control should only be accessible from outside the building or from a protected room inside the building that is remote from the compartment covered by the SHEVS.

4.2.4 *Power supply*

The SHEVS should be provided with at least two supplies of energy to effect the operation of the system, its protected elements, stand-by components and the installation. All associated items, e.g. initiating signal devices such as smoke detectors, should also be provided with at least two sources of energy.

NOTE 1 Electrical systems can be provided with automatic start stand-by generators or amperage monitored and charged batteries. Pneumatic systems can be provided with twin compressors and an air reservoir with sufficient capacity to operate the system and its components for at least three complete cycles once electrical power is removed from the compressors.

NOTE 2 Additional advice can be found in other sources, including BS 5588-11.

4.3 Combined use of natural and powered ventilators

Natural and powered ventilators should not be used together for exhaust in the same smoke reservoir or for inlet air supply in the same smoke reservoir.

A smoke and heat exhaust system should consist of:

a) a natural exhaust system with a natural replacement air supply system; or

b) a natural exhaust system with a powered replacement air supply system; or

c) a powered exhaust system with a natural replacement air supply system; or

d) a smoke and heat exhaust system relying on a powered exhaust system and a powered replacement air supply system (push and pull system).

Items b) and d) should not be designed unless a fully engineered and detailed description of the system is supplied showing how the system works under the design conditions.

4.4 Sequence of operation of devices comprising a single SHEVS

The sequence of activating devices comprising any single SHEVS should not adversely affect the successful operation of any of those devices. For example, fans should not operate before air inlets, if the pressure reduction produced by those fans prevents the opening of those inlets.

The complete SHEVS should achieve its designed performance level within 90 s of receipt of a command signal, where that initiation is automatic.

NOTE Ancillary items such as dampers and air inlets (including doors) should be fully in the fire operational condition in not more than 60 s.

4.5 Interactions between different smoke zones in a building

4.5.1 *Smoke zones forming separate fire compartments*

Either each zone should be provided with separate SHEVS, or where each smoke zone is separated from the others and forms a fire compartment, powered ventilation may be achieved by connecting some or all smoke zones by ducts, with one or more exhaust fan serving all such connected smoke zones.

The volume flow to be extracted should be calculated for the worst case of a possible design fire in the relevant connected compartments (see Clause **5** and Clause **6**).

The method of detecting a fire should be by a smoke detection system conforming to BS 5839-1, which should have a means of triggering smoke control dampers located in the duct leading to the exhaust fan (or fans) from the smoke zone. The smoke control dampers should be located in such positions as to maintain the integrity of the fire-resisting construction.

Each smoke zone should have its own replacement air supply.

4.5.2 *Separation of smoke zones by walls and/or smoke barriers within a larger fire compartment*

4.5.2.1 *Commentary*

*Where each smoke zone is separated from the others by walls and/or smoke barriers the powered SHEVS described in **4.5.1** can be applied or each smoke zone can be equipped with a separate SHEVS, which can either be natural or powered.*

Since the different smoke zones are separated only by walls and/or smoke barriers at certain boundaries, spillage of smoke from the fire-affected smoke zone into an adjacent smoke zone is possible, e.g. through gaps between smoke barriers. This stray smoke might not endanger the means of escape or seriously hinder fire-fighting activities in the adjacent smoke zones but it can trigger smoke detectors that are installed there. If the devices of a SHEVS in another smoke zone outside the fire-affected zone come into operation and adversely affect the function of the SHEVS in the smoke zone on fire this can result in its failure.

This also applies if a fire starts beneath a downstand or smoke barrier, because smoke will enter both zones. In this case it cannot be predicted in which of the neighbouring smoke zones the smoke detectors will respond first and whether the appropriate SHEVS will be activated.

NOTE This scenario can be avoided by preventing any possibility of a fire occurring beneath a downstand or smoke barrier, e.g. by designing this space as travelling path for pedestrians instead of for a fuel array.

4.5.2.2 *Recommendations*

The following recommendations apply where each smoke zone in a building is separated from the others by walls and/or smoke barriers.

a) If there is a shared replacement air supply for all smoke zones contained in the same fire compartment, the inlet openings and doors should be in accordance with **6.8**.

b) If natural smoke exhaust is used the ventilators in an adjacent smoke zone to the smoke zone containing the fire may be opened if activated by the response of smoke detectors in this zone due to stray smoke.

c) If powered smoke exhaust is applied and each smoke zone is equipped with its own SHEVS (including any ducts and exhaust fans), the fans for a smoke zone adjacent to the fire-affected zone may come into operation if activated by the response of smoke detectors in this zone due to stray smoke, provided that the power supply is sufficient for all simultaneously operating fans and that the air velocity across inlet openings is less than 5 $m \cdot s^{-1}$ (see **6.8.2.12**).

Otherwise once a SHEVS has come into operation in one smoke zone it should be ensured that no further actions affecting the function of the SHEVS are activated by response of smoke detectors in an adjacent smoke zone due to stray smoke, e.g. no additional fans start running.

d) If powered smoke exhaust is applied and neighbouring smoke zones are connected by ducts to one exhaust fan or a set of fans as described in **4.5.1** the smoke control dampers in an adjacent smoke zone to the fire-affected zone may be opened if activated by the response of smoke detectors in this zone due to stray smoke, provided that the volume flow exhausted is still sufficient for each single zone when calculated in accordance with **6.1** to **6.8** and if the air velocity across inlet openings is less than 5 $m \cdot s^{-1}$.

Otherwise once a SHEVS has come into operation in one smoke zone it should be ensured that the response of smoke detectors in an adjacent smoke zone due to stray smoke does not result in further actions affecting the function of the SHEVS, e.g. no additional smoke control dampers open.

4.6 Sprinkler protection

Sprinklers, where specified, should be in accordance with BS 5306-2.

4.7 Documentation

4.7.1 *General recommendations*

Documentation indicating that the design philosophy and calculation meet one, or a combination, of the design objectives given in **4.1.2**a) should be provided and made available for the owner of the building where the SHEVS is installed and/or for the user of the system.

This documentation should comprise all the information necessary for clear identification of the installed system, e.g. drawings, description, list of components, certification of installation act, test reports of components, details of calculations made.

Where an existing building with an existing SHEVS is altered structurally or if the usage of the building where the SHEVS is installed is changed, updated documentation should be provided and made available for the owner of the building where the SHEVS is installed and/or the user of the system [see **4.1.2**c)].

A full description of the control software for the SHEVS should be included in the documentation (see **7.6**).

4.7.2 *Computer-based zone models*

Where computer-based zone models are used to carry out the calculations recommended in this standard as part of the design process, all mathematical formulae used in those models, assumptions made, and values of input parameters should be explicitly included in the documentation made available to the owner of the building.

In addition, information concerning validation of the computer-based zone models used in design should be included in the documentation. Where such validation information exists in the publicly available literature, appropriate references should be cited.

4.7.3 *Other information*

The documentation should also include:

a) the arguments to support the reasoning behind the choice of area (*A*) and perimeter (*P*) for fuel arrays [see **6.1.2**f)];

b) evidence of the consideration of external influences as follows (see **6.7.2**):

  1) where design calculations explicitly include wind pressure forces and/or wind pressure coefficients, identification of all zones of overpressure and suction on the buildings surface;

  2) the locations of all exhaust ventilator outlets and replacement air openings in the building;

  3) the relative heights and position of any nearby structures or topography of ground taller than the exhaust location of the SHEVS' ventilators;

  4) assumptions and input parameters used in calculations of the external environment of the building;

  5) assumptions, test details and results of relevant wind tunnel tests;

  6) wind load, snow load, and low ambient temperature assessments for the ventilators;

  7) relative positions of the SHEVS' ventilator exhaust outlets and unprotected openings in neighbouring buildings, pedestrian areas and vehicle roadways in the neighbourhood of the building;

  NOTE This may be done by the provision of plan, elevation and section drawings complete with the relevant design information from 1) to 7) above.

c) information on the provisions for inlet air as follows (see **6.8.2**):

  1) full details of all the inlet air provisions, locations and their method of operation;

  2) the total volume of air to be provided (mechanical systems only);

  3) the calculated air flow speed at the inlets for this air;

d) evidence of the calculation used to show that the pressure difference induced by the ventilator exhausting from a plenum chamber, where this occurs, can overcome the pressure differences due to the flow impedances of the openings of the chamber (see **6.10.2.7**);

e) evidence used to show that a plenum chamber, where this occurs, as a whole is capable of surviving exposure to the predicted design smoke temperatures without any failure or that failure has no adverse effect on the operation of the SHEVS (see **6.10.2.8**);

f) evidence of all design considerations for atrium depressurization, where this has been proposed (see **6.11**);

g) information on the calculation method used to demonstrate the control of smoke where heating, ventilation and air-conditioning systems are installed (see **7.7.2.2**).

4.8 Installation, maintenance and safety

4.8.1 *Installation*

All selected components should be installed in accordance with BS 7346-1, BS 7346-2 and BS 7346-3.

NOTE 1 It is anticipated that BS 7346-1, BS 7346-2 and BS 7346-3 will be replaced by EN 12101 at a future date.

NOTE 2 Further information and additional advice can be found in NFPA 92B [1] and BRE Report BR 368 [2].

4.8.2 *Maintenance and safety*

SHEVS should be maintained and regularly tested in accordance with the requirements of BS 5588-6, BS 5588-7, BS 5588-10 and BS 5588-11.

NOTE 1 Further information and additional advice can be found in BRE Report BR 368 [2].

For SHEVS that serve as protection of a means of escape, a safety management system should be established and staff should be made familiar with the design philosophy in **4.1.2**a) and the function of the SHEVS. Safety management staff should be responsible for maintenance and testing of the SHEVS in accordance with BS 5588-6, BS 5588-7, BS 5588-10 and BS 5588-11.

NOTE 2 Further information and additional advice can be found in BRE Report BR 368 [2].

Inlet air devices should be maintained and tested as frequently as the ventilators. As part of the maintenance, staff should ensure that the inlet air devices are free of any obstacles.

NOTE 3 Further information and additional advice can be found in BS 5588-6, BS 5588-7, BS 5588-10 and BS 5588-11 and in BRE Report BR 368 [2].

5 Calculation procedures

5.1 General

5.1.1 *Commentary*

The flow of thermally buoyant gases away from a fire, through a building, into a smoke reservoir, and their exhaust from a building into the surrounding atmosphere, is influenced by many factors including the shape of the building at each part of the flow, and external factors such as wind pressures and snow loads.

To be successful, the design of a SHEVS needs to consider all such influences.

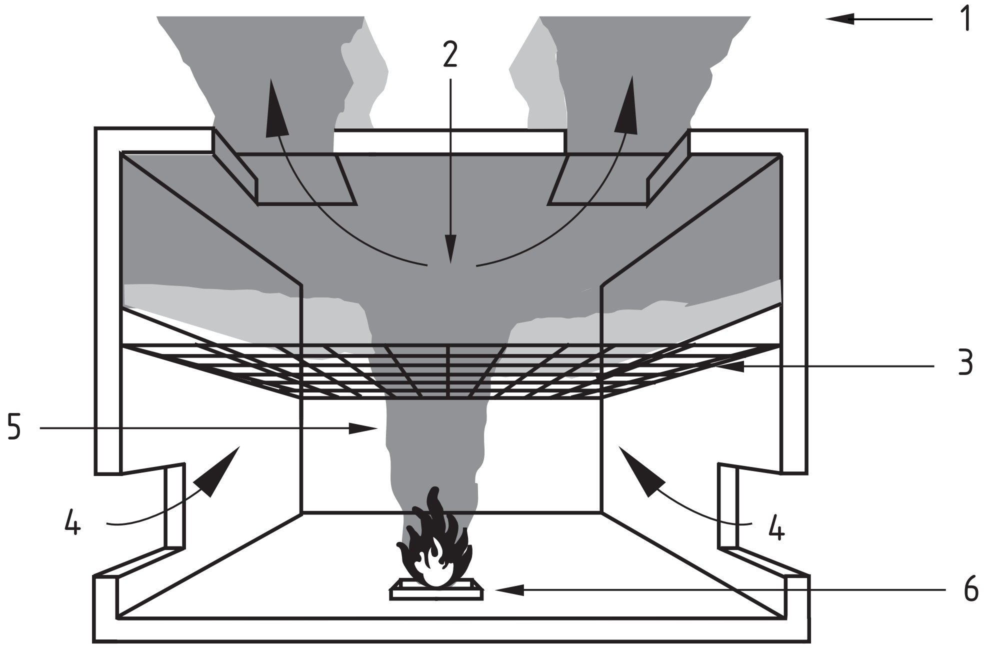
5.1.2 *Recommendation*

The design procedure should consider a succession of zones (also known as design regions), which correspond to successive stages in the path followed by the smoky gases, following the recommendations of **5.2**.

5.2 Design regions

5.2.1 *General*

For large single-volume spaces, i.e. where smoke rises directly from the burning fuel to the thermally buoyant layer in the smoke reservoir, the design regions in **5.2.2** to **5.2.8** should be taken into account in the design of the SHEVS. Figure 1 illustrates the design regions for a large single-volume space.



Key

1	Wind, snow etc.	See **6.7**
2	Smoke reservoir and exhaust	See **6.6**
3	Suspended ceiling	See **6.10**
4	Air inlets and doors	See **6.8**
5	Smoke plume	See **6.2**
6	Fire	See **6.1**

Figure 1 — Design regions for a single-volume space

5.2.2 *The fire*

The design of the SHEVS should be based on a steady-state fire of a size appropriate to the building concerned as well as the building use (see **6.1**).

5.2.3 *The plume above the fire, rising into the smoke reservoir*

The height to the smoke base should be specified for life-safety applications and the mass flow rate of smoky gases entering the reservoir should be calculated in accordance with **6.2**.

For temperature control designs, the temperature of the buoyant smoke layer should be specified. The mass flow rate entering the layer and the height of rise of the plume should be calculated in accordance with **6.2**.

5.2.4 *The smoke reservoir and ventilators*

The smoke reservoir should be of sufficient depth, the gases in it should be between acceptable high and low temperature limits, and the smoke exhaust should be calculated in accordance with **6.6**.

5.2.5 *External influences*

The effect of external influences, such as wind and snow, should be taken into account in the design in accordance with **6.7**.

5.2.6 *Air inlets (including any doors serving as air inlets)*

The design of air inlets should follow the recommendations given in **6.8**.

5.2.7 *Free-hanging smoke barriers*

Where present, the design of free-hanging smoke barriers should take into account the effects of buoyancy-induced deflection away from the vertical, and should follow the recommendations in **6.9**.

5.2.8 *Suspended ceilings*

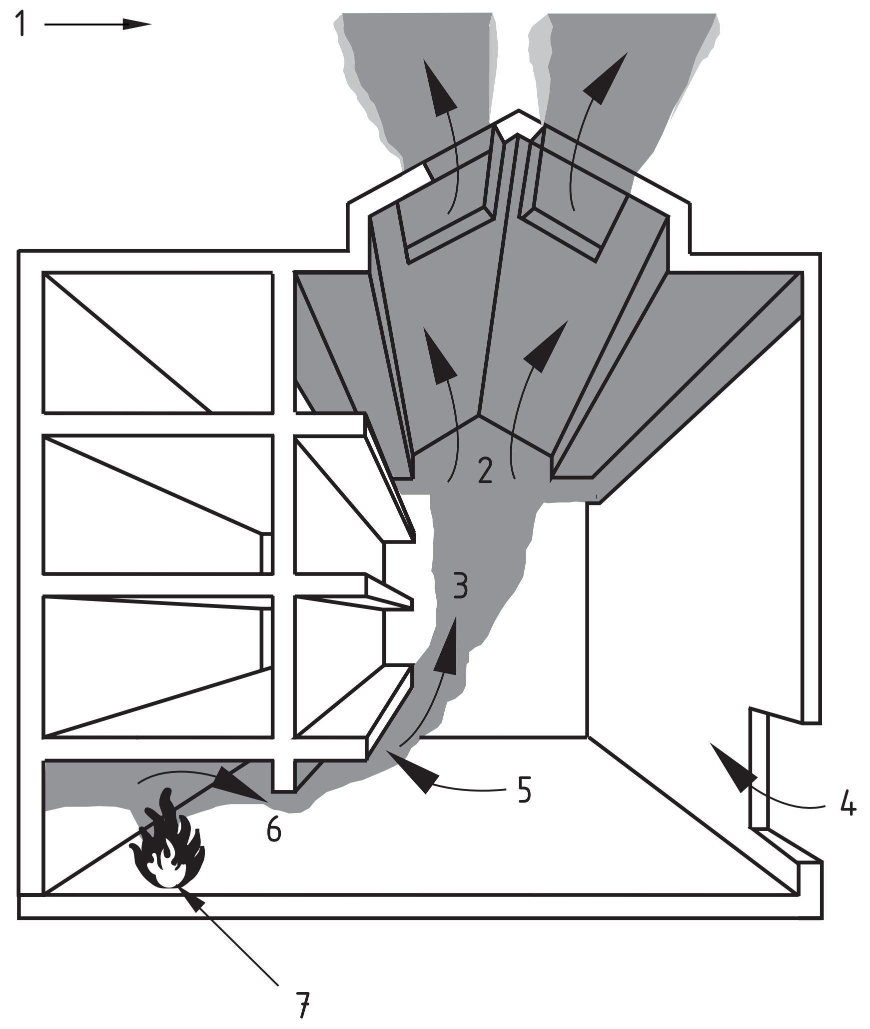
Since suspended ceilings, where present, can complicate the flow of smoky gases the design should take account of this following the recommendations in **6.10**.

5.3 Additional steps in the calculation

5.3.1 *Commentary*

In buildings where the initial plume above the fire is intercepted by a ceiling and the smoke travels laterally before spilling into a higher adjacent space, additional steps in the calculation of smoke movement and the entrainment of air into smoky gases given in ***5.3.2*** *to* ***5.3.6*** *need to be carried out. Figure 2 illustrates the design regions to be considered in this case.*

Examples of such buildings include multi-storey shopping malls, atria and buildings with mezzanine floors that are solid or have less than 25 % open area.



Key

1	Wind, snow etc.	See **6.7**
2	Smoke reservoir and exhaust	See **6.6**
3	Spill plume	See **6.5**
4	Air inlets and doors	See **6.8**
5	Flow under projection/canopy	See **6.4**
6	Flow out of room	See **6.3**
7	Fire	See **6.1**

Figure 2 — Design regions for a space where there is a spill plume

5.3.2 *The design fire*

The design fire should be based on a steady-state fire of a size appropriate to the building concerned following the recommendations in **6.1**.

5.3.3 *The plume above the fire*

The characteristics of the plume above the fire should be calculated in accordance with **6.2**. This may be combined with the flow of smoky gases leaving the fire-room into a single calculation in accordance with **6.3**.

NOTE Methods for preventing smoky gases flowing beyond the opening of the fire-room are also described in **6.3**.

5.3.4 *The canopy*

Where a canopy (or the underside of a balcony) projects beyond the fire-rooms opening, the effect on the smoke flow at the spill edge should be calculated in accordance with **6.4**.

If the smoke exhaust ventilation design requires smoke to be contained beneath the canopy or balcony, and prevented from spilling into the adjacent space, the recommendations of **6.4** should be followed, as appropriate.

5.3.5 *The spill plume*

The mixing of air into the spill plume should be calculated in accordance with **6.5**.

For life safety applications the height of the base of the buoyant layer of smoky gases above the highest escape route open to the same space as the fire should be specified (see **6.5**).

For temperature control systems the temperature of the gases in the smoke reservoir, i.e. in the smoke layer, should be specified and the mass flow entering the layer should be calculated in accordance with **6.5**.

NOTE The calculation procedures for the spill plume in **6.5** can be used to find the height to the smoke layer base.

Measures to prevent smoke affecting higher balconies should be in accordance with **6.5**.

5.3.6 *External influences*

Where the pressures in the smoke layer in an atrium are to be reduced below ambient pressure to prevent smoke moving into rooms adjacent to that atrium, the effects of wind pressure should be included in the design calculations in accordance with **6.11**.

5.4 Compatibility

Compatibility with safety and other systems in the same building should be ensured by following the recommendations of Clause **7**.

6 Performance recommendations

6.1 The fire as a basis for design

6.1.1 *Commentary*

The development of a fire depends on many factors, including:

- *the nature of the materials present;*
- *the quantity of materials present;*
- *the positions of materials relative to each other, e.g. stacked chairs or chairs set out for use;*
- *the position of materials relative to walls, ceilings, etc.;*
- *the availability of oxygen (although oxygen is always freely available when a SHEVS is in operation);*
- *the presence and effectiveness of fire suppression devices, e.g. sprinklers;*
- *whether fuel is shielded from the sprinkler sprays.*

Where available, the largest reasonably likely size of fire can be deduced from statistics of fires in the type of occupancy of interest, or from experiments on appropriately similar arrays of fuel. Otherwise the deduction can be based on common practice, or on the physical dimensions of isolated arrays of fuel materials, or on an assessment of the size a fire might have reached when fire-fighters begin to apply an extinguishing agent.

The heat release rate of the burning fuel needs to be ascertained (see Table 1 and Annex A). However, since virtually all fires are a combination of numerous different materials (rather than one individual element), the heat release rate becomes, of necessity, an average value. Even where the assessment is unscientific, it is important that an assessment of the key parameters (fire area and heat release rate) of the design fire is made.

It is important that all decisions concerning the choice and quantification of a design fire are agreed with the appropriate Regulatory Authority at an early stage in the design process.

6.1.2 *Recommendations*

The following recommendations should be taken into account in the design fire.

a) Possible locations of fire in the space to be ventilated by a SHEVS should be identified.

b) For retail areas of shops, for offices, car parks, and hotel bedrooms, default values of perimeter and heat release rates should be as given in Table 1. Where the fire-room is smaller than the value of A_f given in Table 1, it should be assumed that A_f is the area of the room, and q_f should be reduced proportionately.

c) For occupancies not listed in Table 1, the designer should identify the height of the fuel array in each fire location.

d) Speculative developments where sprinklers are a later option should be treated as unsprinklered when selecting a design fire.

e) A SHEVS based on steady-state design fires should be regarded as unsuitable for any unsprinklered fuel array taller than 4 m.

NOTE SHEVS alone, i.e. no sprinklers, are unlikely to protect a building containing high rack storage.

f) For fuel arrays not included in Table 1 and lower than 4 m, the designer should assess an area (A_f) and a perimeter (P) based on the physical extent of the fuel, or the largest reasonably likely size of fire when fire-fighters first apply an extinguishing agent, or the largest reasonably likely size of fire when the effects of sprinkler action are considered and should document this choice (see **4.7.3**). The designer should agree this choice with the appropriate regulatory authorities at an early stage in the design process.

g) Fuel arrays covered by f) do not, in the vast majority of fires, consist of only one material, but a wide range of different materials with different burning rates and heat outputs. For the purposes of design, the designer should complete calculations for both the high and low heat release rates for either the sprinklered or the unsprinklered condition as appropriate.

NOTE Annex A provides some example values of heat release rates that can be used in this calculation.

Provided that both parallel calculations lead to a successful design in terms of the criteria of this standard, the choice of SHEVS design should be based on the most onerous outcome of these calculations.

h) For piled or racked storage higher than 4 m where there are either ceiling-mounted sprinklers or in-rack-mounted sprinklers, the designer should assess the perimeter of fire accessible to the approaching air (P), and the average smoke temperature above ambient, Θ_f, 1 m above the top of the stored materials, as follows.

1) The value of P should be two complete boxes separation, or the distance from one vertical flue to the next but one flue, or the distance between neighbouring sprinkler heads mounted at the same height, whichever is the greater, when a partition within the fuel array prevents the fire burning through to the opposite face of the stack; or twice this when there is no such partition.

2) The value of Θ_f should be taken to be 150 °C.

NOTE An example method of calculating the value of convective heat flux 1 m above the stored materials is outlined in Annex B.

Table 1 — Default values of design fires

Occupancy	Fire area (A_f) m^2	Fire perimeter (P) m	Heat release rate per unit area (q_f) kW·m^{-2}
Retail areas			
Standard response sprinklers	10	12	625
Quick response sprinklers	5	9	625
No sprinklers	Entire room	Width of opening	1 200
Offices			
Standard response sprinklers	16	14	225
No sprinklers: fuel-bed controlled	47	24	255
No sprinklers[a]: full involvement in fire is predicted for fuel-bed controlled fire above (see **6.3**)	Entire room	Width of opening	255
Hotel bedroom			
Standard response sprinklers	2	6	250
No sprinklers	Entire room	Width of opening	100
Car park (a burning car)	10	12	400

NOTE For design purposes, the fire area of a SHEVS should not be confused with the area of operation of the sprinkler design, which is specified in BS 5306-2.

