

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

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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
- Institution of Fire Engineers
- London Fire and Emergency Planning Authority
- OPDM — Building Regulation Division
- ODPM — Office of the Deputy Prime Minister
- Smoke Vent Association
- Steel Window Association
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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:

- CO₂ 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

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 83 and a back cover.

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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.

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 $50 \text{ m}^{1/2} \text{ s}^{1/2}$ 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 $100 \text{ m}^{1/2}\text{s}^{1/2}$ and $200 \text{ m}^{1/2}\text{s}^{1/2}$

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
$C_{ci}A_{ci}$	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	$kg \cdot m^{-5/2} \cdot s^{-1}$	Entrainment coefficient for a large fire plume
$C_{equivalent}$	—	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	$kJ \cdot kg^{-1} \cdot K^{-1}$	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	$\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$	Turning moment per horizontal metre of smoke barrier deflecting that barrier away from the vertical due to buoyant pressure
G_2	$\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$	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	$\text{m} \cdot \text{s}^{-2}$	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	$\text{kg} \cdot \text{s}^{-1}$	Mass flow rate of smoky gases flowing beneath a balcony or projecting canopy outside the opening from a fire-room
M_{crit}	$\text{kg} \cdot \text{s}^{-1}$	Maximum smoke exhaust rate possible through an individual ventilator without causing plugholing
M_f	$\text{kg} \cdot \text{s}^{-1}$	Mass flow rate of smoky gases rising through a specified height above the fire
M_l	$\text{kg} \cdot \text{s}^{-1}$	Mass flow rate of smoky gases entering the smoke reservoir's buoyant layer
M_n	$\text{kg} \cdot \text{s}^{-1}$	Mass exhaust rate through the n'th ventilator
M_s	$\text{kg} \cdot \text{s}^{-1}$	Mass flow rate exhausted from a layer by all other fans except the slot extract
M_{slot}	$\text{kg} \cdot \text{s}^{-1}$	Mass flow rate of a buoyant layer approaching a slot extract
$M_{slot \text{ exhaust}}$	$\text{kg} \cdot \text{s}^{-1}$	Mass exhaust rate through a slot extract needed to prevent a buoyant layer of smoky gases flowing past the slot
M_w	$\text{kg} \cdot \text{s}^{-1}$	Mass flow rate of smoky gases passing through a vertical opening
M_X	$\text{kg} \cdot \text{s}^{-1}$	Total mass flow rate of smoky gases in a spill plume rising past height X
m	$\text{kg} \cdot \text{m}^{-1}$	Mass per metre length of bottom bar of a hanging smoke barrier
m_c	$\text{kg} \cdot \text{m}^{-2}$	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	$\text{kW}\cdot\text{m}^{-2}$	Heat release rate per square metre from the fire
$q_{f,(\text{low})}$	$\text{kW}\cdot\text{m}^{-2}$	Low value of q_f assumed as a default value
$q_{f,(\text{high})}$	$\text{kW}\cdot\text{m}^{-2}$	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_1	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}	$\text{m}^3\cdot\text{s}^{-1}$	Volume flow rate of smoky gases through an individual opening in a suspended ceiling into a plenum chamber above
V_1	$\text{m}^3\cdot\text{s}^{-1}$	Total volumetric exhaust rate from the smoke reservoir
v_{wind}	$\text{m}\cdot\text{s}^{-1}$	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_1	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	$\text{kg}\cdot\text{K}^{1/2}\cdot\text{L}^{-5/2}$	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}	$\text{kg} \cdot \text{m}^{-3}$	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 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].

4.2.2 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 $5 \text{ m} \cdot \text{s}^{-1}$ (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 $5 \text{ m}\cdot\text{s}^{-1}$.

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 4.1.2a) 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 4.1.2c)].

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 6.1.2f)];
- 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 4.1.2a) 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.

