

Application of fire safety engineering principles to the design of buildings —

Part 2: Spread of smoke and toxic gases within and beyond the enclosure of origin (Sub-system 2)

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Foreword

This Published Document (PD) was published under the Fire Standards Policy Committee. Other parts published or about to be published are as follows:

- *Part 0: Guide to design framework and fire safety engineering procedures;*
- *Part 1: Initiation and development of fire within the enclosure of origin;*
- *Part 3: Structural response and fire spread beyond the enclosure of origin;*
- *Part 4: Detection of fire and activation of fire protection systems;*
- *Part 5: Fire service intervention;*
- *Part 6: Evacuation;*
- *Part 7: Probabilistic risk assessment.*

These Published Documents are intended to be used in support of BS 7974:2001, *Application of fire safety engineering principles to the design of buildings — Code of practice.*

It has been assumed in the drafting of this PD that the execution of its provisions is entrusted to appropriately qualified and competent people.

Drafting of this publication was completed in July 2001.

Acknowledgement is made to the contribution of Dr D. A. Smith and Prof G. Cox, both of FRS/BRE, in the preparation of this publication.

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

Compliance with a Published Document does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 46, an inside back cover and a back cover.

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Introduction

This Published Document is one of a series of documents intended to support BS 7974. The Code of Practice provides a framework for developing a rational methodology for design using a fire safety engineering approach through the application of scientific and engineering principles to the protection of people, property and the environment from fire.

The Published Documents (PDs) contain guidance and information on how to undertake quantitative and detailed analysis of specific aspects of the design. They are a summary of the state of the art and it is intended that they be updated as new theories, calculation methods and/or data become available. They do not preclude the use of appropriate methods and data from other sources. Figure 1 shows the structure of the Code of Practice and the Published Documents.

BS 7974 can be used to define one or more fire safety design issues to be addressed using fire safety engineering. The appropriate PDs can then be used to set specific acceptance criteria and/or undertake detailed analysis.

A fire safety engineering (FSE) approach that takes into account the total fire safety package can often provide a more fundamental and economical solution than more prescriptive approaches to fire safety. It may in some cases be the only viable means of achieving a satisfactory standard of fire safety in some large and complex buildings.

Fire safety engineering can have many benefits. The use of BS 7974 will facilitate the practice of fire safety engineering and in particular it will:

- a) provide the designer with a disciplined approach to fire safety design;
- b) allow the safety levels for alternative designs to be compared;
- c) provide a basis for selection of appropriate fire protection systems;
- d) provide opportunities for innovative design;
- e) provide information on the management of fire safety for a building.

Fire is an extremely complex phenomenon and there are still gaps in the available knowledge. When used by suitably qualified persons, experienced in fire safety engineering, this series of documents will provide a means of establishing acceptable levels of fire safety economically and without imposing unnecessary constraints on aspects of building design.