[a] Where a room is fully involved in fire, some of the heat produced can be generated in flames outside the room's opening. It is rare for the temperature of gases leaving the opening to exceed 1 000 °C.

6.2 Plumes rising directly from the fire into a smoke reservoir

6.2.1 *Commentary*

Selection of a design fire appropriate to the circumstances, as described in ***6.1****, results in the specification of a design heat release rate (q_f) (or a smoke layer temperature, Θ_f, above the racking for high-storage fires), a fire area in plan (A_f), and a fire perimeter (P). In most examples of design the fire is located at the floor.*

For designs intended to protect the use of escape routes open to the space containing the fire, a sufficient height of clear air beneath the smoke layer (Y) needs to be provided. For temperature control designs it is necessary to identify the appropriate smoke layer temperature. Designs intended to protect property might follow either procedure, as appropriate.

Single-storey malls are a special case since they have a geometry that allows smoke to flow beneath a shop ceiling, away from the initial plume, and into the mall before reaching a smoke reservoir. A correlation which assumes, for design purposes, that the fire can be treated as if it were located in the mall and that the plume entrains a larger amount of air than usual, might be used in these cases. However, this correlation ceases to be valid if the layer base in the mall is too far above the opening between shop and mall.

6.2.2 *Recommendations*

The following recommendations should be taken into account in the design.

a) The designer should identify circumstances where the lowest part of the fire could be higher than the floor.

b) No SHEVS should be designed with a height from floor to base of smoke layer less than one tenth of the height from floor to ceiling.

c) No SHEVS should be designed with a height from the base of fire (usually the floor) to the base of the smoke layer of more than nine tenths of the height from the base of fire to the ceiling.

d) The convective heat flux (Q_f) carried by the smoky gases entering the smoke reservoir should be taken to be 0.8 times the heat release rate ($q_f A_f$) identified for the design fire, unless the designer provides evidence to support the use of a different value.

e) For life safety designs where a clear height is recommended between escape routes and the smoke layer's base, the minimum values for this clear height (Y) should be as set out in Table 2.

f) Where the predicted layer temperature is less than 50 °C above ambient temperature, 0.5 m should be added to each minimum value of Y listed in Table 2.

g) Where it is not possible to achieve the minimum clear height (Y) recommended in Table 2 but it is still necessary to provide clear air above escape routes, e.g. for upgrades or refurbishments where safety is to be improved, each case should be considered individually and this should be agreed with the relevant authorities.

h) The example design procedures for single-storey malls in Annex B should not be applied to cases where the layer base in the mall is more than 2 m above the top of the opening between the shop on fire and the mall. Instead the designer should use the procedures for multi-storey malls (see **6.3**).

i) The height of rise of the smoke layer base in the smoke reservoir should provide at least 0.5 m clear height above the top of stacked goods where smoke control is provided for property protection reasons.

j) The designer should follow recommendations a) to i) and use their outcomes together with the selected design fire, to calculate the mass flow rate of smoky gases entering the smoke reservoir.

NOTE Some example calculation methods are given in Annex B.

Table 2 — Minimum clear height above escape routes

Type of building	Minimum height (Y)
Public buildings, e.g. single-storey malls, exhibition halls	3.0 m
Non-public building, e.g. offices, apartments, open hall type prisons	2.5 m
Car parks	2.5 m or 0.8 H, whichever is the smaller
NOTE See **6.2.2**f) and **6.5.2.3** for the increase in Y where smoke layers are cool.	

6.3 The flow of hot smoky gases out of a fire-room into an adjacent space

6.3.1 *Commentary*

Many buildings have rooms opening into a common space with a much higher ceiling, e.g. multi-storey shopping malls, single-storey shopping malls where the mall has a much higher ceiling than the shop's opening height, atria and buildings with mezzanine floors. In such buildings any fire on the floor of the larger space is described as if it were a simple single-storey space with a high ceiling.

*When the fire occurs in one of the rooms adjacent to the tall space further calculations are necessary. In such a room the selection process for the design fire remains unchanged. The plume immediately above the fire is as described in **6.2**, but the smoke layer formed under the ceiling of the room flows horizontally through the opening(s) to the larger space unless special measures are taken to prevent this.*

A physical barrier sealing the opening allows the room to have its own SHEVS, designed as for a simple single-volume space. Drop smoke barriers serve as barriers and can allow replacement air to enter feeding the SHEVS in the room. A slot extract design can be used instead of a physical barrier to prevent smoke from passing beyond the barriers.

If smoke is not to be exhausted directly from the fire-room, the designer needs to calculate the amount of smoke reaching the buoyant layer in the larger space by calculating the mass flow rate of smoke at each stage en route and at the room's opening. It is also necessary to identify whether the selected design fire is realistic for the circumstances. This can be checked by calculating the temperature of the gases beneath the ceiling of the fire-room or at its opening. If the temperature is too high, heat radiation in the room rapidly causes full involvement of all available fuel in the room, i.e. flashover. Post-flashover fires are not used in the design fire scenario for sprinklered buildings.

Experiments have shown that the heat lost from the smoky gases moving through a room into an adjacent space is often much greater than from the plume above the fire.

6.3.2 *Recommendations*

6.3.2.1 Using the selected design fire, the designer should calculate the mass flow rate of smoky gases passing from a representative example of each room into the adjacent space.

NOTE Some example methods are given in Annex C.

6.3.2.2 The value of convective heat flux at the opening used in calculations should be as shown in Table 3.

Table 3 — Convective heat flux at the room opening

Type of room	Convective heat flux Q_w (MW)
Sprinklered shops	5
Shops with fast response sprinklers	2.5
Sprinklered offices	1
Unsprinklered offices	6
Unsprinklered hotel bedroom	1

6.3.2.3 For all other unsprinklered types of occupancy, the default values for the convective heat flux at the opening should be taken as 0.5 times the heat release rate ($q_f A_f$) of the selected design fire, unless evidence can be provided by the designer to support the choice of a different value for the particular circumstances of the design.

6.3.2.4 For all other sprinklered types of occupancy, the convective heat flux at the opening should be taken as 0.25 times the heat release rate ($q_f A_f$) of the selected design fire, unless evidence can be provided by the designer to support the choice of a different value for the particular circumstances of the design.

6.3.2.5 The temperature of gases leaving the room should be calculated. If they are hotter than 550 °C, the design fire should be replaced by all fuel in the room being assumed to burn. In this case the recommendations in **6.3.2.2** should not be followed and it should be noted that this situation is not covered by the scope of this standard.

NOTE Some example methods of calculation are given in Annex C.

6.4 The flow of hot smoky gases under a canopy projecting beyond a fire-room's window or opening

6.4.1 *Commentary*

When the hot smoky gases leave the fire-room's opening and rise to meet the underside of a projecting balcony or canopy some entrainment of air into the flow takes place. If the top of the opening is at the same height as the underside of the balcony or canopy there is no entrainment because the smoky gases continue to flow horizontally. There are two main design options when smoky gases reach the projecting soffit. The gases can be allowed or channelled to flow to the spill edge to rise through the main space or they can be prevented from spilling into the void, creating a smoke reservoir under the projecting soffit.

Spillage can be prevented either by using smoke barriers lowered along the edge of the void, or by using a slot extract along the edge of the void.

6.4.2 *Recommendations*

6.4.2.1 If smoky gases are to be allowed to spill into the main void, the mass flow rate and convective heat flux at the spill edge should be calculated.

NOTE Some example calculation methods are given in Annex D.

6.4.2.2 Smoke barriers, also known as channelling screens, or other structural features should be mounted below the projecting soffit to produce a more compact spill plume. These barriers may be permanent or may move automatically into place when smoke is detected.

NOTE If the projecting soffit extends less than 1.5 m beyond the fire-room's opening no channelling screens are recommended.

6.4.2.3 Smoke barriers, or equivalent structural features, should be at least 0.1 m deeper than the calculated depth of flowing smoky gases beneath the spill edge, and should extend across the full breadth of the projecting soffit.

NOTE An example of this calculation method is given in **D.4**.

6.4.2.4 If smoky gases are to be prevented from spilling into the void, the mass flow rate and convective heat flux in the smoky layer beneath the projecting soffit should be calculated.

NOTE Some example calculation methods are given in Annex D.

6.4.2.5 Any smoke barriers mounted along the void edge should either be permanent or should automatically deploy into position when smoke is detected.

6.4.2.6 Any smoke barriers mounted along the void edge to prevent spillage should be deeper than the smoky gases against that barrier, even when the barrier is mounted at right angles to the flow of smoky gases rising from the fire-room's opening.

NOTE An example of this calculation method is given in **D.4**.

6.4.2.7 The size of a slot extract mounted along the void edge to prevent spillage should be calculated to be large enough to prevent smoky gases spilling.

NOTE An example calculation method is given in Annex D.

6.4.2.8 The clear height beneath the buoyant layer of smoky gases in a smoke reservoir formed beneath a projecting soffit should be in accordance with **6.2**, except for any local deepening of the layer where smoke issuing from the fire-room's opening deepens against a transverse barrier.

6.4.2.9 The design of the smoke exhaust and the smoke reservoir formed beneath the projecting soffit should follow the recommendations given in **6.6** for a smoke reservoir in a simple single-storey space.

6.5 The spill plume

6.5.1 *Commentary*

When the smoke and heat cannot, for various reasons, be confined and removed from the room of origin or associated balcony space, the use of throughflow or steady-state ventilation from the main space, e.g. an atrium, is usually considered.

The base of the base of the thermally-buoyant design smoke layer in such a system is usually at a height chosen for safety reasons or to avoid breaching the limits outlined. Once the height of this layer base is chosen for a lowest-level fire, it is necessary to establish the height above the top of the opening (or above the edge of the projecting canopy or balcony over the opening where relevant) where the fire is in an adjacent room.

*When the fire is on the floor of the atrium and is directly below the smoke layer that forms under the atrium ceiling, entrainment into the rising plume is different to entrainment into spill plumes. This situation is identical to the scenario discussed in **6.2**. In general, however, the worst condition to be catered for is a fire in an adjacent room on the lowest level, since this results in the most entrainment in the rising smoke plume and hence the largest quantity of smoky gas entering the buoyant layer.*

As the smoke flows beneath the spill edge into the main space it rotates upwards around the spill edge. Such plumes are often referred to as spill plumes, or as line plumes. The term line denotes that the base of the plume immediately following rotation is long and relatively narrow.

Line/spill plumes take one of two forms:

- *— adhered plumes, where the smoky gases project directly from a compartment opening, and the plume attaches to the vertical surface above the opening whilst rising upwards [see Figure 3a)];*

  NOTE This also occurs when there is a vertical surface immediately above any rotation point into the void. The surface of the plume in contact with the ambient atmosphere in the atrium causes additional air to be entrained into it. This type of plume is also known variously as a single-sided, attached or wall plume.

- *— free plumes, where the smoky gases project into space beyond a horizontal projection, e.g. a balcony, thus allowing the forming plume to rise upwards unhindered [see Figure 3b)].*

  NOTE This creates a large surface area for entrainment on both sides of the plume along its spill width, for which reason they are also known as double-sided plumes. There is also entrainment into the ends of the plumes (if end walls do not contain the plume).

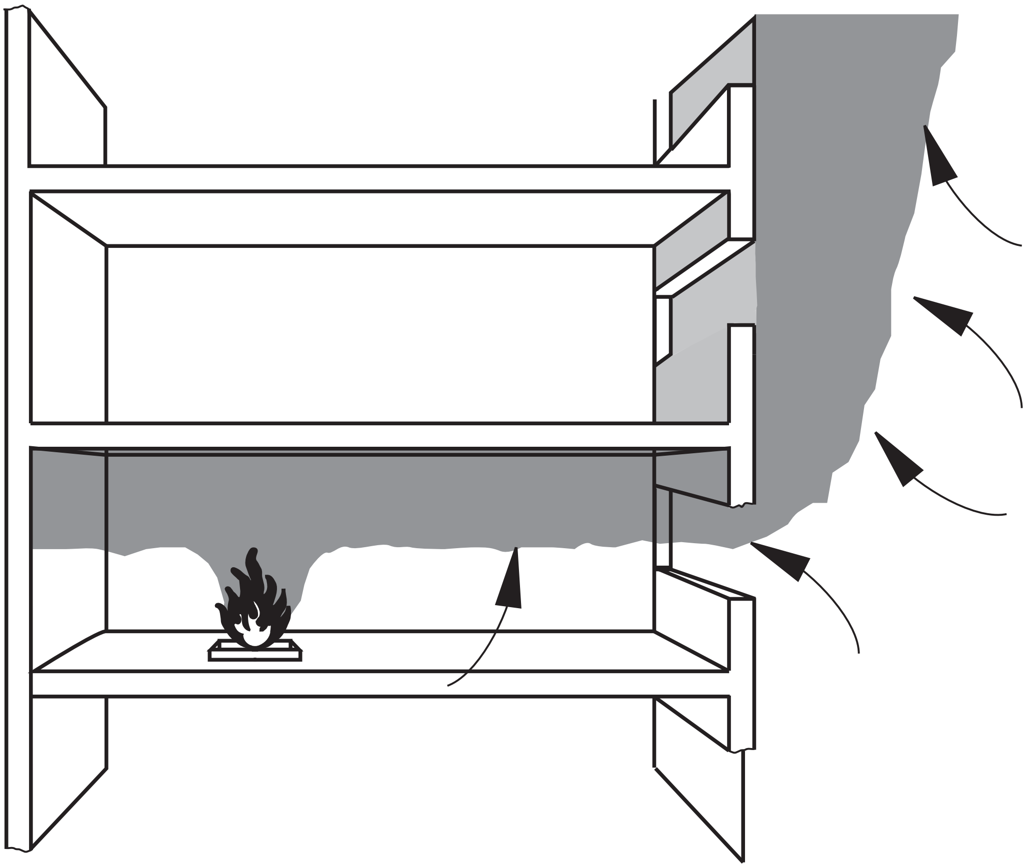


Figure 3a) — Adhered plume

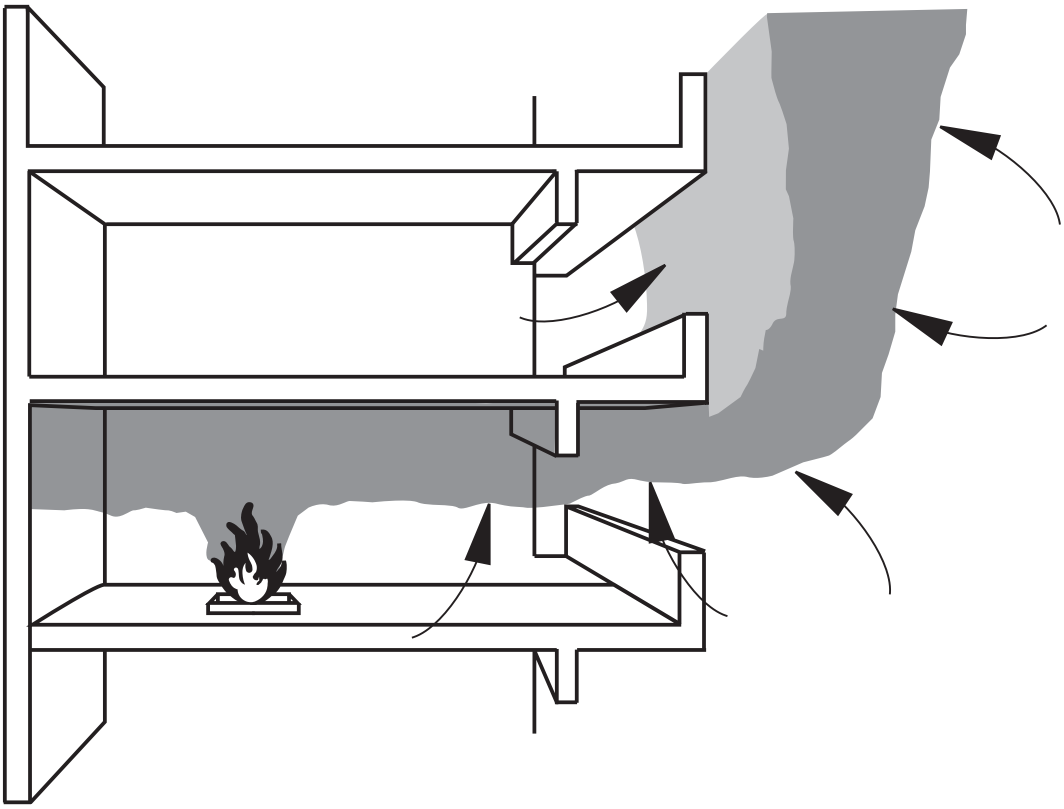


Figure 3b) — Free plume

The degree of entrainment into the rising plume, and hence the total quantity of gases entering the smoke layer forming under the ceiling of the atrium space, is governed by four parameters:

a) the mass flow rate or temperature of the gases at the edge of the rotation point into the atrium;

b) the heat flux of the gases;

c) the length of the line plume entering the atrium, measured along the edge past which the smoke spills;

d) the height through which the plume rises.

The mass flow rate of smoke entering the smoke layer can usually be reduced by changes to c) and d). The length of the line plume can be controlled with the use of channelling screens.

The height of rise of the spill plume needs to be chosen to allow a sufficient height of clear air above the highest escape route open to the space for people to use it freely. People and escape routes below the base of the buoyant layer formed in the smoke reservoir might still be put at risk on those balconies above and near the rising plume if the plume curls back to intercept the next higher soffit [see Figure 4a) and Figure 4b)]. This can be prevented if the balconies project far enough forward from the room openings (see ***6.5.2.5****).*

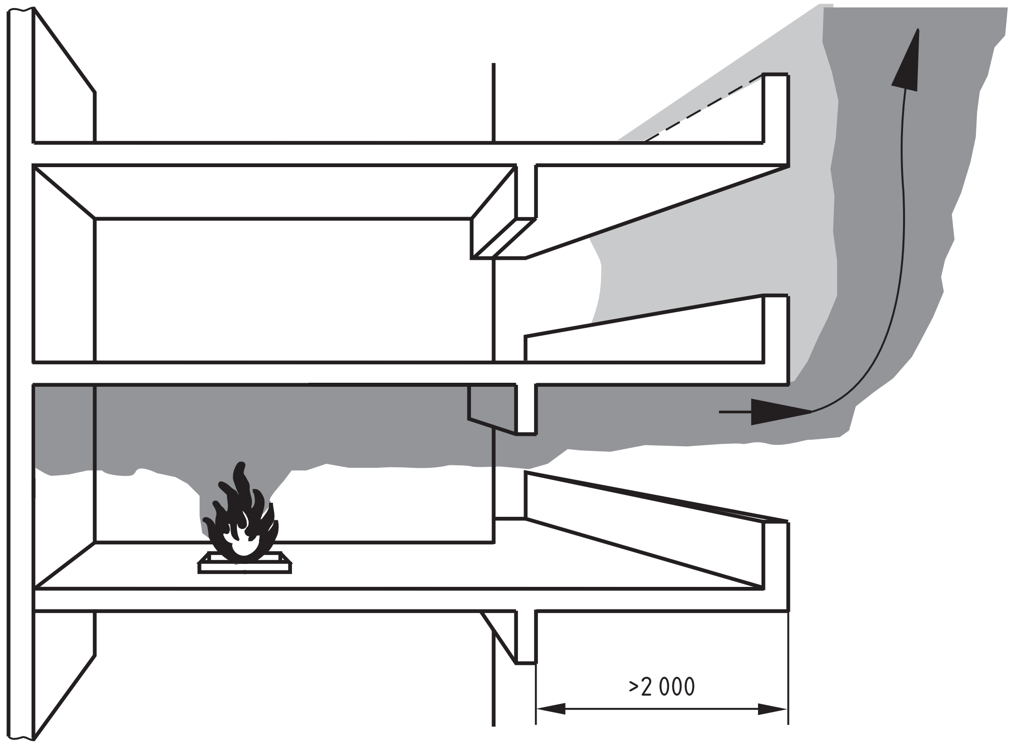


Figure 4a) — Deep balcony projection

Where property protection is the purpose of the design it is necessary to specify a height of rise for the spill plume that allows the layer base to be safely above any vulnerable property or goods. For temperature control systems, the height of rise of the spill plume is chosen to achieve the desired temperature in the smoke reservoir's buoyant layer.

6.5.2 ***Recommendations***

6.5.2.1 SHEVS should not be designed with a height from the spill edge to the base of the smoke layer of more than nine tenths of the height from the spill edge to the ceiling.

6.5.2.2 For life safety designs the clear height between the highest escape route and the smoke layer's base should not be less than the minimum values for Y shown in Table 2.

6.5.2.3 Where the predicted layer temperature is less than 50 °C above ambient temperature, 0.5 m should be added to each minimum value listed in Table 2.

6.5.2.4 Where it is not possible to achieve the minimum clear height specified in **6.5.2.2** or **6.5.2.3**, but it is still necessary to provide clear air above escape routes e.g. for upgrades or refurbishments where safety is to be improved, each case should be considered individually and this should be agreed with the regulatory authorities.

6.5.2.5 Where open balconies above a potential spill edge are to serve as escape routes, they should project more than 4.5 m forward of the façade or room openings.

6.5.2.6 The presence of a downstand at the spill edge should be explicitly allowed for in calculation of entrainment into the spill plume.

6.5.2.7 The mass flow rate of smoky gases entering the buoyant layer in the smoke reservoir should be calculated.

NOTE An example calculation method is given in Annex E.

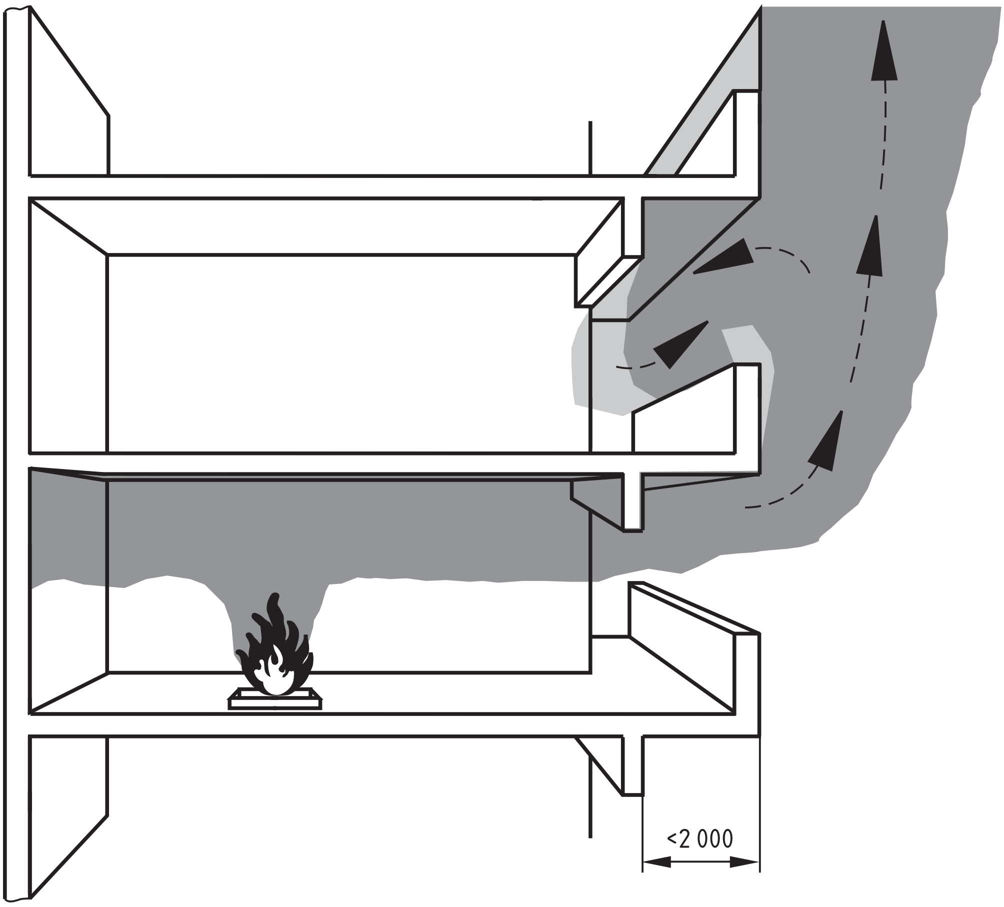


Figure 4b) — Shallow balcony projection

6.6 The smoke reservoir and ventilators

6.6.1 *Commentary*

*By following the recommendations in **6.2**, **6.3**, **6.4** and **6.5**, the mass flow rate and convective heat flow for the smoky gases reaching and entering the thermally buoyant layer in the smoke reservoir can be calculated. Ventilators exhaust an identical mass of smoky gases and this reservoir exhausts an identical mass to that which is entering it to maintain the layer base at a steady height (see **6.6.2**). This exhaust can be provided by either natural smoke exhaust ventilators or by powered smoke exhaust ventilators.*

It is necessary to provide a sufficient number of smoke extract locations, e.g. ventilators or fan intake grilles, to prevent the unintended waste of part of the exhaust capacity drawing air up through the buoyant layer.