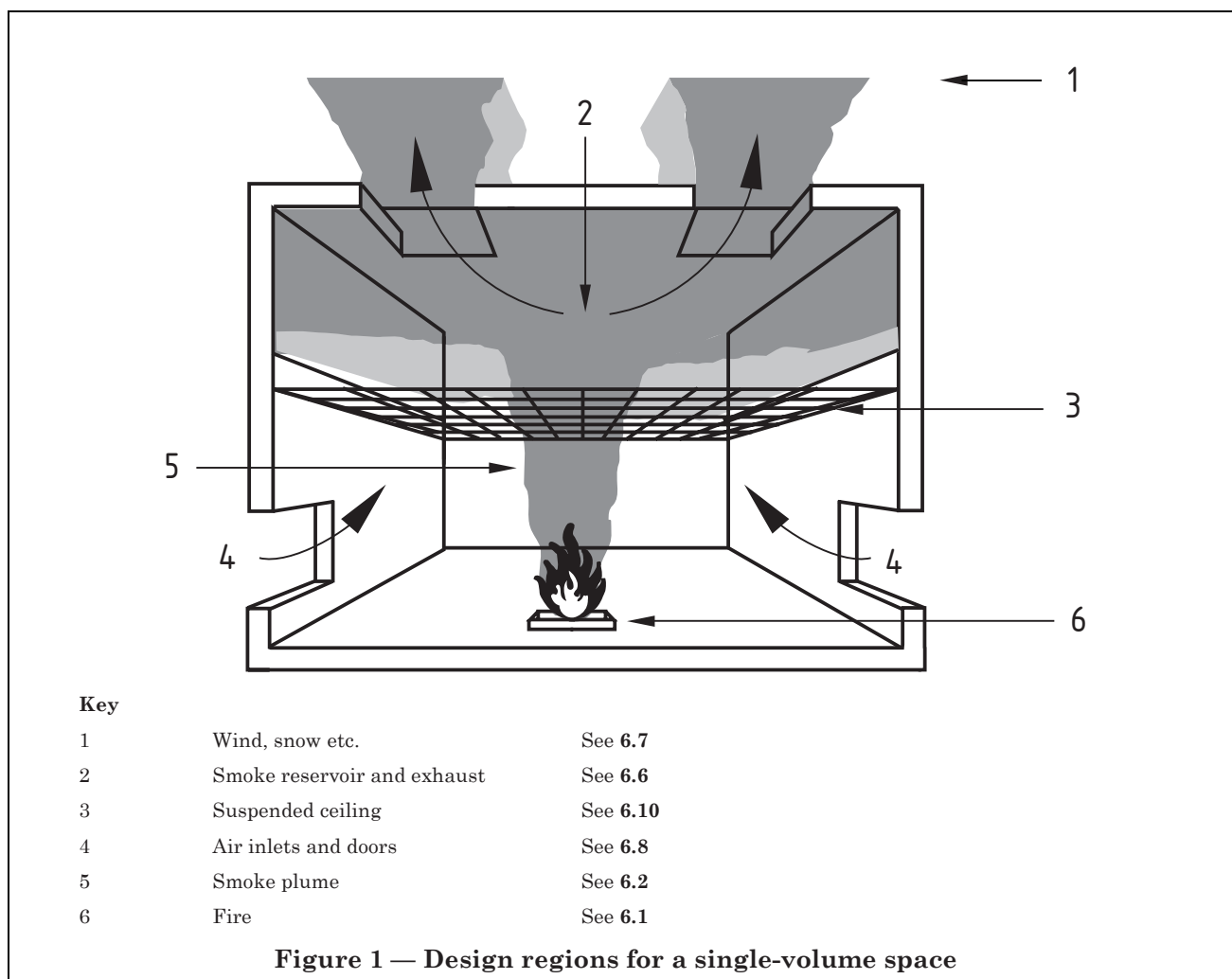
5.1.2 Recommendation

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.



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

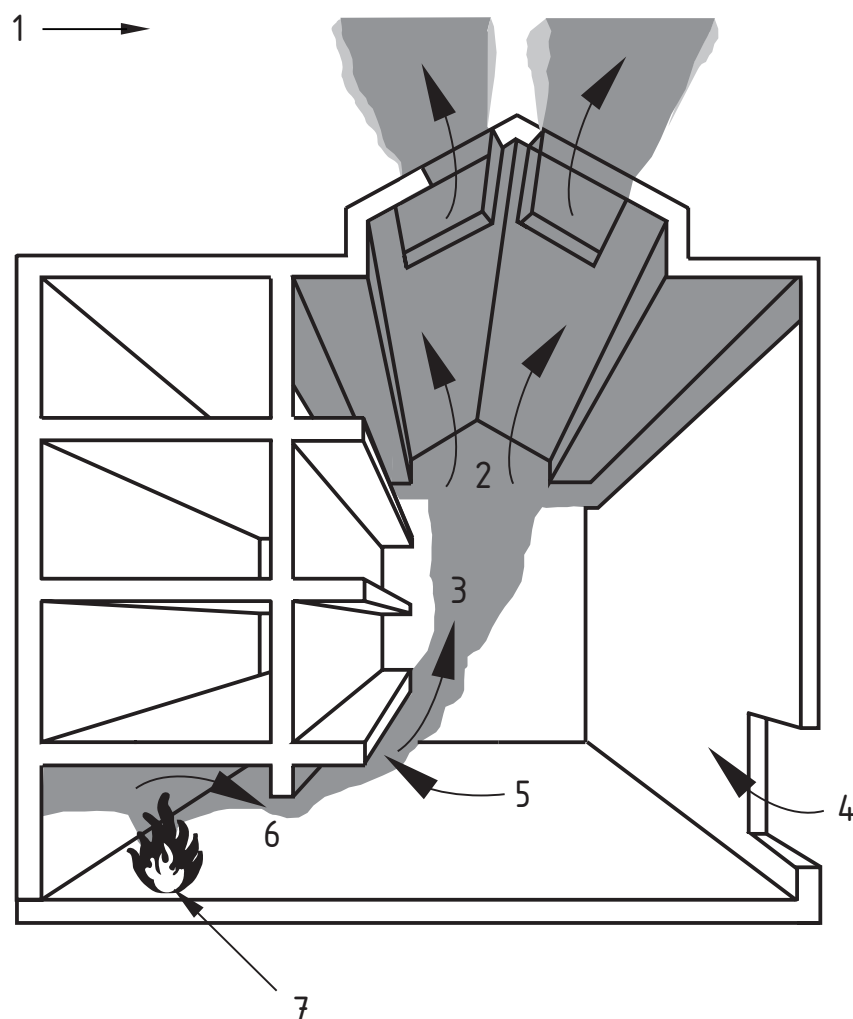
Since suspended ceilings, where present, can complicate the flow of smoky gases the design should take account of this following the recommendations in 6.10.

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