PUBLISHED DOCUMENT

PD 7974-4:
2003

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)

Confirmed
December 2011

ICS 13.220.20; 91.120.99

British Standards

Committees responsible for this Published Document

The preparation of this British Standard was entrusted by FSH/24, Fire safety engineering, to Subcommittee FSH/24/4, upon which the following bodies were represented:

Association of Building Engineering

BRE/LPC Laboratories

Chief and Assistant Chief Fire Officer's Association

DETR

DoH — NHS Estates

District Surveyors Association

Fire Safety Development Group

Home Office

Fire Brigades Union

Fire Service

London Fire and Emergency Planning Authority

This Published Document, was published under the authority of the Standards Policy and Strategy Committee on 14 March 2003

The following BSI references relate to the work on this Published Document:
Committee reference: FSH/24/4

ISBN 0 580 41249 0

Amendments issued since publication

Amd. No.	Date	Comment

Contents

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* (QDR)*;*

— *Part 1: Initiation and development of fire within the enclosure of origin* (Sub-system 1);

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

— *Part 3: Structural response and fire spread beyond the enclosure of origin* (Sub-system 3);

— *Part 5: Fire service intervention* (Sub-system 5);

— *Part 6: Evacuation* (Sub-system 6);

— *Part 7: Probabilistic risk assessment* (Sub-system 7).

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.

Historically, fire detection, alarm and suppression systems have been subject to product orientated prescriptive codes and standards. Research to calculate and predict fire growth and the performance of detection, suppression and smoke control systems is still ongoing. There is much still to be done before the area becomes a mature science.

This document will *not* provide all information necessary to undertake a full fire safety engineering design of fire detection and fire control systems. It will, however, provide a framework and guidance for the design assessment, and will identify other documents that should be referred to, as appropriate.

Drafting of this publication was completed in July 2001.

Acknowledgement is made to the contribution of Mr. N. Smithies of FRS/BRE and Mr. P. Bryant of Kingfell Fire Protection Ltd 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 to ii, pages 1 to 39 and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

1 Scope

This Published Document provides guidance on the development, design and application of fire detection systems, and the activation of fire alarm and fire control systems to fulfil a role in the fire safety engineered design for a building. Scientific and engineering principles are used as part of a structured approach. The key elements covered are:

— *detection*: information is provided on the various types of fire detection system and their application for a given set of circumstances, as derived from a qualitative design review, risk assessment and the results of formulae provided by other Sub-systems;

— *activation and control*: once the fire detection system has detected a fire, it activates a series of measures designed to fulfil the requirements of the fire safety engineered design. These measures may include operation of fire warning systems, the remote signalling to emergency services, and the operation of fire alarm, fire suppression and fire control systems. Guidance is given on the methodology and formulae required in ensuring that the appropriate systems are activated in an appropriate manner and within given criteria.

In the context of this document, fire control includes:

— *fire suppression systems*: active systems designed to suppress a fire, temporarily (i.e. control) or permanently (i.e. extinguish). Examples include automatic water sprinkler systems;

— *fire barrier systems*: active systems designed to contain a fire within a given area or separate a fire from another area. Such systems may be regarded as offering similar benefits to passive fire compartments or separations for the duration of their operation. Examples include fire damper systems and door release mechanisms;

— *smoke/heat control systems*: active systems designed to positively control the movement and build up of fire effluents such as smoke, heat and toxic gases. Examples include smoke venting systems and air pressurization systems.

NOTE This document does not contain detailed design and installation instructions for the systems covered. This information may be obtained from other relevant British Standard codes of practice and specifications.

2 Normative references

BFPSA, COP12, *Code of practice — Category 1 Aspirating Detection Systems.* Issue 1. Available from BFPSA, Neville House, 55 Eden Street, Kingston-Upon-Thames, Surrey KT1 1BW.

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

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

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

BS 5839-8, *Fire detection and alarm systems for buildings — Part 8: Code of practice for the design, installation and servicing of voice alarm systems.*

BS EN 54-2, *Fire detection and alarm systems — Part 2: Control and indicating equipment.*

BS EN 54-3, *Fire detection and alarm systems — Part 3: Fire alarm devices — Sounders.*

BS EN 54-4, *Fire detection and alarm systems — Part 4: Power supply equipment.*

BS EN 54-5, *Fire detection and alarm systems — Part 5: Heat detectors — Point detectors.*

BS EN 54-7, *Fire detection and alarm systems — Part 7: Smoke detectors — Point detectors using scattered light, transmitted light or ionization.*

BS EN 54-10, *Fire detection and alarm systems — Part 10: Flame detectors — Point detectors.*

BS EN 54-11, *Fire detection and fire alarm systems — Part 11: Manual call points.*

BS ISO 14520 (all parts), *Gaseous fire-extinguishing systems — Physical properties and system design*

HAG Report, *A review of the toxic and asphyxiating hazards of clean agent replacements for halon 1301.* Available from The Halon Users National Consortium Limited. Global House. College Street. Petersfield. Hampshire. GU31 4AD.

NFPA 750, *Standard on Water Mist Fire Protection Systems.* NFPA, 1 Batterymarch Park Quincy, MA 02269-9101 USA. http://www.nfpa.org

3 Terms and definitions

3.1
alarm receiving centre
continuously manned premises, remote from those in which the fire alarm system is fitted, where the information concerning the state of the fire alarm system is displayed and/or recorded, so that the fire and rescue service can be summoned

NOTE Alarm receiving centres are also called remote manned centres; the term "central station" is sometimes used as a synonym for alarm receiving centre.

3.2
coincidence detection
facility (provided by a fire detection and alarm system) designed so that an output is obtained only when one signal has been received from a fire detector and one or more confirmatory signals are received from the same or other points

3.3
fire suppression system
system designed to control, suppress or extinguish a fire, via the use of water, chemical or inerting gas, or other means

NOTE These systems may be activated manually or automatically

4 Symbols and abbreviations

Symbols and abbreviations are included with the relevant formulae, for purposes of clarity.

5 Design approach

5.1 The principles of fire detection

Although a fire safety engineered approach to the design and construction of buildings can have a major impact on reducing the risk of fire, it is commonly recognized that fire detection will usually play a critical role. It could be argued that all fires will, if allowed to grow, eventually be detected. However, it is the speed of detection of a fire that will influence how effective the subsequent stages of the active components of a fire safety engineering design will be.

The type and extent of detection system to be employed may be determined by a number of considerations, including the primary objectives for the design. For instance, where a fire is likely to be detected by a person before it will adversely impact on any other person in the building, a system making use of only manual call points might be perfectly adequate. In another case, a mostly unmanned warehouse cannot rely upon a manual response and an automatic fire detection system and/or sprinkler system will be warranted. Historically, the type and extent of fire detection is often dictated by external influences rather than by a measured assessment of the risk and the determination of the most appropriate and effective form of detection. These influences may include the requirements of legislation as enforced by the Fire Authority and Building Control Body, or the requirements of interested parties, such as the Insurer.

The main requirements for a fire detection system are the ability to:

— respond to the likely products of combustion posing a threat to the building, its occupants and/or its processes;

— discriminate between fires posing a threat and non-fires (false alarms);

— provide a signal to activate fire warning or control systems within an acceptable time period;

— be sufficiently available and reliable to perform when required and as intended.

5.2 The principles of activation and control

The detection of a fire is normally the first in a chain of events. Subsequent actions such as the sounding of alarms and the operation of fire suppression systems are normally directly initiated by the fire detection system. In fact, a fire detection system that does not activate other systems is of little benefit. The type, extent and interaction of activated measures will depend on the findings of the QDR and the results of the assessments of other Sub-systems. The end result may be a simple chain of events or may be a complex set of interactions. Figure A.1 in Annex A illustrates how the activated fire control systems interrelate following the detection of a fire. Further guidance is given in Annex A.

5.3 Preparing a fire safety engineering design for detection and control systems

In order to prepare a fire safety engineering design for fire detection and associated active systems, a process should be followed. Typically, forms part of the Qualitative Design Review (QDR) process as described in BS 7974 and could commence with the assessment of the requirements for fire detection. However, there may be just as good an approach by determining the type of fire controls required and working back to determine the most appropriate form of detection to activate those controls. The following process starts with fire detection as this is the way this Sub-system has been structured. Each stage of the process will prompt decisions to be made and will provide a reference for further investigation.

Stage A is shown in Table 1.

Table 1 — Stage A: Fire detection

Step	Title	Detail	Reference(s)
1	Determination of objectives	To determine the requirements for the fire detection system as part of the overall fire safety engineering strategy.	QDR
2	Required time to response	To determine at what stage of fire development the system should respond.	QDR
3	Location and extent of detection	To identify where automatic and/or manual fire detectors are required.	**7.1**
4	Type of detection	To assess the most appropriate form of fire detectors for each of the areas to be monitored.	**7.2**
5	Siting and spacing	To determine how and where the chosen fire detectors are to be sited and spaced.	**7.3** and **7.4**
6	Calculated time to response	To assess the likely time to response for any of the areas fitted with detection. If the period is less or more than that required, Step 3 could be revisited and the siting and spacing of detectors re-assessed.	**7.5**

Stage B: Fire Control and Warning Systems

Once the fire detection system design has been confirmed, the designer should determine the type of fire control and fire warning systems required. Consideration should also be given to the way in which the systems interact. There might also be a need to re-evaluate the design of the detection system to ensure the extent and type of system(s) proposed is suitable for the subsequent stages of the process. can be used for guidance.