If the reservoir is too large, loss of buoyancy due to cooling causes a gradual seepage of smoke downwards from the buoyant layer into the air beneath, impeding visibility and diminishing the effectiveness of smoke exhaust ventilation. If the reservoir is too long, there can be negative psychological effects on people moving through the clean air below the smoke. The potential cooling effect of sprinklers on the buoyant smoke layer needs to be allowed for in calculations dependent on the layer's temperature. If the buoyant layer is at a high enough temperature, it can cause flashover by heat radiation, or damage the building's structure or cause a painful heat irradience on people moving about below the buoyant layer. If the buoyant layer is at a low enough temperature, the layer can become unstable in the presence of air currents likely to be found in the building.

It is important that the buoyant layer is not, for physical reasons, designed to be shallower than the ceiling jet likely to be formed beneath the ceiling, or designed to be so deep that it is likely to destabilize and fill the space to the floor. It needs to be deep enough for smoky gases to flow away from where the plume enters the buoyant layer toward the exhaust ventilators.

6.6.2 *Recommendations*

6.6.2.1 The temperature of gases in the buoyant layer should be calculated.

NOTE An example calculation method is given in Annex F.

6.6.2.2 The design temperature of gases in the buoyant layer should not be so high as to cause ignition of materials beyond the size of fire assumed for design, i.e. the layer temperature should be less than 550 °C, unless it is accepted that the design fire includes all fuel materials beneath (and near) the smoke reservoir.

NOTE Smoke and heat ventilators do not cause any reduction in layer temperature if the fire covers the entire area beneath the reservoir. Consequently they do not on their own reduce the threat to the building's structure if the layer is at flame temperature.

6.6.2.3 The design temperature of gases in the buoyant layer should not be high enough to threaten the structural integrity of the building.

6.6.2.4 The design temperature of gases in the buoyant layer should not exceed 200 °C where escape routes pass below the smoke reservoir.

6.6.2.5 The design temperature of gases in the buoyant layer in the smoke reservoir should not be less than 20 °C above ambient air temperature.

6.6.2.6 The cooling effect of sprinklers on the gases in the smoke reservoir should be included in design calculations.

NOTE Some example calculation methods are given in Annex F.

6.6.2.7 Where the fire is directly below the smoke reservoir, the maximum area of any one reservoir should be 2 000 m^2 if natural smoke exhaust ventilators are fitted or 2 600 m^2 if powered smoke exhaust ventilators are fitted.

6.6.2.8 Where the fire is in a room adjacent to the space containing the reservoir, or is beneath a closed mezzanine in the same space (e.g. single and multi-storey shopping malls and atria) the maximum area of fire-room (or mezzanine) allowed to cause smoky gases to flow into the smoke reservoir should be 1 000 m^2 if natural smoke exhaust ventilators are fitted or 1 300 m^2 if powered smoke exhaust ventilators are fitted. The maximum area of the smoke reservoir should be 1 000 m^2 if natural smoke exhaust ventilators are fitted or 1 300 m^2 if powered smoke exhaust ventilators are fitted.

6.6.2.9 The maximum length of any smoke reservoir along any axis should be 60 m.

6.6.2.10 The buoyant layer in the smoke reservoir should not be designed to be less than one tenth of the floor-to-ceiling height for fires directly below the smoke reservoir, or less than one tenth of the height from spill edge to ceiling for spill plumes.

6.6.2.11 The buoyant layer in the smoke reservoir should not be designed to be deeper than nine tenths of the floor-to-ceiling height.

6.6.2.12 The depth of the buoyant layer in the smoke reservoir should be confirmed by calculation to be deep enough for smoky gases to flow from their location of entry into the layer towards the exhaust ventilators.

NOTE An example calculation method is given in Annex F.

6.6.2.13 Smoke barriers or other features forming part of the boundary of a smoke reservoir should be at least 0.1 m deeper than the calculated height of the base of the buoyant smoke layer, taking into account any deflection of the barrier (see **6.9**).

6.6.2.14 Any slot extract proposed to prevent the passage of smoky gases beyond the smoke reservoir boundary should be calculated to have sufficient exhaust capacity.

NOTE An example calculation method is given in Annex F.

6.6.2.15 The total capacity of powered smoke exhaust ventilators, or the total area of natural smoke exhaust ventilators, should be sufficient to exhaust the mass flow rate calculated to enter the layer from the smoke plume.

NOTE Some example calculation methods are given in Annex F.

6.6.2.16 The smoke exhaust ventilators should exhaust smoky gases without causing air to be drawn unintentionally through the buoyant smoke layer for the design condition.

NOTE Some example calculation methods are given in Annex F.

6.6.2.17 Natural and powered smoke exhaust ventilators should not be used simultaneously in the same smoke reservoir.

NOTE This does not include powered smoke transfer ducts.

6.6.2.18 No part of a smoke reservoir should extend more than three times beyond an exhaust ventilator intake, i.e. an extract point, than the reservoir is wide, unless a smoke transfer duct is fitted to recirculate smoky gases to a position close to an exhaust point. The capacity of the powered smoke transfer duct should be 1 $m^3 \cdot s^{-1}$ or 4 % of the mass flow rate of smoky gases entering the buoyant layer in the design condition, whichever is the greater.

6.6.2.19 Where an average layer depth is used for calculation, e.g. for minimum depth of flow in the reservoir, or in assessing the effective layer depth/effective height of rise of spill plume for large-area reservoirs, the depth of the reservoir should be taken to be that of a rectangular section smoke reservoir having the same width as the smoke layer's base and the same cross-sectional area as the actual reservoir.

NOTE This does not apply where calculations use the layer's depth below a ventilator.

6.7 External influences

6.7.1 *Commentary*

Since the SHEVS of a building is exposed to external influences such as wind, snow, ambient temperature, etc., these external influences need to be taken into account when designing the SHEVS.

Wind can cause pressure differentials across the openings of natural ventilators or inlet openings, which might adversely affect the function of these devices by producing an inverse flow direction through these openings when compared to the designed purpose. These pressure differentials also affect ventilators in their closed position and during operation in their fire safe position by inducing forces that might adversely affect the ventilators' function. It is therefore necessary to consider wind effects on ventilators regarding their stability against wind loads and regarding the aerodynamic performance in side wind conditions.

It is important that the specified wind load class is equal to or greater than the relevant wind load class, or the designed wind load determined from a wind tunnel study, or the wind load calculated according to DD ENV 1991-2-4, to ensure stability of the ventilator.

The aerodynamic efficiency determined according to EN 12101-2 is valid if the natural ventilators are situated in areas of the building envelope showing external suction under all wind directions.

NOTE At the time of drafting of this standard, EN 12101-2 was in preparation.

If natural ventilators are located for certain wind conditions in areas of external overpressure, the aerodynamic efficiency for those locations under adverse conditions needs to be determined in a wind tunnel study, which includes consideration of the wind pressure on the inlets and on other ventilators, of the neighbouring buildings, and of the properties of the atmospheric wind flow.

Snow loads and low ambient temperature can also increase the resistance that the opening forces of ventilators need to overcome. Recommendations for the construction and position of ventilators are outlined in ***6.7.2****.*

The hot smoky gases exhausted from the building by the SHEVS in most cases remain hazardous until they have been diluted with large amounts of air. It is therefore necessary for the designer to consider reducing potential hazards to the environment outside the building, as well as to other parts of the same building.

6.7.2 *Recommendations*

6.7.2.1 The design assumptions should be based on the shape of the building being equipped with the SHEVS, the location and shape of surrounding buildings, and on other features surrounding the building at the time the design is established.

6.7.2.2 The wind load class specified for natural ventilators used in a SHEVS should be equal to or greater than the relevant wind load class, or the wind load determined for each ventilators' designed position from a wind tunnel study, or the wind load calculated according to DD ENV 1991-2-4.

6.7.2.3 Any natural ventilator installed on a roof should be capable of being opened against a side-wind when tested according to BS 7346-1.

6.7.2.4 Any powered ventilator installed on a roof should be capable of being opened against an applied load of 200 Pa.

6.7.2.5 The snow load class specified for either natural or powered ventilators should correspond to a test snow load equal to or greater than the snow load appropriate to the building's locality determined according to DD ENV 1991-2-3.

6.7.2.6 The low ambient temperature class specified for a ventilator should correspond to a test temperature below zero which is lower than the extreme air temperature below zero for the building's locality determined according to ENV 1991-2-5.

6.7.2.7 If natural exhaust ventilators are mounted on upper roofs, the slope of which does not exceed 30 °, ventilators should be regarded as not being submitted to overpressure and the roof may be treated as though it were flat, unless provisions in **6.7.2.9** apply.

6.7.2.8 If the slope of the upper roof, where a natural exhaust ventilator is mounted exceeds 30 °, one of the following methods should be applied.

a) Wind shields that are not integral with the ventilator should be installed to produce underpressure above the natural exhaust ventilators for any wind direction, which are designed and justified by wind tunnel tests.

b) Natural exhaust ventilators should be installed in sufficient numbers and positions, to ensure that there is a large enough area of natural ventilation to satisfy the recommendations of **6.6** for all possible wind directions. These ventilators should be able to open or close automatically under the control of wind direction sensors or wind pressure measurements at the natural ventilators. It should be demonstrated by wind tunnel tests that the aerodynamic free area recommended in **6.6** is available for exhaust for any wind direction.

c) Powered exhaust ventilation should be used instead of natural exhaust.

6.7.2.9 If there are one or more taller structures near to a flat roof or slope less than or equal to 30 ° above the horizontal, wind induced zones of overpressure and underpressure caused by these structures should be taken into account and provisions against adverse effects on the functioning of ventilators should be made. For example, no natural smoke exhaust ventilator should be located within the horizontal distance D_{op} defined in Annex G.

6.7.2.10 The location of smoke exhaust outlets for smoke and heat exhaust ventilators should be selected to avoid the possibility of smoke affecting people or vehicles in the surrounding area, taking wind effects into account as far as is reasonably practical.

6.7.2.11 The distance between ventilators fitted to different fire compartments should be sufficient to avoid the threat of fire spread between compartments (see **6.8.2.16**).

6.7.2.12 Natural inlet ventilators and the building's openings for inlet air (also referred to as inlet openings) should not be provided in zones of suction unless supporting evidence is provided from wind tunnel tests or calculations to show that the SHEVS functions effectively for all wind speeds up to the design wind speed. Natural inlet ventilators should not be located in zones of severe suction.

NOTE 1 Some example methods to identify the location of such zones for simple geometry buildings are outlined in Annex G.

NOTE 2 Where air inlets are evenly distributed on more than one façade of the building, the air inlets may be deemed to be acceptable.

6.7.2.13 Documentation showing evidence of the consideration of external influences should be prepared in accordance with **4.7.3**.

6.8 Inlet air (replacement air)

6.8.1 *Commentary*

Any smoke and heat ventilation system needs to have provision for a sufficient supply of cold air entering the building to replace the amount of exhausted hot smoky gases.

This can be achieved by:

a) permanently open inlet openings;

b) automatically opening inlet openings, e.g. doors, windows, purpose-provided inlet ventilators;

c) smoke and heat exhaust natural ventilators in adjacent smoke reservoirs;

d) a combination of any of these; or

e) a powered inlet supply using fans (and ducting if specified).

It is important that the replacement air is always below the smoke layer when it comes into contact with the smoke and that the same opening is not used simultaneously as outlet and inlet.

It is important that the inlet air arrangements are sited to ensure as far as is practicable that the incoming air does not disturb any smoke layer within a smoke reservoir, so allowing the hot smoky gases to cool and descend or become more turbulent.

If necessary, the edge of the smoke reservoir might be located back from any inlet provided in any external wall to avoid wind induced turbulence.

NOTE In some buildings it might be necessary to set back the reservoir boundary barrier.

Powered inlets might require the provision of diffusers to prevent these effects occurring.

Since inlet openings and fans and ducting for powered replacement air supply are intended only to be exposed to cold air, there are no recommendations for temperature stresses in this standard.

6.8.2 *Recommendations*

6.8.2.1 Natural and powered ventilators should not both be used for inlet air in the same reservoir, neither should the inlet air arrangements make use of both powered and natural ventilators for the same system except in the circumstances outlined in **6.8.2.2**.

6.8.2.2 Where for design reasons it is desirable to use both natural and powered inlet supplies a fully engineered and detailed description of the system should be supplied showing how the system works under the design conditions.

6.8.2.3 The closures of inlet openings should be equipped with devices to open the closure automatically, e.g. by motor or spring, whenever the smoke and heat exhaust ventilation system comes into operation.

6.8.2.4 Each automatically opening air inlet opening should also be capable of being manually operated.

6.8.2.5 Where the automatic opening of doors is used to provide the inlet air this should not preclude the normal use of the doors or their manual operation.

6.8.2.6 The inlet vent arrangements and any power supply to operating systems and controls for the inlet air vents should meet integrity and reliability requirements equivalent to BS 7346-1 or BS 7346-2 for the exhaust ventilators.

6.8.2.7 All automatic means of providing inlet air for systems installed for life safety purposes should either be of fail safe function or, where provided by powered means be provided with alternative power supplies.

6.8.2.8 All arrangements for the provision of inlet air to systems installed for life safety purposes should be permanently available or be fully automatic so as to come into operation at the same time as the exhaust system. Such systems should be operated by smoke detection in accordance with BS 5839-1.

6.8.2.9 For systems provided for property protection only, the operation of inlet air arrangements should be initiated automatically by smoke or heat detection or by manual operation.

6.8.2.10 The aerodynamic free area of an inlet opening should be obtained by multiplying the geometric free area of the opening by the coefficient of discharge C_i. The coefficient of discharge C_i may be estimated to be 0.6 for doors and windows opened through an angle equal to or more than 60°. The validity of any value of C_i adopted for other, special, types of inlet opening should be demonstrated by appropriate documentation.

6.8.2.11 In the case of a system having powered exhaust ventilators or natural ventilators where the design allows high inlet air speeds, the designed air speed through any door or escape route through or along which persons need to travel should not exceed 5 $m \cdot s^{-1}$.

NOTE This maximum air speed of 5 $m \cdot s^{-1}$ is based upon studies of human behaviour by the Home Office.

6.8.2.12 Where fans are to be used to provide the inlet air, it should be demonstrated that the system can be effectively balanced under all conditions that the smoke and heat control system is designed to meet. The exhaust should always achieve the design flow rates, the air speed through any exit door should never exceed 5 $m \cdot s^{-1}$ and any force to be exerted at the handle of any exit door in order to open that door, should never exceed 100 N.

6.8.2.13 To avoid the incoming air disturbing the smoke layer or pulling down smoke from the layer (Venturi effect) the upper edge of an inlet opening should be 1 m or more below the smoke layer base or the inlet air speed beneath the layer should be less than 1 $\mathrm{m \cdot s^{-1}}$.

6.8.2.14 If the distances or inlet air speeds recommended in **6.8.2.13** cannot be followed, e.g. at doors, smoke barriers or other means should be installed defining the end of the reservoir at least 3 m back from air inlets, giving the inflow an increased cross-section and drop-in velocity. If the layer base is designed to be at least 2 m above the top of the air inlets it is not necessary to set back the reservoir screen.

6.8.2.15 Systems designed to use the exhaust ventilators in other smoke reservoirs to provide the inlet air should be designed so that the incoming air of the adjacent smoke reservoir is not contaminated by smoke from the reservoir from which smoke and heat is being vented. The minimum separation should be 5 m between an extract outlet and a ventilator being used as inlet when there is a reservoir boundary between them.

6.8.2.16 To avoid any stagnant region in the cold clearer air beneath the smoke layer, which would suffer from a steady accumulation of smoke, the number and location of air inlets should be chosen to ensure that flows of cold air flush through all areas of the smoke compartment below the ceiling reservoir so that any smoke wisps that enter the lower clearer air are swept back into the main body of the hot smoke. This choice should take into account the fact that not only the fire itself, but also any site of the moving smoke plume where air entrainment occurs, act as air pumps sucking air into the plume and therefore accelerate the surrounding cooler air towards the plume.

6.8.2.17 Documentation showing evidence of the consideration of inlet air should be prepared in accordance with **4.7.3**.

6.9 Free-hanging smoke barriers

6.9.1 *Commentary*

Smoke barriers can be either fixed or movable. Most movable barriers are designed to deploy vertically downwards on receipt of an appropriate signal and are generally referred to as drop barriers. This category can be further subdivided into guided barriers (where the barrier or its bottom bar move in vertical channels) or free-hanging barriers. Free-hanging barriers are in widespread use, but are subject to being deflected sideways by the buoyant pressures developed in a hot smoke layer.

Any barrier of a fixed length suspended from its upper edge rotates (and bows) away from the smoke layer. The bottom bar consequently deflects both sideways and upwards. It follows that the amount of fabric in the barrier, i.e. its depth when hanging in the absence of smoke, needs to be such that the barrier can fulfil its role in containing the smoke layer even when deflected. Estimating the depth of barrier, and the weight needed of the barriers' bottom bar to reduce the deflection, becomes part of the design of an SHEVS since these parameters can vary with the depth and temperature of the smoke layer.

If the smoke barrier is not mounted at a right angle to a fixed vertical plane surface, the deflection of the barrier's bottom bar tends to change the size of the edge gap as it moves. If the deflection is such as to reduce the size of the edge gap this actually reduces smoke leakage past the smoke barrier. If the deflection is such as to make the gap wider, however, the smoke leaking past the smoke barrier increases. Where applicable, it is necessary to show by separate and fully documented fire engineering calculations specific to the circumstances that the leakage will not create hazardous conditions.

6.9.2 *Recommendations*

6.9.2.1 It should be demonstrated by calculation that the depth and bottom-bar weight of a free-hanging smoke barrier is sufficient to follow the recommendation of **6.6.2.13**. The barrier in its deflected position should be at least 0.1 m deeper than the design layer base.

NOTE An example calculation method is given in Annex H.

6.9.2.2 Care should be taken to ensure that the smoke barriers are positioned in the construction works in such a way as to minimize problems caused by deflection, e.g. barriers placed between curved columns may follow this recommendation in the passive condition but when subjected to deflecting conditions can move away from the columns creating large gaps and unacceptable smoke leakage.

6.9.2.3 Free-hanging smoke barriers designed to close off openings between a smoke reservoir and adjacent storeys, e.g. open storeys adjacent to an atrium, and by dropping from top to bottom of that opening, should remain in contact with the bottom of the opening, e.g. the floor, in addition to following the recommendation in **6.9.2.2** when in the deflected position.

NOTE An example calculation method is given in Annex H.

6.9.2.4 Fully documented calculations specific to the circumstances should be provided for each smoke barrier capable of deflecting in a direction which will increase the size of its edge gap/s where the barrier meets a side wall or another smoke barrier, in order to demonstrate that the resulting smoke leakage will not create hazardous conditions.

6.10 Suspended ceilings

6.10.1 *Commentary*

Many smoke reservoirs occur where there is a suspended ceiling below the structural soffit. These suspended ceilings might be closed (apart from leakage cracks) or might have a greater or lesser proportion of free area. Where a suspended ceiling has a large proportion of free area it does not significantly disturb the movement of smoky gases and its presence can be ignored for design purposes. Smaller proportions of free area can allow the space above the ceiling to be used as a smoke exhaust plenum.

6.10.2 *Recommendations*

6.10.2.1 Closed suspended ceilings should be treated as the top of the smoke layer, e.g. in the fire-room, under a balcony, in the smoke reservoir. Provided that there is evidence that the suspended ceiling would not break down upon being exposed to hot gases at the predicted design temperatures, channelling screens and smoke barriers need not be continued above those closed suspended ceilings.

6.10.2.2 Partially open suspended ceilings with more than 25 % of evenly-distributed geometrical free area should not be taken into account when considering smoke movement.

6.10.2.3 Channelling screens and smoke barriers should be continued above the suspended ceiling to the structural soffit except for closed suspended ceilings where the recommendation in **6.10.2.1** applies.

6.10.2.4 The space above a partially-open suspended ceiling having less than 25 % of geometrical free area should be treated as a plenum chamber.

NOTE Further information on plenum chambers is given in Annex I.

6.10.2.5 Where the space above the suspended ceiling serves as a plenum chamber, all design calculations for smoke below the suspended ceiling should treat the suspended ceiling as the top of the buoyant smoke layer.

6.10.2.6 For design purposes, the combination of plenum chamber and natural ventilator should be considered as a single plenum chamber ventilator. This ventilator should meet the design exhaust rates for mass- and volume-flow of smoky gases calculated according to **6.6** with the smoke layer depth being measured from the top of the chamber downwards to the layer base. An example is given in Annex I. If the plenum chamber is extended by means of a duct, the smoke layer depth should be measured from the centre point of the final exhaust opening downwards to the layer base. The added resistance of the duct can be calculated using common heating, ventilation, air-conditioning (HVAC) procedures and this should be applied to reduce the natural ventilator coefficient of discharge.

6.10.2.7 The design should ensure that the pressure difference induced by the ventilator exhausting from the plenum chamber can overcome the pressure differences due to the flow impedances of the openings of the chamber (see also Annex I) using common HVAC calculation methods. This should be documented in accordance with **4.7.3**.

NOTE Further information on plenum chambers is given in Annex I.

6.10.2.8 The design should ensure that the plenum chamber as a whole is capable of surviving exposure to the predicted design smoke temperatures without any failure or that failure has no adverse effect on the operation of the SHEVS. This should be documented in accordance with **4.7.3**.

6.11 Atrium depressurization

6.11.1 *Commentary*

Greater architectural freedom becomes possible if the atrium façade does not need to be sealed, but can be allowed to be leaky, even if the upper atrium is filled with smoke. Examples of such leaky façade designs include:

a) hotel bedrooms having doors on to decorative balconies, i.e. not access or escape routes, overlooking the atrium, small enough to be evacuated through the doors in a few seconds;

b) where unsealed windows are used;

c) where small ventilation openings allow air to circulate between the accommodation spaces and the atrium and there are no escape routes open to the upper atrium.

If these doors and other leakage paths do not have tight seals, smoke from the atrium can enter many adjacent rooms on many levels, causing a loss of visibility in those rooms and possibly affecting escape routes away from the atrium. This might happen simultaneously on many floors.

Hence it is important to prevent smoke from passing in appreciable quantities through these small leakage openings. One way of achieving this is to depressurize the atrium.

NOTE 1 The principles involved in atrium depressurization are explained in more detail in Annex J.

Depressurization does not, however, protect any large leakage openings on any storey above the layer base in the atrium, nor does it protect any escape routes on that storey open to the atrium.

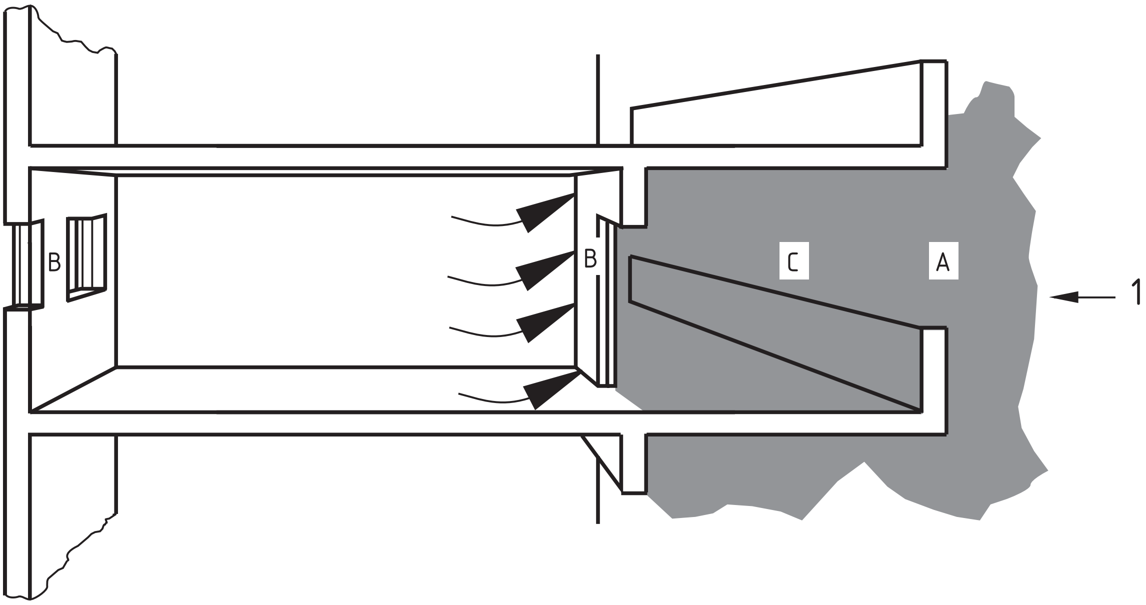
However, it is often the case that architects want to maximize use of the atrium space. One way of achieving this is to allow greater freedom of design on the lowest storeys, with lesser freedom on leaky façades allowed by the depressurization technique. In this hybrid design the ratio of exhaust vent area to fresh-air inlet area is determined by the needs of depressurization whereas the actual values of these areas are consistent with the appropriate SHEVS recommendations. In such a hybrid design the smoke layer temperature in the atrium recommended for the depressurization calculations is a natural outcome of the plume entrainment calculations needed for the smoke extract calculation (see ***6.6****).*

NOTE 2 Hybrid designs are similarly possible where powered ventilators are used for atrium smoke exhaust.