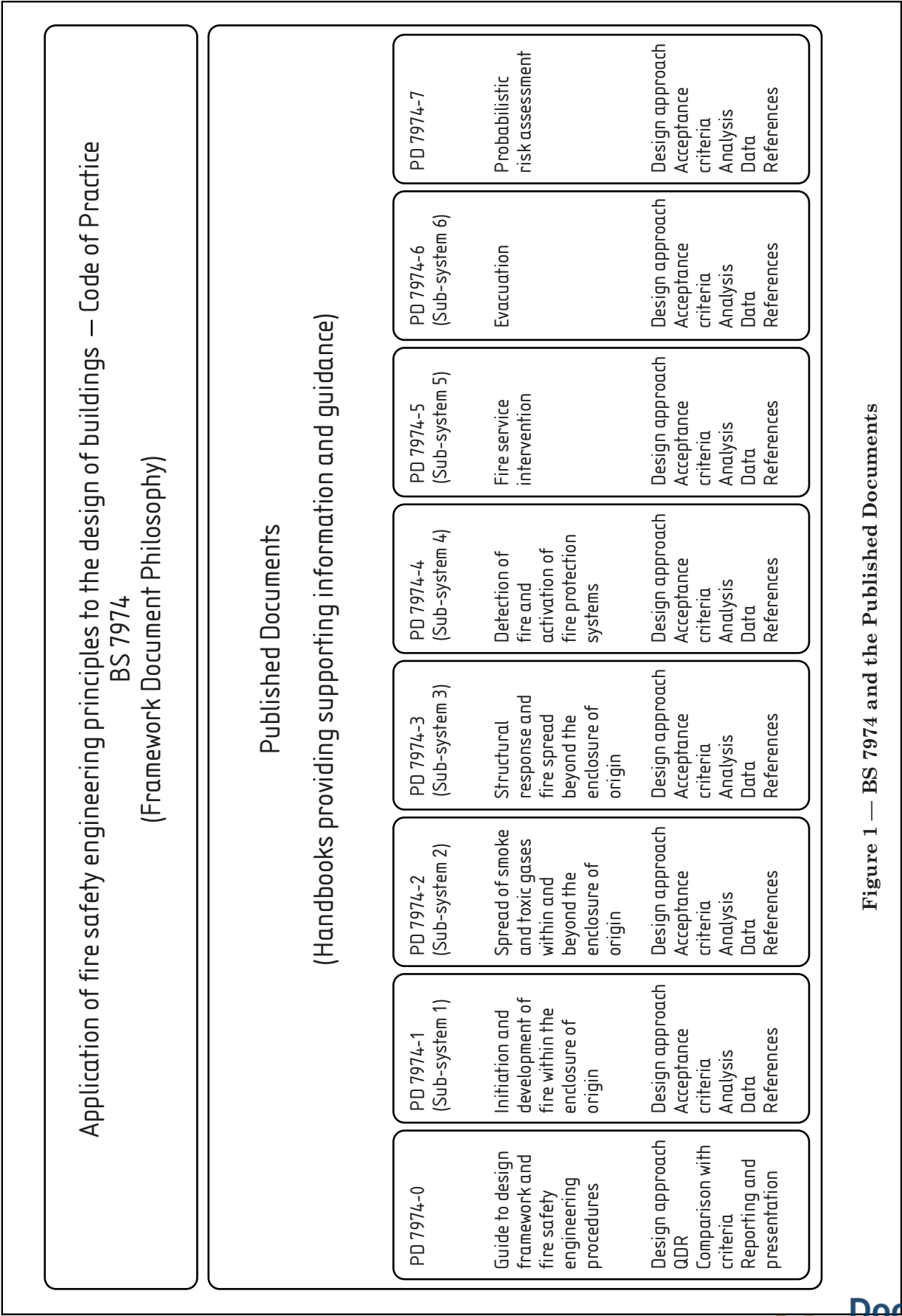


Figure 1 — BS 7974 and the Published Documents

1 Scope

This Published Document provides guidance on the application of fire safety engineering principles for the treatment of smoke movement, control and management problems. The guidance is intended primarily for professional engineers with a responsibility for the design or assessment of fire safety in buildings.

Sub-system 1 (PD 7974-1) provides information on the rate of production of heat and combustion products from the fire source. The aim of Sub-system 2 is to provide design approaches to estimate the spread of the combustion gases within and beyond the room of origin and to evaluate their properties, i.e. temperature, visibility and concentration of toxic products. This information can be used to calculate the time between the detection of a fire to conditions developing which would be dangerous to building occupants. This will enable the design of fire safety measures to ensure that sufficient time is available for escape. It also provides information that will allow property issues to be assessed.

This Published Document forms part of a series of Sub-systems 1 to 6 (PD 7974-1 to PD 7974-6), but may, in consultation with the appropriate references, be regarded as “stand-alone” guidance.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of this Published Document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 476-31.1:1989, *Methods for measuring smoke penetration through doorsets and shutter assemblies*.

BS 5588-4:1998, *Fire precautions in the design, construction and use of buildings — Code of practice for smoke control using pressure differentials*.

BS 7974:2001, *Application of fire safety engineering principles to the design of buildings — Code of practice*.