Stage B.1: Determine the type and extent of local and remote fire warning systems and the likely response times of persons within the premises and fire fighting personnel. See Clause **8** for information.

Stage B.2: Fire suppression systems: see Clause **9**.

Stage B.3: Fire barrier systems: see Clause **10**.

Stage B.4: Smoke control systems: see Clause **11**.

Stage C: Review

A thorough review of each of the systems should now be undertaken to:

— ensure that the systems meet with the requirements of the fire safety engineering design;

— ensure that the systems function together as designed and that there are no adverse aspects created by the mutual interaction of any of the systems.

6 Design inputs and outputs

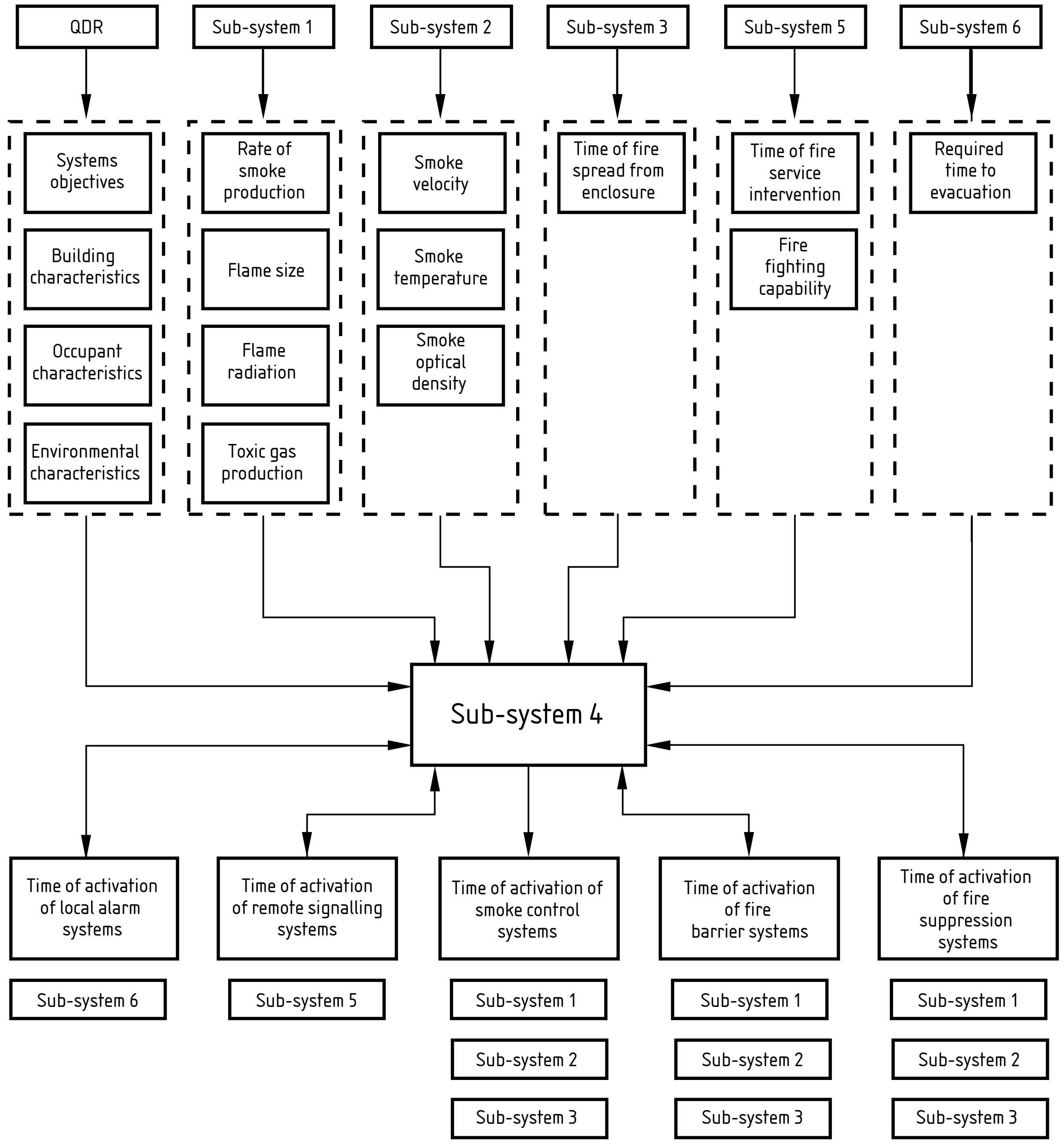


Figure 1 — Flow chart indicating design inputs and outputs

6.1 Design inputs

This design inputs required by other Sub-Systems are as follows (see Figure 1):

— *QDR*: This assessment provides the qualitative framework for determination of the most important parameters involved in the choice, extent and application of both the fire detection systems and the activation of the fire warning, suppression and control systems. Key considerations include the pre-determined objectives and the characteristics of the building, occupancy and environment;

— *Sub-system 1*: The initiation and growth phase of a fire within the enclosure of origin provides details of initial smoke production, heat release rate, flame size and toxic gas production. This information will help to determine the most appropriate fire detection strategy, the likely time to detection and alarm, and the choice and efficacy of fire control and suppression systems;

— *Sub-system 2*: Analysis of the spread of smoke within and beyond the enclosure of origin provides further data to help determine how smoke detection and control can be most effectively applied;

— *Sub-system 3*: Deals with aspects of structural failure and the key output of this Sub-system determines the growth rate outside the enclosure of origin and how detection and control will impact on subsequent growth;

— *Sub-system 4*: The criteria involved in fire service intervention will helps to determine the type of remote signalling necessary post detection, and the extent of measures designed to control fire growth until attendance by the fire service and the provision of fire location information to the fire and rescue service;

— *Sub-System 6*: This input focuses on how the detection system should be designed around the occupant and the most appropriate form of alarm warning(s).

6.2 Design outputs

This Sub-system been prepared to help predict the likely time to activation of the following:

— fire warning systems within the building;

— remote signalling systems to external bodies such as the fire service;

— smoke control systems – those systems positively designed to affect smoke movement;

— fire barrier systems – those systems positively designed to prevent or channel fire movement;

— fire suppression systems – those systems designed to suppress and/or extinguish a fire.

Note that fire detection in itself is not an output; it is simply part of a process that can be represented as a time delay between sensing the appropriate fire phenomena and triggering the warning or control system. How the design outputs interact is shown in Figure A.1.

7 Fire detection

7.1 Extent of coverage of detection system

The extent of coverage of a fire detection system within premises will be determined by a number of factors. These factors will include the objectives for the system (life safety, property protection, business protection, or a combination of each objective), and the level of risk from fire found as a result of an assessment of the building.

BS 5839-1 has introduced a system of categories to allow a designer to designate rooms and areas to be fitted with fire detection. The categories are based upon the objectives for the system (i.e. life safety or property protection) and are sub-categorized based on the extent of detection monitoring. BS 5839-1 should be consulted for more information.

An alternative approach is proposed within this Sub-system that allows for a more site-specific assessment by prompting a full analysis of every part of the premises to be monitored. This analysis may allow for life safety and/or property protection objectives but also for the results of a risk assessment of the building and any other factors introduced as part of the fire safety engineering design.

7.2 Choice of detector

7.2.1 *General*

The performance of a fire detection system is largely dependent upon the choice of detector type and principle. Consequently, a thorough assessment should be undertaken based upon the following:

— the assessment of the building and occupancy as results from the QDR;

— probable fire characteristics and growth within each compartment of origin and beyond (Sub-systems 1 and 2).

Figure 2 provides a set of considerations that will assist with a practical evaluation of the most appropriate types of detector or detection system for any specific application.