Hybrid designs typically follow one of two approaches.

a) Mass flow-based, where the atrium is designed with a plume of a specific height.

b) Temperature-based, in order to cool a potentially hot smoke layer by the deliberate entrainment of ambient air into the rising plume. This can enable the use of façade materials that cannot withstand high temperatures, e.g. float glass.



Key

1	Atrium
A	Opening to atrium
B	Leakage paths from exterior into room C
C	Room/space adjacent to atrium

NOTE 1 In this context a large opening is one where the flow resistance of the opening in the atrium façade is larger than the combined flow resistance of openings further along the same leakage path away fron the atrium, e.g. if the atrium façade opening is larger than openings in the external wall.

NOTE 2 If flow resistance of B and B ' > flow resistance of A, then C is not protected. Figure 5 illustrates this situation.

Figure 5 — Flow resistance through openings in an atrium

6.11.2 *Recommendations*

6.11.2.1 Where an atrium depressurization system is proposed, the designer should determine whether the atrium may be regarded as having a dominant inlet.

NOTE An example method is given in Annex J.

6.11.2.2 The designer should, by inspection of the building drawings, establish the location of the highest vulnerable leakage path by which smoke may pass from the atrium to adjacent spaces.

6.11.2.3 The designer should show by calculation that the highest vulnerable leakage path experiences a pressure difference driving clean air into the atrium with the neutral pressure plane above the highest vulnerable leakage path taking wind pressure effects into consideration.

NOTE Some example calculation methods are given in Annex J.

6.11.2.4 The designer should provide full supporting documentation in accordance with **4.7.3**.

7 Interaction with other fire protection systems and other building systems

7.1 Sprinklers

Sprinklers are effective in reducing fire losses by controlling the fire at a manageable size or by extinguishing the fire. A SHEVS allows for more effective manual fire-fighting and protection of escape routes in buildings. It is important that where sprinklers and SHEVS are employed together the overall effectiveness of the fire protection (including fire service action) is increased and not reduced.

Where sprinklers and SHEVS are both present, care should be taken to ensure optimum performance of the combined system.

NOTE Annex K contains guidance on the interaction between sprinklers, smoke and heat exhaust ventilation systems and fire-fighting actions.

7.2 Smoke and fire detection systems

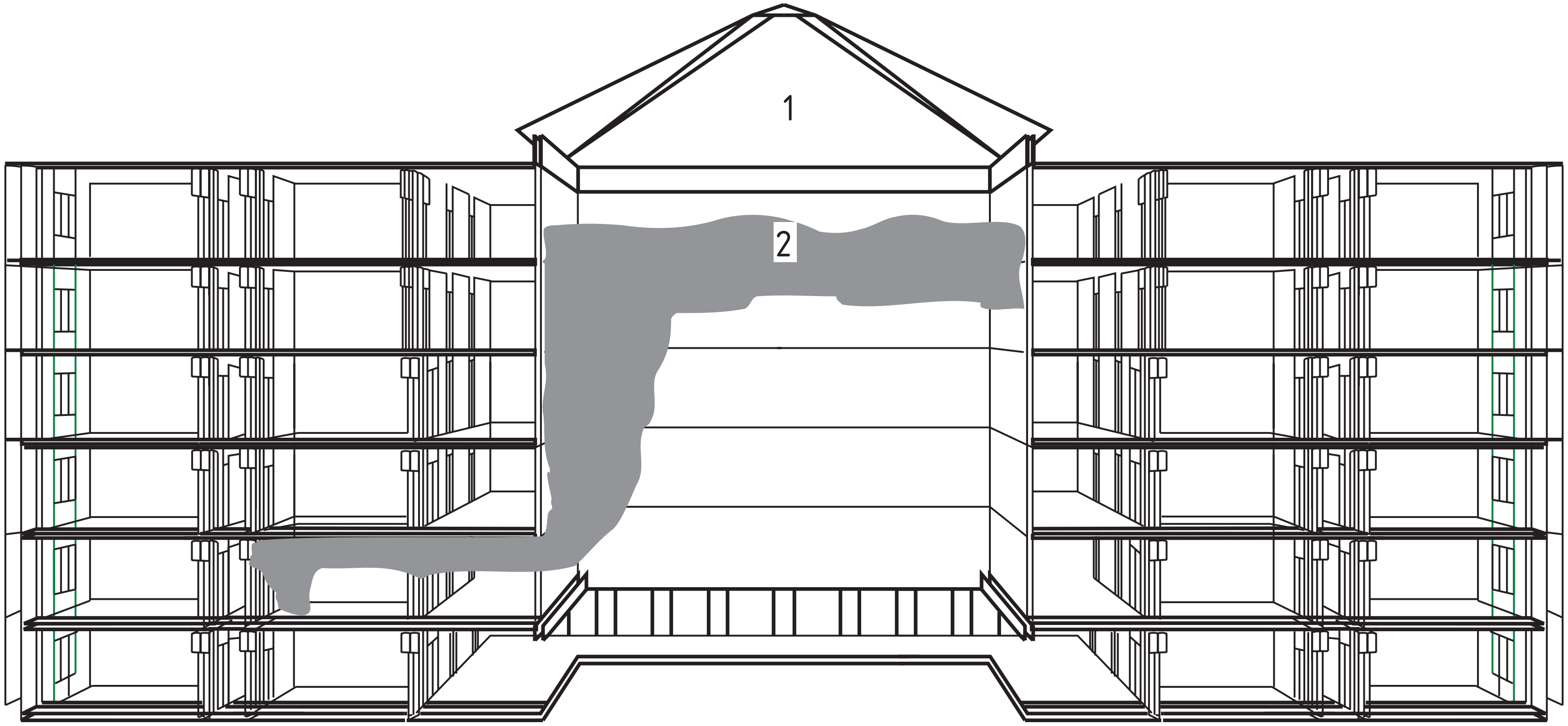
7.2.1 *Commentary*

Many SHEVS are designed to be triggered automatically by smoke or other fire detection systems. The detection system needs to be capable of providing signals to the SHEVS in a way that allows the zoned operation of SHEVS, where appropriate. It is important that the SHEVS is initiated by detection as early as possible in the fire.

Some large spaces, e.g. tall atria, experience a gathering of warm air below the ceiling due to the HVAC system's operation, solar heating of a glazed roof, etc. Where this occurs the plume above a fire, especially in its early stages when the fire is still small, can become cooler by entrainment as it rises and results in a stratified smoke layer before it reaches the ceiling.

NOTE Figure 6 illustrates the early stratification of smoke.

In such a circumstance, smoke detectors mounted near the ceiling do (correctly) not report the existence of smoke. It is often not possible to predict the height at which smoke first stratifies, e.g. this is often dependent on the weather. It is important that detectors are located in positions that will detect such stratified layers.



Key

1	Warm air
2	Stratification of smoke

Figure 6 — Early (or premature) stratification of smoke

7.2.2 *Recommendations*

7.2.2.1 The smoke and fire detection system should conform to BS 5839-1.

7.2.2.2 The smoke and fire detection system should be capable of locating the fire in a manner which allows different zones of the SHEVS to respond appropriately where this is recommended by the design.

7.2.2.3 The type and location of smoke detectors in tall spaces where warm, clean air is likely to gather beneath the ceiling under non-fire conditions should be chosen to be capable of detecting smoke below such warm air layers.

NOTE See BS 5839-1 for more detailed advice.

7.3 Pressure differential systems

7.3.1 *Commentary*

Pressure differential systems provide a method of protecting escape routes and other areas of a building against the entry of smoke by maintaining a pressure differential relative to the fire zone such that air is induced to flow from unaffected spaces into the fire zone and its associated spaces. A SHEVS is only likely to interact with a pressure differential system when the protected space, e.g. a pressurized stairwell, contacts the thermally buoyant smoke layer via leakage paths, e.g. door cracks. An example of this situation is when a pressurized stairwell has doors opening onto balconies which are in turn open to an atrium and that atrium has a SHEVS with a smoke layer base below some of those balconies.

*The height in the design smoke layer at which the pressure is equal to the external air pressure is established by calculation (see **7.3.2.1**). This is conventionally known as the height of the neutral pressure plane. Above this height the buoyancy of the smoke layer causes pressure to rise above ambient pressure. Below this height the buoyancy of the smoke causes a reduction in pressure below ambient pressure.*

The pressure differential system for the stairwell should conform to BS 5588-4, except that the minimum design pressure rise in the stairwell should be increased to compensate for the extra buoyancy in the layer above the neutral plane.

7.3.2 *Recommendations*

7.3.2.1 Where it is desirable to pressurize spaces adjacent to a smoke layer the height of the neutral pressure plane in the smoke layer should be assessed by calculation.

NOTE An example calculation method can be found in Annex L.

7.3.2.2 The difference between the buoyant pressure and ambient pressure at the highest leakage path connecting the smoke layer and the pressurized space, should be assessed by calculation.

NOTE An example calculation method can be found in Annex L.

7.3.2.3 The minimum design pressure rise in the pressurized space should be 40 Pa higher than that calculated in **7.3.2.2**.

NOTE This includes a similar arbitrary safety margin to the minimum design pressure rise specified in BS 5588-4.

7.3.2.4 No leakage paths should be allowed between the smoke layer and any pressurized space if the minimum design pressure rise calculated in **7.3.2.3** exceeds 75 Pa.

NOTE This criterion ensures the minimum pressure rise does not approach too closely the maximum acceptable pressure rise causing door opening forces at the handle of any door to exceed 100 N.

7.3.2.5 All other criteria for the pressurized space should conform to BS 5588-4.

7.4 Public address and voice alarm systems

Sound levels of public address and voice alarm systems, and of the SHEVS, should be such that when the SHEVS is activated, messages are clearly audible and intelligible. The designers of the SHEVS, public address and voice alarm systems should consult each other at the design stage to optimize the performance of the combined systems.

7.5 Lighting and signage

The height of the smoke free layer chosen for design purposes should be high enough for the base of the buoyant layer of smoky gases to be above emergency lighting and emergency exit signs.

7.6 Computerized control systems

7.6.1 Where the operation of a SHEVS is directed by or is linked to a computerized control system, any changes to software controlling fire safety functions, or changes to the computer running that software, should not affect the operation of the installed SHEVS.

7.6.2 Where such changes are made, there should be tests of the entire SHEVS by simulated fire detection, e.g. by blowing smoke into smoke detectors, to confirm the continued functioning of the SHEVS according to the design.

7.6.3 The fire safety mode should override the general day-to-day ventilation mode.

7.7 Heating, ventilation and air-conditioning (HVAC)

7.7.1 *Commentary*

A HVAC system (or an air-conditioning and mechanical ventilation system) is designed to achieve different objectives in comparison to a SHEVS. Not only are the quantities of gases being moved usually smaller, they are generally moved in different directions. For example, it is common for HVAC systems to introduce replacement air at high level in a room, and to exhaust used air at low level: the opposite to that recommended for a SHEVS. Even when a HVAC system has been shut off, its ducts can provide pathways for the unwanted movement of smoke unless measures have been taken to prevent this from happening.

HVAC systems can be incorporated, in whole or in part, in a SHEVS. Where this is done it is necessary to isolate those parts not incorporated, and to ensure that the parts which are incorporated meet the same performance standards as the rest of the SHEVS. Dampers which can only be reset manually can make the regular functional testing of a SHEVS extremely difficult. Consequently, it is necessary for smoke dampers to be capable of being both opened and closed by powered mechanisms.

Where the internal air temperature in a building, e.g. in an atrium, is lower than the external by an amount such that the initial hot buoyant smoke layer is itself cooler than the outside air, opening a natural SHEVS causes the smoke layer to exhaust downwards. This could adversely affect the means of escape.

7.7.2 *Recommendations*

7.7.2.1 In the event of a fire in a building or a smoke control zone, the HVAC fans should be stopped automatically by means of a signal from the detection installation, unless the HVAC system is incorporated into the SHEVS.

7.7.2.2 In order to avoid smoke siphoning from one smoke control zone to another through the HVAC ducting, smoke dampers should be installed on the boundaries of the smoke control zones. These smoke control dampers should operate on receipt of a signal originating from the smoke detection system. Alternatively the smoke control system designer should demonstrate by calculation that smoke is not able to pass from one smoke control zone into another and document this in accordance with **4.7.3**.

7.7.2.3 All smoke control dampers in that part of the HVAC system corresponding to the affected smoke control zone should move into their fire operational positions simultaneously with the HVAC fans.

7.7.2.4 The functions described in **7.7.2.1**, **7.7.2.2** and **7.7.2.3** should be extensively tested after the system has been installed by creating a smoke detection signal.

7.7.2.5 If parts of the HVAC system are used in the SHEVS, those parts of the HVAC system which are incorporated into the SHEVS should follow all appropriate recommendations in this standard.

7.7.2.6 All smoke control dampers should be capable of being opened and closed by a powered device.

7.7.2.7 Natural smoke and heat exhaust ventilators should not be used where the SHEVS serves a tall space in a building which is air-conditioned to more than 10 °C below the anticipated external ambient air temperature.

7.8 Security systems

Security systems should not adversely affect the operation of the SHEVS. For example, where doors are recommended to act as air inlets, and can be locked for part of the day, they should unlock and open automatically when the SHEVS is activated.

Security provisions should not block escape routes, or hinder fire-fighting access.

Annex A (informative) Default value heat release rates

Although some research has been completed on heat release rates for a number of specific individual materials, these are not relevant to a fire in all situations. A wide range of combustible materials is likely to be involved in any fire. Therefore, a specific material value is not applicable but it is necessary to assess the heat release rate for both a high and low value, to determine which results in the worst-case recommendation. The following values and equations can be used to calculate both the high and low heat release rates for either the sprinklered or the unsprinklered condition as appropriate.

For sprinklered fires:

$q_{\mathrm{f,(low)}} = 250\ \mathrm{kW \cdot m^{-2}}$

$q_{\mathrm{f,(high)}} = 625\ \mathrm{kW \cdot m^{-2}}$

For unsprinklered fires with fuel arrays up to 2 m high:

$q_{\mathrm{f,(low)}} = 250\ \mathrm{kW \cdot m^{-2}}$

$q_{\mathrm{f,(high)}} = 1250\ \mathrm{kW \cdot m^{-2}}$

For unsprinklered fires with fuel arrays between 2 m and 4 m high:

$q_{\mathrm{f,(low)}} = 250 \times (h_{\mathrm{f}} - 1)\ \mathrm{kW \cdot m^{-2}}$

$q_{\mathrm{f,(high)}} = 1250 \times (h_{\mathrm{f}} - 1)\ \mathrm{kW \cdot m^{-2}}$

These equations do not apply to the high piled or high racked storage described in **6.1.2**.

Annex B (informative) The plume rising directly from the fire into a smoke reservoir

B.1 Plumes above large fires – where the clear height *Y* is specified

Plumes above large fires are those where:

$$Y \leq 10 \times (A_{\mathrm{f}})^{0.5} \qquad \text{(B.1)}$$

The entrainment of air into the plume (that is the amount of air mixing into the fire gases as they rise) is large. For all practical purposes the mass of the actual products of combustion can be ignored, and the smoky gases can be treated for calculation purposes as contaminated hot air. The rate of air entrainment into a plume of smoke rising above a fire (M_{f}), expressed in kilograms per second ($\mathrm{kg \cdot s^{-1}}$), can be obtained using Equation (B.2):

$$M_{\mathrm{f}} = C_{\mathrm{e}} P Y^{3/2} \qquad \text{(B.2)}$$

where

C_{e} is equal to 0.19 for large-space rooms such as auditoria, stadia, large open-plan offices, atrium floors, etc., where the ceiling is well above the fire;

C_{e} is equal to 0.337 for small-space rooms such as unit shops, cellular offices, hotel bedrooms, etc., with ventilation openings predominantly to one side of the fire, e.g. from an office window in one wall only.

NOTE 1 Most small rooms therefore take this value.

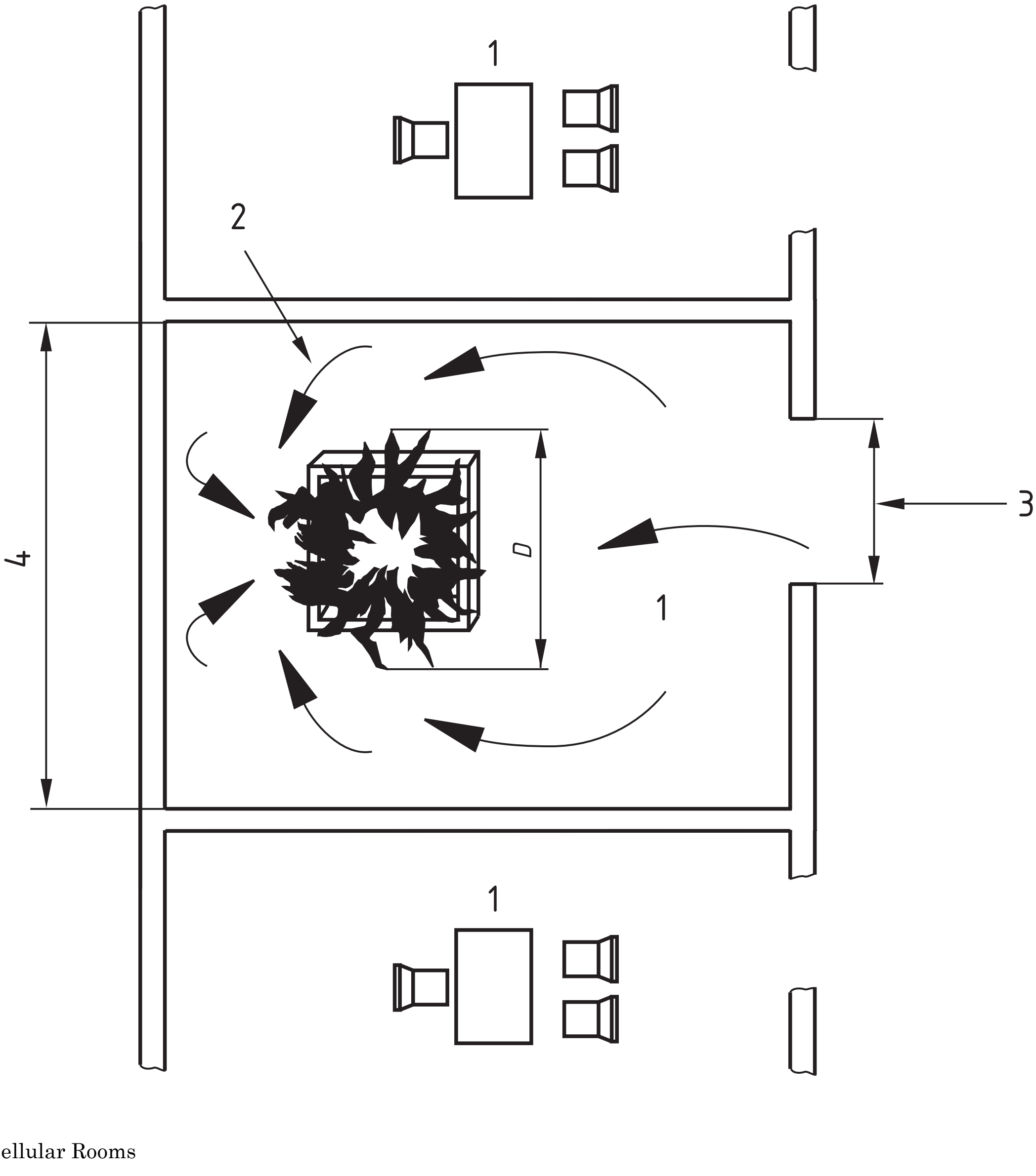
Equation (B.1) has been validated experimentally for fires in large spaces with heat release rates between 200 and 1 800 $\mathrm{kW \cdot m^{-2}}$.

There is no information available to show how Equation (B.2) (or any current alternatives) can be modified to allow for the effects of sprinkler spray interactions. Consequently, it is used here unmodified.

The demarcation between a large-space and small-space room is determined by the ability of the incoming air to flow into the rising plume from all sides. The narrower the room becomes, the less easily the air can flow behind the plume.

Small-space cellular rooms are considered to be those in which the maximum room dimension is less than or equal to five times the diameter of the design fire size, and the incoming air can only enter from one direction. Figure B.1 illustrates this situation.

NOTE 2 This demarcation dimension was chosen arbitrarily and has no theoretical derivation. Research in this area is highly desirable.



Key

1	Cellular Rooms
2	Restricted air flow to fire and plume
3	Opening width (W)
4	Room width <5D

Figure B.1 — Limiting size of a cellular room

B.2 Plumes above large fires – temperature control designs

In temperature control designs the temperature of the smoke reservoir gases above ambient temperature (Θ) is specified. The convective heat flux in the smoky gases entering the buoyant smoke layer is also known. The mass flow rate entering the buoyant layer is calculated using the following equation:

$$M_f = \frac{Q_f}{c\Theta_1} \tag{B.3}$$

NOTE If it is desirable to calculate the clear height in this case, the value of M_f derived from Equation (B.3) can be used together with Equation (B.2) to calculate Y.

B.3 Plumes above small fires – where the clear height is specified

Plumes above small fires are those where:

$$Y > 10 \times (A_f)^{0.5} \tag{B.4}$$

The entrainment of air into the plume above a small fire can be found as follows.

a) First calculate z_o, the height of the virtual origin of the plume measured above the top of the burning fuel, using Equation (B.5):

$$z_o = -1.02D + 0.083Q_f^{0.4} \tag{B.5}$$

b) Express the clear height as Z, measured above the top of the burning fuel.

c) Calculate the mass flow entering the smoke layer using Equation (B.6):

$$M_f = 0.071Q_f^{0-33}(Z - z_o)^{1.67}\ \{1 + 0.026Q_f^{0.67}(Z - z_o)^{-1.67}\} \tag{B.6}$$

B.4 Plumes above small fires – temperature control designs

The calculation procedure, which is very similar to **B.2**, is as follows.

Calculate M_f using Equation (B.3). If the clear height is to be calculated, use this value of M_f in Equations (B.5) and (B.6) to find Z, and hence Y.

B.5 Plumes above high storage fires

For high-stored goods the design fire parameters resulting from **6.1** have values assigned to the perimeter of the fire accessible to approaching air (P) and to the layer temperature above ambient, above the fire (Θ_l). The position of the base of the buoyant smoke layer in the reservoir is also specified, giving a value for the clear height Y.

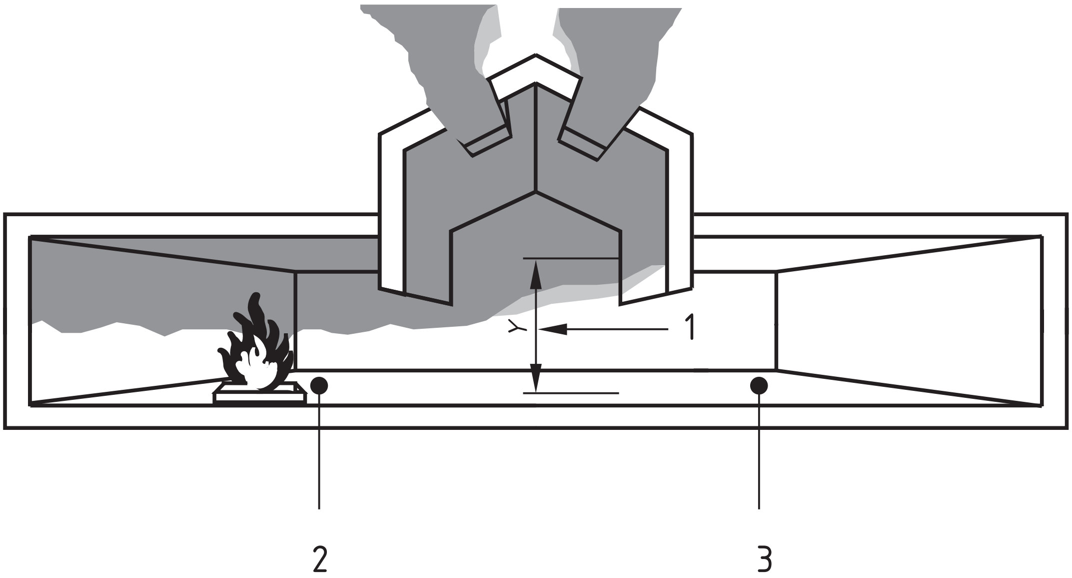
The mass flow rate of smoky gases entering the layer (M_f) can by calculated using Equation (B.2) with C_e equal to 0.19.