DD 240:1997, *Fire safety engineering in buildings — Part 1: Guide to the application of fire safety engineering principles*.

ISO DIS 13943:2000, *Fire safety — Vocabulary*.

ISO/TR 13387-1:1999, *Fire safety engineering — Part 1: Application of fire performance concepts to design objectives*.

ISO/TR 13387-2:1999, *Fire safety engineering — Part 2: Design fire scenarios and design fires*.

ISO/TR 13387-3:1999, *Fire safety engineering — Part 3: Assessment and verification of mathematical fire models*.

ISO/TR 13387-4:1999, *Fire safety engineering — Part 4: Initiation and development of fire and generation of fire effluents*.

ISO/TR 13387-5:1999, *Fire safety engineering — Part 5: Movement of fire effluents*.

ISO/TR 13387-6:1999, *Fire safety engineering — Part 6: Structural response and fire spread beyond the enclosure of origin*.

ISO/TR 13387-6:1999, *Fire safety engineering — Part 7: Detection, activation and suppression*.

ISO/TR 13387-8:1999, *Fire safety engineering — Part 8: Life safety-occupant behaviour, location and condition*.

PD 7974-0, *Application of fire safety engineering principles to the design of buildings — Part 0: Guide to design framework and fire safety engineering procedures*.

PD 7974-1, *Application of fire safety engineering principles to the design of buildings — Part 1: Initiation and development of fire within the enclosure of origin* (Sub-system 1).

PD 7974-3, *Application of fire safety engineering principles to the design of buildings — Part 3: Structural response and fire spread beyond the enclosure of origin* (Sub-system 3).

PD 7974-4, *Application of fire safety engineering principles to the design of buildings — Part 4: Detection of fire and activation of fire protection systems* (Sub-system 4).

PD 7974-5, *Application of fire safety engineering principles to the design of buildings — Part 5: Fire service intervention* (Sub-system 5).

PD 7974-6, *Application of fire safety engineering principles to the design of buildings — Part 6: Evacuation* (Sub-system 6).

3 Terms and definitions

For the purpose of this part of PD 7974, the following terms and definitions apply.

3.1

ambient condition

property of the surroundings outside the influence of a fire

3.2

air entrainment

mixing of ambient air into a jet or plume of gas or liquid as a result of momentum transfer

3.3

axi-symmetric plume

plume of combustion products and entrained air rising above a fire source where the air is entrained symmetrically towards the source

3.4

backdraught

explosive or rapid burning of unburnt pyrolysis products that occurs when oxygen is introduced into a building that has not been properly ventilated and has a depleted supply of oxygen due to fire

3.5

ceiling jet

flow of hot fire gases driven away from the smoke plume ceiling impingement point

3.6

channelling screen

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

3.7

compartment

space defined by fire resisting boundary elements

3.8

Computational fluid dynamics model

CFD model

field model

computer simulation model where the fundamental equations of heat and mass transfer are solved using numerical methods

NOTE In contrast to zone models, computers provide the enabling technology for these models.

3.9

convective heat flux

heat flux carried by the convected motion of the fire gases

3.10

design fire

hypothetical fire that is agreed as representative of actual severe fires likely to occur in a particular fire scenario

3.11**discharge coefficient**

ratio of actual flow rate, measured under specified conditions, to the theoretical flow rate through an opening

NOTE For example, a vent.

3.12**discretize**

process of replacing a continuous mathematical function by its numerical counterpart where it has a value at only discrete intervals

NOTE For example, grid points in a numerical mesh.

3.13**enclosure**

space defined by boundary elements (on all sides) around the point of origin of the fire

3.14**escape time**

sum of pre-movement time and travel time to and through an exit to a place of safety

3.15**fire scenario**

set of circumstances, chosen as an example, that defines the development of fire and the spread of combustion products throughout a building or part of a building

3.16**flashover**

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

3.17**fire detection and alarm**

detection of a fire by occupants and/or mechanical device and visual, audible or some other method of alerting the occupants

3.18**fire safety engineering**

use of engineering principles for the achievement of fire safety

3.19**free-hanging smoke curtain**

smoke curtain fixed only along its top edge

3.20**iteration**

repeated calculation performed on discretized equations

NOTE These are normally performed by taking the solution from one calculation, the previous iteration, as an input to the next iteration. This process is repeated many times over until the differences between successive iterations are acceptably small.

