Components for smoke and heat control systems —

Part 5: Functional recommendations and calculation methods for smoke and heat exhaust ventilation systems, employing time-dependent design fires — Code of practice

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Committees responsible for this British Standard

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Building Services Research and Information Association (BSRIA)

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Contents

Foreword

This part of BS 7346 was prepared under the direction of Technical Committee FSH/25. The other parts that comprise BS 7346 are as follows:

— 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*;

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

— Part 6: *Specification for cable systems*.

Parts 1, 2 and 3 of BS 7346 will eventually be replaced by the equivalent parts of BS EN 12101. The parts of BS EN 12101, Smoke and heat control systems, relevant to BS 7346-5 will include:

— Part 1: *Specification for smoke barriers — Requirements and test methods*;

— Part 2: *Specification for natural smoke and heat exhaust ventilators*;

— Part 3: *Specification for powered smoke and heat exhaust ventilators*;

— Part 7: *Smoke control ducts*[1)];

— Part 8: *Specification for smoke control dampers*[1)];

— Part 9: *Control panels and emergency control panels*[1)];

— Part 10: *Power supplies*[1)].

This British Standard gives recommendations for the design of smoke and heat exhaust ventilation systems.

It is assumed in the drafting of a standard that the execution of its provisions is entrusted to appropriately qualified and competent people.

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.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

[1)] In preparation.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 36, an inside back cover and a back cover.

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Introduction

0.1 General

Smoke and heat exhaust ventilation systems (SHEVS) create a smoke-free layer above the floor by using the buoyancy of the smoke to form a layer beneath the ceiling above the smoke-free layer, and by removing smoke from that buoyant layer, they allow the continuation of clear conditions.

SHEVS are of value in:

— assisting in the evacuation of people and animals from buildings;

— preventing smoke logging by exhausting hot gases released by a fire in the developing stage;

NOTE Ventilation systems for smoke exhaust serve simultaneously for heat exhaust.

— reducing roof temperatures;

— retarding the lateral spread of fire;

— reducing fire damage to property and thereby financial loss;

— facilitating fire-fighting, while the fire is still in its early stages.

For these benefits to be obtained, it is essential that smoke and heat exhaust ventilators operate fully and reliably whenever called upon to do so during their installed life. A SHEVS is a scheme of safety equipment intended to perform a positive role in a fire emergency. Components for a SHEVS ought to be installed as part of a properly designed smoke and heat exhaust system.

Fire Safety Engineering (FSE) is the discipline whereby Fire Science is applied quantitatively to the design of buildings to ensure safety in the event of a fire. As such, the design procedures for a SHEVS can be seen as a subsidiary part of FSE, with FSE encompassing a much broader range of techniques and concerns. BS 7974 serves to guide the fire safety engineer through this wider field of application. It is the purpose of this British Standard to cover the design process for SHEVS in greater detail than is possible in BS 7974, and with a focus that is restricted to SHEVS. In brief summary, this British Standard is intended to be complementary to BS 7974 and is not to be regarded as an alternative to BS 7974.

This British Standard focuses on the design of SHEVS based on time-dependent design fires. It therefore complements BS 7346-4, which focuses on the design of SHEVS based on steady-state fires and which therefore bears a similar complementary relationship to BS 7974.

The flow of thermally buoyant smoky gases through a building depends on the properties of the gases and any influences imposed on the gases by the building through which the smoky gases pass. These influences include:

— the internal shape of the building controlling the flow path of the gases through the building;

— the heat losses from the smoky gases to the building;

— the heat losses to fire suppression systems in the building, such as sprinklers;

— the external shape and the situation of the building and the likely external pressure field.

The external pressure field is dominated by the wind. It follows that if SHEVS are to meet the recommended levels of performance in the building, it is essential that the design of that system takes explicit account of the shape of the building (external and internal) and of the external influences (e.g. wind). If the building roof design is uncomplicated and it is unlikely to be affected by high adjacent buildings, normal assessment methods will be appropriate. If this is not the case, the design process ought to employ calculation procedures or directly measured data appropriate to the building concerned. Such data may come from studies of the existing building, from scale-model studies, or from generically similar building data.

Natural SHEVS operate on the basis of the thermal buoyancy of the gases produced by a fire. Powered SHEVS operate on the basis of removing fire gases using mechanical devices, usually fans.

The performance of the installations depends for example on:

— the temperature of the smoke;

— the aerodynamic free area of the ventilators, or the volume of smoke exhausted by powered ventilators;

— the wind influence;

— size, geometry and location of the air inlets;

— size, geometry and location of smoke reservoirs;

— the time of actuation;

— the location and conditions of system (for example 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 structure and the time recommended for initiation of successful fire-fighting. These assessment procedures fall outside the scope of this British Standard, which only outlines procedures for calculating the times to the onset of danger. It is essential that the time required for safe evacuation, and for initiation of successful fire-fighting, is assessed as accurately as possible.

Whilst fire brigade target arrival times are detailed within other documents (for example PD 7974-5), the set-up time for the fire brigade will be specific to the building (and to some extent to the fire type and location). This set-up time is vital to bringing the fire under control and thus limiting smoke production. It is therefore necessary to agree with the appropriate fire authority both the SHEVS systems, and the effects of operational fire-fighting times. Wherever doubt exists about the accuracy of these latter times, the designer needs to calculate in a safety margin when comparing the time to danger against the time needed for success.

It is essential that fire growth curves are selected which are appropriate to the circumstances of the building occupancies, fuel arrangements, and sprinkler performance. It is the purpose of this British Standard to present recommendations and guidance for the design of smoke and heat exhaust ventilation based on time-dependent, or "growing" fires.

Many of the detailed calculation procedures, and most of the danger criteria defining the boundary between success and failure, are the same for time-dependent design fires as for steady-state design fires, and it is essential that this British Standard be used in conjunction with BS 7346-4.

0.2 Smoke exhaust ventilation design philosophies – steady-state and time-dependent designs

The fundamental objectives as given in **0.3** are the same for time-dependent fire designs as for steady-state fire designs but it is the way in which these objectives are approached that differs.

Where 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 fire is not to be confused with steady fires that achieve full size instantly and then burn steadily. Rather, the procedure assumes that a SHEVS that is able to cope with the largest fire assumed for design will also cope with the (usually earlier) smaller stages of the fire. Design procedures based on steady-state design fires are presented in BS 7346-4.

The purpose of a steady-state designed SHEVS, as described in BS 7346-4, is to ensure that the objective is achieved throughout the entire duration of the fire – with the recognized exception of an acceptably small proportion of fires that can grow larger than assumed by the design. For example, although there is a finite mathematical probability of a meteorite crashing into the building, the probability is regarded as being too small to consider during design.

The purpose in a time-dependent designed SHEVS is to ensure that the time between ignition of the fire and the onset of a significant danger is acceptably longer than the time required to succeed in the design objective. Even in a successful design, an acceptably small proportion of design fires will grow faster and/or larger than assumed for the design. For example, the extreme of a fast-growing fire is an explosion, although the probability of an explosion in most buildings will usually be too low to be worth considering in most SHEVS designs.

0.3 Objectives for time-dependent design fire SHEVS designs

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

The objective is to delay the onset of dangers on escape routes (which are in the same space as the fire) for a long enough time for people to evacuate safely, by creating by calculation a desired smoke-free height beneath a smoke layer, and exhausting smoke from that layer at a rate that will slow the downward filling of the space with smoke. If the clear height and smoke layer temperature remain sufficient for safety until the fire is brought under control (or the fuel is exhausted), the time available can become effectively infinite in the same way as for a steady-state design.

0.3.2 *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 same calculation procedures (formulae) as for **0.3.1** in a different way. The smoke exhaust can be designed to limit the temperature of the gases in the buoyant layer. This allows the use of materials that would otherwise be damaged by the hot gases. For example, where an atrium façade has glazing which is not fire resistant, 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. Further guidance on the incorporation of atria into new and existing buildings is given in BS 5588-7.

0.3.3 *Facilitating the fire-fighting operation*

In order for fire-fighters to successfully deal with a fire in a building, it is first necessary for them to drive their fire appliances to entrances giving 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, the distance can be long and involve travel to upper or lower levels. Even in single-storey buildings, the fire-fighters within will 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 also seriously hamper and delay fire-fighters' efforts to effect rescues and carry out fire-fighting operations. The provision of a SHEVS recommended to assist means of escape or to protect property will also aid fire-fighting. It is possible to design a SHEVS similar to that described in **0.3.1** to provide fire-fighters with a clear-air region below the buoyant smoke layer, which will not become dangerous to them, or have reduced visibility, for the time needed for them to find and control the fire.

This British Standard 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.

0.3.4 *Property protection*

Smoke exhaust ventilation does not by itself prevent fires growing larger. It guarantees that a fire in the ventilated space has a continued supply of oxygen. This, in turn, facilitates a quicker and more effective fire-fighting operation as described in **0.3.3**, which in turn results in a reduction in the damage caused by thermal decomposition products, hot gases and heat radiation and hence the protection of the building, equipment and furnishing.

0.4 Applications of smoke and heat exhaust ventilation

SHEVS help to:

- — keep the escape and access routes free from smoke;
- — facilitate fire-fighting operations by creating a smoke-free layer;
- — reduce the potential for flashover and thus full development of the fire;
- — protect equipment and furnishings;
- — reduce thermal effects on structural components during a fire;
- — reduce damage caused by thermal decomposition products and hot gases.

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

Examples include:

— single- and multi-storey shopping malls;

— single- and multi-storey industrial buildings and sprinklered warehouses;

— atria and complex buildings;

— enclosed car parks;

— stairways;

— tunnels;

— theatres.

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

Depending on differing circumstances and the building's surrounding environment, either powered or natural SHEVS can be used.

0.5 Other forms of smoke ventilation

Although the term smoke ventilation has been applied in the past to other design philosophies, none of the following are covered by this document:

— 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;

— smoke dilution, where wind-induced or fan-induced air currents mix with the smoke and other combustion products to dilute them to a safe concentration.