NOTE This approach is approximate.

If it is necessary to calculate the convective heat flux entering the smoke layer (usually this is not necessary) this value of M_f can be used with Equation (B.3) to calculate Q_f.

B.6 Single-storey shopping malls – fire in an adjacent shop

The mass flow rate of smoky gases entering the smoke reservoir in a single-storey shopping mall from a fire in an adjacent shop is approximately double the amount that would apply if the fire was located in the mall, with the same height to the smoke layer's base, i.e. double the result of Equation (B.2) where C_e is equal to 0.19. Figure B.2 illustrates smoke ventilation in a single-storey shopping mall.



Key

1 Mall

2 Shop (fire-room)

3 Shop

Figure B.2 — Smoke ventilation in a single-storey mall

It follows that the mass flow rate of smoky gases entering the mall's smoke layer is given by the following equation:

$$M_f = 0.38PY^{3/2} \tag{B.7}$$

This is the result of an empirical correlation, which becomes invalid if the layer's base is too high above the top of the shop's opening. If this height difference is greater than 2 m it is necessary to calculate the entrainment using the procedures for spill plumes (see **6.3**, **6.4** and **6.5**).

Annex C (informative) The flow of hot smoky gases out of a fire-room into an adjacent space

C.1 Fuel-bed controlled fires

A design fire is fuel-bed controlled if it results in layer temperatures too cool to induce flashover. All other fires are (or will rapidly become) fully-involved.

The mass flow rate out of the room's opening (or window) can be calculated as follows.

The mass flow rate of smoky gases passing through a vertical opening (M_w), expressed in kg·s^{-1}, is found from the following equation:

$$M_w = \frac{C_e P W h^{3/2}}{\left[W^{2/3} + \frac{1}{C_d}\left[\frac{C_e P}{2}\right]^{2/3}\right]^{3/2}} \tag{C.1}$$

NOTE The number "2" in Equation (C.1) is the result of combining various parameters, and has dimension.

Where the smoke flow directly approaches a spill edge with no downstand, e.g. where the ceiling is flush with the top of the opening, $C_d = 1.0$. For other scenarios the following procedure can be adopted.

M_w calculated above is used with the value of Q_w appropriate to the design fire, and Equation (B.3), to calculate the average gas temperature above ambient, Θ_w , at the opening. If $\Theta_w < 68$ °C, then Equation (C.1) is not valid, and fire safety engineering methods need to be adopted instead. In this latter case, full supporting documentation needs to be provided.

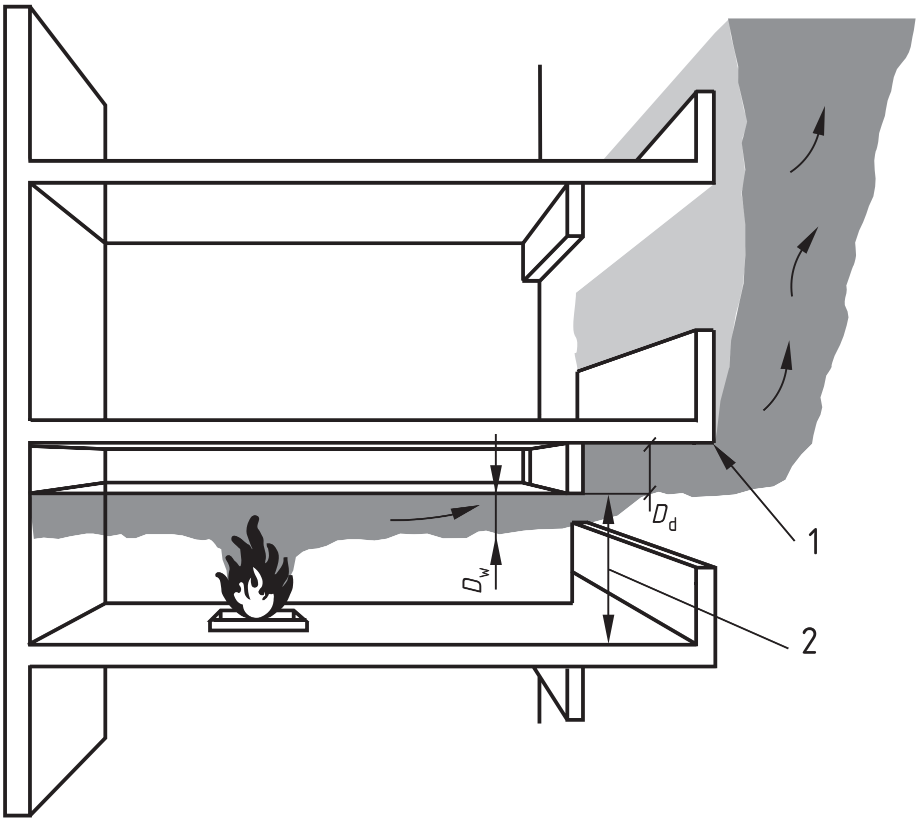
The flowing layer depth of smoke through the opening (D_w), expressed in metres (m) is determined from:

$$D_w = \frac{1}{C_{do}} \left[\frac{M_w}{2W}\right]^{2/3} \qquad \text{(C.2)}$$

where

D_w is the flowing layer depth in the plane of the opening, measured below the bottom of the downstand in metres (m) or below the soffit if there is not downstand at the opening (see Figure C.1).

NOTE 1 The number “2” in Equation (C.2) is the result of combining various parameters, and has dimension.

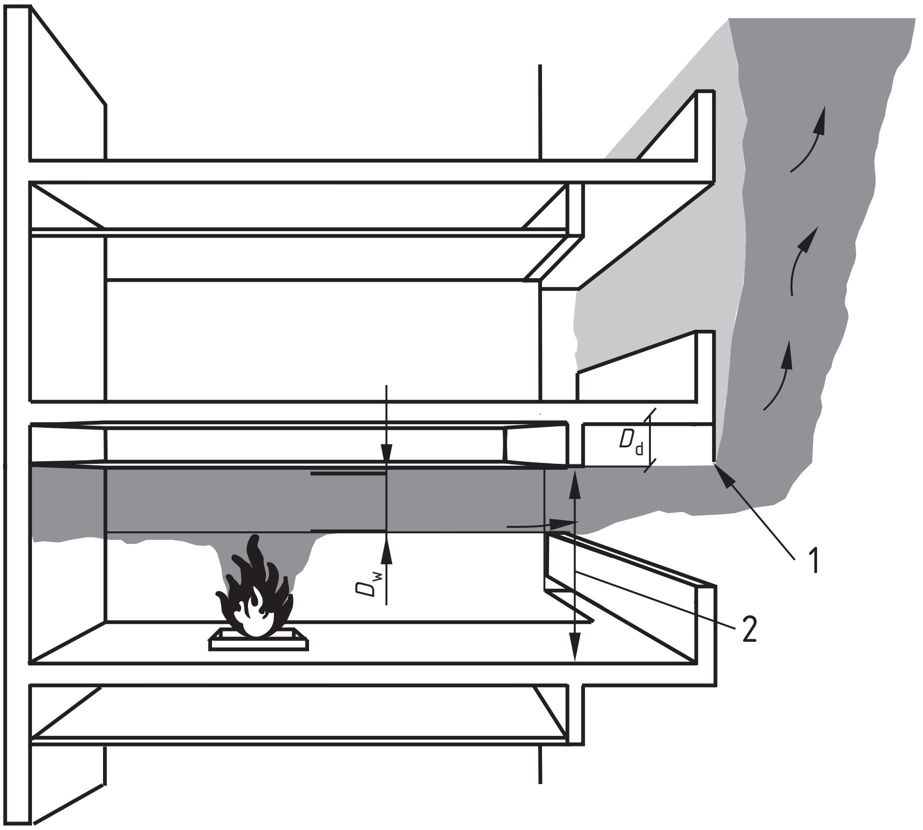


Key

1 Spill edge

2 Opening

Figure C.1 — Flow out of an opening with high balcony



Key

1	Spill edge
2	Opening

Figure C.2 — Flow out of an opening with downstand and projecting balcony

The parameter C_d in Equation (C.2) is a discharge coefficient affecting the outflow of buoyant gases at the opening (see Figure C.2), and represents the effect of a downstand present at that opening.

Where the smoke flow directly approaches a spill edge with no downstand, i.e. where the ceiling is flush with the top of the opening, $C_d = 1.0$. This corresponds to the smoke flow approaching the spill edge in Figure C.2.

Where there is a downstand at the spill edge, at a right angle to the direction of flow, the downstand depth (D_d) is defined as being the depth of the downstand at the room opening, measured below the ceiling soffit inside the fire-room.

For other scenarios the following procedures can be adopted.

a) Make an initial assessment of the mass flow rate using Equation (C.1) and a trial value of C_d ($C_{do} = 0.65$), and thus an initial assessment of the flowing layer depth D_W can be made from Equations (C.1) and (C.2). Note that Equation (C.2) is both simplified and approximate. While it is sufficiently accurate for the purposes of the iterative procedure described herein, it is more appropriate to use Equation (D.3) where the actual layer depth has to be calculated.

b) If $D_d \leq 2D_W$ [based on the calculated value of D_W from step a)] continue with the values calculated from step a) in the remainder of the calculation.

c) If $D_d \leq 0.25D_W$ [based on the calculated value of D_W from step a)] then set C_d equal to 1.0 and recalculate new values of M_W and D_W. Use these new values in subsequent calculations.

d) If $0.25\ D_W < D_d > 2D_W$ [based on the calculated value of X from step a)] then set C_d equal to 0.8 and recalculate new values of M_W and D_W. Use these new values in subsequent calculations.

NOTE 2 This method occasionally gives rise to certain situations where, when re-calculated, the value of D_W falls into a different range, apparently suggesting a different value of C_d. Limitations inherent in this method of assessment make such situations unavoidable. For the purposes of calculation such situations are ignored, and the values of C_d given by the procedure detailed in a) to d) are used.

NOTE 3 It is hoped that this procedure for assigning a value to C_d for the intermediate depth downstands will be superseded by a more accurate procedure in the light of further research.

C.2 Assessment of flashover

Several methods are possible. The following procedure is approximate.

Using the value of M_w calculated in Equation (C.1), and the convective heat flux at the opening, Q_w, calculate the layer temperature above ambient using Equation (C.3):

$$\Theta_w = \frac{Q_w}{cM_w} \tag{C.3}$$

Calculate the layer temperature using Equation (C.3):

$$t_w = \Theta_w + t_{ambient} \tag{C.4}$$

If $t_w \geq 550$ °C, the room becomes fully involved in fire.

C.3 Fully-involved fires

It is not usually good practice to base smoke exhaust ventilation designs on fully-involved room fires, since they usually involve flames passing into and through the larger space. Heat radiation from these flames can represent a significant hazard in the adjacent space. It is desirable that smoke and heat exhaust ventilation systems based on flashed-over room fires are considered individually, with detailed evidence supplied by the designer to justify this approach in the circumstances of his/her design.

C.4 Slot extract

It is possible to prevent the passage of smoky gases through the fire-room's opening by exhausting smoke and air through a slot at the top of the opening, running across the full width of the opening.

NOTE This principle is discussed more fully in Annex D.

Annex D (informative) The flow of hot smoky gases under a soffit projecting beyond a fire-room's opening or window

D.1 The mass and heat flows in the smoky gases

Where the top of the fire-room's opening or window is at the same height as the projecting soffit, there is no entrainment into the smoke leaving that opening. Hence the following equation applies:

$$M_B = M_W \tag{D.1}$$

Where there is a downstand causing the gases to rise to meet the soffit there is entrainment. For the purposes of engineering design the mass flow rate of smoke entering the under-soffit buoyant layer can be taken as approximately twice the mass flow rate beneath the downstand, i.e.:

$$M_B = 2M_W \tag{D.2}$$

Equations (D.1) and (D.2) apply both to smoky gas flows moving beneath the spill edge and to smoky gas flows entering a smoke reservoir created beneath the soffit by preventing spillage. In all cases the under-soffit heat flux can be taken to be the same as at the fire-room's opening.

D.2 The depth of channelling screens

It is necessary for channelling screens to be as deep as the gases flowing between them beneath the spill edge (see Figure D.1 and Figure D.2). Knowing the values of both M_B and Q_B, as well as the geometrical aspects of the building, the designer can select the separation (L) of the channelling screens at the spill edge. The depth of the flowing layer is also influenced by the presence or absence of any downstand at the void edge, since this changes the discharge coefficient for the flow at the spill edge. The depth of flow is given by Equation (D.3):

$$d_B = \frac{0.36}{C_d}\left[\frac{M_B T_B}{L\theta_B^{0.5} T_{amb}^{\;0.5}}\right]^{0.67} \tag{D.3}$$

where

Θ_B is equal to $\dfrac{Q_B}{cM_B}$;

T_B is equal to $T_{amb} + \Theta_B$;

C_d either takes the value 1.0 if there is no downstand across the flow at the void edge or takes the value 0.6 if there is a downstand across the flow at the void edge.

The minimum depth of a channelling screen needs to be (d_B+ 0.1) m.

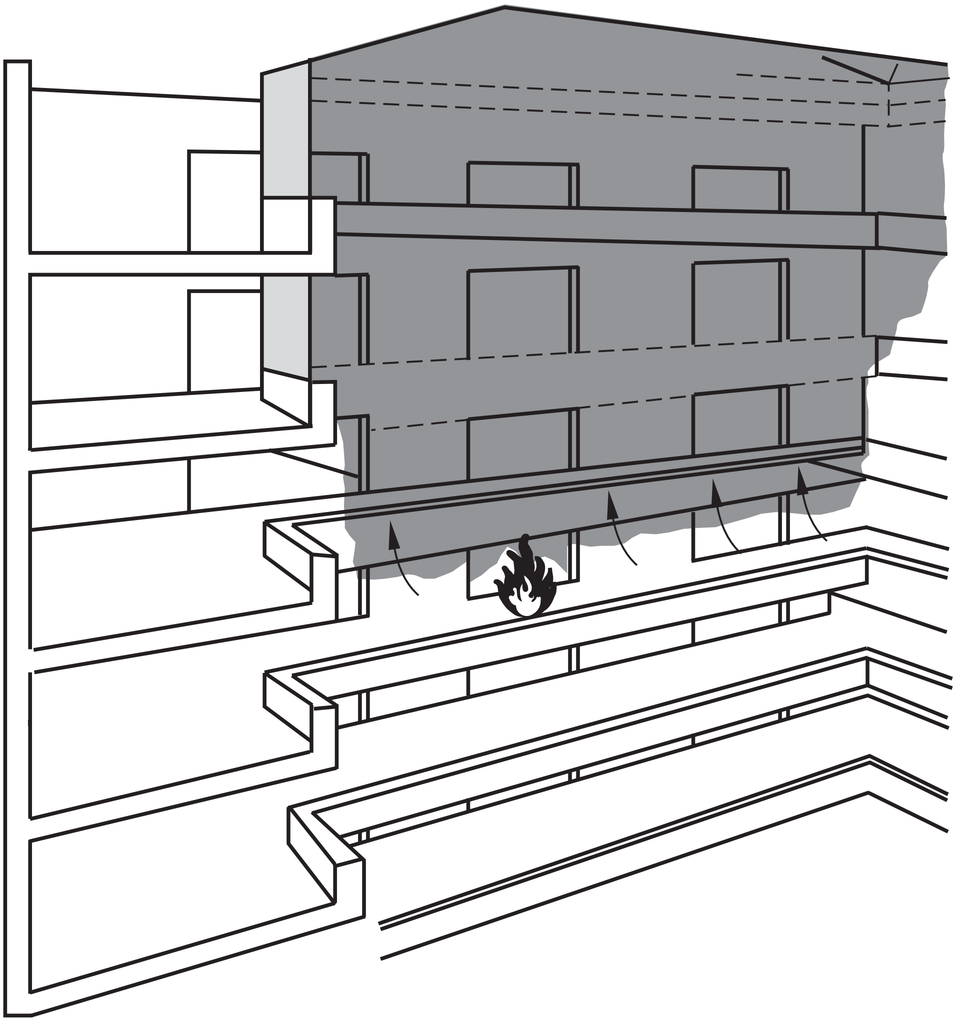


Figure D.1 — Smoke spreading sideways beneath a projecting canopy or balcony

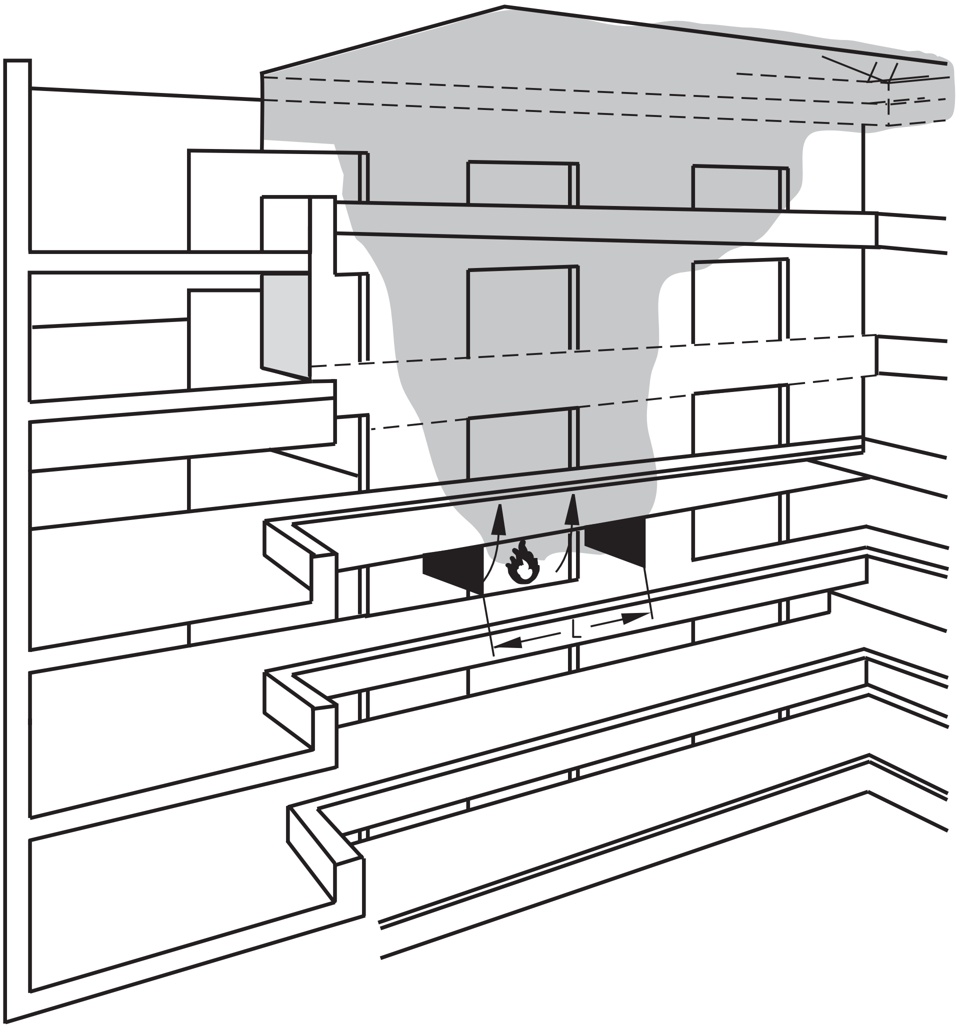


Figure D.2 — Smoke confined to a compact spill plume by channelling screens

D.3 The depth of smoke barriers at the void edge to prevent spillage

Where a buoyant layer of hot smoke flows beneath a ceiling and meets a transverse barrier, it deepens locally against that barrier and, as the gases are brought to a halt, the kinetic energy of the approaching layer is converted to buoyant potential energy against the barrier.

When designing a smoke and heat exhaust ventilation system in which the projecting soffits are acting as reservoirs, it is often necessary to control the path of smoke flow using downstand smoke barriers. These are typically installed around the edge of the voids to prevent smoke flowing up through the voids. If the void edge is close to the fire-room this local deepening could cause smoke to spill under the smoke barrier and flow up through the void, possibly affecting the ability to escape from other storeys. It is therefore necessary for the void edge screens to be deep enough to contain not only the established layer, but also the additional local deepening outside the room on fire.

The extent of local deepening can be found from Equation (D.4). The depth of the established layer (d_B) under the balcony immediately downstream of the local deepening is first found using the design procedure given in **6.6**.

NOTE Usually this means the depth of the established layer in the channel formed between the void edge screen and the room façade.

The additional depth, Δd_B, can then be found using Equation (D.4) allowing the necessary minimum overall depths ($d_B + \Delta d_B$) of the void edge screen to be calculated.

$$\Delta d_B = 0.4H \left[\frac{1 - \log_e \left[\frac{5 d_B}{H} \right]}{\log_e \left[\frac{5 W_B}{H} \right]} \right] \tag{D.4}$$

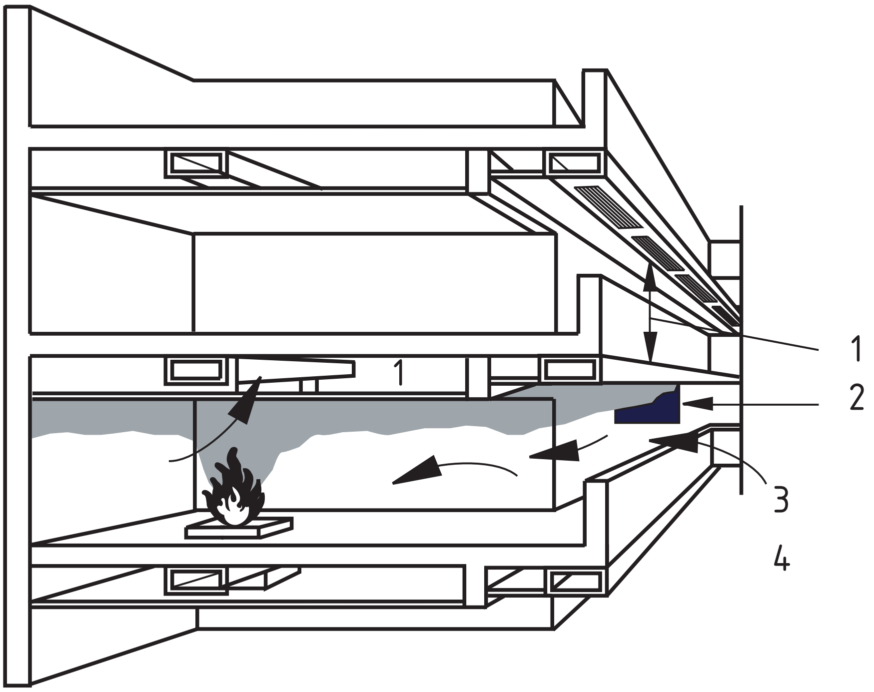
where

H is the floor-to-soffit height in metres (m).

D.4 The capacity of a slot exhaust needed to prevent the passage of smoke

The slot exhaust needs to be as long as the gap through which smoky gases would otherwise pass. Figure D.3 illustrates the principle of slot exhaust. If there are no other smoke exhausts, all the smoky gases flow towards the slot, i.e.:

$$M_{slot} = M_B \tag{D.5}$$



Key

1 Exhaust slot

2 Balcony resevoir screen

3 Air inlet

4 Atrium void

Figure D.3 — Slot exhaust

If there is some other exhaust from the smoke reservoir totalling a mass flow rate of M_s kg·s^{-1}, then the following equation applies:

$$M_{slot} = M_B - M_s \tag{D.6}$$

It has been shown that powered exhaust from a slot at right angles to the direction of flow of a thermally buoyant layer can completely prevent smoke passing that slot, provided that the exhaust rate at the slot is at least 1.67 times the flow rate of gases approaching the slot in the layer. It follows that to prevent the passage of smoke, Equation (D.7) applies:

$$M_{slot\ exhaust} = M_{slot} \tag{D.7}$$

Annex E (informative)
The spill plume

E.1 Entrainment into spill plumes

There are several alternative approaches to calculating entrainment into spill plumes, and other related properties, both for free and for adhered spill plumes. For a more complete discussion see, for example, BRE Report BR 368 [2].