3.21**natural ventilation**

ventilation resulting from the exploitation of the thermal buoyancy of the smoky gases to exhaust them to be replaced at inlets by ambient air

3.22**powered smoke and heat exhaust ventilation**

ventilation resulting from the application of externally powered ventilators (e.g. fans) to exhaust smoky gases to be replaced at inlets by ambient air

3.23

place of safety

predetermined place in which persons are in no danger from the effects of fire

3.24

pre-movement time

interval between the time at which a warning of fire is given and the time at which the first move is made towards an exit

3.25

sensitivity analysis

calculation of changes in outputs for variations in an input parameter of interest

3.26

smoke curtain

curtain to restrict the spread of smoke and hot gases from a fire

NOTE It often forms part of the boundary of a smoke reservoir.

3.27

smoke explosion

explosion of a mixture of flammable fire gases (pyrolized fuel and partial combustion products) and air

NOTE A particular case of a backdraught.

3.28

replacement air

ambient air replacing the mass flow of smoky gases vented to the external environment

3.29

smoke reservoir

region within a building or other construction work limited or bordered by smoke curtains or structural elements so as to retain a thermally buoyant smoke layer in the event of a fire

3.30

spill plume

vertically rising plume resulting from the an initially horizontally-flowing smoke layer encountering a free edge

3.31

steady state design

design solutions which are time invariant, i.e. hot gas layer depth and temperature remain constant over time

NOTE These are usually based upon the design fire burning steadily at its largest size.

3.32

time dependent design

design solutions based upon time-dependent input parameters

NOTE Usually these are designed to maintain safe conditions for a specific time, e.g. time required for people to reach a place of safety.

3.33

travel distance

actual distance to be travelled by a person along an escape route to the nearest exit to a place of safety or a refuge or a protected escape route, having regard to the layout of walls, partitions and fittings

3.34

virtual origin

point or line from which a plume appears to have emerged

NOTE It can be above or below the real fire source depending on its buoyancy and momentum.

3.35

visibility

ability to see through smoke

3.36

zone model

theoretical simulation of the whole system characterizing the enclosure fire by a series of relatively few separable component processes. Each component is represented by an equation or estimation formula

3.37 Nomenclature

α	is an entrainment coefficient (dimensionless);
κ	$= \left(\frac{2}{3} \frac{\rho_0}{T} \sqrt{2g\theta} T_0 \cdot \kappa_m \right) \text{ (kg} \cdot \text{s}^{-1} \cdot \text{m}^{-5/2}\text{);}$
κ_m	is a “profile correction factor” (dimensionless);
ρ_0	is the ambient air density (kg/m ³);
ρ_α	is the density of the species α (kg/m ³);
ρ_c	is the density of the boundary surface;
θ	is an excess temperature (°C);
θ_c	is the maximum temperature rise in the ceiling jet (°C);
θ_{imp}	is the maximum temperature rise in the vertical plume at the impingement point (C);
θ_1	is the excess temperature of the smoke layer (°C);
θ_{max}	is the maximum temperature rise in the ceiling jet (C);
χ	is the fraction of the total heat release convected by the plume (dimensionless);
A_i	is the total area of all inlets (m ²);
A_v	is the throat area of the ventilator (m ²);
b	is the horizontal distance from the opening to balcony edge (m);
c_α	is the mass concentration of species α (kg/m ³);
C_d	is a discharge coefficient for the opening (dimensionless);
C_e	is the constant of proportionality in equation (8) or equation (18) (kg/s · m ^{5/2});
C_i	is the entry coefficient for inlets (dimensionless);
C_p	is the specific heat of air at constant pressure (kJ/kg · K);
C_v	is the coefficient of discharge (dimensionless);
C_w	is the specific heat of the bounding solid;
C_α	is the volume concentration of species α (dimensionless);
d_s	is the longer linear dimension of the source (m);
d	is the smoke layer depth (m);
D	is the optical density per unit path length of the smoke (m ⁻¹);
D_c	is the deflection of the curtain (m);
D_m	is the mass optical density for the fuel concerned (m ² /kg);
D_s	is the source diameter or characteristic length (m);
f_b	is the total mass of fuel burnt (kg);
g	is the acceleration due to gravity (m/s ²);
h	is the height of opening (m);
H	is the height of the ceiling above the fire source (m);
I/I_0	is the fraction of light transmitted through smoke (dimensionless);
k_w	is the thermal conductivity of the bounding solid (kW/m · K);