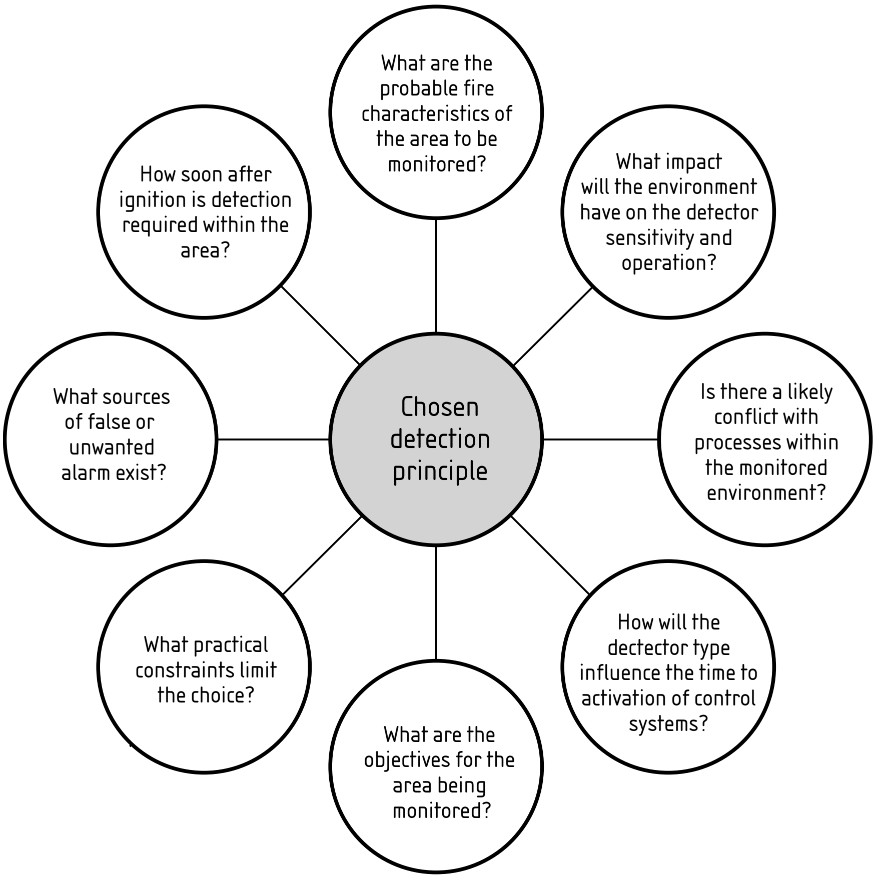


Figure 2 — Fire detection characteristics diagram

7.2.2 *The automatic fire detection system*

A fire detection system may utilize a number of different types of fire detector or detection system. There may be a number of different control panels located around the protected building, either acting as repeater panels for the main system, or controlling special systems such as aspirating systems. In such cases, it is recommended that all detection functions are signalled back to a central control and indicating point. This control point should be agreed with all parties involved with the fire safety engineering design. By having a central point of reference, a co-ordinated approach to the receipt of one or more alarm events is more likely.

Detailed technical aspects of the fire detection system components and installation should conform to the appropriate parts of the BS EN 54 and BS 5839 series of standards unless otherwise stated by the QDR.

Failure modes: As with all electrical systems, fire detection systems are subject to failure. However the type of failure could have a range of consequences for the overall fire safety engineering design. Examples of typical failure modes with consequences are given in Table 2:

Table 2 — Failure modes for fire detection systems

Failure mode	Consequences
Power supply failure	There is a standard requirement that system should be fitted with standby power supplies. In most cases, this mode should have negligible impact for at least 24 h after the failure.
Failure of panel displays	The appropriate European Standard requires a display configuration where, if one fails there is at least indication of main fire and fault conditions.
Major control panel failure	The consequences may vary from the worst case condition of complete system loss to default activation of warning and/or control systems to no consequence where another panel can automatically take over all functions.
Fault in an individual device	Where a defined fault occurs, there is a requirement that the fault should be indicated within a period as specified by the relevant BS EN 54 and BS 5839 series of standards. If a back-up emergency call-out contract is in place, the consequences are relatively small.
Loop cable failure	Relevant requirements are given in the BS EN 54 and BS 5839 series of standards to limit the consequences of a loop cable failure.

Failure data and the most appropriate corrective actions can often be provided by the relevant suppliers of the equipment.

7.2.3 *Point-type smoke detectors*

Point-type smoke detectors are the most common form of fire detector. They may be of the ionization type or may use optical means to detect smoke. In most cases for internal building protection, point smoke detectors are highly suitable. They are relatively inexpensive and easy to install, and the more modern devices incorporate sophisticated techniques providing high levels of discrimination against false alarms whilst maintaining high sensitivity to fires. The specification for point-type smoke detectors is BS EN 54-7.

Point smoke detectors rely on the movement of smoke towards the device. Furthermore, research [1] has shown that in order for smoke to enter the detector chamber, the gas (smoke) velocity would need to be at least 0.15 m/s.

The modelling of smoke production and movement from a fire is typically more difficult than for the assessment of heat production and movement. This is especially true for smouldering fires. Consequently, there is little in the way of validated models for the prediction of time to response for smoke detectors and for smoke detector spacing, although guidance is given by some sources [2]. In order to provide an initial assessment of point type smoke detection response time in the pre-flashover stages of a flaming fire, the equation (1) (from DD 240-1) can be used to assess the mass of burnt fuel:

$$f_b = 0.1\left(\frac{DV_t}{D_m}\right) \tag{1}$$

where

f_b is the mass of burnt fuel (kg)

V_t is the total volume of smoke (m^3)

D is the optical density of the smoke (dB/m)

D_m is the mass optical density (m^2/kg) – typically, a value of 300 can be used for general building contents

By calculating the mass of burnt fuel at the point at which the optical density, D, of the smoke reaches the detector sensing threshold, the time to response can be assessed, as this will be the time at which the value of f_b is reached. Note that this analysis assumes that the device is in the immediate vicinity of the fire.

Note that, for non-flaming fires, alternative methods will need to be sought. As and when further conclusive data is made available, this Sub-system will be appropriately revised.

When calculating and assessing detection criteria, the most appropriate smoke detector for the combustible materials found should be used. Detectors tested to BS EN 54-7 will have been assessed on their response to a series of test fires. By analyzing this information (usually contained within third party certification test reports), a suitable profile can be drawn up. Note that, as many smoke detector response thresholds can be adjusted in the detector head or via the fire detection system, different response thresholds in different areas may be possible.

A simplified method of predicting smoke detector operation for cases where sufficient heat is generated, uses the basis that the smoke obscuration created by a fire is directly proportional to its rise in temperature. There are obviously many considerations to be made as to the type of smoke and the properties of the smoke detector. Some research has shown that, for ionization detectors responding to wood crib fires, response would be achieved at a temperature rise of 13 °C [3] measured at the detector.

In addition the determination of the overall response time, consideration should be given to potential delays inherent in the detector design. A time lag between smoke arriving at the detector and entering the sensing chamber has been recognized during the course of research. The term "characteristic length" is similar to the RTI measurement of heat sensitive devices (see **7.2.4**) and can be represented by a detector time constant as shown in equation (2) [4]:

$$L = \tau U \tag{2}$$

where

- L characteristic length, i.e. the distance the smoke would travel at a given velocity before the sensor inside the detector reaches the value outside the detector (m). Note that this would be an inherent property attributed to a detector
- τ is the detector time constant (s)
- U is the ceiling jet velocity flowing past the detector (m/s)

An approach for estimating the response time of smoke detectors is proposed by Evans [5]. It suggests that, since no analogous method exists to calculate the time lag of smoke concentration below the ceiling to the concentration in the sensing chamber, a smoke detector should be thought of as a heat detector with no thermal lag (an RTI of 0) and with a low activation temperature. The following equation gives a relationship between temperature rise and the smoke optical density necessary for alarm:

$$\frac{D_a}{\Delta T_a} = \frac{3330_{\rho} C_p m_{effl}}{Q_g} \tag{3}$$

where

- D_a is the optical density necessary to trigger an alarm (dB/m)
- ΔT_a is the temperature rise, above ambient, necessary to trigger an alarm (°C)
- ρ is the density of air (kg/m^3)
- C_p is the specific heat of air (kJ/kg·K)
- m_{effl} is the mass of smoke effluent produced per mass of fuel consumed (kg/kg)
- Q_g is the heat output of the fire (kW)

7.2.4 *Point-type heat detectors (including sprinkler head operation)*

As with point-smoke detectors, point-type heat detectors are commonly found devices and are either specified where the response to heat is most appropriate for the monitored area or where smoke detection may lead to false alarms. They may utilize the following methods to detect fire:

— the signalling of a fire condition when a pre-determined temperature has been reached;

— the signalling of a fire condition when a pre-determined rate-of-rise of temperature has been reached.

Within the UK, rate-of-rise devices should also incorporate a fixed temperature element, in order to avoid slow fire growth being ignored by the device. The specification for point-type heat detectors is BS EN 54-5. This grades heat detectors on their application temperatures, and requires that the detectors lie within lower and upper response time limits as follows in Table 3 and Table 4:

Table 3 — Response time limits of heat detectors to BS EN 54-5

Rate-of-rise of air temperature	Class A1 detectors				Class A2,B,C,D,E,F and G detectors			
	Lower limit of response time		Upper limit of response time		Lower limit of response time		Upper limit of response time	
K/min	min	s	min	s	min	s	min	s
1	29	0	40	20	29	0	46	0
3	7	13	13	40	7	13	16	0
5	4	9	8	20	4	9	10	0
10	1	0	4	20	2	0	5	30
20		30	2	20	1	0	3	13
30		20	1	20		40	2	25

Table 4 — Heat detectors classification to BS EN 54-5

Detector class	A1	A2	B	C	D	E	F	G
Typical application temperature °C	25	25	40	55	70	85	100	115

BS EN 54-5 should be consulted for detailed information.