E.2 Temperature control systems

Where a maximum layer temperature in the smoke reservoir is specified, the following procedure applies.

a) Select a trial value of X (the effective height of rise of a spill plume above the spill edge).

b) Calculate the mass flow rate entering the buoyant layer in the smoke reservoir.

c) Calculate the new layer temperature, Θ_l, using the following equation:

$$\Theta_l = \frac{Q_l}{M_X c} \tag{E.1}$$

d) Compare Θ_l with the specified value of layer temperature.

e) Repeat this procedure until agreement is reached.

Annex F (informative)
The smoke reservoir and ventilators

F.1 The temperature of the smoke layer

The average temperature of the gases in the smoke layer (near the point of entry of the plume) can be taken to be:

$$\theta_l = \frac{Q_l}{cM_l} \tag{E.2}$$

Where there are no sprinklers in the smoke reservoir, and recommendations to limit the reservoir area and to prevent the formation of stagnant regions have been followed, this value of Θ_l can be taken as the value for the total reservoir.

Where sprinklers are present, their cooling effect can be considered as follows.

— A powered exhaust system, to a reasonable approximation, removes a fixed volume of smoke irrespective of temperature. Therefore, if the extent of sprinkler cooling is overestimated, the system could be under-designed.

— A system using natural ventilators depends on the buoyancy of the hot gases to expel smoke through the ventilators. In this case the system would be under-designed if the sprinkler cooling were underestimated.

The heat loss from smoky gases to sprinklers is currently the subject of research, although data suitable for design application are not yet available. Nevertheless, an approximate estimate can be obtained as follows.

If the smoke passing a sprinkler is hotter than the sprinkler operating temperature, that sprinkler eventually activates and its spray cools the smoke. If the smoke is still hot enough the next sprinkler is then activated, cooling the smoke further. Eventually the smoke temperature becomes insufficient to activate further sprinklers. The smoke layer temperature can thereafter be assumed to be approximately equal to the sprinkler operating temperature beyond the radius of operation of the sprinklers. This radius is generally not known.

In the absence of more precise information, it is reasonable to assume that the number of operating sprinklers does not exceed the maximum number assumed in the design of sprinkler systems and their water supply.

For powered exhaust systems the cooling effect of sprinklers can be ignored when determining the volume exhaust rate. This errs on the side of safety. Alternatively, this further cooling and the consequent contraction of smoky gases can be approximately estimated on the basis of an average value between the sprinkler operating temperature and the calculated initial smoke temperature. Where the fan exhaust openings are sufficiently well separated it can be assumed that one opening is close to the fire and exhausts gases at the full initial temperature. The other openings can be assumed to be outside the zone of operating sprinklers and exhaust gases at the sprinklers' effective operating temperature.

The number of potential hot and cool intakes needs to be assessed when calculating the average temperature of exhausted gases.

If the sprinkler operating temperature is above 140 °C, or above the calculated smoke layer temperature, sprinkler cooling can be ignored for natural ventilators. For all other circumstances, it is necessary for the smoke layer temperature assumed for designs involving natural ventilators to be equal to the sprinkler operating temperature.

NOTE 1 The effect of sprinkler cooling is to reduce the heat flux (Q_l) without significantly changing the mass flux.

NOTE 2 The smoke layer temperature outside the region of active sprinklers is very sensitive to ambient temperature, and in warm conditions this could produce low values of Θ_l. Consideration might be given to using a higher temperature rating on any sprinkler bulbs in the smoke reservoir to compensate for this.

F.2 Minimum depth of reservoir layer for flow toward exhaust ventilators

Smoke entering the ceiling reservoir flows from the point of entry towards the vents of fans. This flow is driven by the buoyancy of the smoke. Even if there is a very large ventilation area downstream, e.g. if the downstream roof were to be removed, this flowing layer would still have a depth related to the width of the reservoir, the temperature of the smoke and the mass flow rate of smoke.

This depth, d_l, expressed in metres (m), can be calculated for unidirectional flow under a flat ceiling, as follows:

$$d_1 = \left[\frac{M_1 T_1}{\gamma \theta_1^{0.5} W_1}\right]^{2/3} \tag{F.2}$$

where

Θ_l is the temperature rise of the smoke layer above ambient in degrees Celsius (°C);

γ is the downstand factor and is equal to 36 if deep downstand is present at right angles to the flow, or 78 if no downstand is present at right angles to the flow.

The depth is measured below the lowest transverse downstand obstacle to the flow, e.g. structural beams or ductwork, rather than the true ceiling. Where smoke flows away from the point of entry in more than one direction (or is bi-directional if equal in opposite directions), W_1 is equal to the sum of the width, at right angles to the individual flows.

F.3 The use of a slot exhaust instead of a boundary smoke barrier

The design parameters for powered exhaust through a slot exhaust to prevent any smoky gases passing out of the reservoir can be calculated as follows.

The mass flow rate toward the slot is given by the following equation:

$$M_{\text{slot}} = \gamma \frac{\theta_1^{0.5} L_{\text{s}}}{T_1} d_{\text{slot}}^{\;1.5} \tag{F.3}$$

where

γ is equal to 78 if the slot is flush with the ceiling or 36 if the slot is mounted at the lowest part of a downstand.

The exhaust from the slot ($M_{\mathrm{slot\ exhaust}}$) is then as follows:

$$M_{\mathrm{slot\ exhaust}} = M_{\mathrm{slot}} \tag{F.4}$$

NOTE M_{slot} can be considered as part of the total exhaust capacity from the smoke reservoir.

F.4 The total exhaust capacity of powered smoke exhaust ventilators

A powered smoke exhaust system consists of fans and associated ductwork designed to remove the mass flow of smoke entering the smoke reservoir and to be capable of withstanding the anticipated smoke temperatures.

It is necessary to protect the controls and wiring to maintain the electrical supply to the fans during a fire.

For selection of the appropriate fans, the mass flow rate of smoke determined from previous calculation of entrainment into the rising smoke plume can be converted to the corresponding volumetric flow rate and temperature, using Equation (F.5):

$$V_1 = \frac{M_1 T_1}{\rho_{\mathrm{amb}} T_{\mathrm{amb}}} \tag{F.5}$$

F.5 Total area of natural smoke exhaust ventilators

A natural ventilation system uses the buoyancy of the smoke to provide the driving force for exhaust. The rate of exhaust depends on the depth and temperature of the buoyant smoky gas layer. The total aerodynamic free area of ventilators needed is given by Equation (F.6):

$$A_{\mathrm{vtot}} C_{\mathrm{v}} = \frac{M_1 T_1}{\left[2\rho_{\mathrm{amb}}{}^2 g d_1 \theta_1 T_{\mathrm{amb}} - \frac{M_1{}^2 T_1 T_{\mathrm{amb}}}{(A_{\mathrm{i}} C_{\mathrm{i}})^2} \right]^{0.5}} \tag{F.6}$$

Where ventilators are placed at different heights above the layer base, a different procedure is needed. If $A_{\mathrm{i}}C_{\mathrm{i}}$ is large compared to the vent area for each ventilator Equation (F.7) applies:

$$M_{\mathrm{n}} = \frac{\rho_{\mathrm{amb}} A_{\mathrm{vn}} C_{\mathrm{vn}} (2 g d_{\mathrm{n}} \theta_1 T_{\mathrm{amb}})^{0.5}}{T_1^2} \tag{F.7}$$

where

$A_{\mathrm{vn}}C_{\mathrm{vn}}$ is the aerodynamic free area of the n'th ventilator in square metres (m^2);

d_{n} is the depth of the layer beneath the centre of the n'th ventilator's free area in metres (m).

It is then necessary to select (by trial and error) parameter values such that:

$$\sum_n M_{\mathrm{n}} = M_1 \tag{F.8}$$

Where $A_{\mathrm{i}}C_{\mathrm{i}}$ is not much larger than the total $A_{\mathrm{vtot}}C_{\mathrm{v}}$ resulting from this exercise it is necessary to carry out a more detailed flow network calculation beyond the scope of this standard.

F.6 Minimum number of exhaust locations

The number of exhaust openings within the reservoir is important since, for any specified layer depth, there is a maximum rate at which smoky gases can enter any individual exhaust opening. Any further attempt to increase the rate of exhaust through that opening merely draws air into the opening from below the smoke layer. This is sometimes known as plugholing. It follows that, for efficient exhaust, the number of exhaust openings should be chosen to ensure that no air is drawn up in this way.

The number of exhaust openings can be determined by calculating the critical exhaust rate for an opening, beyond which air is drawn through the smoke layer. This critical exhaust rate (M_{crit}), expressed in kilograms per second ($\mathrm{kg{\cdot}s^{-1}}$) can be found for ventilators mounted in a wall or closer to the wall than the characteristic width of the ventilator using Equation (F.9):

$$M_{\mathrm{crit}} = 1.3(g d_{\mathrm{n}}^{5} T_{\mathrm{amb}}\, \theta_{\mathrm{l}}/T_{\mathrm{l}}^{2})^{1/2} \tag{F.9}$$

The critical exhaust rate for a ventilator further from any wall than the characteristic width of that ventilator is given by Equation (F.10):

$$M_{\mathrm{crit}} = \frac{2.05\rho_{\mathrm{amb}}(gT_{\mathrm{amb}}\theta_{\mathrm{l}})^{0.5} d_{\mathrm{n}}^{2} D_{\mathrm{v}}^{\ 0.5}}{T_{\mathrm{l}}} \tag{F.10}$$

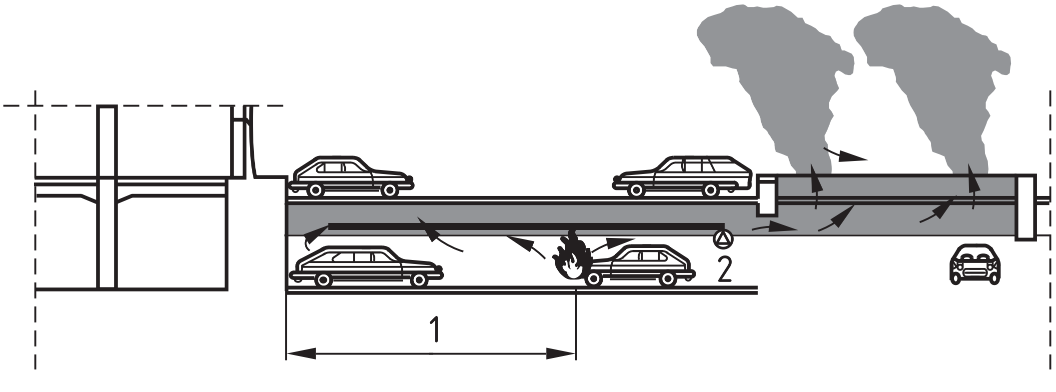
The recommended number of exhaust vents (N) is then given by:

$$N \geq \frac{M_{\mathrm{l}}}{M_{\mathrm{crit}}} \tag{F.11}$$

Where very large or physically extensive ventilator intakes are used, e.g. a long intake grille in the side of a horizontal duct, an alternative method of calculation is possible. Equation (F.3) applies, and the resulting value of M_{slot} is the largest that can be exhausted from the slot (or the perimeter of the large ventilator intake) without the onset of plugholing. If M_{slot} is set equal to M_{l}, i.e. the mass flow rate of gases entering the smoke layer, the same equation can be solved for L_{i}, which then becomes the minimum length of intake needed to prevent plugholing.

F.7 Smoke transfer ducts

Stagnant regions of a smoke reservoir suffer from continued heat loss resulting in downward mixing into the air below. A good distribution of ventilator exhaust positions can reduce the significance of this. Where this solution is impracticable smoke transfer ducts can be installed to move smoke from the stagnant region to another part of the smoke reservoir to rise with an existing flow towards a vent or exhaust fan. The use of smoke transfer ducts is illustrated in Figure F.1.



Key

1 Potentially stagnant region

2 Fan

Figure F.1 — Use of smoke transfer ducts in otherwise stagnant regions

If the reservoir continues beyond an exhaust opening more than three times as deep as the reservoir is wide, a smoke transfer duct might be necessary. A recommended value of the minimum exhaust rate is 4 % of the smoke layer's net flow or 1 $m^3 \cdot s$, whichever is the greater (see **6.6.2.18**).

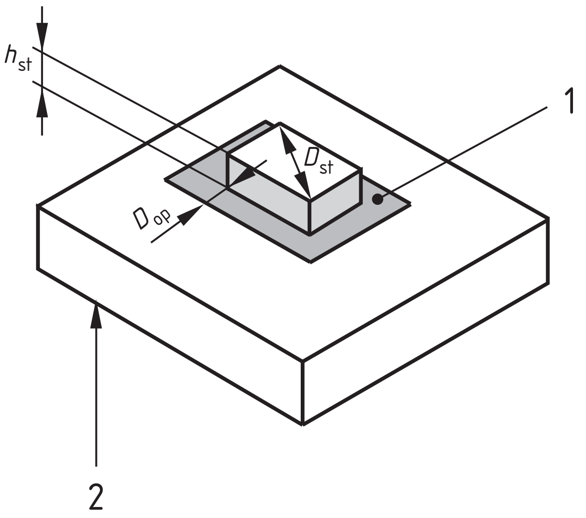
Annex G (informative)
The influence of zones of overpressure and/or zones of suction upon a SHEVS

G.1 Zone of overpressure

G.1.1 The zone of overpressure surrounding an outstanding structure due to wind is assessed to be the area of the roof surrounding this structure limited at a horizontal distance, D_{op}, measured from this structure. Figure G.1 illustrates the zones of overpressure on a roof with an outstanding structure.

The width of the overpressure zone around an outstanding structure on a roof can be calculated to be:

$D_{op} = 3h_{st}$ or $D_{op} = \frac{3D_{st}}{2}$, whichever is the smaller value.



Key

1 Zone of overpressure

2 Podium

Figure G.1 — Zones of overpressure on a roof with an outstanding structure

If there is a parapet present on the roof, h_{st} is assessed as shown in Figure G.2.

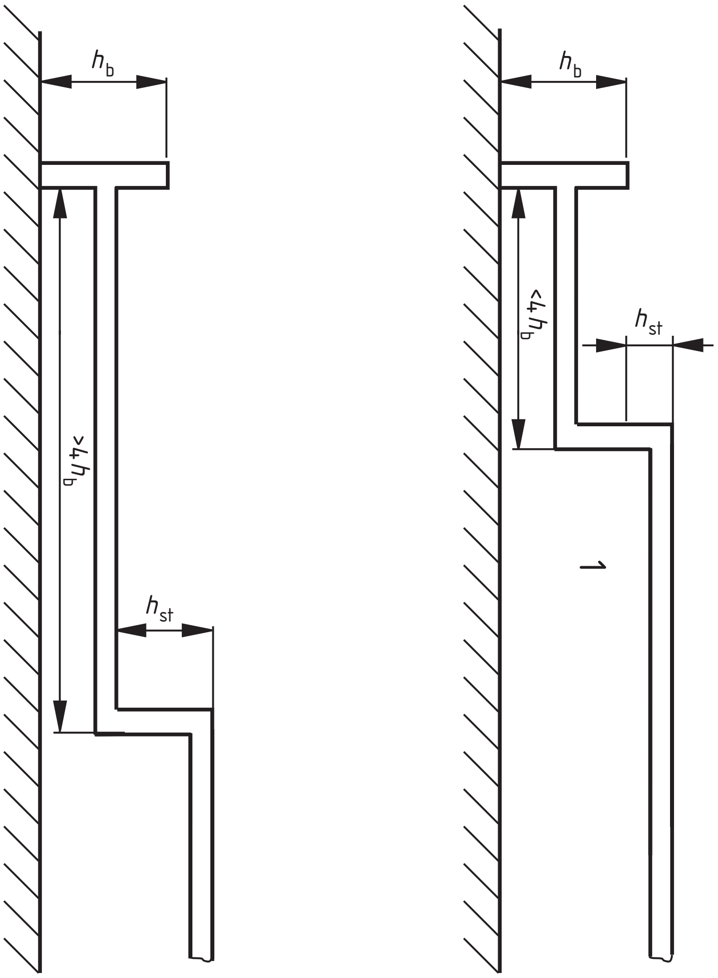


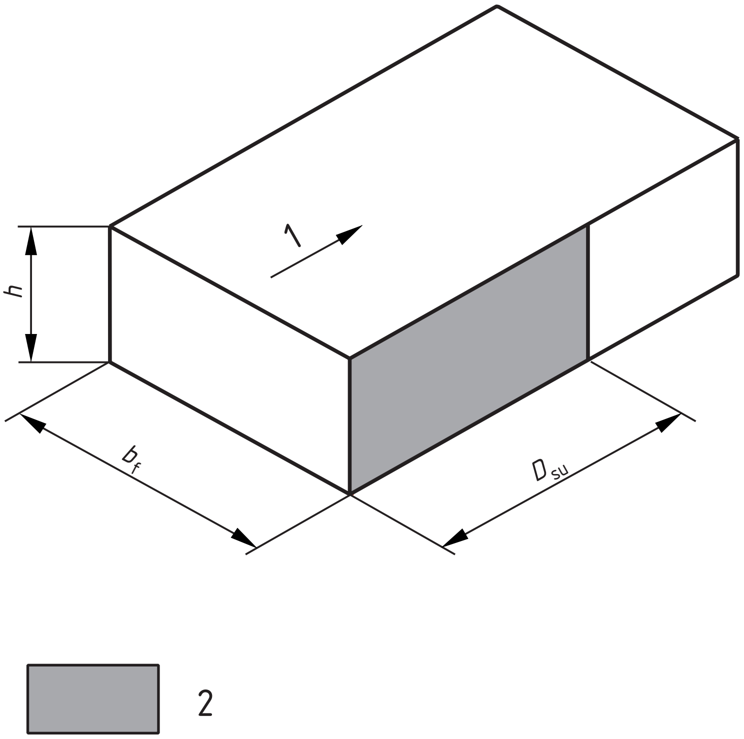
Figure G.2 — Assessment of h_{st} in case of a roof with an outstanding structure and a parapet

G.1.2 Location of natural vents is possible in any other case provided that wind tunnel tests show that the ventilator is not subject to overpressure.

G.2 Zones of suctions

The zones of suctions on the façades of a building due to wind are assessed to be the areas of the sides adjacent to the windward façade, extending from the two corners to a distance, D_{su}, measured along the sides and covering the full height of the façade.

The symbols used for further assessments or calculations are shown in Figure G.3.



Key

1	Wind direction
2	Zones of suction

Figure G.3 — Zones of suctions affecting the location of inlet openings

If b_f is the given length of the wind impacted façade, D_{su} is assessed as follows:

— if $b_f > 2h_b$ then $D_{su} = 2h_b$;

— if $b_f \leq 2h_b$ then $D_{su} = b_f$.

The zone of severe suctions extends up to $\frac{D_{su}}{5}$ from the boundary edge of the façade and it is not appropriate to install inlet openings in this zone.

Annex H (informative)
Deflection of free-hanging smoke barriers

H.1 A smoke barrier not reaching the floor

Where there is a large opening below the barrier, and the smoke layer's base is close to the bottom of the barrier, the force due to the smoke layer's buoyancy acts horizontally (neglecting the effects of bowing and of aerodynamic lift) at the centre of pressure.

NOTE This is a reasonable simplifying approximation in most designs.

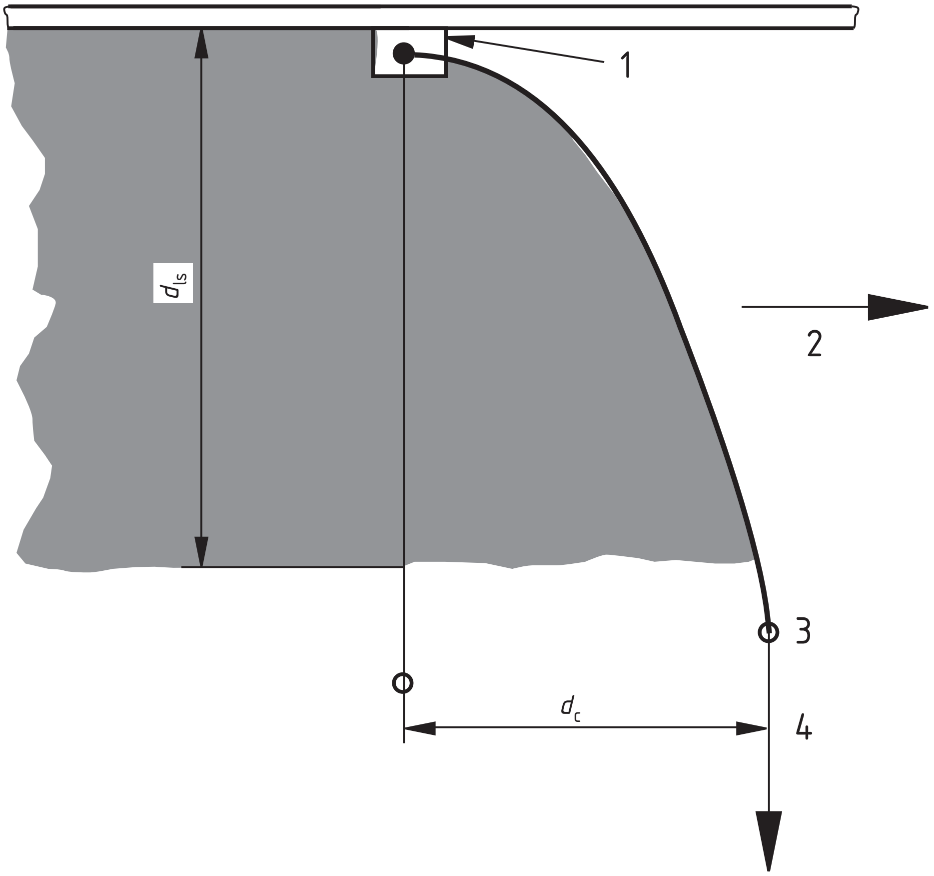
The designer usually needs to calculate the length of barrier material (d_h) to ensure that the smoke barrier still contains the smoke layer without spillage even when the barrier is in the deflected position. In practice, the barrier bows outward like the sail of a sailing ship, but the following analysis assumes that the barrier remains rigid, and deflects as if hinged at its top edge. A deliberate safety margin is introduced at the end of the analysis to compensate for bowing.

The forces acting on a free-hanging smoke barrier are illustrated in Figure H.1. The turning moment away from the smoke layer per horizontal metre length of barrier is given by Equation (H.1):

$$G_1 = \frac{\rho_{amb}\theta_l}{6T_l} g d_{ls}^3 \tag{H.1}$$

The restoring moment is given by Equation (H.2):

$$G_2 = \left(m + m_c \frac{d_h}{2}\right) g d_c \tag{H.2}$$



Key

1	Smoke barrier box
2	Buoyant force
3	Bottom bar
4	M.g. (Weight force)

Figure H.1 — Forces acting on a deflected smoke barrier

When in equilibrium, the horizontal deflection is given by Equation (H.3):

$$d_c = \frac{(1.2)\rho_{amb}}{6} \cdot \frac{\theta_l d_{ls}^3}{\left(m + m_c \frac{d_h}{2}\right) T_l} \tag{H.3}$$

where

(1.2) is an empirical constant to allow for bowing of the barrier.

The barrier is deflected away from the vertical by an angle as follows:

$$\beta = \tan^{-1}\left(\frac{d_c}{d_{ls}}\right) \tag{H.4}$$

The total length of barrier needed to contain the layer when deflected (d_h) is given by Equation H.5:

$$d_h = d_{ls} + d_c \tan\left[\frac{\tan^{-1}\left(\frac{d_c}{d_{ls}}\right)}{2}\right] \tag{H.5}$$

The solution method for d_h is as follows.

a) Assume a value for $d_h \geq d_{ls}$.

b) Calculate d_c using Equation (H.3).

c) Calculate d_h using Equation (H.5).

d) Repeat steps a) to c) with new assumed values of d_h until the value of d_h calculated in step c) is acceptably close to the value assumed in step a) of the same iteration.