K	is light extinction coefficient (m^{-1});
l	is the corridor half width (m);
L	is the lateral extent of the spill plume (m);
L_c	is the length of the smoke curtain measured along the fabric (m);
m	is the mass flow rate entering the layer (kg/s);
m_{air}	is the mass flow rate of air entrained (kg/s);
m_{fuel}	is the mass burning rate of fuel (kg/s);
m_{smoke}	is the mass flow rate of smoke (kg/s);
m_b	is the mass flow rate of smoke approaching a balcony edge (kg/s);
m_{crit}	is the critical mass flow rate of an exhaust point prior to plug-holing (kg/s);
M_b	is the weight per unit length of the curtain's bottom bar (kg/m);
M_c	is the weight per unit area of the curtain fabric (kg/m^2);
n	is a constant in equation (28) (dimensionless);
N	is the number of extract vents (dimensionless);
p	is the perimeter of the source (m);
Q_p	is the rate of heat release convected by the plume (kW);
Q	is the total rate of heat release of the fire source (kW);
Q''	is the total rate of heat release per unit area of fire source (kW/m^2);
Q^*	$= \frac{Q}{\rho_a T_a C_p g^{1/2} D_s^{5/2}} = \frac{Q}{1110 D^{5/2}}$ for "normal" ambient conditions when Q is in kW and D in metres (dimensionless);
r	is the radial distance from the ceiling impingement point (m);
s	is optical path length (m);
S	is the visibility distance (m);
t	is the thermal penetration time (s);
T	is the local smoke temperature (K);
T_0	is the ambient air temperature (K);
u_{max}	is the maximum gas velocity in the ceiling jet (m/s);
V	is the volume flow rate of smoke (m^3/s);
V_t	is the total volume of smoke at a location (m^3);
w	is the width of the opening on to the balcony (m);
w_V	is the characteristic width of the ventilator (m);
y	is the distance along the corridor from the impingement point (m);
Y_α	is the mass yield the species α (kg/kg)-the ratio of mass generation rate of the species, α , to mass gasification rate of the fuel;
Y_{fu}	is the local mass fraction of fuel (dimensionless);
Y_{ox}	is the local mass fraction of air (dimensionless);
z	is height above the fuel surface or balcony edge (m);
z_0	is the height of the virtual source above the fuel surface (m);
z_{fl}	is the mean height of luminous flames above the fuel surface (m);
z_{max}	is the maximum height of rise of smoke plume (m).

4 Design approach

4.1 Objective of Published Document

A framework of the application of engineering approaches to fire safety in buildings is provided in BS 7974. PD 7974-0 provides additional guidance to assist the fire safety engineer through the design process.

The quantitative analysis necessary as part of the design is divided into a number of separate parts or Sub-systems. Each Sub-system can be used in isolation when analysing a particular aspect of design or they can all be used in combination as part of an overall fire engineering evaluation of a building. A representation of the concept is shown in Figure 1. Some of the potential interactions between Sub-systems are illustrated. The parameters are often both inputs into one particular Sub-system and outputs from another.

This Published Document provides guidance on the application of fire safety engineering principles for the treatment of smoke movement, control and management problems. The guidance is intended primarily for professional engineers with a responsibility for the design or assessment of fire safety in buildings.