1 Scope

This British Standard gives functional recommendations and guidance on the calculation method for smoke and heat exhaust ventilation systems (SHEVS) for time-dependent design fires. A variety of building types is addressed.

For a pre-determined critical time, this British Standard can be used to determine required performance of a SHEVS needed to avoid the onset of a significant danger. Or, for a pre-determined SHEVS, this British Standard can be used to determine the time available between ignition and onset of significant danger.

This British Standard uses accepted and authoritative methods to define some design parameters, e.g. the time needed for safe evacuation or attendance time of the fire-fighting services. This information can be sought from other sources when generating the overall fire-safety concept for a specific building project.

Many of the detailed calculation procedures, and most of the danger criteria defining the boundary between success and failure, are the same for time-dependent design fires as for steady-state design fires, and it is essential that this British Standard be used in conjunction with BS 7346-4.

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 5588, *Fire precautions in the design, construction and use of buildings.*

BS 7346 (all parts), *Components for smoke and heat control systems.*

BS EN 54 (all parts), *Fire detection and fire alarm systems.*

BS EN 12101, *Smoke and heat control systems.*

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

BS EN 12845, *Fixed firefighting systems — Automatic sprinkler systems — Design, installation and maintenance.*

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

3.1.2
ambient
properties of the surroundings

3.1.3
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.

3.1.4
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

3.1.5
authority
organization or individual responsible for approving SHEVS equipment and procedures

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

3.1.6
calorimeter
device for measuring the heat produced by the combustion of a fuel material or an assembly of fuel materials

3.1.7
ceiling jet
flow of hot fire gases driven away from where the smoke plume impinges on the ceiling by the kinetic energy of the plume prior to impingement

3.1.8
coefficient of discharge
aerodynamic efficiency

ratio of actual flow rate, measured under specified conditions, to the theoretical flow rate through the ventilator (C_v), as defined in BS EN 12101-2, or through an inlet opening (C_i)

NOTE The coefficient of discharge takes into account any obstructions in the ventilator such as controls, louvres and vanes, and the effect of external side winds.

3.1.9
computer-based zone model
zone model expressed as a computer program

3.1.10
convective heat flux
total heat energy carried by the gases across a specified boundary per unit time

3.1.11
design fire
hypothetical fire having characteristics which are sufficiently severe for it to serve as the basis of the design of a SHEVS

3.1.12
exhaust ventilator
device used to move gases out of the building

3.1.13
external pressure field
pattern of air pressures distributed over the external surfaces of the building

NOTE External pressure field can be due to, e.g. wind.

3.1.14
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 fire compartment has regulatory connotations. The term is not to be confused with room of origin or fire cell.

3.1.15
fire perimeter
length of the horizontal circumference of burning fuel material(s)

3.1.16
fire suppression device
device for limiting the size of fires and/or extinguishing fires

NOTE A sprinkler is an example of a fire suppression device.

3.1.17
flashover
rapid transition to a state of total surface involvement in a fire of combustible materials within an enclosure

3.1.18
free-hanging smoke barrier
smoke barrier fixed only along its top edge

3.1.19
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 No reduction is made for controls, louvres or other obstructions.

3.1.20
heat flux
total heat energy crossing a specified boundary per unit time

NOTE Heat flux includes radiant heat.

3.1.21
heat release rate
rate of heat release

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

3.1.22
inlet air
replacement air

ambient air entering the building to replace smoky gases being removed by the SHEVS

3.1.23
natural smoke and heat exhaust ventilator
smoke and heat exhaust ventilator using the thermal buoyancy of smoky gases to displace those gases through the ventilator

3.1.24
plugholing
inefficient mode of operation of a smoke and heat exhaust ventilator whereby air is drawn through the buoyant smoke layer from below

3.1.25
powered smoke and heat exhaust ventilator
smoke and heat exhaust ventilator using powered devices to displace smoky gases through a ventilator

NOTE Fans are usually used to produce powered ventilation.

3.1.26
powered ventilation
ventilation using a source of power external to the gases to displace those gases through a ventilator

NOTE Fans are usually used to produce powered ventilation.

3.1.27
pressure differential system
system of fans, ducts, vents, and other features provided for the purpose of creating a lower pressure in the fire zone than in the protected space

3.1.28
regulatory authority
authority having responsibility for the enforcement of regulations

NOTE A regulatory authority is usually but not always a representative of local or central government.

3.1.29
set-up time
time taken from the arrival of the fire service to the application of fire-fighting media to the fire

3.1.30
slot extract
slot exhaust
slit extract
slit extraction

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

NOTE A slot extract could be, for example, a long intake grill in a ceiling, leading to a powered ventilator.

3.1.31
smoke control system
arrangement of components installed in a building to control the production and/or movement of smoke within and/or from the building

3.1.32
smoke and heat control system
arrangement of components installed in a building to limit the effects of smoke and heat from a fire

3.1.33
smoke and heat exhaust system
smoke control system which exhausts smoke and heat from a fire in a building or part of a building

3.1.34
smoke and heat exhaust ventilation system
SHEVS
throughflow ventilation system

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

3.1.35
smoke and heat exhaust ventilator
device specially designed to move smoke and hot gases out of a building under conditions of fire

3.1.36
smoke barrier
smoke curtain
smoke blind
smoke screen

barrier to restrict the spread of smoke and hot gases from a fire, forming part of the boundary of a smoke reservoir or used as a channelling screen or a void edge screen

3.1.37
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).

3.1.38
smoke-free layer
layer of cooler air uncontaminated by smoke, below a thermally buoyant layer of smoky gases where the latter is formed beneath a soffit

NOTE A ceiling or the underside of a projecting balcony is an example of a soffit.

3.1.39
smoke logging
build-up of unacceptable quantities of smoke within a space or volume

3.1.40
smoke reservoir
region within a building limited or bordered by smoke barriers or structural elements that can retain a thermally buoyant smoke layer in the event of a fire

3.1.41
spill edge
rotation point

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 The soffit, for example, might be the underside of a balcony or canopy.

3.1.42
spill plume
vertically rising plume resulting from the rotation of a 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.

3.1.43
stagnant region
region within a smoke reservoir where the smoky gases do not move after the layer has been established

3.1.44
steady-state design fire
design fire based on the largest fire with which the SHEVS is expected to cope, assumed for calculation purposes to burn in a steady-state manner

NOTE Steady-state design fires are usually assumed to be either square or circular.

3.1.45
temperature control SHEVS
temperature control system

SHEVS designed to cool a potentially hot smoke layer by the deliberate entrainment of cooler air into the rising plume

NOTE This can enable the use of façade materials that cannot withstand high temperatures.

3.1.46
time-dependent fire
fire for which the heat release rate and/or other parameters change with time

3.1.47
time-dependent design fire
design fire having time-dependent characteristics

3.1.48
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 the smoke will be exhausted from the building

3.1.49
ventilator
device for moving gases into or out of a building

3.1.50
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.

3.1.51
zone model
combination of mathematical formulae describing a physical process by reducing that process to a limited number of simplified zones or regions where each zone is described by a small number of formulae

NOTE 1 The zone model is usually empirically derived.

NOTE 2 Zone models are usually expressed in the form of a computer program.

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
C_i	—	coefficient of discharge, i.e. coefficient of performance, of an opening supplying inlet air
C_v	—	coefficient of discharge, i.e. coefficient of performance, of a natural ventilator
q	kW	heat release rate
q_f	$kW \cdot m^{-2}$	heat release rate per square metre generated at the fire
Q_f	kW	convective heat flux in the smoky gases leaving the flames above the fire
t	s	time after ignition
t_1	s	time to onset of hazard, with no smoke exhaust
t_2	s	time to onset of hazard, with smoke exhaust and plugholing
t_3	s	time to onset of hazard, with smoke exhaust, but ignoring plugholing
Y	m	height from base of fire to base of thermally-buoyant smoke layer
γ	$kW \cdot s^{-2}$	a constant defining the steepness of the curve in a time-squared (t^2) fire growth curve

4 General recommendations

4.1 Design

4.1.1 *Design objectives*

The purpose for which a SHEVS is designed (as discussed in **0.3**) should be clearly defined. The designer should indicate in the documentation as given in Annex A, whether the SHEVS will serve as:

a) protection of means of escape; or

b) temperature control; or

c) facilitating fire-fighting operations; or

d) property protection; or

e) a combination of any of these.

4.1.2 ***Time to onset of significant danger***

The time to onset of significant danger should be clearly stated by the designer in the documentation as given in Annex A.

NOTE 1 The nature of SHEVS designed on the basis of a time-dependent fire incorporates a wide range of other fire safety features which can affect its overall efficiency. All of the following will have an effect upon the time to onset of significant danger and thus affect the overall growth period for a time-dependent SHEVS design.

While no detailed recommendations are given in this British Standard, the following fire safety engineering concepts, should be taken into account and detailed within the documentation as given in Annex A.

NOTE 2 Guidance on these fire safety engineering concepts can be found in BS 7974 and its associated PDs.

a) Building risk assessment including at least the following:
   1) occupancy;
   2) process carried out;
   3) structure;
   4) materials within the building;
   5) storage arrangements.

b) Fire safety management systems in place including at least the following:
   1) staff training;
   2) systems maintenance and testing;
   3) security/fire marshal staff;
   4) evacuation procedures;
   5) fire safety manual.

c) Time needed for escape including at least the following:
   1) detection time;
   2) recognition time;
   3) response time;
   4) travel time;
   5) allowances made (if any) for human error.

d) Other safety systems within the building including at least the following:
   1) fire suppression measures;
   2) smoke and/or fire detection;
   3) structural/fire compartmentation;
   4) alarm system type;
   5) provisions for fire-fighting.

e) Fire-fighter safety including at least the following:
   1) alerting the fire service (automatic, manual or reliant upon the public);
   2) attendance time;
   3) set-up time;
   4) search and rescue time;
   5) fire control (to contain fire growth) time.