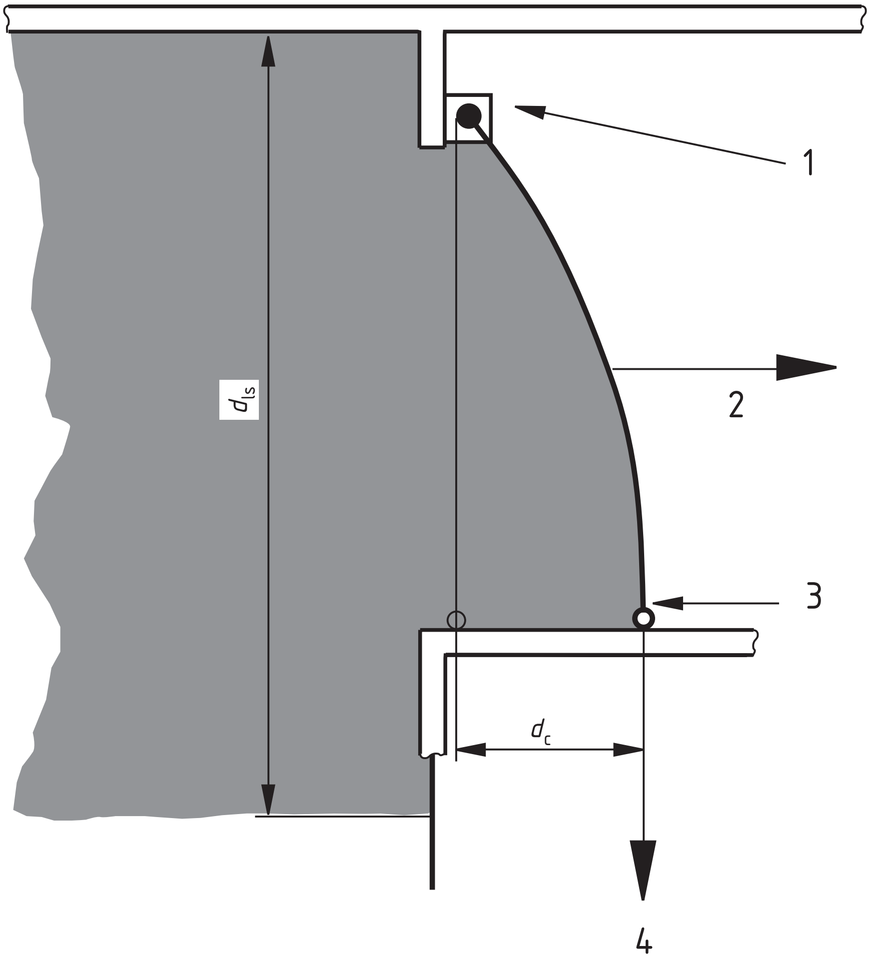
NOTE It is suggested that discrepancies of less than 1 % are acceptable. This is the correct value of d_h.

e) Apply a safety margin to allow for bowing of the barrier, by adding an additional length $\Delta d_h = 1.7(d_h - d_{ls})$, where the constant is empirical.

Hence the total installed length is $d_h + \Delta d_h$.

H.2 Barriers closing an opening

Another application for a smoke barrier is to achieve closure of an opening between a storey and a deeper smoke layer, e.g. a higher storey opening to an atrium in which a smoke layer is deeper than that opening (see Figure H.2). This smoke barrier can deflect away from the vertical driven by the buoyancy of the layer gases on one side, in a similar way to the free-hanging barrier discussed in **H.1**.



Key

1	Smoke barrier box
2	Buoyant force
3	Bottom bar
4	M.g. (Weight force)

Figure H.2 — Forces acting on a deflecting smoke barrier closing an opening

In a similar way to **H.1**, the turning moment away from the layer, per horizontal metre length of barrier is given by Equation (H.6):

$$G_l = \frac{\rho_{amb}}{6} \cdot \frac{\theta_l}{T_l} g(3d_{ls} - 2d_o)d_o^2 \qquad \text{(H.6)}$$

The restoring moment is given by Equation (H.2).

When in equilibrium, the horizontal deflection of the bottom bar is given as follows:

$$d_c = \frac{(1.2)\rho_{amb}\theta_l(3d_{ls} - 2d_o)d_o^2}{6T_l\left(m + m_c\,\dfrac{d_h}{2}\right)} \tag{H.7}$$

where

the factor (1.2) is assumed to be the same as for Equation (H.3).

The total length of barrier needed to contain the layer when deflected (d_h) is given by Equation (H.8):

$$d_h = d_o + d_c\,\tan\left[\frac{\tan^{-1}\dfrac{d_c}{d_o}}{2}\right] \tag{H.8}$$

The solution method for d_h is as follows.

a) Assume a value for $d_h \geq d_o$.

b) Calculate d_c using Equation (H.7).

c) Calculate d_h using Equation (H.8).

d) Repeat steps a) to c) with new assumed values of d_h until the value of d_h calculated in step c) is acceptably close to the value assumed in step a) of the same iteration.

NOTE It is suggested that discrepancies of less than 1 % are acceptable. This is the correct value of d_h.

e) Apply a safety margin to allow for bowing of the barrier by adding an additional length $\Delta d_h = 1.7(d_h - d_o)$.

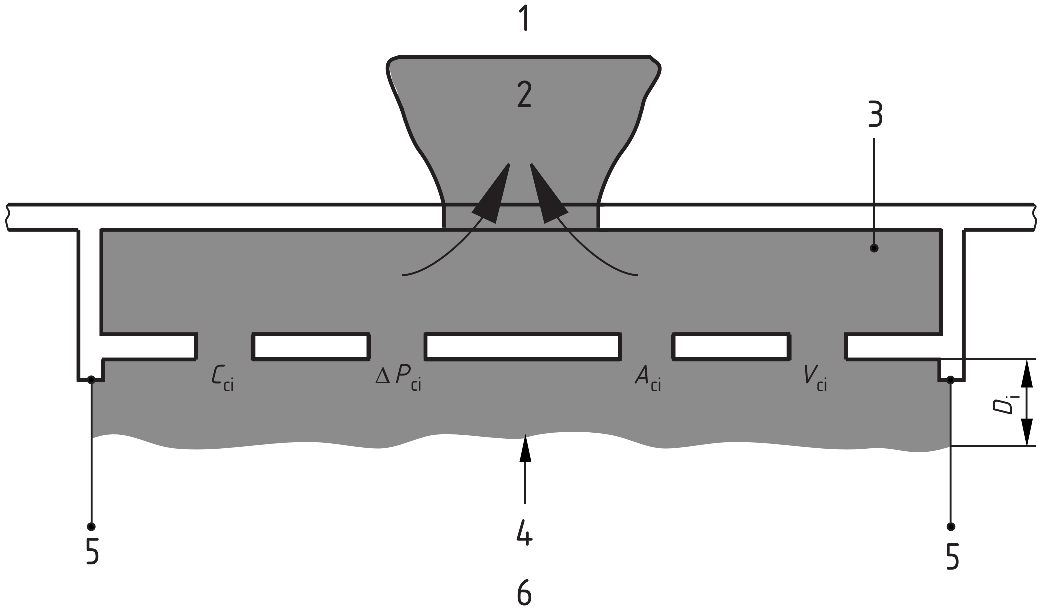
Hence the total installed length is $d_h + \Delta d_h$.

Annex I (informative)
Plenum chamber

I.1 General

A plenum chamber is a three-dimensional space inside a smoke reservoir or a space containing the smoke reservoir. It is limited above by an imperforate ceiling, e.g. roof or balcony, and on its sides by smoke tight structures, e.g. walls, structural downstands or smoke screens, and below by a suspended ceiling having less than 25 % of geometrical free area capable of being penetrated by smoke. Within a plenum chamber an under pressure is caused either by natural or powered exhaust ventilation so that smoke inside this space is removed directly. Smoke from below the suspended ceiling is drawn into the plenum chamber through the openings of the suspended ceiling into the space, from where it is removed by the natural or powered exhaust ventilation. Figure I.1 illustrates this principle.

Two types of plenum can be identified: naturally vented plenums and powered vented plenums.



Key

1	Exhaust either by natural or powered ventilation
2	AvCv or Vfan
3	ΔP_{ci}
4	Smoke layer base
5	Smoke barrier
6	Ambient conditions

Figure I.1 — Plenum chamber

I.2 Naturally ventilated plenums

For design purposes the naturally vented plenum chamber can be regarded as an equivalent natural ventilator having the following features.

Its lower boundary, i.e. the limit of the plenum chamber downwards, is the suspended ceiling. Therefore the depth of the smoke layer, d_l, for reservoir design purposes is measured down from the suspended ceiling to the smoke base below it.

NOTE However, in order to calculate the performance of the natural smoke exhaust ventilators the depth of layer is specified as that below the centre of the ventilators exhausting smoky gases from the plenum to the exterior.

The effect of the plenum chamber on the exhaust ventilation can be expressed as an equivalent coefficient of performance, which is applied to the total area of the ventilators exhausting from the plenum to the exterior. This combines the effect of the openings in the suspended ceiling and the ventilators exhausting from the plenum chamber to the exterior.

The effective free area of the combination, $C_{\mathrm{equivalent}}A_{\mathrm{vtot}}$, can be found from Equation (I.1):

$$\frac{1}{(C_{\mathrm{v}}A_{\mathrm{v}})^2}+\sum_i \frac{1}{(C_{\mathrm{ci}}A_{\mathrm{ci}})^2} = \frac{1}{(C_{\mathrm{equivalent}}A_{\mathrm{vtot}})^2} \tag{I.1}$$

This aerodynamic free area, $C_{\mathrm{equivalent}}A_{\mathrm{vtot}}$, of the equivalent plenum chamber ventilator can be used in Equation (F.6) or (F.7) when calculating the natural ventilation performance of the SHEVS.

I.3 Powered ventilated plenums

The top of the buoyant smoke reservoir layer is again taken as the suspended ceiling (in a similar way to naturally ventilated plenums).

The powered ventilator/s exhausting from the plenum chamber cause a pressure difference, Δp_{fan}, between the plenum chamber and the top of the smoke layer below.

The designed volume flow, V_l, which is exhausted from the smoke layer beneath the plenum chamber, can be calculated in accordance with **6.6** and is equal to the sum of the volume flows, V_{ci}, through the separate openings into the plenum chamber through the suspended ceiling.

The volume flows, V_{ci}, caused by Δp_{fan} and the resulting pressure losses, Δp_{ci}, due to the flow impedance can be calculated using common HVAC calculation methods, i.e. Δp_{fan} is adjusted so that the pressure losses, Δp_{ci}, at exhaust openings are overcome and:

$$\overset{\circ}{V}_l = \sum_i \overset{\circ}{V}_{ci} \tag{I.2}$$

The maximum value, Δp_{ci}, is used by the designer as the base pressure differential system needed to achieve a differential pressure.

Annex J (informative)
Atrium depressurization

J.1 Principles of depressurization

J.1.1 *Natural depressurization*

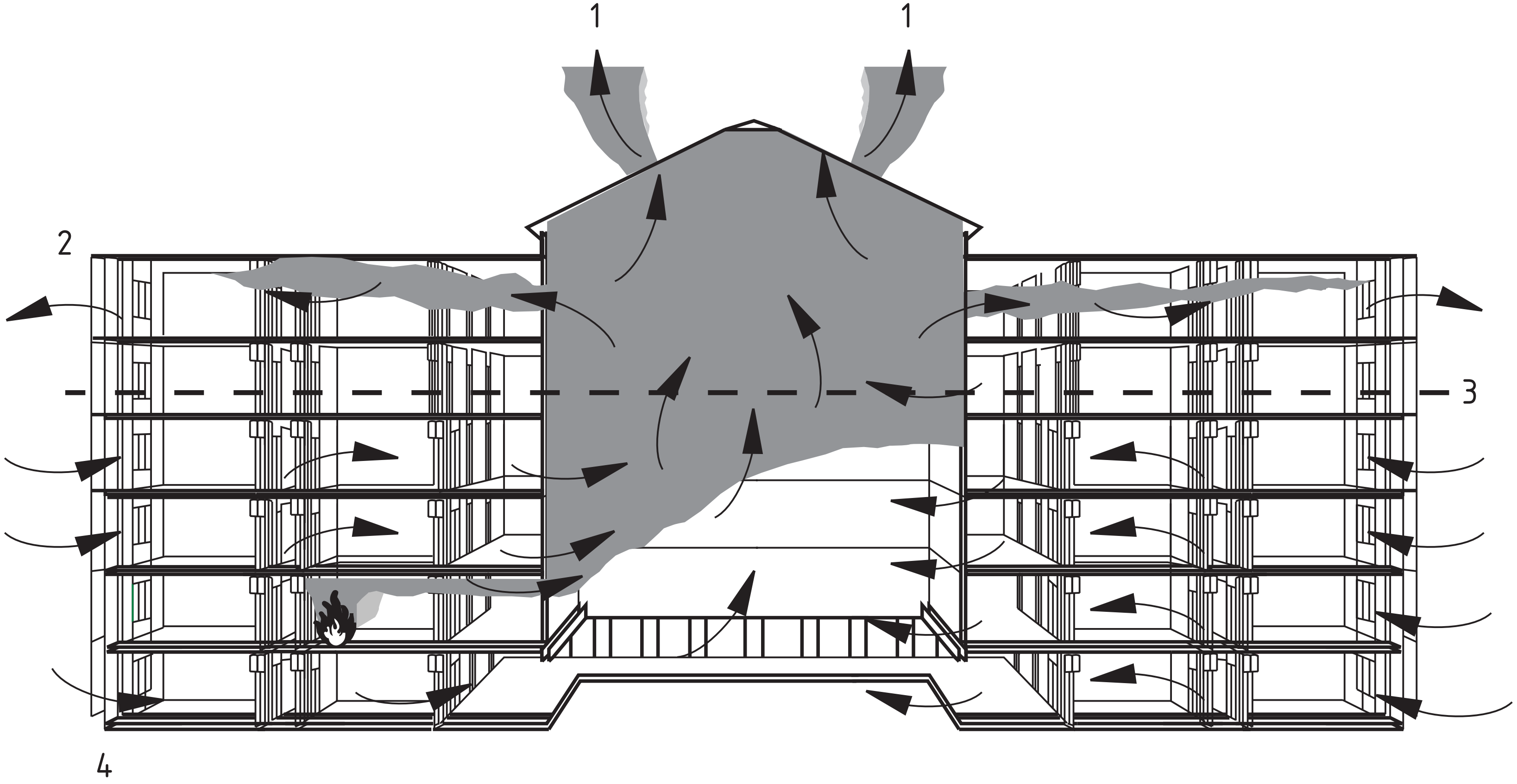
In any structure with natural ventilation openings at high and low levels, and with a quantity of heat trapped inside, a ventilation rate is created due to the stack effect.

In order for air to move out through the high-level opening, the internal pressure at high-level is greater than the external pressure, otherwise there would be no air movement. Similarly, for air to flow inwards at low level the internal pressure at low level is less than that outside. Thus there is a position within the structure where the pressure inside is equal to that outside. This is known as the neutral pressure plane (NPP). Openings situated at the NPP have no airflow through them, since there is no pressure differential at that point.

In buildings where a throughflow ventilation system is installed and the inlet vent area is equal to the exhaust vent area, the NPP exists approximately midway within the smoke layer (see Figure J.1). If the inlet vent area is smaller than the exhaust vent area, then the NPP moves upwards (see Figure J.2).

Openings above the NPP are under a positive pressure (defined as positive outwards from the atrium). Thus there is a flow of smoke from the atrium into rooms above the NPP through any leakage path that might exist.

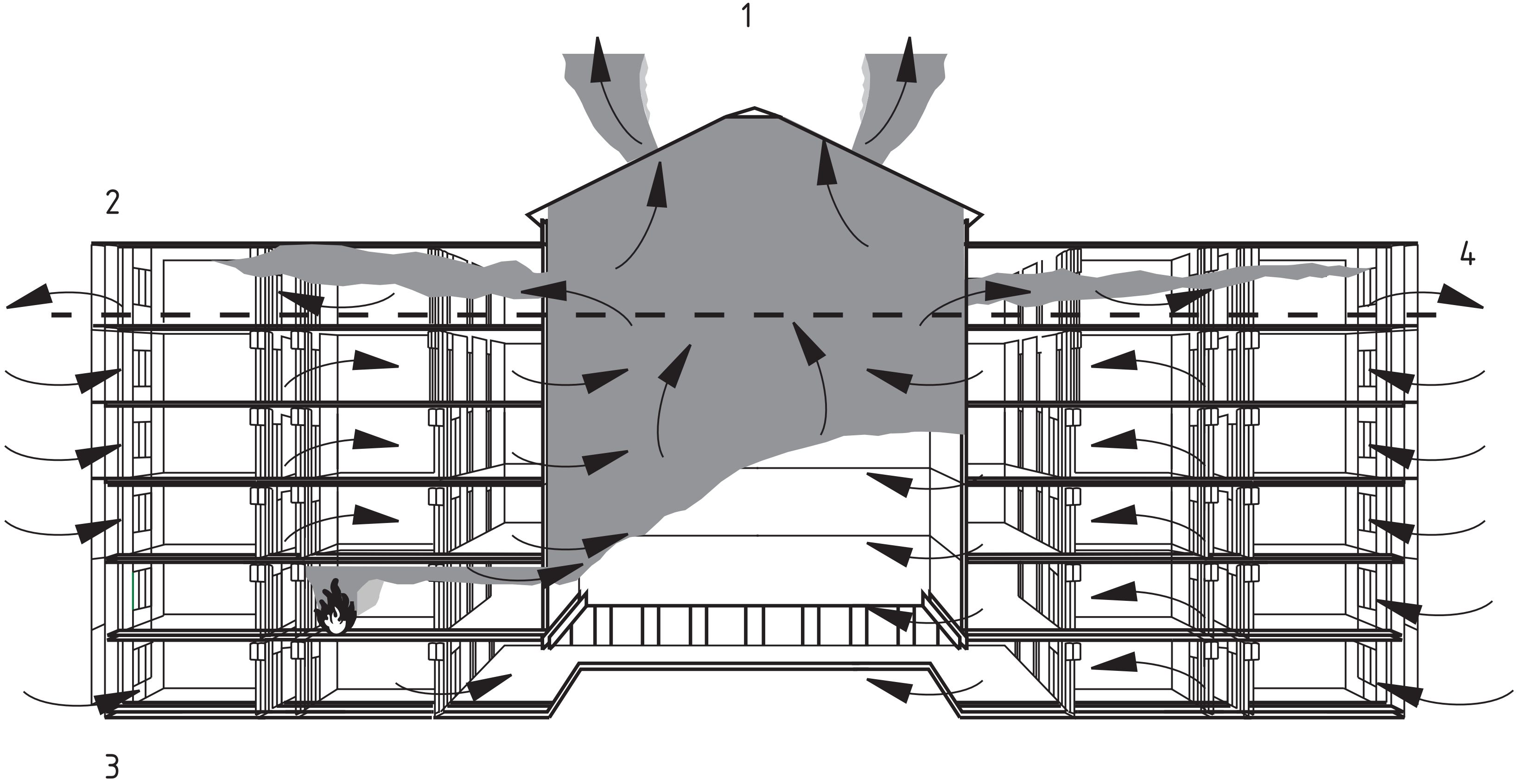
However, careful manipulation of the NPP can raise it to a safe height above sensitive levels, where there is little or no threat from the positive pressure above (see Figure J.3).



Key

1 Open ventilation
2 Leakage
3 Neutral pressure plane
4 Inlet: equals vent area

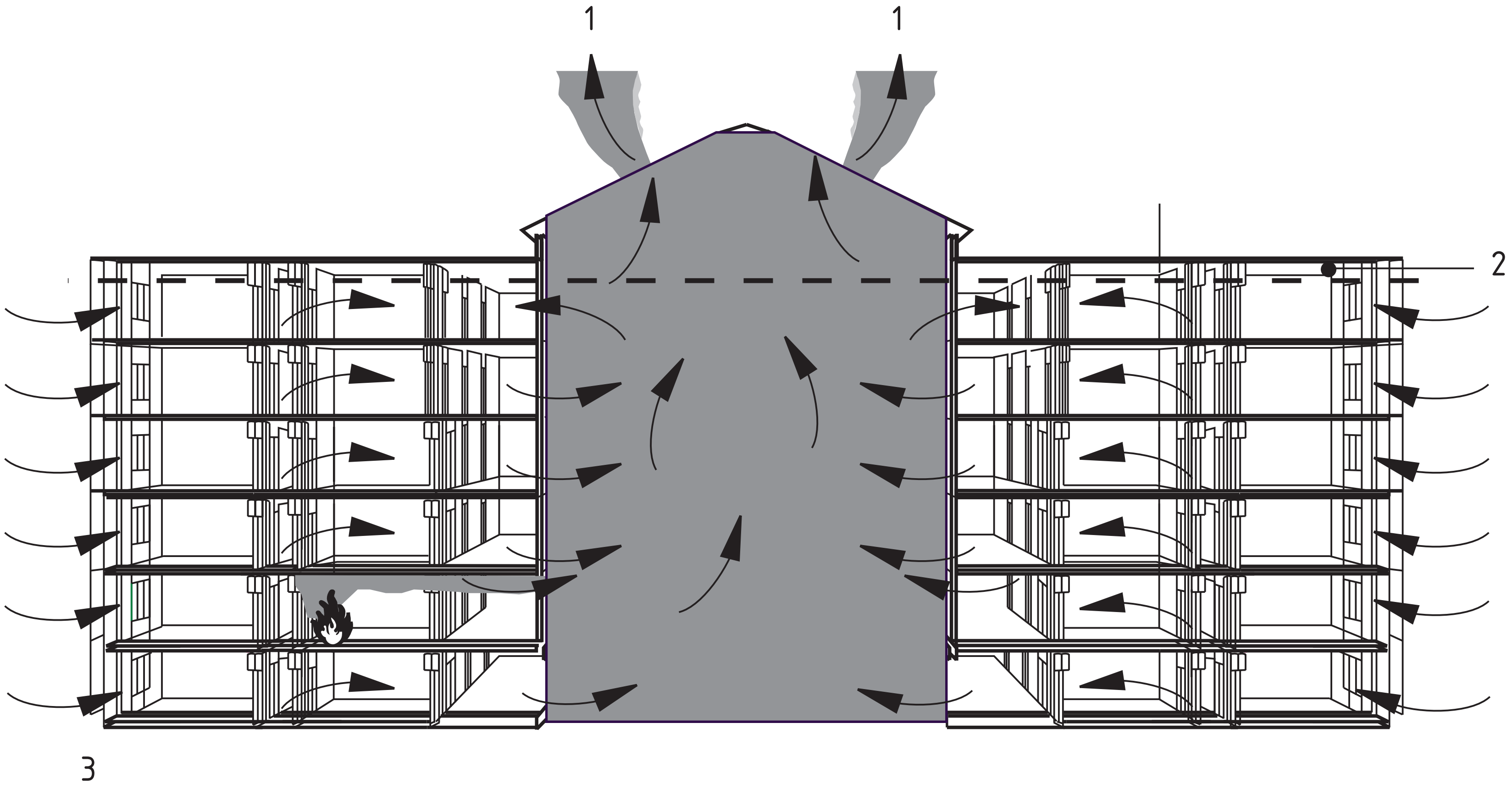
Figure J.1 — Neutral pressure plane – throughflow ventilation



Key

1	Open ventilation
2	Leakage
3	Inlet smaller than vent area
4	Neutral pressure plane

Figure J.2 — Neutral pressure plane – exhaust larger than inlet



Key

1	Open ventilation
2	Neutral pressure plane
3	Inlet much smaller than vent area

Figure J.3 — Neutral pressure plane above highest leaky storey

The pressure in the atrium below the NPP is at a lower pressure than the ambient pressure, thus any airflow is from the room into the atrium. Hence the levels below the NPP are protected from heat and smoke contamination.

The NPP lies somewhere within the depth of the smoke layer in the atrium depending upon factors such as inlet/vent area ratio, gas temperatures, wind pressures, etc. It is not the actual base of the smoke layer, although this confusion can arise.

The equation describing the above relationship, in the absence of wind effects is as follows:

$$\frac{(C_{\mathrm{v}}A_{\mathrm{vtot}})^2}{(C_{\mathrm{i}}A_{\mathrm{i}})^2} = \frac{T_{\mathrm{l}}}{T_{\mathrm{amb}}\left[\dfrac{d_{\mathrm{lv}}}{\psi} - 1\right]} \tag{J.1}$$

Equation (J.1) represents the condition where the atrium has a dominant inlet leakage path from the exterior, e.g. access doors, but smaller leakage paths between the atrium, the accommodation and the exterior.

It is difficult to give a simple general rule to identify when a building can be regarded as having a single dominant inlet. Nevertheless, it can be sufficient to adopt the following guideline from the related field of air infiltration. A dominant inlet can be assumed if the total area of all openings below the layer base is more than twice the total area of all openings above the layer base (excluding the area of the ventilators themselves).

With the above technique it is possible for the atrium to be entirely filled with smoke in which case d_{lv} approaches the height of the atrium (H), i.e. d_{lv} -> H.

Where the smoke layer temperature has been determined, e.g. from **6.6**, it is a straightforward task to calculate the ventilation rates for a pure depressurization system using Equation (J.1).