Sub-system 1 (PD 7974-1) provides information on the rate of production of heat and combustion products from the fire source. The aim of Sub-system 2 is to provide design approaches to estimate the spread of the combustion gases within and beyond the room of origin and to evaluate their properties, i.e. temperature, visibility and concentration of toxic products. This information can be used to calculate time to danger from the detection of a fire and to design any fire safety measures required to ensure that sufficient time is available for escape.

It is recommended that a sensitivity analysis be conducted to examine the consequences of the choices made for smoke control and for design fire on the rigour of the solution proposed. The objective of the analysis is to establish the impact on the output parameters caused by variation of the input parameters. If a particular choice is shown to be critical to the design, consideration should be given to providing a degree of redundancy to the design.

It is important to appreciate that what may be conservative for one component of the design may be a best case for another. A large or fast growing design fire can, for example, be conservative for estimation of smoke exhaust capacities but would be overly optimistic for fire detection or suppression activation times.

The calculation methods and data contained in this Sub-system are included with the known limitations. Alternative data and calculation methods are not precluded and may be required. Satisfactory justification of any calculation method or approach selected should always be provided.

This Published Document forms part of a series of Sub-systems 1 to 6 (PD 7974-1 to PD 7974-6), but can, in consultation with the appropriate references, be regarded as “stand-alone” guidance. Guidance is also available from other Published Documents including the ISO/TR 13387 series and references [1] to [5].

4.2 Qualifications of the user

The complexity of the interactions between people, buildings and fire is such that no single set of calculation procedures can be applied to all types of buildings in all circumstances. Therefore fire safety engineering requires a greater degree of care and responsibility by the designer than does the application of prescriptive codes. It is essential that the application of fire safety engineering be conducted by suitably qualified and experienced personnel. In assessing the suitability of fire safety engineering design personnel, professional qualifications (e.g. Chartered Membership of the Institution of Fire Engineers), knowledge of current engineering guidance and handbooks and experience on complex projects should be taken into account.

4.3 The hazard associated with smoke

Smoke is the term used to describe the “airborne” products of combustion from the fire together with large volumes of air that become entrained into them due to their motion. These combustion products can contain solid and liquid particulates within a gaseous mass.

Almost all fires produce smoke which when enclosed by a building has the potential to become extremely hazardous to its occupants and damaging to property. Most deaths in fires are due to smoke inhalation rather than to the victim having been burned.

The gaseous combustion products, chiefly carbon dioxide and water usually include toxic gases, the most common being carbon monoxide, although hydrogen cyanide and other minor species might be present to some extent. Amongst these, irritant gases such as acrolein can have a significant effect on people attempting to escape fire.

The solid and liquid fractions of the products of combustion are responsible for the poor visibility through smoke. This adds to the problems presented by the smoke. Not only is it physiologically hazardous in its own right but escape through it is made more difficult by it obscuring escape routes. These fractions can themselves be irritants, and can be particularly dangerous to people who are subject to asthma or other respiratory problems.

The reduction in oxygen due to combustion can itself be dangerous in some situations and can result in the suffocation of victims trapped in smoke. The heat of the combustion products is also potentially hazardous to the building occupants, either through their potential immersion in the smoke or by thermal radiation from the hot smoke layer.

Smoke can also cause damage to property. Most fires produce soot and many generate corrosive gases such as hydrogen chloride. The effect of these on sensitive equipment can be responsible for large monetary losses due to equipment damage, the need for system clean-up and consequent business interruption.

There are also hazards that have been termed “smoke explosions” associated with smoke containing the unburnt pyrolysis products of fire. These hazards are more properly considered within the broader category of backdraught that can occur as a result of the sudden availability of fresh air.

All fires start small and grow, some only smoulder. In the earliest stages when detection is the priority, the fire will not yet be controlling the airflow patterns. At this time the smoke is simply a “passenger” on the prevailing natural air currents caused by space heating, wind pressures etc. Most of what follows describes the processes after the fire has become large enough for buoyancy to dominate these currents. The treatment of these very early conditions is not covered here except in the section on CFD modelling which does encompass both situations.