4.1.3 ***Fire growth characteristics***

The fire growth characteristics selected by the designer should be clearly stated and detailed within the documentation as given in Annex A.

The fire growth can be affected by a number of different considerations. While no detailed recommendations are given in this British Standard, the following should be taken into account by the designer where relevant.

a) Building details:
   1) height;
   2) construction;
   3) air replacement and its characteristics;
   4) room shape.

b) Fire type:
   1) materials, including packing;
   2) fuel arrangement;
   3) potential for heat release rate per unit area.

c) Design of the fire suppression systems and the effect upon the fire growth:
   1) fire suppression type;
   2) activation time;
   3) suppression effectiveness.

4.1.4 ***Structural alterations***

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 whole system should be reassessed, including any changes to the external environment. The documentation as given in Annex A should be made available for the designer of the new system, and 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.

4.2 Reliability

4.2.1 ***Selection of components and their installation***

All selected components and their installation should conform to the relevant parts of BS 7346 and BS EN 12101. Other components and their installation should be fit for purpose.

The components should be selected to both meet the design criteria determined (e.g. for the time and temperature of operation necessary) and operate effectively where required (e.g. ensuring natural ventilators are not located where their performance could be affected by adverse wind pressure).

NOTE 1 It is essential that the SHEVS functions correctly when it is needed in an emergency. The installation of the smoke control system can affect its operation in a fire, e.g. inappropriate electrical cables could fail. The range of potential system failures caused by poor product selection, system interface failures and/or incorrect installation is extensive.

The SHEVS should be commissioned by a suitably qualified engineer upon the completion of the installation. This should incorporate testing the operation of the system, including all interface signals (e.g. smoke detectors, fire alarms) and ensuring the correct sequence of events occur in accordance with the system design, recording system performance (e.g. air volumes, vent sizes, secondary power supplies if appropriate). All tests conducted and their results should be documented in a written report.

NOTE 2 Further information is available from the Smoke Control Association, and contained in the relevant parts of BS 5588 and BR368 [1].

4.2.2 ***Maintenance and regular testing***

SHEVS should be maintained and regularly tested in accordance with the relevant parts of BS 7346, BS 5588 and BS EN 12101.

NOTE 1 Regular testing and maintenance of SHEVS is necessary to ensure that the SHEVS is operational when required.

For SHEVS that serve as protection of a means of escape or for fire service search and rescue operations, a fire safety management system should be established.

The fire safety management staff should be familiar with and understand the smoke control system design philosophy in **4.1.1** and **4.1.2**, and the function and operation of the SHEVS. These staff should also be responsible for ensuring the maintenance and testing of the SHEVS and keeping an up-to-date record of all such events. The frequency of such tests and maintenance is given in the relevant parts of BS 5588, BS 7346 and BS EN 12101.

The maintenance of smoke control systems should only be undertaken by appropriately trained engineers. The documentation as given in Annex A should be available to the engineers to ensure that inappropriate modifications to the system have not occurred and system failures are repaired in a manner whereby the original design intent is met.

NOTE 2 Further information is available from the Smoke Control Association, and contained in the in the relevant parts of BS 5588 and BR368 [1].

4.2.3 ***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 SHEVS for the protection of means of escape (life safety) should be activated by smoke detection systems conforming to the relevant part of BS EN 54. 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 **4.2.4**.

A SHEVS for property protection should be activated by a water flow device conforming to BS EN 12259-1 and BS EN 12845, operating at a pressure flow equivalent to that of the lowest flow through a single sprinkler, or by manual release or by both methods.

A SHEVS to facilitate fire-fighting operations should be activated by a fire detection system conforming to BS EN 54 (all parts), 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 EN 12845, or by manual release or by a combination of these methods.

4.2.4 ***Additional recommendation in case of manual activation of a SHEVS***

If there is the possibility of additionally activating or deactivating a SHEVS, which is normally activated by an automatic fire or smoke detection system, by manual control which overrides the automatic activation, this manual control should only be capable of being executed by authorized persons who are familiar with the SHEVS, e.g. safety management staff as described in **4.2.2** or the fire and rescue service.

4.2.5 ***Power supply***

The operation of the SHEVS should rely on fail-safe function, back up power supply, protected components, stand-by components and installation in accordance with the relevant parts of BS 7346 and BS EN 12101.

4.3 Combined use of natural and powered ventilators

Natural and powered ventilators should not both be used for exhaust in the same smoke reservoir.

A smoke and heat exhaust system should consist of either:

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

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

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

d) a smoke and heat exhaust system relying on a powered exhaust system and a powered inlet air supply system (push and pull system). This should not be designed unless a fully engineered and detailed description of the system is supplied showing that the system will work under all design conditions without introducing pressure differences adversely affecting the means of escape.

4.4 Sequence of operation of devices comprising a single SHEVS

4.4.1 The sequence of activating devices comprising any single SHEVS should not adversely affect the successful operation of any of those devices.

NOTE For example, fans are not to operate before air inlets if the pressure reduction produced by those fans will prevent the opening of those inlets.

4.4.2 The complete SHEVS should achieve its designed performance within 90 s from receipt of a command signal, whether that initiation is automatic or by manual switch.

NOTE Ancillary items such as dampers and air inlets (including doors) will need to 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 *General*

Where each smoke zone is separated from the others by walls and/or smoke barriers more than one zone may be served by a common SHEVS as described in **4.5.2** or each smoke zone may be equipped with a separate SHEVS either natural or powered as described in **4.5.3**.

4.5.2 *Smoke zone separated from the others by walls and/or smoke barriers forming separate fire compartments*

4.5.2.1 *Commentary*

Each smoke zone may be equipped with a separate SHEVS. Where each smoke zone is separated from the others and forms a fire compartment, ventilation may be achieved by connecting some or all smoke zones by ducts, serving all such connected smoke zones. Where exhaust ducts penetrate through a fire compartment boundary those ducts and associated dampers need to have the same fire resistance as the boundary.

NOTE Products conforming to the proposed BS EN 12101-7 and BS EN 12101-8 for multi-compartment applications will have the same fire resistance as the boundary between compartments.

4.5.2.2 *Recommendations*

The following recommendations should be applied where each smoke zone in a building is separated from the others by walls and/or smoke barriers forming a fire compartment.

a) Smoke control damper construction should contain no device that is able to change the position of the damper once the safety position has been reached, i.e. the position of the damper should not change unless required by direct instruction from a control system.

b) Power should be maintained throughout a building where a system referred to in this British Standard is installed. Consequently smoke control damper assemblies should have no thermal devices that cause uncontrolled operation and no automatic return mechanisms that may, for instance, operate on loss of power.

c) The exhaust flow to be extracted should be calculated for the worst case of a possible design fire in the fire compartment.

d) A fire should be detected by a smoke detection system conforming to the relevant part of BS EN 54 which triggers smoke control dampers located at openings between the smoke zone and the ductwork leading from that zone in such a way that only the smoke zone where the fire is detected is connected to the exhaust duct (e.g. smoke control damper open) and the other smoke zones are isolated from the exhaust duct (e.g. smoke control dampers closed).

e) The design of the system should incorporate an inlet air supply.

4.5.3 ***Smoke zone separated from the others by walls and/or smoke barriers without forming different fire compartments***

4.5.3.1 *General*

As 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. Stray smoke will not endanger the means of escape or hinder fire-fighting activities seriously in the adjacent smoke zones but it can trigger smoke detectors which are installed there. This can result in failure of the SHEVS if 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 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. use this space as a travelling path for pedestrians instead of for a fuel array).

4.5.3.2 *Recommendations*

The following recommendations should be applied where each smoke zone in a building is separated from the others by walls and/or smoke barriers without forming different fire compartments.

a) If there is a shared inlet air supply for all smoke zones contained in the same fire compartment, these inlet openings and doors should conform to **6.9**.

b) 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, no additional smoke control dampers open) with the following exceptions.

1) 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 an adjacent smoke zone 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 $5\ m \cdot s^{-1}$.

2) 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 **4.5.2**, 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 as calculated by applying **5.4** and if the air velocity across inlet openings is still less than $5\ m \cdot s^{-1}$.

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

4.6 Sprinkler protection

Sprinklers, where used, should be installed in accordance with BS EN 12845.

5 Recommended calculation procedure

5.1 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 a SHEVS needs to be designed in a way that includes consideration of all such influences.

The design procedure needs to consider a succession of zones (also known as design regions), which correspond to successive stages in the path followed by the smoky gases. These zones can be taken for the purpose of this British Standard to be the same as described in BS 7346-4:2003, Clause ***5*** *and Clause* ***6****.*

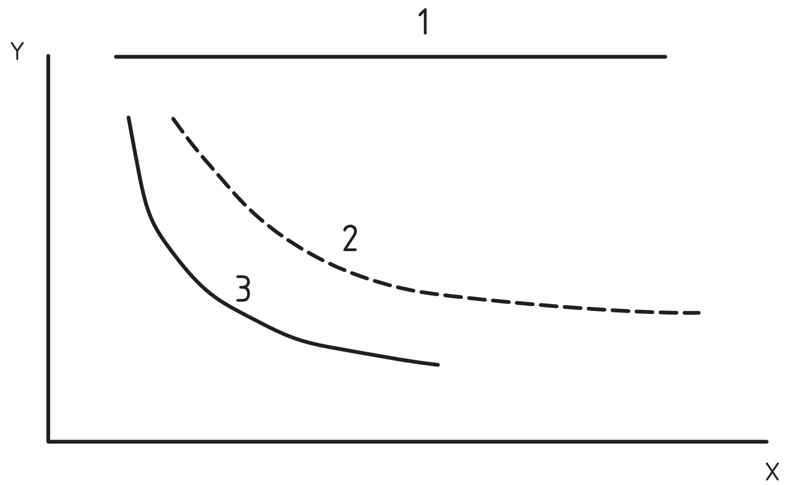
It is first necessary to identify how the fire will vary with time, in a way that is appropriate to the circumstances of the building. In practice, this usually depends on the contents and their configuration within the building and the intended use of the building. This is discussed in more detail in **5.2**.