Research [6] has shown that point-type heat detectors can play a life-safety role in protecting areas outside the enclosure of origin (e.g. escape corridors). In this case, heat detectors located above the door opening within the enclosure of fire origin will detect and indicate a fire condition before smoke from that fire enters the outside area in quantities likely to impede escape.

Furthermore, heat detectors are sometimes preferred when the detection of smoke is not deemed strictly necessary (such as for premises or areas that do not include sleeping persons). The recognized benefits of additional tolerance over smoke detectors to many non-fire events, whilst being able to respond to the rate-of-rise of temperature associated with many types of fire (where incorporated within the detector), mean that the devices should be seriously considered as the main form of detection, in relevant cases.

The devices rely upon the movement of heat towards the sensing element. The heat would normally arrive at the device as convected or possibly radiated heat, although convected heat transfer should normally be assumed for assessment purposes. The modelling criteria for heat detector spacing and operation time, is more widely accepted than for smoke detectors, as the heat release rate of fires can, in many cases, be more accurately predicted than can smoke production and movement.

As with fixed temperature point heat detectors, sprinkler heads incorporating a heat-sensitive element can be modelled similarly, although there is a difference in that operation of the heat-sensitive element of the sprinkler head will directly lead to water discharge over the protected area without further actions required by a detection system.

When modelling a fire scenario, a fixed temperature heat sensor can be given a rating based on a response time measured under specified test conditions. This is defined as the Response Time Index (RTI) whose units are $m^{\frac{1}{2}}\,s^{\frac{1}{2}}$. This index is applicable to both point-type heat detectors and sprinkler heads although it tends to be much more widely applied to the latter within the UK. The RTI is calculated by exposing the device to a plunge test where it is instantaneously immersed into a flow of hot gas whose temperature and velocity are known.

Using the RTI value in the equation (4) [7], the time t at which the device is likely to operate can be estimated from the following differential equation:

$$\frac{dT_d}{dt} = \frac{\sqrt{u}(T_g - T_d)}{\mathrm{RTI}} - \frac{C(T_g - T_u)}{\mathrm{RTI}} \qquad (4)$$

where

T_d is the temperature of the detector sensing element at time t (°C)

u is the instantaneous velocity of fire gases (m/s)

T_g is the temperature of the fire gases at time t (°C)

T_u is the temperature of the ambient area around the detector device (°C)

C is the conductivity factor $(m/s)^{\frac{1}{2}}$

RTI is the Response Time Index $(m^{\frac{1}{2}}s^{\frac{1}{2}})$

Following on from this, equation number (7) of Sub-system 1 may also be applicable in some cases of controlled room environments as shown:

$$\theta = 6.85\left(\frac{Q^2}{\left(A_w h_w^{\frac{1}{2}}\right)\left(A_t h_k^{\frac{1}{2}}\right)}\right)^{\frac{1}{3}} \qquad [8]\ (5)$$

where

- θ is the temperature rise above ambient in the upper gas layer (°C)
- Q is the rate of heat release (kW)
- A_w is the area of the ventilation opening (m^2)
- h_w is the height of the ventilation opening (m)
- A_t is the total surface area of the enclosure (m^2)
- h_k Is the effective heat transfer coefficient ($kW \cdot m^{-2} \cdot K^{-1}$)

Referring to equation (5), if a standard fixed temperature heat detector is used, the operating temperature can be entered as θ, enabling the value of Q at the time of detection to be calculated. Note that special conditions and limits apply to the use of equation (5) (see Sub-system 1).

It should be noted that the above formula is suitable for the determination of fixed temperature devices but not for those that also measure the rate-of-rise of temperature. In many cases, the response of the rate-of-rise element is likely to occur prior to the fixed temperature element. It could therefore be assumed that the above provide for worst-case pessimistic detection times.

7.2.5 *Point-type multi-sensor/multi-criteria detectors*

Point-type multi-sensor and multi-criteria detectors will contain more that one sensing element (e.g. smoke and heat). Such devices are relatively new and are often used as enhanced smoke detectors. No published standard is available at present. Further information is given in BS 5839-1.

7.2.6 *Carbon monoxide point-type fire detectors*

Carbon monoxide fire detectors are not widely specified at present although their use is increasing. There are no published standards to refer to at this stage although further information is given in BS 5839-1.

As carbon monoxide movement does not necessarily rely on convection currents from a fire (i.e. it may diffuse through the air), there may be some validity in siting devices in places other than on ceilings. However, until more research is conducted, siting should be as recommended by the manufacturer of the device.

For calculation purposes, it can be assumed that rate of CO production is proportional to the rate of burning materials as illustrated by the following equation:

$$m_{CO} = 0.013\ m_f \qquad [9]\ (6)$$

where

- m_{CO} is the mass rate of carbon monoxide production (kg/s)
- m_f is the rate of burning of fuel by mass (kW/s)

Note that the above equation assumes that detection will occur during the growth phase of the fire, where the overall level of carbon monoxide production is increasing with time. As the rate of which CO is converted to CO_2 increases, the equation becomes less appropriate. Typically, devices may be programmed to a range of sensitivities thus affecting detection time, although some manufacturers have used a figure of 40 ppm as a standard threshold value.

7.2.7 *Beam smoke detectors*

Beam smoke detectors make use of the obscuration property of smoke to detect a fire. They may consist of a combined transmitter and receiver unit with reflective element, or a separate transmitter and receiver unit. They are normally mounted on walls at either side of a monitored area, such that there is a clear line of sight between one unit and the other. Typically, an infrared beam is transmitted along this length. In the event of smoke passing through the beam, the receiver measures the resultant attenuation. The value "C_L", expressed in dB, is used to identify the reduction in intensity of the light beam, defined by the following equation:

$$C_L = 10\log_{10}\left(\frac{I_0}{I}\right) \quad [10]\ (7)$$

where

I_0 = received intensity without reduction in intensity

I = received intensity after reduction in intensity

The main requirements are that:

— the detectors have sufficient immunity to false alarm conditions such that $C_{L,min}$ is less than 0.5 dB;

— The variation in response between successive operations should be limited such that the ratio between the maximum value of $C_{L,max}$ recorded and the minimum value $C_{L,min}$ is less than 1.6.

Although this data is used in testing detectors, it may also be appropriate in assessing on-site conditions.

7.2.8 *Aspirating smoke detectors*

Aspirating smoke detection systems draw the ambient air/smoke mix from the monitored environment via air sampling pipework to a separate detection unit where the monitored air is sampled for the presence of smoke. The sampling pipework usually contains predetermined holes through which the air is drawn. Such systems can be programmed to be extremely sensitive, i.e. values as low as 0.000 5 dB/m can be reached.

The effect of actively affecting smoke movement due to the drawing of air from the monitored environment is normally marginal and barely overcomes any resistance caused by the upper thermal layer against the ceiling. When considering the location of sampling points, the best analogy is to consider them as individual point smoke detectors. Specific siting requirements may be based on the application.

Aspirating smoke detection systems are commonly specified in cleaner air environments such as computer rooms and can also be used to monitor individual computer cabinets for the first signs of overheating cable or components. They are also used for aesthetic purposes where the sampling pipe can be more easily hidden within a ceiling than a point type detector.

When using such a system, some considerations include:

— the method used to discriminate between smoke from a fire and other smoke like sources. Some systems use particle-filtering systems whilst others rely on direct interpretation of the analysed sample;

— the design and commissioning of the system such that all sampling points along the pipework are able to provide an air/smoke sample able to be sufficiently analysed at the detector. In this case, a percentage for the volume of air drawn through different points will need to be determined;

— the transport time (time taken for the smoke to enter the pipe and reach the detector) for the least favourable sampling point should be determined. Figures for this time should be available from the aspirating system supplier.

The *Code of practice for Category 1 Aspirating Detection Systems*. Issue 1: British Fire Protection Systems Association, Kingston-upon-Thames 1996 should be referred to for further information.

7.2.9 *Linear heat detectors*

Linear heat detectors are heat detecting cables (electrical or fibre-optic) which respond to temperature along their length. There are two types of cable:

— integrating cable, where heat distribution along the length is summed and averaged such that the resultant signal given does not necessarily equate to the highest temperature at any point on the length;

— non-integrating cable, where heat sensed at any point along the length will be detected and signalled as appropriate. The operation of fibre-optic cables falls into this category as do cables where the conductors form a "short-circuit" above a predetermined temperature.

Linear heat detectors are normally used for specific applications, e.g. monitoring of cables in cable tunnels/flats, road and rail tunnels, escalators, conveyors, and other special hazards. The main benefits of these systems are that they are effective in detecting a rise in temperature at any point along their length, Furthermore, the fibre optic variety would be suitable for use in intrinsically safe environments.

When assessing the response of linear heat detectors, the most practical approach is to view them as a continuous line of point heat detectors.