4.4 Smoke dynamics

It is important to understand the basic mechanisms that control the growth of fire in an enclosure.

- a) The fire starts for whatever reason, its rate of growth depending upon the materials involved, their orientation and positions relative to each other. In most situations there is sufficient oxygen to support combustion in the first few minutes and the fire growth and smoke production are controlled by the fuel.
- b) Because of its buoyancy the smoke rises from the fire. Initially the buoyancy is low and the smoke will follow the ambient air currents present before the fire occurred but as its heat release increases, its buoyancy increases and it soon begins to dominate air currents in the enclosure. When the fire reaches a sufficient size the smoke rises in a plume towards the ceiling. As it does so it entrains large volumes of air greatly increasing smoke volume but reducing its temperature and concentrations of chemical constituents.
- c) The total entrained volume increases substantially with increasing height of rise of the plume. With sufficient buoyancy the smoke eventually impinges the ceiling, spreading out radially to reach any side-walls and then to begin to form a layer which deepens as more smoke is produced.
- d) Smoke eventually flows out into adjacent spaces through any high level openings. This outflow is balanced by an inflow of air usually at low level. The openings may be by design or by failure of, for example, a glass partition.
- e) As new flammable material becomes involved as a result of increasing heat transfer to it, more air is required for the fuel volatiles to burn. If this is not available the fire will either not grow any further or the fuel volatiles will instead burn outside the enclosure of origin in the open air or in an adjacent space. This is particularly likely after flashover when a sudden dramatic growth in the fire occurs as a result of the simultaneous involvement of all flammable material in the enclosure.

5 Smoke control

5.1 Design objectives

5.1.1 General

Since smoke control can have a major impact on the overall design of the building it needs to be considered at the earliest possible stage of the design process. Indeed where it is used to allow increased means-of-escape travel distances it will have a profound effect on the overall concept.

Smoke control systems are usually designed to maintain a tenable environment for occupants to enable their safe escape from the building or to a place of refuge. They can also be required to assist in property protection; to assist the entry and subsequent operations of fire-fighters; and, by limiting the temperature of the smoke layer, assisting the fire performance of the structure.

Smoke control systems are required both for protection of the enclosure of fire origin as well as preventing smoke spread to adjoining spaces. These two requirements may need to be satisfied by different types of system.

It will be for the QDR to determine where these different treatments should be applied and to ensure their compatibility. References [4] and [5] (CIBSE Guide E Fire Engineering, Chapter 7 *Fire and Smoke ventilation* and BRE 368) provide additional guidance to assist the decision-making process.

There are very few cases where Codes of Practice require smoke control measures. Approved Document B [6] specifies that new shopping malls in England and Wales conform to BS 5588-10, which specifies use of smoke control in those premises. Smoke control is also required for basements (for fire fighting) and service corridors in shopping malls although it is becoming common in large department stores as well. The only other scenario where smoke control is mandatory is atrium buildings that are over 30 m high (BS 5588-7), although it is a permitted alternative in other scenarios.

The four main objectives for the smoke control systems are given in 5.1.2, 5.1.3, 5.1.4 and 5.1.5.

5.1.2 Protection of means of escape

The objective is to achieve a desired smoke free clear layer beneath a smoke layer. This approach is commonly used where the purpose of the smoke exhaust ventilation system is to allow the continued use of escape routes which are in the same space as the fire (examples include enclosed shopping malls and many atria or large single storey spaces e.g. for public assembly). The thermally buoyant smoke forms a layer beneath the ceiling. The smoke exhaust (using either natural smoke exhaust ventilators or powered smoke exhaust ventilators) is calculated to be large enough to keep the smoke at a safe height above the heads of people long enough for them to make their safe escape. It is essential that the system comes into operation as early as possible during the fire, and it is usual to initiate operation automatically on receipt of a signal from a smoke detection system.

Smoke control using pressure differentials is a different technique often used to protect stairwells and sometimes corridors against the ingress of smoke. The use of smoke control doors in conjunction with a well-sealed corridor or stairway construction can also resist smoke ingress onto protected routes.