The time-dependent behaviour of a fire will be strongly influenced by such factors as the operation of sprinklers or of other fire suppression methods. One can expect a radical change in the fire behaviour starting at the moment that the suppression method is activated. It is essential that a time-dependent calculation includes both an assessment of the time at which the fire suppression commences (which itself will usually be a function both of fire size and fire growth rate), and an assessment of how the key fire parameters behave after that time. In practice, it is often the case that firm evidence is lacking on which to base this latter assessment, and it is necessary to assess a worst-case post-activation fire behaviour. Annex B gives more information on an iterative calculation procedure.

The establishment of a thermally buoyant smoke layer in the smoke reservoir, and the consequences of that layer's developing properties with time, depend strongly on the presence of a functional SHEVS. This is illustrated in Figure 1. Where the SHEVS is normally closed but activates on receipt of a signal (for example from the control panel after activation of an automatic fire detection system, or from a manual fire-fighter's switch) the initial filling of the smoke reservoir will be the same as if the SHEVS were not present. It follows that it is necessary to carry out initial stages of the calculation with the SHEVS inactive; then to assess the time when the automatic fire detection system generates its signal to the control panel (or the time when the manual switch is operated); then to assess the time until the SHEVS itself is fully operational; and then to continue with the main time-dependent calculations under the new conditions of ventilation. It is recommended in this British Standard that the SHEVS will achieve its design performance in 90 s, which is the maximum recommended in **4.4.2***. Annex B gives more information on an iterative calculation procedure.*

Unlike for a steady-state SHEVS, it is not possible to calculate directly the capacity of powered smoke and heat exhaust ventilators, or the areas of natural smoke and heat exhaust ventilators, as an end result of the design process. It is instead necessary to postulate these parameters at the start of the process, and use the calculation method to deduce the consequences. In practice therefore, it can be expected that the designer will have to adopt a succession of trial values before arriving at a satisfactory solution.

In a similar way, the number and physical dimensions of the ventilator openings need to be stipulated at the start of the calculation, and repeated trial values used to find an acceptable combination. This is a consequence of the potential importance of the phenomenon of plugholing in assessing the effectiveness of smoke and heat exhaust ventilators. Annex C gives a more detailed discussion of the phenomenon.



Key

X Time

Y Depth below ceiling of smoke layer boundary

1 Ceiling

2 With SHEVS

3 No SHEVS

Figure 1 — Effect of smoke ventilation on smoke layer depth

5.2 Selection of a design fire

5.2.1 *Commentary*

The development of a fire will depend 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 as opposed to chairs set out for use);*
- *the positions 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.*

Design fire characteristics will be dependent on a number of variable factors as discussed in more detail in Annex D. It is this variable nature of a growing dynamic fire that results in the difficulty in calculating fire development, except for the simplest fuel arrays.

The design is characterized in terms of:

a) *heat release rate;*

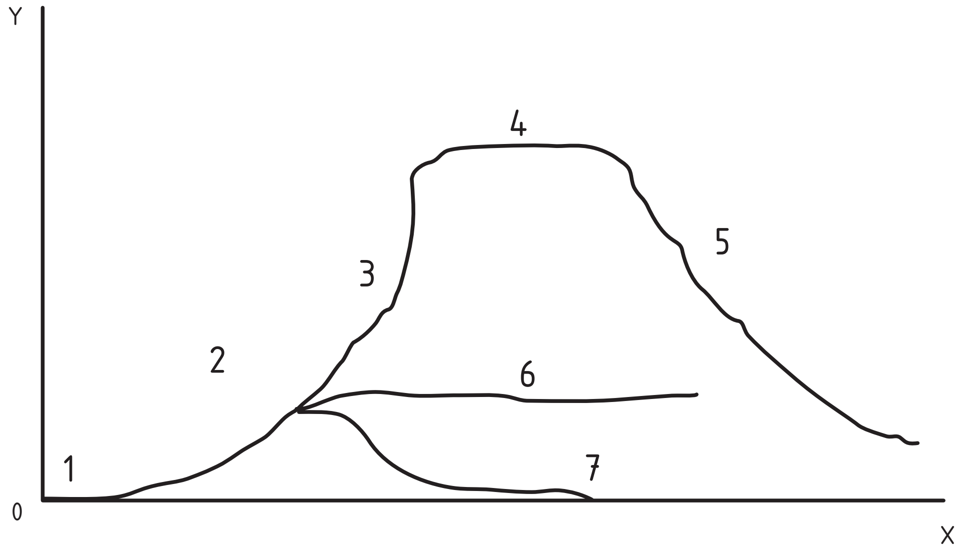
b) *fire size;*

c) *time to key events, e.g. flashover.*

Where these characteristics cannot be calculated, design fires are based on source data.

In reality, of course, any actual sample of fires occurring in the same nominal occupancy will never be describable by a single growth curve. There will be a distribution of growth curves depending on such factors as variations in fuel layout and variations in the location of the initial ignition. This distribution in principle means that the designer needs to choose an appropriately pessimistic curve. Put perhaps too simply, any design based on an average curve implies a failure rate of one in two. This is usually unacceptable where life safety is involved. It is nevertheless unreasonable for the designer to base the design on the worst curve possible – this would be an explosion. The designer needs to decide where the limits of reasonableness lie. Ideally this could be specifiable in terms of the constant γ *in Equation 1 being a specified number of standard deviations away from the mean value appropriate to the class of occupancy. Unfortunately, this ideal is unattainable for most scenarios in the absence of appropriate statistics. Also, for some scenarios, the growth rate may vary with time, e.g. a fire may grow at a medium rate for the first few minutes and then change into a fast fire.*

It is axiomatic that a real fire can follow an infinite number of possible growth and decay curves. It is necessary to simplify for the purposes of design. In general, the fire can be divided into several idealized stages as illustrated in Figure 2. There is an initial stage where the fire is very small and there are no detectable flames. This can last from milliseconds to days, and can be ignored in any pessimistic assessment of the design of a SHEVS. The next stage is the growth of the fire involving flaming combustion. The next stage is of sustained burning – in a successful SHEVS this is only likely to occur where the fuel is present in limited quantities preventing further fire growth, or where the fire-suppression technique has achieved control without extinguishing the fire. This sustained burning stage might be absent where the fire suppression method adopted causes the fire to change immediately from growth into decay. The final stage is decay of the fire, either because of the effect of fire suppression or because of the combustion of available fuel.



Key

X	Time	4	Fully
Y	Heat release rate	5	Decay
1	Effective time of ignition	6	Controlled
2	Growth	7	Extinguished
3	Flashover		

Figure 2 — Examples of fire development curves

Many fuel arrays follow a time squared (t^2) curve in the growing stage of a fire when flames are visible and before the fire reaches a condition changing its fire growth (e.g. before sprinkler operation; or before the onset of flashover).

$$q = \gamma t^2 \quad (1)$$

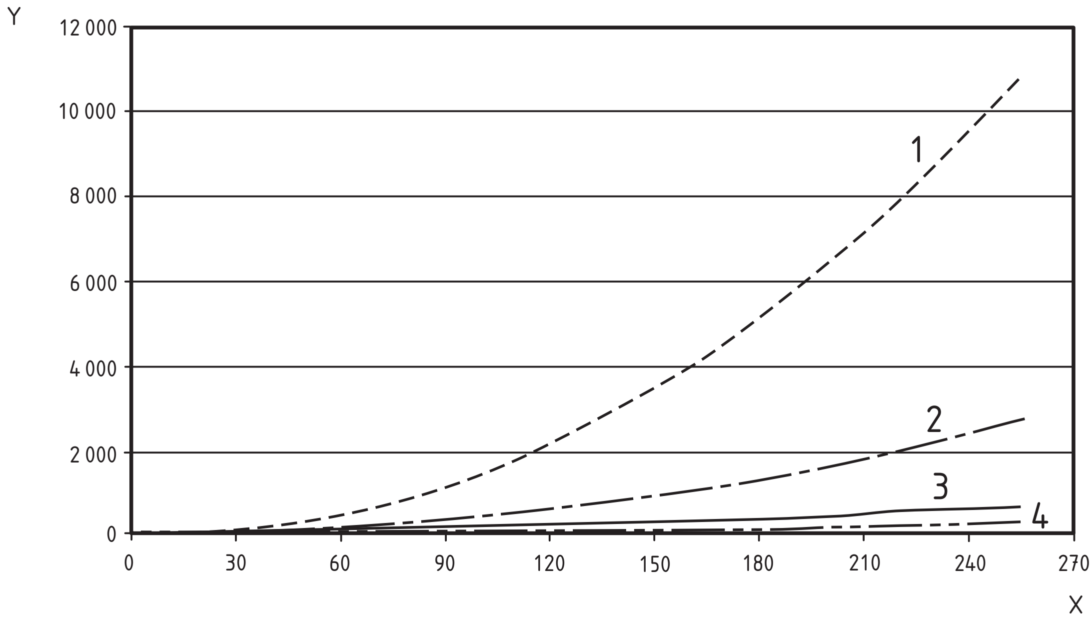
where

- q is the heat release rate (kW)
- γ is the constant defining the steepness of the curve ($kW \cdot s^{-2}$)
- t^2 is the time after ignition (s)

Where this approach is used, it is desirable to carry out other calculations (e.g. the fire size at the onset of flashover) to set an upper limit to what would otherwise be an infinite fire growth.

Many fuel arrays have a growing stage that can be approximated to a time-squared growth. In either case the curves can be further approximated by classifying them as slow, medium, fast or ultra fast. This is detailed in Table 1 and illustrated in Figure 3. The result is an idealized design fire, but one which can nevertheless be regarded as a reasonable representation of real fires in that fuel array. It is always necessary to ensure that the selected class is appropriate to the fuel array being considered. Further information is given in **5.2.2**.