7.2.10 *Flame detectors*

Flame detectors monitor an area for visible and near visible flames or heat representative of a fire. They monitor for at least one of the wavelengths in Table 5:

Table 5 — Flame generated light wavelengths

Ultraviolet	0.1 to 0.35 microns
Visible light	0.35 to 0.75 microns
Infrared	0.75 to 220 microns

Detectors may be tuned into specific bandwidths of light associated with those commonly emitted by a fire. A form of light modulation filtering in normally combined with their light-sensing capabilities is to ensure that static light-emitting sources or other forms of modulated light are not mistaken as a fire.

Due to their principle of operation, they rely on a direct line-of-sight with the fire before detection can be achieved. Therefore a number of devices may need to be trained on specific areas to provide for full coverage. Even then, objects, furniture, etc., introduced after the detectors have been placed, can adversely affect the detection function. However, in some cases it may be possible to utilize building materials to "reflect" light from dead areas onto the detector.

Once the flame is visible to the detector, operation is nearly instantaneous. For this reason, flame detectors are particularly useful as part of an explosion suppression system. It is important, though, to ensure that the detector is within an acceptable distance from the risk to properly respond to specific fuel fires. Equation (8) can be used to determine the level of radiation reaching the detector:

$$S = \frac{kP_{\text{rad}}e^{\xi d}}{d^2} \qquad [11]\ (8)$$

where

S Is the radiant power reaching the detector (W)

k is the proportionality constant for the detector

P_{rad} is the radiant power emitted by the fire (W)

ξ is the extinction coefficient of air

d is the distance between the fire and the detector (m)

A European Standard, BS EN 54-10, *Fire detection and alarm systems — Part 10: Flame detectors — Point detectors* is available.

7.2.11 *Fire detectors monitoring visual images*

Specialist system using CCTV equipment designed to pick up a fire signature from a video image. The systems typically use software decoding of the monitored image to compare against one or more pre-programmed signatures of the early phase of fire development. In this way, it may be possible to provide an indication of fire even in low light conditions. As with flame detectors, the system relies on a line-of-sight. Therefore, many cameras might be required to properly monitor an area.

The system has yet to be fully third party tested at the time of preparing this document. Consequently, where such a system is considered as part of a fire safety engineering design, a full assessment should be undertaken, preferably *in situ*.

7.2.12 *Manual operation*

There is no doubt that the most discriminating and sensitive fire detector is still the human. Consequently, manual operation of the fire detection system should always be included in any fire safety engineered design where people are expected to be. The key objective is to ensure that:

— the manual call point is mounted in a visible and accessible position;

— any person within a building will have access to a manual call point within a *reasonable* time after noticing a fire or potential fire condition; and

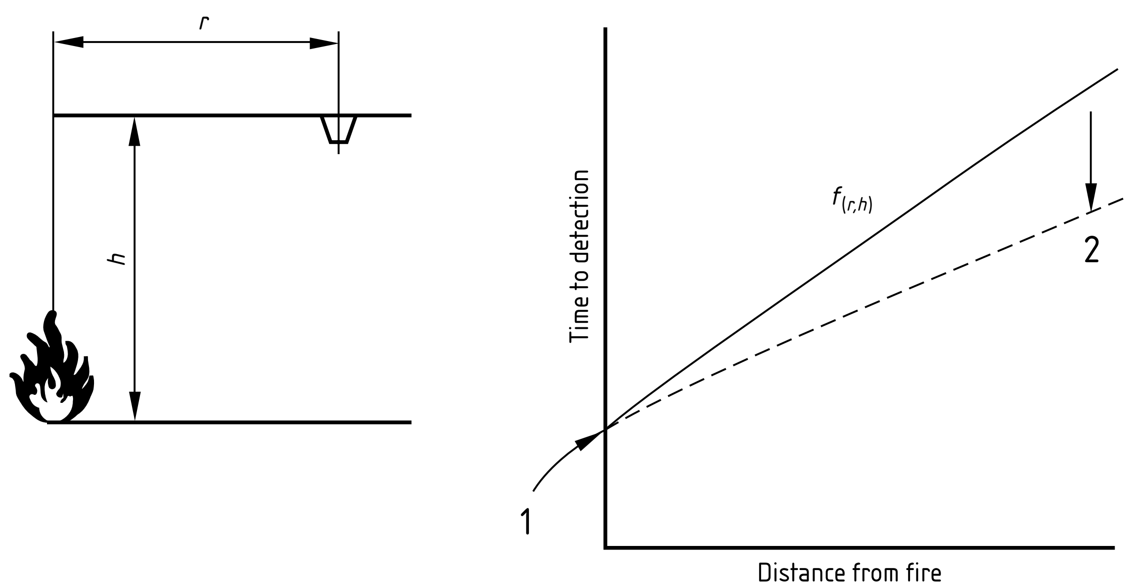
— the person, whilst operating the manual call point, is not unnecessarily exposed to the fire.

The conditions for determining location of manual call points will need to be based upon the outcome of the QDR and Sub-system 6. The specification for manual call points is BS EN 54-11.

7.3 Siting and spacing of detection devices

Traditionally, the siting and spacing of point type fire detectors has been based around recommendations developed by the results of experience and testing as contained within BS 5839-1. Although the criteria appear to have been successful in that many fires have been properly detected when installed to the Standard, they take little into account of the types of fire growth and the impact of the local building structure, environment and processes. At the early stages of a fire the normal convection currents induced by, for example, the heating system, will be the main means of transporting the fire products to the detector. As the fire develops will the fire plume become dominant.

Consequently, the spacing of detectors in different building types, when using BS 5839-1, will be similar. There are some benefits in this approach in that detector positioning can be easily designed and validated. The weaknesses in the approach are that the optimum level of monitoring is unlikely to be reached. In such circumstances, the optimum level of monitoring could be described as that level that provides detection of a fire within an acceptable period without unnecessarily increasing the density of detectors. Conversely, the greater the density of point type detection devices, the nearer a device will be to a fire, and thus the earlier a fire will be detected.



Key

1 Earliest time at which detection will be achieved.

2 Reduction in detection time by assessment of local conditions.

Figure 3 — Detector spacing vs. time

Figure 3 shows a linear relationship between distance (encompassing a function of both height and radius from a fire) and time, where, in reality, the relationship is likely to be more complex. This is a simplistic view but holds with both the prescriptive approach and a fire safety engineering assessment. The main conclusions for typical heat and smoke detectors are:

— there will always be a delay between the onset of a fire and detection by a detector;

— the greater the vertical distance between the detector and the fire, the greater the time to detection. Conversely, as the ceiling height increases, a greater rate of development of a fire is necessary to activate the same detector in the same length of time;

— as the radius between the detector and the centre of the fire plume increases, the time to detection will also increase. Evaluation of the velocity of the plume jet will be required to allow the determination of *r* within an acceptable time;

— the increase in time to detection could be limited by careful assessment of the prevailing local conditions affecting detection. This may include air movement caused by forced or natural means, air circulation caused by open doors/windows, the effects of stratification, etc. In some cases, such conditions can be used for the benefit of detection response, as shown in Figure 3.

There are a number of established methodologies for determining spacing of detection devices. More information can be obtained from reference [12]. Annex B illustrates one method of calculating the necessary spacing of heat detectors.

Where fire detectors are sited in optimum positions predicted by formulae, it is recommended that some substantiation of the predictions are used to provide a level of confidence akin to that held with prescriptive siting and spacing. In this case, the following criteria should be included:

— evidence of the methodology and calculations used, identifying the predicted smoke and fire movement, likely and worst case times to alarm, and assumptions made;

— on-site or mock-up testing of a sample of the typical building sub-divisions including environmental conditions. The test fires used should be as predicted by prior analysis. The test fires should prove, within agreed tolerances, the results of the prior formulae.

The results should be approved by all interested parties.

7.4 Other practical considerations

7.4.1 *False alarms*

False alarms (or unwanted alarms) can lead to both loss of confidence in the fire detection and alarm system and, where connected to control systems, to inappropriate activations. It is therefore essential that the choice of the system and components, the quality of installation, and the control of conditions causing false alarms are such as to limit both the probability and impact of their occurrence. It should be noted that fire detectors are designed to respond to secondary fire phenomena such as smoke particles and electro-magnetic radiation (IR, UV). Therefore such devices can also respond to aerosols, fumes, dust, sunlight, arc welding, etc.

— *Choice of system and components*: The choice of the equipment used and their suitability for the environments can play a major part in the control of false alarms. Most modern systems include sophisticated methods designed to optimize their detection properties whilst rejecting “false alarm” phenomena. In addition, the detection principle for a given area should be chosen to minimize the possibility of environmental conditions being mistaken for a fire.

— *Quality of installation*: Installing equipment in inappropriate places, even if installation standards are adhered to, can increase the likelihood of false alarms. It is therefore recommended that installation companies specialize in fire detection installations. There are third party certification schemes that verify the competence of companies to install fire detection and alarm systems.

— *Control of environmental conditions*: Where systems could be affected by environmental conditions that could lead to false alarms, these should, as far as possible, be controlled. Typical examples are electromagnetic interference, electrostatic discharges, smoking, dirty or dusty environments, etc.