If the NPP were to descend below the desired design depth then some of the higher storeys might become endangered. This can arise from an increase in the actual inlet leakage area available, for example where the fire brigade have opened access doors to the atrium to investigate the severity of the fire. A successful depressurization design can prevent smoke infiltration into adjacent spaces on the higher floors even in this condition.

In addition, it is possible that the fire might cause windows to break on both the external façade and the atrium façade of the fire-room. In this case the broken areas can act as a dominant leakage path from the exterior.

Thus it is necessary to assess all potential inlet leakage paths when using Equation (J.1).

The simple approach set out here is invalid where the leakage paths across the atrium boundary have appreciable areas on several storeys [although all leakage areas below the smoke layer's base can be aggregated and regarded as being at the layer's base for calculation purposes using Equation (J.1)]. Where there are appreciable significant leakage paths on several storeys above the layer's base the same depressurization principle can be employed, but a more complicated flow network calculation is then used. This is outside the scope of this standard.

J.1.2 *Natural depressurization and wind pressures*

The NPP is sensitive to the effects of wind, and adverse wind pressures might cause the NPP to fall to a lower position on the leeward side of the building, possibly contaminating the topmost leeward storeys. It follows that the depressurization design procedure needs to take wind force into account.

To assess the efficiency of operation of a depressurization system a knowledge of the wind pressure coefficients acting upon a building is necessary.

NOTE These coefficients relate the wind pressure anywhere on a building to the wind velocity at roof level.

Wind pressure coefficients have often been measured so that structural wind-loading can be calculated. DD ENV 1991-2-4 describes such a procedure.

Where complete certainty is desirable for a novel or complicated building, wind-tunnel observations using scale models yield usable results. In practice, it would be necessary to identify the most pessimistic values for each storey, in which case the problem can be simplified to a two-dimensional problem.

For a dominant inlet opening, to prevent smoke leakage into the top leeward storeys for all wind speeds, Equations (J.2) and (J.3) apply.

$$\left[(\Omega - 1)C_{\mathrm{pv}} - \Omega C_{\mathrm{pl}} + C_{\mathrm{pi}}\right] \leq 0 \tag{J.2}$$

$$\Omega = \frac{T_{\mathrm{amb}}}{T_{\mathrm{l}}}\left[\frac{C_{\mathrm{v}}A_{\mathrm{vtot}}}{C_{\mathrm{i}}A_{\mathrm{i}}}\right]^2 + 1 \tag{J.3}$$

Providing the values of Equation (J.2) are satisfied, a natural ventilation system works at all wind speeds. This implies that the roof ventilation system is subjected to suction wind pressures at all times. However, if it is impossible to employ a natural ventilator on a particular building, fans can be used instead.

J.1.3 *Powered depressurization*

The necessary fan capacity is more difficult to calculate. The most effective fan is one that is not affected by wind pressures on its exhaust. With a fan however, a maximum wind speed is always assumed for design purposes. The recommended volumetric flow rate can be calculated using Equation (J.4):

$$V_{\mathrm{l}} = \left[\frac{T_{\mathrm{l}}C_{\mathrm{i}}A_{\mathrm{i}}}{T_{\mathrm{amb}}}\right]\left[(C_{\mathrm{pi}} - C_{\mathrm{pl}})v^2{}_{\mathrm{wind}} + \frac{2g\theta_{\mathrm{l}}\Psi}{T_{\mathrm{l}}}\right]^{1/2} \tag{J.4}$$

where

V_{l} is the fan capacity recommended in metres cubed per second ($\mathrm{m}^3\cdot\mathrm{s}^{-1}$);

$v^2{}_{\mathrm{wind}}$ is the design wind velocity in metres per second ($\mathrm{m}\cdot\mathrm{s}^{-1}$).

A natural smoke control system is affected by the wind pressures operating against all the openings in the structure. Thus, pressure differentials vary with wind direction and opening position, and the throughflow of air varies with wind velocity.

However, when the hole in the roof is replaced by a fan, it is necessary to change the pressure differentials within the building by mechanically altering the throughflow of air and to design the system with a maximum design wind velocity to cater for all significant conditions.

Further sophistication can be achieved by the use of an anemometer and by having groups of fans, each group operating at a different wind speed. So if the wind speed is low, one group of fans would operate and, if the wind speed increases, further groups might be activated as necessary.

J.2 Depressurization combined with a SHEVS (a hybrid system)

J.2.1 *Mass flow-based system*

NOTE Figure J.4 illustrates an example of a mass flow-based system.

The following procedure applies for a mass flow-based system.

a) Determine the height of rise of the smoke plume, with the design fire chosen to be on the lowest open level. This also gives the smoke layer depth (d_{lv}), measured from the centre line of the ventilator.

b) Determine the mass flow rate (M_1) entering the base of the layer using the procedures given in **6.1**, **6.2**, **6.3**, **6.4** and **6.5**.

c) Determine the smoke layer temperature, using the procedure given in **6.6**. If the smoke layer temperature is below 20 °C above ambient temperature then the height of rise of plume might need to be reconsidered, or some (or all) of the lower levels vented independently from the atrium.

d) Set the NPP height (Ψ) to that recommended in **6.11.2.3** above the base of the smoke layer, and determine the value of $(C_v A_{vtot}/C_i A_i)^2$ from Equation (J.1).

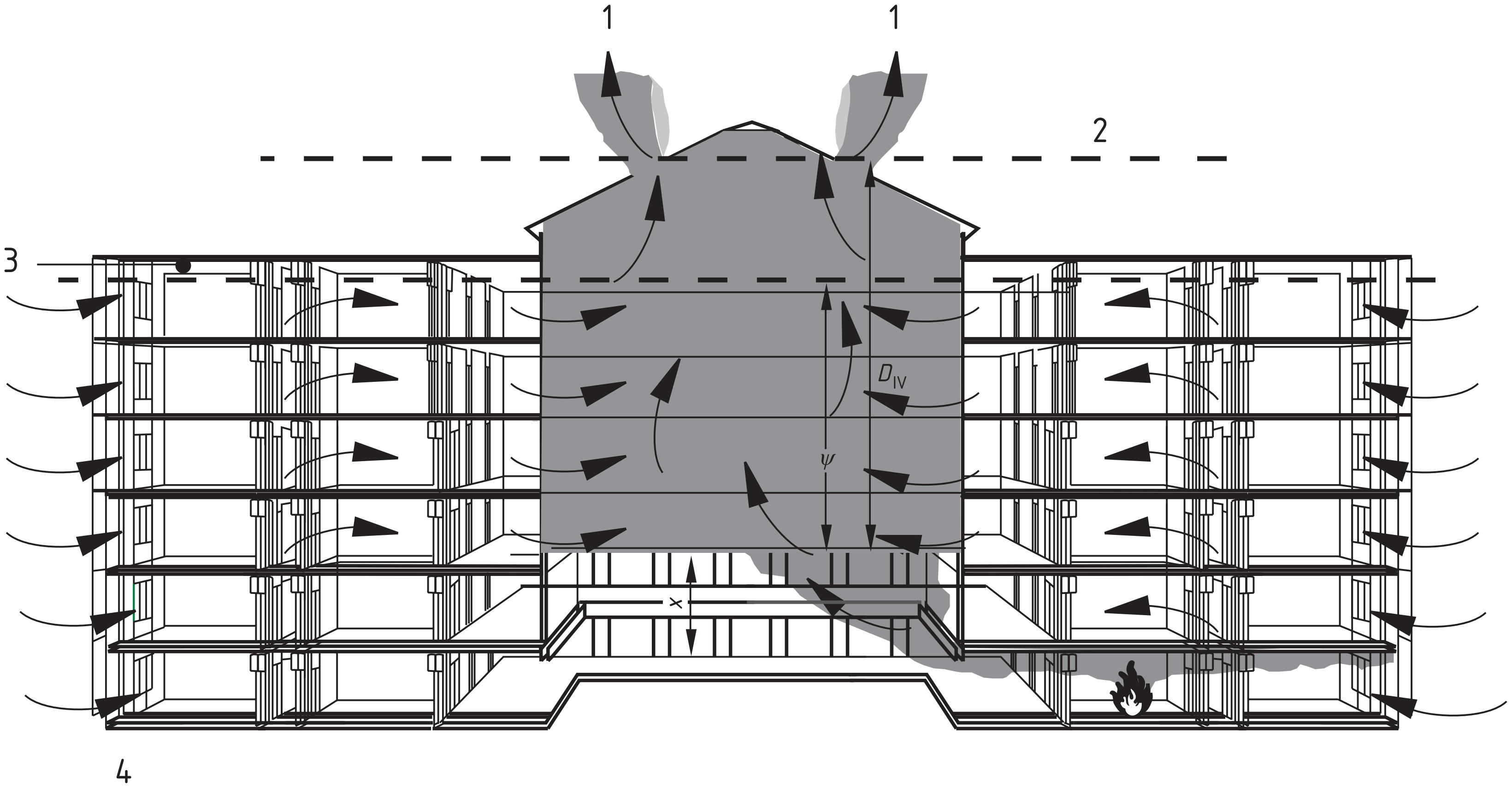
e) Using the values of $(C_v A_{vtot}/C_i A_i)^2$, d_{lv}, M_1 and Θ_1, calculate the ventilation area using the procedure given in **6.6**.

f) With the values of $(C_v A_{vtot}/C_i A_i)^2$ and $C_v A_{vtot}$ known, calculate the quantity of inlet ventilation. In the event that the actual inlet area available is greater than that recommended by calculation, then the ventilation area needs to be increased to maintain the ratio of $(C_v A_{vtot}/C_i A_i)$.

g) Using Equations (J.2) and (J.3) and the appropriate wind pressure coefficients, check the system operation with regard to wind effects.

h) In the event that the wind effects might adversely affect the operation of a natural ventilation system or if a powered smoke and heat exhaust ventilation system is employed for other reasons, calculate the fan capacity using Equation (J.4), with an appropriate value of design wind velocity.

i) Check that the anticipated suction pressure and/or air inflow velocities do not in themselves endanger the safe use of any escape routes away from the atrium (see **6.8**).



Key

1	Open ventilation
2	Centre line of ventilators AvCv
3	Neutral pressure plane
4	Inlet AiCi

Figure J.4 — Principles of hybrid smoke ventilation system – mass flow-based

J.2.2 *Temperature-based systems*

NOTE Figure J.5 illustrates an example of a temperature-based system.

The following procedure applies for a temperature-based system.

a) Decide upon a smoke layer temperature rise (Θ_l) compatible with the façade material employed.

b) Determine the mass flow rate using Equation (B.3).

c) Using the procedures given in **6.1**, **6.2**, **6.3**, **6.4** and **6.5** determine the height of rise (Y) to the base of the layer necessary to give the calculated mass flow rate.

d) With the design fire at the lowest level and taking into account the necessary height of rise (Y) for cooling purposes, determine the maximum smoke layer depth (d_{lv}). Set the NPP height (Ψ) to that recommended in **6.11.2.3** above the base of this smoke layer depth, and determine the value of $(C_v A_{vtot}/C_i A_i)^2$ from Equation (J.1).

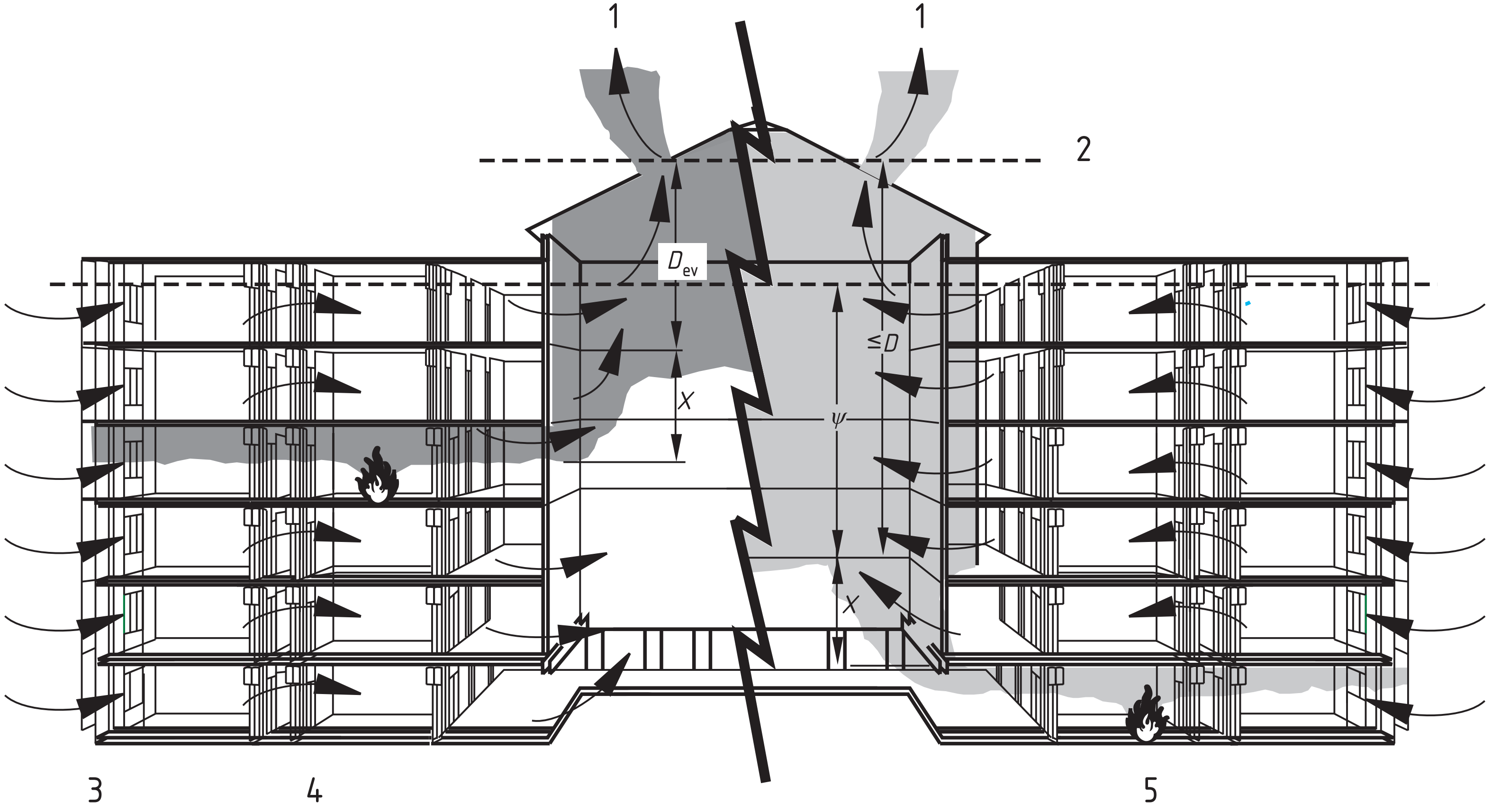
e) With the recommended value of Y, determine the shallowest smoke layer depth (d_{lv}), compatible with the depressurization concept.

f) With these values of $(C_v A_{vtot}/C_i A_i)^2$, d_{lv}, M_l and Θ_l calculate the ventilation area using **6.6**. In the event that the actual inlet area available is greater than that recommended by calculation, then the ventilation area should be increased to maintain the ratio of $(C_v A_{vtot}/C_i A_i)$.

g) Using Equations (J.2) and (J.3) and the appropriate wind pressure coefficients, check the system operation with regard to wind effects.

h) In the event that the wind effects might adversely affect the operation of a natural ventilation system or if a powered smoke and heat exhaust ventilation system is employed for other reasons, calculate the fan capacity using Equation (J.4), with the appropriate value of design wind velocity.

i) Check that the anticipated suction pressure and/or air inflow velocities do not in themselves endanger the safe use of any escape routes away from the atrium (see **6.8**).



Key

1	Open ventilation
2	Centre line of ventilators
3	Inlet AiCi
4	Situation A
5	Situation B

Figure J.5 — Principles of hybrid smoke ventilation system – temperature-based

Annex K (informative)
The interaction of sprinklers, a SHEVS and fire-fighting actions

K.1 Objectives and single systems

K.1.1 *Protection of means of escape (life safety)*

A SHEVS is often used to protect the means of escape, regardless of the expected time of arrival of the fire services.

A SHEVS is not able to cope with fires larger than the assumed design size.

Sprinklers (without a SHEVS) are not always specified to protect means of escape in buildings although it is recognized that they can provide a useful contribution by delaying the build-up of smoke and heat as a side benefit to controlling the fire. Quick response sprinklers are more effective in a life safety role than standard response sprinklers.

K.1.2 *Property protection*

Sprinklers reduce the probability of a fire becoming large. A sprinkler system aids the fire brigade by keeping the fires small, since it is easier for them to fight small fires more effectively with less damage.

Generally the SHEVS helps the fire service by creating a smoke free zone. SHEVS cannot control the fire growth. They delay the filling of the building with smoke and delay the rise of gas temperatures in the thermally buoyant smoke layer.

K.2 Objectives and combined systems

K.2.1 *Protection of means of escape (life safety)*

The main combined system for protecting the escape of occupants in the event of fire consists of a SHEVS assisted by sprinklers, whose primary purpose is to control the fire within a size within the capability of the SHEVS. Sprinklers can also reduce the threat to life of fire-fighters by controlling fire size. Vents can reduce the threat to life of fire-fighters by preventing the possibility of backdraft, and also by reducing the possibility of fire-fighters becoming disorientated and lost in smoke.

K.2.2 *Property protection*

In practice, many fires are controlled by sprinklers, but are extinguished by the fire brigade and sprinklers acting together. SHEVS can be of tremendous benefit to the fire services. SHEVS are also only useful in protecting property when acting together with fire-fighting. They are, therefore, primarily viewed as an adjunct to active fire-fighting. Sprinklers and vents together, but in the absence of fire-fighting, are largely as effective as the sprinklers alone. Where the fire service attendance time is expected to be long it might be better to restrict ventilation of the fire until the fire service arrive and can operate the SHEVS by a manual switch.

K.3 Some further considerations for combining SHEVS and sprinklers

K.3.1 Local effects of the sprinkler spray on nearby natural ventilators can reduce the efficiency of those ventilators. Since it is usually unlikely in a successful design that more than one natural ventilator will be affected, it is possible to adopt the guideline of discounting one ventilator.

It is necessary to always fit at least one more ventilator than is recommended by design calculations that ignore local SHEV/sprinkler interactions.

K.3.2 Each fan intake can be regarded as equivalent to a natural ventilator for the purposes of **K.3.1**.

NOTE It is necessary for designers of buildings with both SHEVS and sprinklers to consciously avoid creating situations where a localized downdrag of smoke could obscure an escape route from another region of the building.

Annex L (informative) The effect of a buoyant layer on the minimum pressure recommended for a pressure differential system

L.1 Assessment of height of the neutral pressure plane (NPP)

L.1.1 *General*

The height of the NPP is assessed from the depth, D, calculated in **6.6**, the temperature, Θ_c, of the buoyant smoke layer and the ventilator and inlet parameters, including the mass exhaust rate of smoky gases (M_e).

L.1.2 *With a dominant inlet*

A dominant inlet occurs when the total area of inlets below the smoke layer's base is more than twice the total area of all openings, other than the ventilators themselves, above the smoke layer's base.

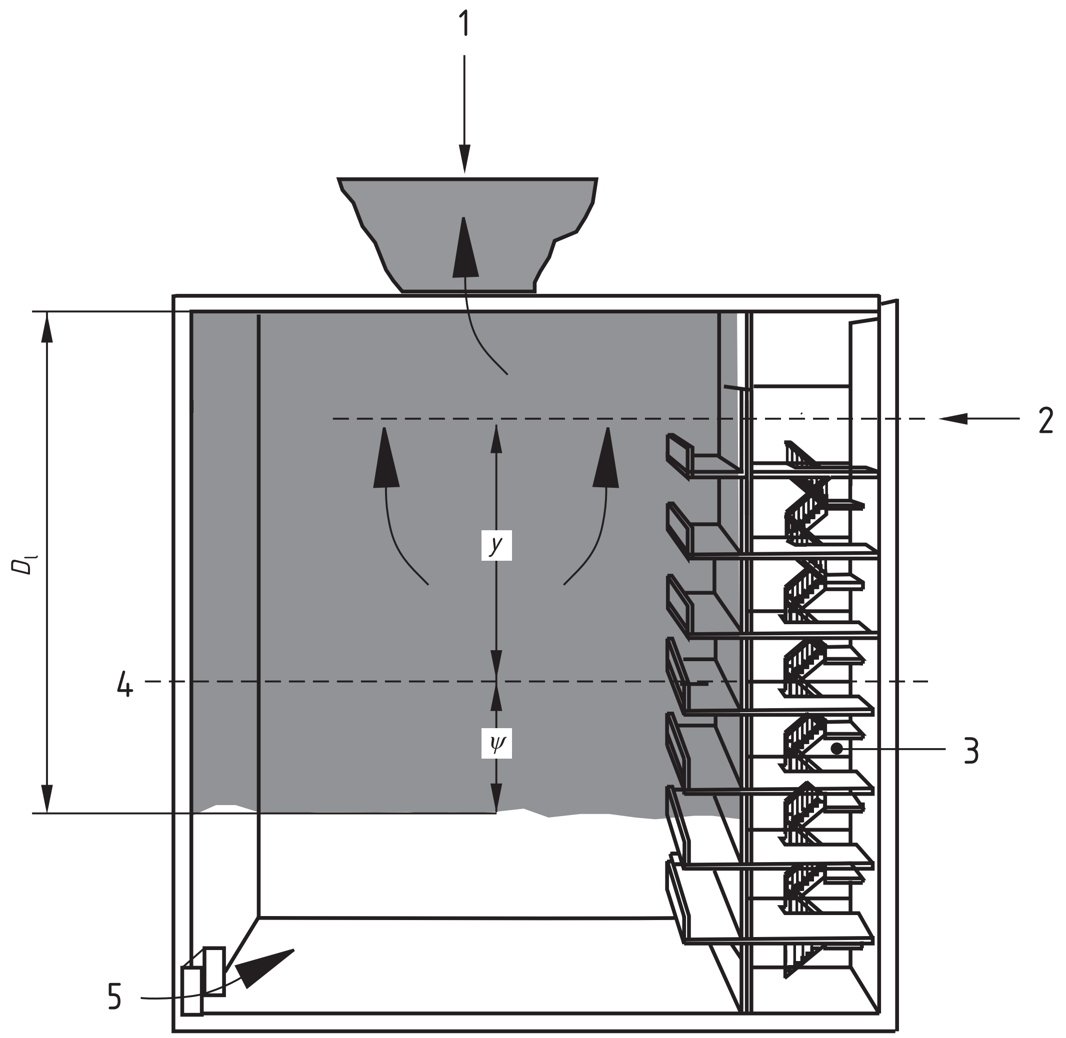
The height of the NPP above the base of the smoke layer for natural smoke and heat exhaust ventilators (neglecting wind effects) is given by Equation (L.1) (see also Figure L.1):

$$\psi = \frac{d_{lv} T_{amb} r^2}{T_{amb} r^2 + T_l} \qquad \text{(L.1)}$$

where

$$r = \frac{C_v A_{vtot}}{C_i A_i};$$

$C_i A_i$ is the total aerodynamic free area of the dominant inlet, i.e. of all inlets below the smoke layer's base.



Key

1	Smoke exhaust M_e ($A_v C_v$ if a natural ventilator)
2	Height of highest leakage path to pressurized space
3	Pressurized space
4	Height of Neutral pressure plane
5	Inlet $A_i C_i$

Figure L.1 — The neutral pressure plane and layer buoyant pressure

For powered smoke and heat exhaust ventilators neglecting wind effects Equation (L.2) applies (see also Figure L.1):

$$\psi = \frac{T_l M_l^2}{2g\theta_l \rho_{amb}^2 (C_i A_i)^2} \qquad \text{(L.2)}$$

L.1.3 *With no dominant inlet*

Where there is no dominant inlet there is no simple calculation, and it is necessary to calculate the height using a flow network analysis considering all significant leakage paths. This is outside the scope of this standard.

L.2 The pressure rise at a specified height above the NPP

The buoyant pressure at a height y above the NPP is expressed as follows:

$$\Delta p_y = \frac{\theta_l}{T_l} \rho_{amb} g y \qquad \text{(L.3)}$$

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[1] Parts 5 to 8 and 13 are published as BS EN 12094-5, BS EN 12094-6, BS EN 12094-7, BS EN 12094-8 and BS EN 12094-13. Parts 1 to 4, 9 to 12 and 16 are in preparation.

[2] Part 3 is published as BS EN 12101-3. Parts 1, 2, 4 and 6 are in preparation.

[3] Parts 1 to 4 are published as BS 12259-1, BS 12259-2, BS 12259-3 and BS 12259-4. Parts 5 and 9 to 12 are in preparation.

[4] In preparation.

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