NOTE High stored goods present different fire growth characteristics which are not describable in the simple form of Equation 1. The upward movement of the fire in high stored goods is likely to be extremely rapid and to be combined with a less speedy lateral growth. Equation 1 will therefore underestimate the heat release rate relative to time for most high stored goods fires. It is not appropriate to use Equation 1 for goods stored above a height of 4 m as recommended in **5.2.2***g).*



Key

X	Time (s)	2	Fast
Y	Heat release rate (kW)	3	Medium
1	Ultra fast	4	Slow

Figure 3 — Fire growth rates

Table 1 — Various t^2 fire growth rates

Fire growth	γ kW·s^{-2}
Ultra fast	0.18760
Fast	0.04689
Medium	0.01172
Slow	0.00293

Annex D discusses factors influencing the choice of a design fire growth curve including the assessment of the consequences of initiating a fire suppression system such as sprinklers.

Fuel arrays will 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 release rates. For the purposes of design, the designer needs to assess the reasonably appropriate maximum and minimum values of heat release rate and fire growth curves. The use of these two limits are necessary to determine the likely worst-case for the wide range of combustibles that will be involved in a fire. Upon completion of both the high and low heat release rate assessments, the worst-case system recommendations will be apparent and are used as the basis of the SHEVS design.

Even where the assessment is unscientific, it is essential that an assessment of the key parameters (fire growth curve and heat release rate) of the design fire be made. This assessment needs to draw on procedures available outside this British Standard, and needs to be fully detailed in the documentation as given in Annex A.

It is advised that the choice and quantification of a design fire be agreed with the appropriate regulatory authority at an early stage in the design process.

5.2.2 *Recommendations*

The following recommendations should be incorporated into the design fire.

a) Possible locations of fire (e.g. at floor level, at a height within racking, at a lower or upper storey of a shopping mall) in the space to be ventilated by a SHEVS should be identified and the worst case included in the design procedure.

b) The heat release rate should be expressed as a function of time, in a manner appropriate to the circumstances, including an assessment of the effect of the operation of any fire suppression method present (e.g. sprinklers). This assessment should draw on procedures available outside this British Standard, and should be fully detailed in the documentation as given in Annex A.

NOTE See, for example, PD 7974-1.

c) The heat release rate per unit area should be identified.

d) For the purposes of design, the designer should assess the reasonably appropriate maximum and minimum values of heat release rate and fire growth curves.

NOTE The use of these two limits are necessary to determine the likely worst case for the wide range of combustibles that will be involved in a fire.

Upon completion of both the high and low heat release rate assessments, the worst-case system recommendations will be apparent and should be the basis of the SHEVS design.

e) The outcome of a), b), c) and d) should be discussed with the relevant authority as being suitable for the circumstances.

f) Reasons for the choice of time-dependent design fire, together with any supporting evidence, should be included in the documentation as given in Annex A.

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

h) A SHEVS should be regarded as of very limited benefit for any unsprinklered fuel array taller than 4 m.

NOTE The rapid upward fire growth in such fuel arrays without any fire suppression can generally be expected to result in the total loss of the building. However, in certain circumstances, this might not be the case (e.g. where the 4 m high fuel array is located in a relatively tall building). Where such a design is proposed, there will be a need for the designer to justify the specific design calculations and to identify all associated measures to be included in the proposal.

i) Where the purpose of the SHEVS is to assist fire-fighting, the time expected to pass between ignition and initiation of successful control of the fire by fire-fighters should be assessed. The designer should provide arguments to support the choice in the documentation as given in Annex A. The designer should agree on the time needed with the appropriate regulatory authorities at an early stage in the design process.

NOTE The designer needs to especially take account of the time line from when the fire and rescue service arrives at the scene of the fire, to fire-fighters actually reaching the seat of the fire and making a first attack on it.

j) The effect of external influences, such as wind and snow, should be allowed for in design, as recommended in BS 7346-4:2003, **6.7**.

5.3 Advance selection of key success/failure criteria

5.3.1 *Commentary*

Many of the same criteria apply to a time-dependent fire design as to a steady-state fire design, for example, the minimum clear height, the maximum acceptable smoke layer temperature and the minimum smoke layer temperature. Some of these criteria need to be decided in advance of calculations. For time-dependent fire calculations, unlike for steady-state calculations, it is either necessary to assume values for the total aerodynamic free area of natural smoke and heat exhaust ventilators in a smoke reservoir, or for the total volume exhaust rate of powered smoke and heat exhaust ventilators, prior to starting the time-based calculations. Design then becomes a matter of repeating the entire process with successive trial values of exhaust until results are assessed as being satisfactory.

5.3.2 ***Recommendations***

The following recommendations should be applied in the advance selection of key success/failure criteria.

a) The minimum acceptable clear height beneath a buoyant smoke layer should be decided upon the criteria recommended in BS 7346-4:2003, **6.2**. These are reproduced here in Table 2.

Table 2 — Minimum clear height above floor level on escape routes

Type of building	Minimum height Y m
Public buildings (e.g. single-storey malls, exhibition halls)	3.0
Non-public building (e.g. offices, apartments, open hall type prisons)	2.5
Car parks	2.5 or 0.8H whichever is the smaller
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.	

b) The convective heat flux Q_f, both maximum and minimum values (see **5.2**) carried by the smoky gases entering the smoke reservoir from an axisymmetric plume should be taken to be 0.8 times the heat release rate ($q_f \cdot A_f$) identified for the design fire, at all stages during the fire unless the designer can provide evidence to support the use of a different value.

c) The convective heat flux leaving a compartment through an opening into another space should be taken to have the same relationship to the heat release rate ($q_f \cdot A_f$) as would be used for a similar steady state fire unless evidence can be provided by the designer to support the choice of a different value for the particular circumstances of the design.

d) The maximum acceptable smoke layer average temperature at any stage of the fire's development should follow the criteria of BS 7346-4:2003, **6.6.2.2**, **6.6.2.3** and **6.6.2.4** (i.e. not high enough to threaten the structural integrity of the building; not exceeding 550 °C in any circumstances; or 200 °C where escape routes pass beneath the smoke layer).

e) The minimum smoke layer average temperature in the design condition should not be less than 20 °C above ambient after 5 min following the start of the growth curve.

f) The maximum smoke reservoir area should be in accordance with BS 7346-4:2003, **6.6.2.7** and **6.6.2.8**.

g) The maximum length of a smoke reservoir should be as described in BS 7346-4:2003, **6.6.2.9**.

h) The design depth of the smoke reservoir should be as recommended in BS 7346-4:2003, **6.6.2.10** and **6.6.2.11**.

5.4 Calculation procedures for time-dependent fires

5.4.1 ***Commentary***

It is first necessary to identify the time-dependent design fire appropriate to the circumstances of the building and the presumed location of the fire. This has been discussed in more detail in **5.2.1**. *It is also essential that the design objectives have been clearly identified and agreed.*

Where the geometry is simple (e.g. where the smoke reservoir is a simple rectangle with a rectangular cross-section, and the smoke layer is directly above the fire); and the fire growth curve is a single simple function; and there is a single danger criterion of interest, it may be possible for the designer to derive a single analytical expression for the onset of time to danger. In practice, with realistic buildings, this is rarely possible, and it can be more effective to use an iterative procedure. One approach to an iterative procedure is described in Annex B.

It is important that the time of detection of the fire (where this is by automatic means) be assessed using accepted and authoritative methods; and that this will then form the basis of an assessment of when the SHEVS becomes operational. This change of state of the SHEVS needs to be explicitly included in the design calculation process.

5.4.2 *Recommendations*

The following recommendations should be applied to calculation procedures for time-dependent fires.

a) Confirm the nature of the desired objective that the SHEVS design has to achieve as discussed in **4.1**.

b) Choose a design fire curve in accordance with **5.2**. Include an assessment of the time of operation of any fire suppression medium, and an assessment of the change in the fire curve subsequent to that operation.

NOTE Factors influencing the choice of time are given in Annex D.

c) Establish the time needed to achieve the desired objective (e.g. time needed for evacuation, or time to initiation of effective fire-fighting). The time needed should be agreed with the relevant authorities at an early stage in the procedure.

NOTE This may be done using methods such as those found in PD 7974-5 and PD 7974-6.

d) Specify trial values of the total powered exhaust capacity from the smoke reservoir, or the total area of natural ventilators serving that smoke reservoir, as appropriate. Also specify trial values of the number and physical dimensions of the openings providing that exhaust.

e) Calculate the time from the start of the fire growth curve to the onset of relevant dangers, either by an analytical method or by an iterative method.

NOTE An example of an iterative calculation procedure is given in Annex B.

f) In the documentation, as given in Annex A, provide:

1) details of the method adopted, of the design fire growth curve, and of results of calculation;

2) where computer-based zone models are used to carry out the calculations recommended by this British Standard as part of the design process, all mathematical formulae used in those models, assumptions made, and values of input parameters;

3) information concerning validation of the computer-based zone models used in design.

NOTE Where such validation information exists in the publicly available literature, it is sufficient to cite appropriate references.

6 Further acceptability criteria

6.1 General

Where the design has passed the criteria for layer temperature and layer depth for all times prior to the time needed to achieve the objective (as discussed in **B.4**), the SHEVS should meet the recommendations given in **6.2** to **6.7** using the properties appropriate to the hottest, and separately if different the deepest, smoke layer in the smoke reservoir.