5.1.3 Temperature control

Smoke and heat exhaust ventilation systems can be designed to minimize the temperature of the gases in the buoyant layer in critical areas of the design. This protects the use of materials that would otherwise be damaged by the hot gases. A typical example is where an atrium facade has glazing which is not fire resisting, but which is known to be able to survive gas temperature gradients up to some specified value. The use of a “temperature control” smoke exhaust ventilation system 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.

5.1.4 To assist fire fighting operations

In extensive and multi-storey complex buildings fire-fighting and rescue operations can be severely hampered by the presence of hot smoky gases. The travel time from the fire appliances to upper and lower levels can be improved by the provision of smoke control systems installed primarily for the occupants’ means of escape or protection of property.

Smoke control systems can also be installed for fire-fighting alone and here the design criteria will be different reflecting the specialist equipment clothing and training of the fire service.

5.1.5 Property protection

Smoke control systems can be used to protect not only the contents of a building but also some aspects of the structure. Heat can be vented by the smoke exhaust system to ensure that the heat flux to critical structural elements is kept below acceptable criteria. Such smoke control systems usually depend on the inclusion of measures to limit fire size.

Depending on the materials present, a property protection philosophy can be based on the need to maintain the hot buoyant smoke layer above sensitive materials, or can be based on the need to maintain the smoke layer below a critical temperature.

5.2 Smoke control techniques in common use

5.2.1 Smoke containment

Smoke containment relies on physical barriers to limit the spread of smoky gases from one space in a building to another space. Passive compartmentation such as doors, shutters, walls and floors, can provide some protection against smoke penetration. The extent to which smoke leaks through these barriers depends on the size and shape of leakage paths and the pressure differentials across them.

These leakage paths can be eliminated, or substantially reduced by the incorporation of linear gap sealing systems, penetration sealing systems, smoke control doorsets and their associated seals. Control of high temperature smoke can be achieved with the use of intumescent seals.

Quantitative measurements of smoke leakage through doorsets etc. are achieved by reference to BS 476-31.1:1989.

5.2.2 Smoke clearance

This term describes any method of removing relatively cool smoky gases from a space in a building when smoke is no longer entering or being created in that space. This can be achieved by providing natural cross-ventilation, e.g. by the opening of windows, or by activation of powered exhaust systems.

5.2.3 Smoke dilution

This term describes any method of mixing the smoky gases with enough clean air to increase visibility and reduce the threat from toxic combustion products. This can require a very large dilution to achieve a safe visibility. With smoky fuels such as those from many plastics materials this dilution may need to be one thousand times the initial volume of combustion gases. This can be difficult to achieve for all except the smallest design fires in a large building volume.

5.2.4 Smoke exhaust ventilation

This is a method providing a separation between an upper layer of smoke and a lower layer of relatively clean air. This is achieved by exhausting smoke from the buoyant smoke layer using either natural or powered ventilators, and replacing it with clean air entering the space below the layer.

Hot, buoyant gases from a fire rise to form a stable layer in a reservoir below the ceiling such that a cooler clear layer of sufficient height may be present for long enough to achieve safe evacuation of occupants.

It is rare to find circumstances where a dedicated smoke exhaust ventilation system is required within a small room although the process may play an important part in fire fighting.

Guidance on the design of smoke exhaust ventilation can be found in BS 7346-4 (draft) and BS 7346-5 (draft).

5.2.5 Pressurization

Pressurization is a form of smoke control using pressure differentials, in which the air pressure in spaces being protected is raised above that in the fire-affected area. Airflow through the leakage paths prevents infiltration of smoke to the protected high-pressure side.

Guidance on the design of pressurization systems can be found in BS 5588-4:1998.

The pressure difference across any small openings onto an escape route should be large enough to offset the fire-generated pressure as well as any adverse pressures caused by external winds and stack effects. It should also be low enough to allow the escape doors to be opened with relative ease. The requirements can be contradictory and difficult to reconcile.