— *System management*: There is, in many instances, a strong relationship between the quality of the management of the fire detection system and the incidence of false alarms.

The British Fire Protection Systems Association has conducted some research into the false alarm phenomenon and can provide details of its findings [13].

7.4.2 *Impact of ceiling mounted obstructions, beamed ceilings and sloping ceilings*

Where point detectors are used, it is important to consider the effects of ceiling mounted obstructions. These may include light fittings, ductwork, etc. In such cases, it is advisable to place the detector some distance from the obstruction, based on practical assessment. Research [14] on the effects of ceiling obstructions on fire detection has concluded the following:

— where beams are sufficiently deep, no smoke gets into adjacent channels;

— beams cause flow near the ceiling to slow down and, as a result, temperatures are warmer near the ceiling for beam cases than for non-beam cases. Due to their dependency on flow velocity, heat detectors can be adversely affected by this reduction;

— conditions in beam channels may be equivalent to conditions under beams, consequently installation on the beam or in the channel may both provide similar results.

It is therefore a practical solution to install detection devices on every nth beam or in the nth channel where *n* should be determined based on the size and frequency of beams (and the created reservoirs) in comparison to the ceiling arrangement. Reference [14] can be consulted for more information.

When considering sloped ceilings, a similar effect to a beamed ceiling will be noticed in that the slope will direct smoke or heat towards the top of the incline. By assessment of the slope characteristics, detectors can be located in the most advantageous positions. The effect of the slope will also aid the velocity of gases towards the detector thus reducing detection time, or allowing greater distances between a fire and the nearest detector.

7.5 Determination of detection response times

7.5.1 *General considerations*

As indicated earlier in this document, the focus on the use of detection is how quickly a fire detection system can detect a fire whilst maintaining an acceptable level of immunity against false alarms. Following on from this detection process, activation of the required warning, suppression and control systems will be initiated. The final objective will therefore be to calculate the activation times for these outputs, which will commence after the detection time.

It is commonly recognized that the calculation of the time to response of a fire detection system in any given set of circumstances is fraught with difficulties. Even in laboratory-controlled conditions and whilst testing a batch of the same fire detector using the same test fire, variations in operating times have been found. It is therefore important to gather all available data and make suitable assumptions about the likely type of fire, its growth pattern, the movement of the detected phenomena around the premises, and the technical and functional properties of the fire detector and system.

The information provided in the earlier in this clause will help to focus on these attributes. The following formula will assist in the determination of detection operating time by breaking the total time down into constituent parts. By evaluating each part separately, a better assessment of the likely response time for each detector can be made. It should be assumed that the detection time can be represented as:

$$t_{\mathrm{det}} = t_{\mathrm{growth}} + t_{\mathrm{move}} + t_{\mathrm{sense}} + t_{\mathrm{proc}}. \tag{10}$$

where

t_{det} is the calculated detection time;

t_{growth} is the fire growth period from the effective ignition time. This period is based upon the time taken for the fire to reach a size appropriate for detection Annex A of Sub-system 1 provides a set of tables for a range of combustible materials, giving the growth time to reach their peak heat release rate. If detection is to be achieved at the maximum heat release rate (or after this point), a value for t_{growth} can be taken from the appropriate table. However, it is usually preferred that detection is achieved earlier, i.e. at a designated percentage of the maximum heat release rate. This may be determined by choosing the heat release rate at the point of detection. Data in Sub-system 1 may assist in this case by providing the growth time at a specific rate of heat release;

t_{move} is the time taken for the appropriate fire phenomena to reach the detector. This period is based upon the movement of heat, smoke, gases, etc. towards the detector and will be based upon criteria such as the velocity of the jet plume. This can be assessed by a review of Sub-Systems 1 and 2;

t_{sense} is the time taken for the fire detector to sense the phenomena. This will be an inherent time delay within the fire detector (see equation (3) for smoke detectors and RTI figures for heat detectors);

t_{proc} is the time taken for the detection system to process the signal. Again, this figure is unlikely to be more than a couple of seconds. BS 5839-1 recommends that the maximum value for this figure is 10 s. Consequently, 10 s should be used for worst-case conditions.

The basis for calculation is divided into different detection objectives as follows:

— detection within the enclosure of origin;

— detection outside the enclosure of origin;

— detection in large open areas;

— special detection applications.

7.5.2 ***Detection within the enclosure of origin***

In many cases, fire detection devices are installed in rooms and are designed to detect a growing fire within that room. A starting point for formulae should be the determination of the design fire within the enclosure as provided by the outcome of the QDR and Sub-system1. It should be assumed that detection is desirable at an early stage after ignition and prior to flashover. Consequently, the design formulae used in PD 7974-1 **8.2.1** of Sub-system 1 should be referred to together with the formulae provided in **6.1** of this Sub-system.

From the above, it should be possible to calculate t_{growth}. Furthermore the value of t_{move} may prove to be relatively small as the enclosure area should relatively quickly fill up with the heat, smoke and gases from the fire; the calculation of t_{growth} should be sufficient. From this analysis, a value of the total detection time can be determined. It is recommended that the calculation details include the assumptions made so that modified design frameworks can be re-calculated.

7.5.3 ***Detection outside the enclosure of origin***

In **7.2**, the extent of detection monitoring was determined. It might be found that detection has been eliminated from some rooms or areas. In this case, it must be assessed if a fire could conceivably start in these unmonitored areas and, if so, should the fire be detected by the detection system. Typical examples include corridors where certain communicating, adjacent or adjoining rooms are not fitted with detection.

The likely initial signs of a fire outside the enclosure of origin will be the flow of smoke and gases through any gaps, voids, ventilation units, etc. Further uncontrolled growth can then lead to fire penetration through walls, doors, floors, etc.

As it is likely that fire should be detected at the earliest possible movement, a form of smoke and/or carbon monoxide detection should be used.

In terms of formulae, both t_{growth} and t_{move} will need to be assessed:

— t_{growth} will be based upon continued fire growth until smoke and gas products exit the enclosure of origin. In this, it could be assumed that the maximum rate of heat release has been reached within the enclosure of origin;

— t_{move} will be based upon the movement of the smoke and gas products to the nearest fire detector. Sub-system 2 provides guidance on the spread of smoke and gases beyond the enclosure of origin.

NOTE Recent research [15] has shown that, within the enclosure of origin, the smoke layer height during fire development, close to the doorway entrance to a corridor, is kept higher than that close to the fire source. This is due to the air inflow from the corridor. It was found that this effect is almost independent of the corridor size or arrangement. Within the corridor, the smoke layer descent differs slightly; for large corridors the descent is slow until the fire decays, when the descent is much quicker. For smaller corridors, as would be expected, smoke descent is quick. The research has found that there is continued mixing of smoke with air as the smoke descends and especially after smoke decay and that this effect is not adequately catered for in zone modelling codes and software programs.

7.5.4 ***Detection in large open areas***

When detecting in large open areas such as atria, warehouses, etc., the detection device is likely to be some distance vertically and horizontally from the fire source. Consequently, detection methods should be applicable for such circumstances. There are a number of considerations for protecting such environments. These can include smoke and heat dilution as the fire plume rises towards the fire detectors, the effects of stratification, and air currents taking the smoke and gases away from the detectors.

When attempting to assess the probable time to detection, there would need to be a detailed assessment of the environmental conditions affecting fire growth, as the environment is likely to play a major part in the success or failure of the detection system. In this case:

— t_{growth} will be based upon typical fire growth models for the range of likely combustibles;

— t_{move} will be based upon a number of assumptions of how the environment will affect the way the detected products will travel towards the detectors. Parameters to be considered here are the effects of HVAC, the continued entrainment of air as the smoke plume rises (with the possible eddy currents created by cooling of the smoke), and the effects of stratification.

7.5.5 *Special detection applications*

There will always be situations where special applications of fire detection or specialist systems, will be deemed appropriate. Examples include in-cabinet protection of computer systems and protection of escalators. In such cases, special studies might need to be undertaken to determine how the system will function and what the objectives for the system will be. Reviews of similar applications can prove useful. There may be justification for specialist mock-up and testing to determine the operation and likely times to detection and subsequent activation.

7.5.6 *Impact of the use of coincidence detection*

When using fire detection systems to activate fire control systems there is a need to avoid spurious operation due to false alarms in the detection system. A method commonly used is coincidence detection, where the fire detection system logic processing is such that, an output is obtained only when one signal has been received from a fire detector and one or more confirmatory signals are received from the same or other points. confirm the condition before control and suppression systems are initiated. This form of operation impacts on the total calculated period to activation as follows:

$$t_{\mathrm{det}} = t_{\mathrm{det1}} + \Delta t_{\mathrm{coinc}} \tag{11}$$

where

- t_{det} is the calculated detection time
- t_{det1} is the time to detection of the first detector using information supplied in Clause **6**
- $\Delta t_{\mathrm{coinc}}$ is the additional time taken for the coincident detector or detectors to operate. This figure can be determined by assessment of the overall detection siting and spacing and making suitable assumptions

7.5.7 *Adjustments to the siting of devices*

Even though the assessment of detection time is unlikely to be exact, it should give a fair idea of the expected performance. If the detection times are greater than that required, then the siting and spacing of devices will need to be reviewed and possibly the density of detectors increased. Conversely, if the detection times are much quicker than that required, a relaxation in the density of detection may be warranted. Alternatively, the sensitivity of the detectors may be adjusted.