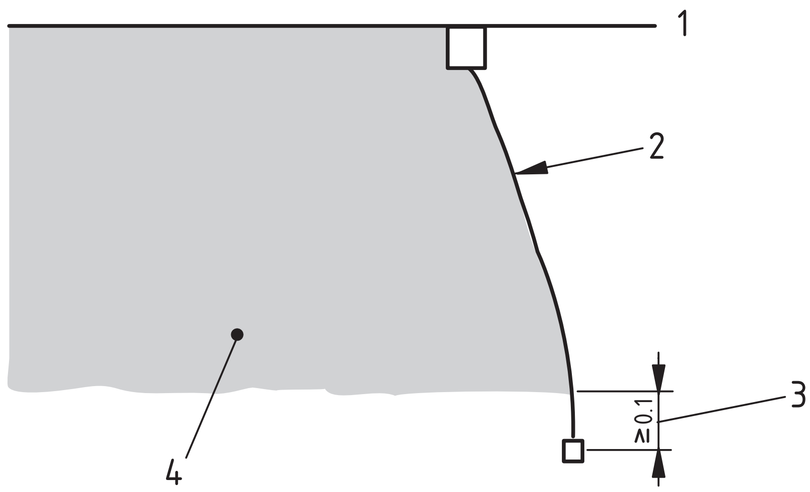
6.2 Confirmation that layer depth selected is greater than minimum possible

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 A calculation procedure is included in BS 7346-4:2003, Annex F.

6.3 Depth margin for smoke reservoir boundary smoke barriers

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 as illustrated in Figure 4.



Key

1 Ceiling
2 Smoke barrier
3 Depth margin
4 Smoke

Figure 4 — Smoke barrier depth margin (with barrier in deflected position)

6.4 Slot extracts used to define a smoke reservoir boundary

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 A calculation procedure is given in BS 7346-4:2003, Annex F.

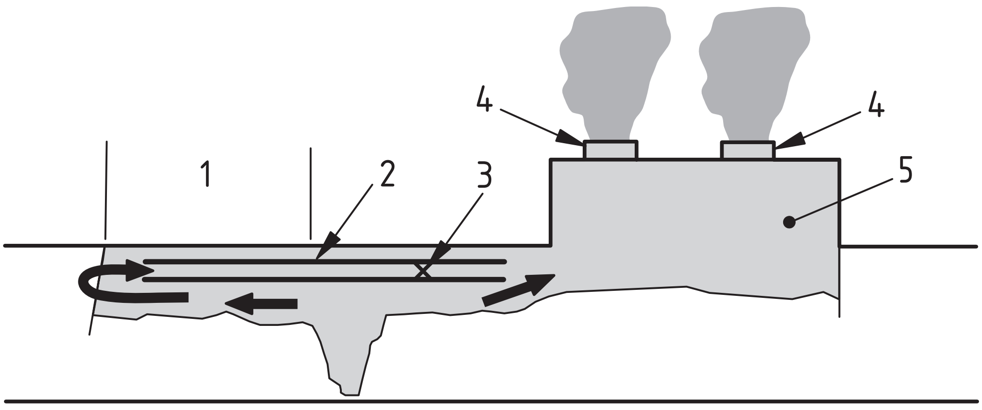
6.5 Avoidance of natural and powered smoke exhaust ventilators in the same smoke reservoir

Natural and powered smoke exhaust ventilators should not be used simultaneously in the same smoke reservoir because it could lead to loss of visibility below the smoke layer.

NOTE This does not include powered smoke transfer ducts.

6.6 Smoke transfer ducts

Where part of a smoke reservoir extends more than three times beyond an exhaust ventilator intake (i.e. an extract point) than the smoke reservoir is wide, a smoke transfer duct should be fitted to recirculate smoky gases to a position close to an extract point as illustrated in Figure 5. The minimum 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.



Key

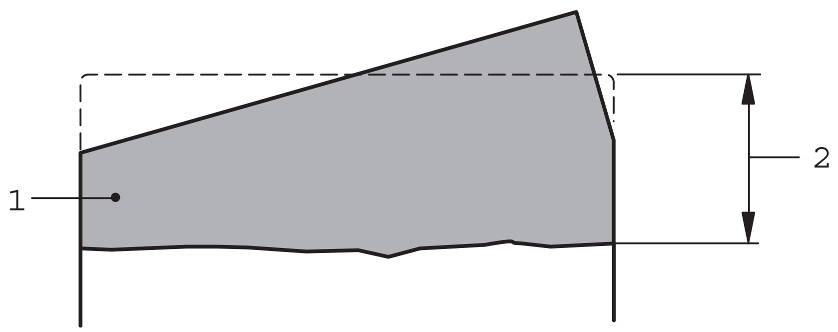
1 Potentially stagnant region
2 Transfer duct
3 Fan
4 Exhaust ventilator
5 Smoke reservoir

Figure 5 — Smoke transfer duct

6.7 Average buoyant layer depth in non-rectangular section smoke reservoirs

Where an average layer depth is recommended for calculation (e.g. for minimum depth of flow in the smoke reservoir, or in assessing the effective layer depth/effective height of rise of spill plume for large-area smoke reservoirs) the depth of the smoke 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 smoke reservoir as illustrated in Figure 6.

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



Key

1 Smoke reservoir
2 Effective layer

Figure 6 — Effective layer depth

6.8 External influences

The external influences (e.g. wind, snow, ambient temperature) to which the SHEVS of a building is exposed should be taken into account when designing the SHEVS.

For external influences on the SHEVS design, the guidance in BS 7346-4:2003, **6.7** should be followed.

6.9 Inlet air (replacement air)

Any smoke and heat ventilation system should have provisions for a sufficient supply of ambient air entering the building replacing the amount of exhausted hot smoky gases (see also **4.3**). This should be achieved by:

a) one or more of:

1) permanently open inlet openings;

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

3) smoke and heat exhaust natural ventilators in adjacent smoke reservoirs; or

b) powered inlet supply using fans and ducting if necessary.

For inlet openings for inlet air, the guidance given in BS 7346-4:2003, **6.8** should be followed.

6.10 Free-hanging smoke barriers

6.10.1 *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, will rotate (and bow) away from the smoke layer. The bottom bar will consequently deflect 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 by the barriers' bottom bar to reduce the deflection, becomes part of the design of a SHEVS as these parameters can vary with the depth and temperature of the smoke layer.

6.10.2 *Recommendations*

The following recommendations should be applied to free-hanging smoke barriers.

a) It should be demonstrated by calculation that the depth and bottom-bar weight of a free-hanging smoke barrier is sufficient to meet the recommendation of BS 7346-4:2003, **6.6.2.13**. The barrier in its deflected position should be at least 0.1 m deeper than the design layer base (see **6.3**).

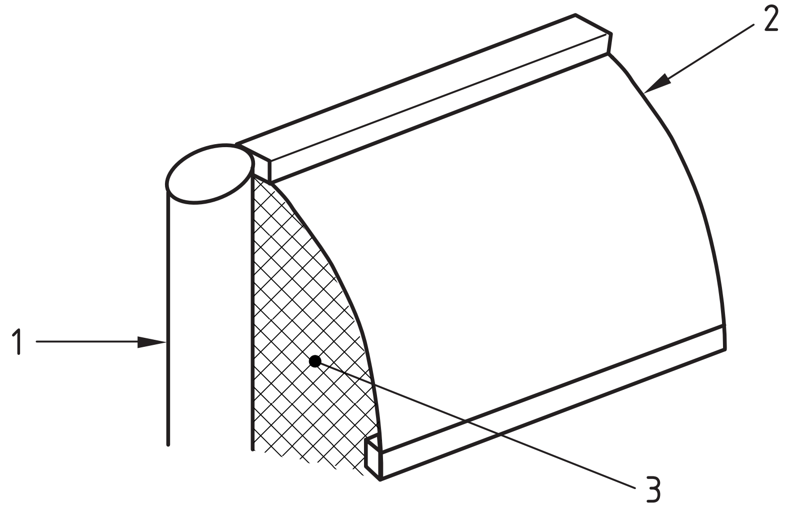
NOTE A calculation method is given in BS 7346-4:2003, Annex H.

b) 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 (see Figure 7).

NOTE Calculation procedures for assessing the quantity of smoke leakage through gaps can be found in BR368 [1].

c) Free-hanging smoke barriers designed to close off openings between a smoke reservoir and adjacent storeys (e.g. open storeys adjacent to an atrium) 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 meeting the recommendation given in BS 7346-4:2003, **6.9.2**, when in the deflected position.

NOTE A calculation method is given in BS 7346-4:2003, Annex H.



Key

1 Adjacent column

2 Smoke barrier

3 Excess gap

Figure 7 — Example of excess gap caused by deflection of smoke barrier mounted adjacent to a column

6.11 Suspended ceilings

6.11.1 *Commentary*

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

6.11.2 *Recommendations*

For suspended ceilings, the guidance given in BS 7346-4:2003, **6.10.2** should be followed.

7 Interaction with other fire protection systems and other building systems

As a SHEVS always has to co-exist in the building with other systems, it should not interfere with the day-to-day operations of the building, and it should not reduce the overall performance of the other fire protection measures designed into the building. The design intention should be to optimize the total performance of the building as a whole. Consequently, the designer of the SHEVS should consider the potential interactions with these other systems and, wherever necessary, should consult with the designers of these other systems in order to achieve a better optimization.

Important examples of other systems that should be considered include:

a) sprinklers;

b) smoke and fire detection systems;

c) pressure differential systems;

d) public address and voice alarm systems;

e) lighting and signage;

f) computerized control systems;

g) heating, ventilation and air conditioning (HVAC);

h) security systems.

NOTE Additional guidance on all the interactions listed in items a) to h) is given in BS 7346-4:2003, Clause **7**.

Annex A (normative) Supporting documentation

For identification of the purpose and function of a SHEVS design, supporting documentation should be provided and made available to the owner of the building and the user of the system where the SHEV is installed. It should comprise the following information:

a) description of relevant aspects of building;

b) design objective of the system as given in **4.1.1**, including the reasons for choosing a time-dependent design fire as given in **5.2.2** and **5.4.2**;

c) time to onset of significant danger as given in **4.1.2**;

d) assumptions made on the fire safety engineering concepts as given in **4.1.2**;

e) characteristics including assessments of building details, fire type and the design of the fire suppression systems as given in **4.1.3**;

f) structural alterations made as given in **4.1.4**;

g) heat release rate expressed as a function of time, in a manner appropriate to the circumstances, including an assessment of the effect of the operation of any fire suppression method present as given in **5.2.2**.

h) compatibility and interaction with other systems as given in Clause **7**;

i) details of calculations made, including:

1) details of the method adopted, of the design fire growth curve, and of results of calculation, as given in **5.4**;

2) where computer-based zone models are used to carry out the calculations recommended by this British Standard as part of the design process, all mathematical formulae used in those models, assumptions made, and values of input parameters, as given in **5.4**;

3) information concerning validation of the computer-based zone models used in design as given in **5.4**;

j) drawings illustrating details of any important aspects of the design;

k) list of components as selected and installed in **4.2.1**.

Annex B (informative) Example of an iterative calculation procedure

B.1 Design fire curve

Choose a design fire curve for the initial flaming fire growth.

Identify the average heat release rate per square metre for the selected scenario.

B.2 Time

Establish the time needed to achieve the desired objective (e.g. time needed for evacuation, or time to initiation of effective fire-fighting) using methods from sources outside this British Standard. Where there is a strong dependence on human behaviour, or where there is uncertainty about some of the methods, safety margins are needed.

NOTE It is recommended that the time needed be agreed with the relevant authorities at an early stage in the procedure.

B.3 Time to onset of danger

B.3.1 *General*

Use an iterative calculation procedure based on the principle of a quasi-steady-state calculation, where the growing fire is treated as if it is a succession of steady fires, each in its own defined time interval, with the whole approximating to the actual curve.

NOTE This lends itself well to converting into a computer program, and can be much more general in application than a fully analytical solution, since the latter will yield very complicated formulae for all but the simplest of building geometries.

B.3.2 ***Selection of time increment for calculation***

Select a time increment for calculation.

NOTE Too large a time increment will give poor accuracy and could result in the calculation being mathematically unstable, i.e. inherently unable to give the correct answers. The smaller the increment, the more accurate the results of this method of calculation, but too small an increment can lead to arithmetical errors arising in computers which specify numbers by using too few digits. One second has been found to be convenient and suitable in most cases.

B.3.3 ***Iterative procedure***

B.3.3.1 Identify mass of smoky gases resident in the smoke reservoir at the end of the previous iteration. Set it equal to zero for the first iteration.

B.3.3.2 Identify total heat resident in the smoky gases in the smoke reservoir at the end of the previous iteration. Set it equal to zero for the first iteration.

B.3.3.3 Identify the location of the buoyant smoke layer's base in the smoke reservoir at the end of the previous iteration. Set it equal to the ceiling height for the first iteration. Hence, identify the height of rise to the layer base at the start of the current iteration.

B.3.3.4 Use the layer parameter values from the previous iteration to predict whether an automatic fire detection system would have operated. If yes, continue the iteration with the same ventilation input parameters for 60 s or the response time of the SHEVS if this is known, and then adopt the SHEVS operational parameters (e.g. vent area for natural ventilators) for all subsequent iterations.

B.3.3.5 Use the layer parameter values from the previous iteration to predict whether any fire suppression system present would have operated. If yes, adopt a modified fire growth curve as illustrated in Annex D.

B.3.3.6 Using the appropriate growth curve, and the heat release rate per unit area, calculate the average fire perimeter during the time interval for the current iteration.

B.3.3.7 Calculate the average convective heat flux in the smoky gases during the time interval for the current iteration as described in **5.3.2**b).

B.3.3.8 Using the height of rise, the convective heat flux, and the fire perimeter, calculate the average mass flow rate of smoky gases entering the layer during the current iteration, using the same methods as for a steady-state design fire described in BS 7346-4:2003, **6.2** to **6.5**.

NOTE This will cover both single-storey geometries and the more complicated atrium-like geometries.

B.3.3.9 Using results calculated for the layer from all previous iterations, calculate the critical mass exhaust rate which corresponds to the onset of plugholing for the stipulated number and size of exhaust openings.

NOTE Methods for calculating the critical mass exhaust rate can be found in BS 7346-4:2003, Annex F.

B.3.3.10 Using results calculated for the layer from all previous iterations and steady-state formulae for the ventilators, calculate the exhaust mass flow from the smoke reservoir during the current time interval in accordance with BS 7346-4:2003, **6.6.2.15**.

B.3.3.11 Compare the calculated critical exhaust corresponding to the onset of plugholing with the calculated exhaust rate, and adopt whichever is the smaller as the mass exhaust rate from the smoke layer itself.

B.3.3.12 Calculate the heat flux exhausted from the layer during the time interval using the calculated mass exhaust rate from the smoke reservoir and the average layer temperature calculated at the end of the previous iteration.

B.3.3.13 From the difference between the mass entering the layer and the mass being exhausted, calculate the net mass of smoky gases adding to the layer during the current increment. If the exhaust is greater than the flow rate entering the layer, and the layer depth is equal to or is less than one tenth of the height between the base of the fire and the ceiling, default the layer depth to one tenth of the height between the base of the fire and the ceiling.

NOTE This is approximately the ceiling jet depth.

B.3.3.14 From the difference between the heat carried into the gases and the heat being exhausted from the layer, calculate the net heat adding to the layer during the current increment.

B.3.3.15 By adding the net addition of mass to the mass resident at the start of the increment, calculate the mass of smoky gases resident in the layer at the end of the current increment.

B.3.3.16 By adding the net addition of heat to the heat resident at the start of the increment, calculate the heat resident in the layer at the end of the current increment.

NOTE It is conventional to ignore heat losses from the layer other than by the exhaust gases, but one could include the effect of sprinkler cooling if necessary, using the methods discussed in BS 7346-4:2003, **6.6.2.6**. Inclusion of heat losses to the building structure is difficult.

B.3.3.17 Calculate the excess temperature of the gases residing in the layer at the end of the current increment. Apply the maximum smoke layer temperature above ambient criteria from **5.3.2**. If the layer is too hot, end the iteration and branch out to **B.4**.

B.3.3.18 Using the mass of smoky gases and the layer temperature, resident in the layer at the end of the current increment, and the known horizontal area of the smoke reservoir, calculate the layer depth at the end of the current increment.

NOTE One can introduce non-rectangular-section smoke reservoirs by making the area a function of height.

B.3.3.19 Using minimum clear heights recommended as for the steady-state design method, check whether the calculated layer depth has reached the deepest acceptable limit. If it has, stop the iterative calculation and branch out to **B.4**.

B.3.3.20 Check whether the total time to the end of the current iteration has reached the time needed for achieving the design objective. If it has, stop the iterative calculation and branch out to **B.4**.

B.3.3.21 Loop back to **B.3.3.1**, the start of the iterative process, and start the calculations for the next time interval.

NOTE When using calculation procedures developed for steady state fires within this iterative quasi-steady-state method there can be discontinuities due to step functions in the procedures. An example of this can be seen when using the BRE spill plume calculation as described in BR368 [1]. There will be a sudden increase in mass flow rate into the smoke layer at the point where the effective height of rise formula changes in transition between a shallow and a deep smoke layer (defined relative to the plan area of the smoke layer). In the absence of any further research or evidence the most suitable option is considered to be to accept any discontinuities without modification. This generally yields conservative results.

B.4 Acceptability criteria for calculated times

Where the layer temperature is higher than the chosen criteria earlier than the time needed to achieve the design objective, the design is not acceptable.

Where the layer depth exceeds our chosen criteria earlier than the time needed to achieve the design objective, the design is not acceptable.

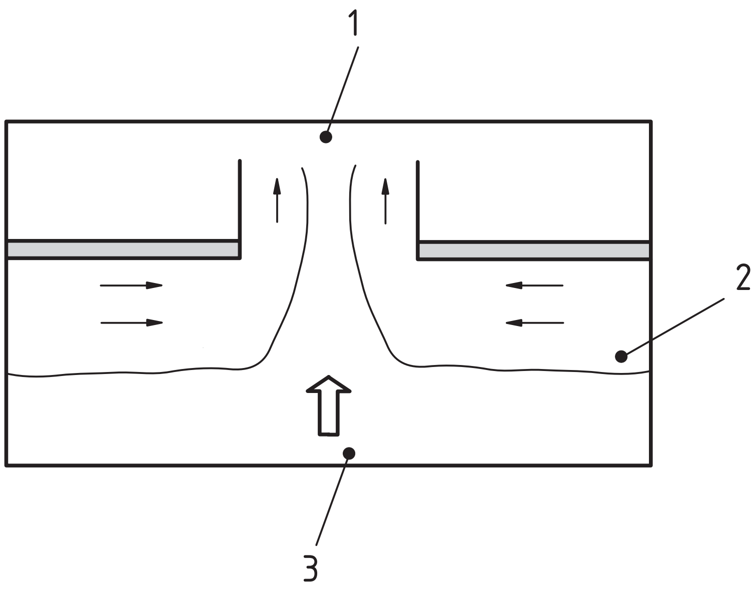
When the design does not fail on these criteria prior to the time needed to achieve the design objectives, the design is acceptable in principle, but still has to be subjected to the other criteria from Clause **6**.

NOTE The reader's attention is drawn to the importance of plugholing in time-dependent SHEVS design.

Annex C (informative)
Plugholing

C.1 Plugholing phenomenon

Plugholing is the phenomenon that occurs when a smoke and heat exhaust ventilator draws air from below the smoke layer as well as smoky gases from the smoke layer into its exhaust opening. This is illustrated in Figure C.1a). When in this condition, the flow into the ventilator can be described as supercritical.



Key

1 Ventilator

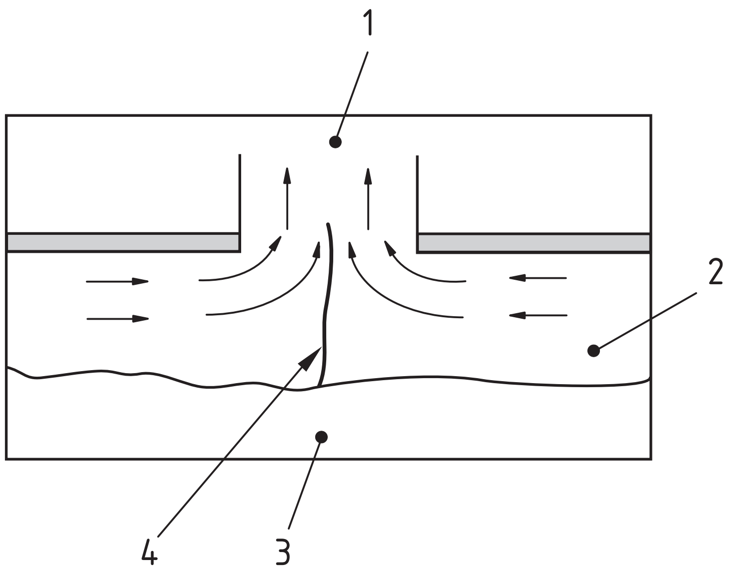
2 Smoke layer

3 Clear air

Figure C.1a) — Plugholing at a supercritical ventilator opening

If the ventilator's exhaust rate is reduced, the proportion of air being drawn in reduces, until a condition is reached where the amount of air being drawn in becomes insignificant. This condition of the ventilator can be described as critical. This is illustrated in Figure C.1b). It is also described as the onset of plugholing.

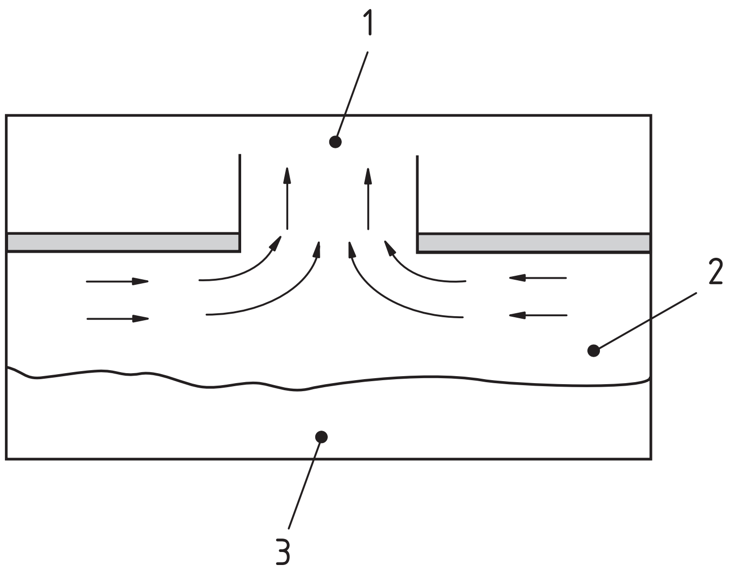
If the ventilator's exhaust rate is reduced further (and assuming no change in the layer's depth) the base of the layer below the ventilator appears undisturbed. This condition of the ventilator can be described as subcritical. This is illustrated in Figure C.1c).



Key

1 Ventilator
2 Smoke layer
3 Clear air
4 Initial (or trace) amounts of clear air drawn up through smoke layer

Figure C.1b) — Onset of plugholing at a critical ventilator opening



Key

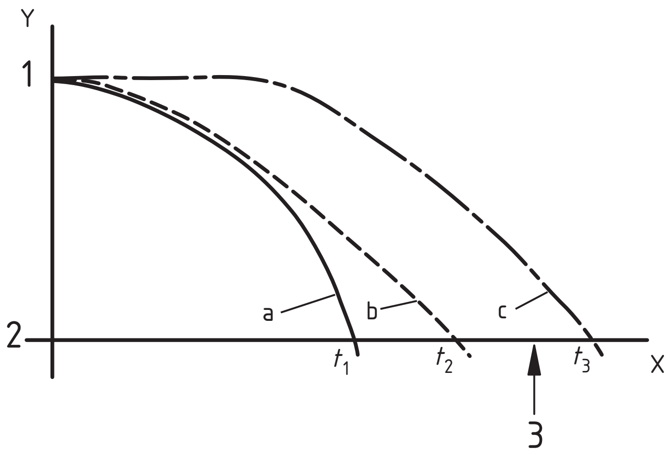
1 Ventilator
2 Smoke layer
3 Clear air

Figure C.1c) — Absence of plugholing at a subcritical ventilator opening

Plugholing can occur with both natural smoke ventilators and powered smoke ventilators.

BS 7346-4:2003, **F.6** provides generally accepted formulae for calculation of the critical exhaust rate for a ventilator, based on research findings.

There is, however, currently no design formula in the published literature that allows the quantitative calculation of the mass flow rates of clear air and smoky gases being drawn into a supercritical ventilator opening. Nevertheless, it can be expected that conditions may be supercritical during the early stages of ventilation and plugholing will then occur. This cannot be overlooked (as it has been in the past) since plugholing will reduce the mass flow of smoky gases through the ventilator and hence allow the smoke layer to descend more rapidly. This may cause the predicted time to safety to exceed the time to danger. This is illustrated in Figure C.2.



Key

X	Time	t_1	Time to onset of hazard, with no smoke exhaust
Y	Depth of smoke layer	t_2	Time to onset of hazard, with smoke exhaust and plugholing
1	Ceiling jet depth	t_3	Time to onset of hazard, with smoke exhaust, but ignoring plugholing
2	Depth at onset of hazard		
3	Safety		
a	No ventilation		
b	With plugholing		
c	With ventilators, ignoring plugholing		

Figure C.2 — Qualitative examples of time-based layer deepening

It can be expected that the importance of plugholing (i.e. the relative gap between t_2 and t_3) will vary from case to case. By analogy with the formulae for the onset of plugholing, it can be expected that plugholing will be less significant for deeper and/or hotter smoke layers; and will be more significant for layers whose depth approaches the size of the ventilator opening and/or which are cooler.

C.2 Calculation

It is known that the critical condition representing the onset of plugholing can be eased for an entire smoke reservoir by spreading the exhaust capacity over a larger number of smaller ventilator openings. This is the principle adopted in BS 7346-4 and elsewhere (e.g. BR368 [1], or PD 7974-2) to avoid wasting exhaust capacity in SHEVS design using steady-state design fires.

Similarly, spreading the exhaust capacity over a larger number of smaller ventilator openings as part of a time-dependent SHEVS design, will ensure that critical exhaust conditions will be reached earlier, which will in turn have the effect of moving curve c in Figure C.2 closer to curve b – and hence moving t_2 closer to t_3.

Until such time as research provides a better method, it is proposed that the following method be adopted:

a) Assume that the mass exhaust rate at the critical onset of plugholing remains the maximum mass exhaust rate of smoky gases from the smoke layer while plugholing in bulk.

NOTE This can be calculated from the formulae given in BS 7346-4:2003, **F.6**.

b) Calculate the critical mass flow rate and the fan (or natural ventilator) exhaust rate at each time increment, and subtract the smaller value from the plume entrainment to give the contribution to the change in layer parameters needed for the next time-increment.

NOTE The number and physical dimensions of openings in the smoke reservoir have to be specified as inputs, rather than being calculated.

Annex D (informative) Factors influencing the choice of time-dependent design fires

The development of a fire will depend 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 as opposed to chairs set out for use);

— the positions 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.

It is currently beyond the state of the art to calculate fire development in arrays of fuel materials for all except the simplest fuel arrays. It is therefore often necessary to use other sources of information.

In reality, of course, any actual sample of fires occurring in the same nominal occupancy will never be describable by a single growth curve. There will be a distribution of growth curves depending on such factors as variations in fuel layout and variations in the location of the initial ignition. This distribution in principle means that the designer should choose an appropriately pessimistic curve. Put perhaps too simply, any design based on an average curve implies a failure rate of one in two. This is usually unacceptable where life safety is involved. It is nevertheless unreasonable for the designer to base the design on the worst curve possible – this would be an explosion. The designer needs to decide where the limits of reasonableness lie. For the initial flaming fire growth, ideally this could be specifiable in terms of the constant γ in Equation 1 being a specified number of standard deviations away from the mean value appropriate to the class of occupancy. Unfortunately, this ideal is unattainable for most scenarios in the absence of appropriate statistics. Also, for some scenarios, the growth rate can vary with time, e.g. a fire can grow at a medium rate for the first few minutes and then change into a fast fire.

There is a remaining group of time-dependent fires for design use. These are where the fuel load corresponding to a specific occupancy has been recreated under a calorimeter and has been burned so that the heat release rate and other important parameters are known as a function of time. These data can then be used by designers to predict the consequences of what would have happened if that same fire had been burned in the building geometry of interest to the design. This technique is useful in that it can allow a confident departure from the more usual design fires for a specific application where the fuel load is not likely to vary much from the arrangement studied in the experiment.

Note here that the time at which the suppression system is activated is crucially important for the time-dependent calculation, but needs to be calculated using accepted and authoritative methods.

It is often cited that it is sufficient for design to take as the largest size fire, that which triggers the first sprinkler and thereafter remains constant. However, this commonly held assumption remains controversial. An alternative, more pessimistic, assumption is that the fire continues to grow unaffected by the operating suppression system until it reaches the steady-state size adopted by designers of steady-state SHEVS designs in accordance with BS 7346-4 and thereafter remains constant.

It is here proposed without evidence that a practical compromise would be to assume that at the moment of operation of the suppression system, the fire growth curve slows to the next slower growth category listed in Table 1 (or remains slow if that is the initial curve), while continuing to grow to the steady-state fire size as described in the previous paragraph.

The ideal design practice, of course, would be to have available actual empirical data describing the entire curve appropriate to the occupancy of interest, including the operation of the fire suppression system and the subsequent changes to the fire behaviour. Such data only exist in the research literature for a limited number of scenarios.

Information on the heat release rate per square metre and/or on the key time-dependent fire parameters can be found in the published literature. Some examples of such references can be found in the Bibliography.

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