8 Activation of local and remote alarm systems

8.1 Building alarm systems

One of the prime objectives of a fire detection and alarm system is to warn the occupants of a building that there is a fire within the building. This is traditionally achieved by the sounding of bells or electronic sounders throughout the building. However, in multi-storey and complex building designs a simple evacuation alarm will probably be inappropriate. In such cases, multi-stage or coded alarms may be introduced. Furthermore, voice alarm systems are found to be extremely useful where large numbers of persons are to be evacuated. BS 5839-8 provides useful guidance on voice alarm systems, which is sufficiently flexible to be used in a fire safety engineered alarm strategy. Sub-system 6 provides analysis of human behaviour. The output from this document will help develop the building alarm strategy. The appropriate standard for audible alarm devices for sounder systems is BS EN 54-3.

By formulating the alarm strategy, an estimate of the response time can be made, from the development of a fire to the acknowledgement of a fire by occupants of the building. The following time formula can be used:

$$t_{\mathrm{response}} = t_{\mathrm{alarm}} + t_{\mathrm{verify}} + t_{\mathrm{pre}} \qquad [16](12)$$

where

- t_{response} is the total response time to the alarm warning
- t_{alarm} is the alarm system processing time *after* the time to detection
- t_{verify} is the verification time to determine the validity of an alarm indication
- t_{pre} is the time taken for persons in the building to be aware of the alarm and to respond to the alarm. This is referred to as “pre-movement time”. Note that evacuation time is not included within this period

The period t_{alarm} is the internal processing period of the alarm system and may be found from the system suppliers. The period t_{verify}, may be specifically introduced to avoid nuisance and false alarms. In this case, once an alarm has been signalled to the fire control panel, a verification period may be initiated whereby staff investigate the cause of the alarm incident. A period of 120 s to 180 s, or other figure may be used, depending on the size and the complexity of the building. The alarm would automatically operate after the expiry of this period unless the system has been intentionally reset by the investigating personnel. The period t_{pre} will be based upon the type of occupants expected and could be evaluated as part of the assessment of Sub-system 6. Note that a figure for the building evacuation time will need to be included. This should be based upon the analysis of the building and its occupants as part of the QDR.

8.2 Remote signalling systems

As well as warning the occupants of a building that there is a fire, another objective of a fire detection and alarm system may be to signal an alarm condition to the emergency services. In this case, the services may either be a retained fire brigade and/or the professional emergency services such as the Fire Brigade. Manual means may be used such as a telephone call from the premises via the PSTN Network. This may be the least reliable method, although should not be discounted if special arrangements have been made. There are a number of methods of signalling, which include:

— automatic remote signalling via the PSTN Network (Digital Communicators);

— automatic superior signalling via the PSTN Network. These systems may be routed on high speed semi-secure networks or may use special carrier signals;

— proprietary systems. These systems are specifically designed to transmit fire information via secure, high reliability methods. These may make use of the PSTN, ISDN and GSM specialist networks;

— Direct line systems where there is, in effect a direct wire connection from the premises to the emergency services.

NOTE BS EN 50131-1 provides details of gradings for different types of signalling system.

Where automatic signalling systems are employed, they are usually routed via an alarm receiving centre. These centres are continuously manned and take the incoming signal and arrange for the emergency services to attend the premises and provide pre-determined information on the premises.

Sub-system 5 provides analysis of the response of the emergency services. By formulating the alarm signalling strategy, an estimate of the response time can be made, from the development of a fire to the receipt of the signal by the emergency services. The following time formula can be used:

$$t_{acknow} = t_{signal} + t_{verify} + t_{remote} \quad (13)$$

where

t_{acknow} is the acknowledgment time of the alarm by the emergency services following detection

t_{signal} is the signalling system processing time from detection

t_{verify} is the verification time to determine the validity of an alarm indication

t_{remote} is the time taken for the remote signal to be acknowledged and routed to the emergency services. Note that response time by the emergency services is not included within this period

As discussed in **8.1**, t_{verify}, may be specifically introduced to avoid nuisance and false alarms. In this case, once an alarm has been signalled to the fire control panel, a verification period may be initiated whereby staff investigate the cause of the alarm incident. The period may be zero seconds, the same as that chosen for the alarm system, or a different figure.

The period t_{signal} is the internal processing period of the signalling system and may be found from the system suppliers. The period t_{remote} will be based upon the operations of the alarm receiving centre and can be obtained from them.

Note that in addition to these formulae, a figure for the emergency response time will need to be included. This will be provided by Sub-system 5.

9 Activation of fire suppression systems

9.1 Extent of coverage of suppression system

There are a range of suppression systems with characteristics that make them suited to a variety of applications. Similarly, when the extent of suppression is considered, only some systems may be suitable due to practical, environmental or other reasons.

When determining the extent of coverage by a suppression system, typically it should be assessed where the risks from fire are, what form of fire loading exists in these areas and whether the suppression system is designed to extinguish the fire at source.

If a set of defined areas to be protected have been established, and suppression systems have been designed to extinguish a fire within the enclosure of origin for each of the areas, then, from a fire safety engineering perspective, no additional suppression should be necessary.

Furthermore, if each of these areas are further assessed, there might be justification to remove a form of automatic fire suppression in favour for an alterative solution that leads to the same design objective.

In such an appraisal, it might be possible that only *specific areas* contain a form of fire suppression and that *differen*t forms of fire suppression are found in one premises, each form chosen to be most effective and practical for the fire and local characteristics of the protected areas.

Nevertheless, where sprinkler systems have been specified for building protection, it is often the understanding that all parts of the building are protected by the system. This may be due to the view that the risk of fire exists in all parts of the building or that the sprinkler system has been provided as a trade-off for passive fire protection or means of escape measures.

A fire safety engineering design should therefore only use fire suppression in the following ways:

— to protect specific areas where the fire must be suppressed before endangering other areas;

— to protect areas adjoining the space(s) where there is a calculated chance that the fire cannot be contained within the risk areas;

— to protect areas designated as requiring protection as an alternative to passive or other measures.

As a practical tool for assessment, equation (9) may be used and converted for use with suppression systems.

9.2 Choice of suppression system

9.2.1 *General*

There are a number of types of systems that can be used to control, suppress or extinguish a fire. All systems have certain features that would suit the expected fire type, the building, the occupancy and local environmental conditions. Consequently, a thorough assessment of the key factors will need to be undertaken based upon:

— the assessment of the building and occupancy as results from the QDR;

— probable fire characteristics and growth within each compartment of origin and beyond (Sub-systems 1 and 2).

This can be represented by eight contributing factors leading to the eventual choice as indicated in Figure 4.

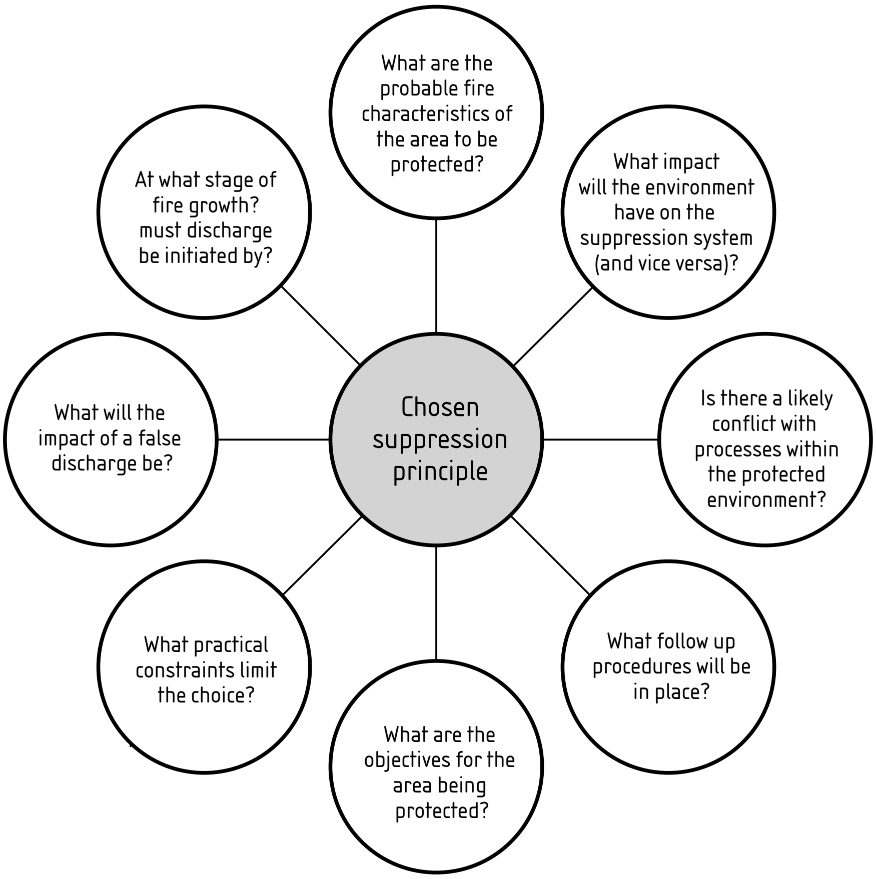


Figure 4 — Fire suppression system choice matrix

Fire suppression systems are chosen to cater for at least one of the following objectives:

Objective A: To extinguish the fire

Where systems are designed to fully suppress and extinguish a fire, the following time formula can be used:

$$t_{\text{ext}} = t_{\text{predis}} + t_{\text{discharge}} + t_{\text{hold}} \qquad (14)$$

where

t_{ext} is the total time taken to extinguish a fire from detection of that fire

t_{predis} is the time taken for the extinguishing system to prepare to start the discharge sequence;

$t_{\text{discharge}}$ is the discharge time for the extinguishing medium

t_{hold} is the hold time (if applicable) where the discharge medium is held within the protected area until the fire is properly extinguished

Objective B: To control a fire condition until manned assistance is summoned to extinguish the fire

As highlighted, there is often a follow up strategy after a fire is extinguished, whether implicit or explicit. It is therefore recognized that some suppression systems might not fully extinguish a fire, but suppress it until another step in the fire protection strategy is realized. In this case, the suppression system would need to control the fire either at the same state it was at the time of activation of the suppression system, or suppress the fire to a state appropriate for later extinguishment by in-house staff or the professional emergency services.

The system would need to positively suppress the fire for at least the period until the persons attend site, and then for a further period whilst they make preparations to extinguish the fire. Following on from Clause **7**, and assuming that the manned attendance is the fire service, the following time formula can be used:

$$t_{sup} > (t_{assist} = t_{acknow} + t_{attend} + t_{prep}) \quad (15)$$

where

t_{assist} is the time for manned assistance to start extinguishing the fire

t_{sup} is the time for the fire suppression system to maintain the fire at the desired state (and will use the same formula as used for text)

t_{acknow} is the acknowledgment time of the alarm by the emergency services (see **7.2**) and includes the calculated detection time

t_{attend} is the attendance time of the fire brigade (see Sub-system 5)

t_{prep} is the time taken by the fire fighters to prepare to extinguish the fire

Objective C: To provide a fire control *equivalent* to other fire safety and protection strategies

Fire Safety Engineering is often used to replace or "trade off" one strategy for another. Typically, sprinkler systems may be installed as an alternative arrangement to fire compartment sizing where it can be shown that the sprinkler will have the same or similar end result by restricting the movement of a fire in a similar manner to a fire compartment. Such arrangements have been formally accepted by UK Building Regulations [17] for life safety protection. The final arrangement can then be assessed in a similar manner as highlighted above.

Also of importance to the choice of suppression system, is an assessment of likely failure modes. Typical failure modes are given in Table 6. Failure data and the most appropriate remedies can often be provided by the relevant suppliers of the suppression system.

Table 6 — Failure modes for fire suppression systems

Failure mode	Consequences
Water supply failure	Where suppression systems are reliant on a water supply, failure in the supply, or even fluctuations in rate and pressure, can adversely affect the performance of the system. One way of addressing the problem is to increase the level of control over the supply, such as by using water tanks and pump sets.
Extinguishing agent failure	For non-water supply extinguishing agents, the failure mode can be more complex to analyze than for a water supply system and could include analysis of the extinguishing make up and ageing properties, the holding cylinders and lock off valves, pilot line failure, etc. The consequences will be failure of the system to properly control or extinguish a fire.
Activation system failure	The activation system may range from direct activation, i.e. a sprinkler frangible element in a wet system through to a more complex system relying on the fire detection system together with the actuating mechanism (possibly electromechanical). The consequences of failure will, as above, be the failure of the system to control or extinguish the fire.
Valve and pipework failure	Although the pipework or valves supplying the extinguishing medium to the nozzle can be less likely to fail than other parts, failure is likely to mean reduced efficacy in controlling or extinguishing a fire.
Nozzle / head failure	Although the likelihood for a nozzle to fail may be less likely than other parts, failure is likely to mean reduced efficacy in controlling or extinguishing a fire.
Room integrity failure	Where system rely on the integrity of the enclosure of the protected area, once again, failure is likely to mean reduced efficacy in controlling or extinguishing a fire.

Assessing the effects of fire suppression systems

Following on from the assessment of Sub-system 1, the effect on the heat release rate by fire suppression systems was considered. It is acknowledged that, to be successful, the system should be activated at a stage where it will positively influence the continued fire growth. Failure to do so might mean that the fire will still grow despite operation of the system. This is best illustrated by Figure 5. In Figure 5a), suppression is achieved prior to the maximum rate of heat release which can be controlled ($Q_{control}$. Consequently, control or extinguishment will be achieved with the rate of heat release affected based on system type. Figure 5b) illustrates that where the suppression system is initiated after $Q_{control}$, the rate of growth might be reduced but further growth can still be expected.

9.3 Types of fire suppression system

9.3.1 *General*

There are a number of commercially available fire suppression systems that cater for a range of fire types and building and occupant criteria. Furthermore, specialist systems may be introduced to cater for specific risks.

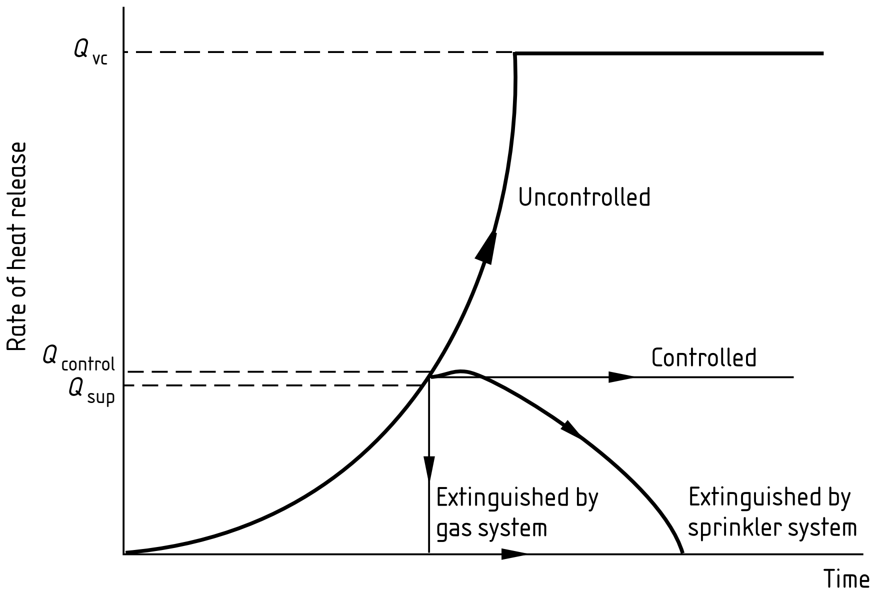
9.3.2 *Automatic water sprinkler systems*

9.3.2.1 *General*

Sprinkler systems are the most common form of fire suppression system for buildings. They are often regarded as property protection systems, although there is increased recognition of their use for life safety sprinkler systems may be designed for fire control (also referred to as control mode) *and/or* fire extinguishing (also referred to as suppression mode).

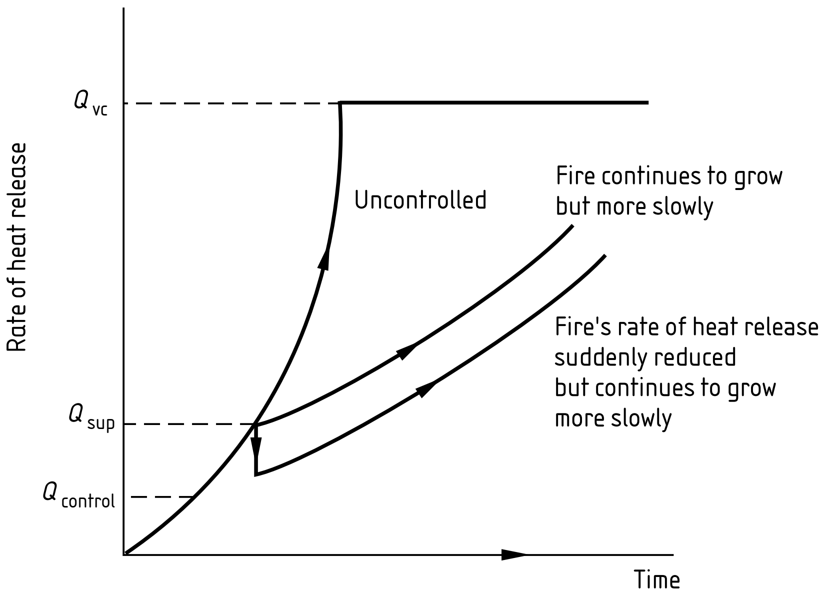
9.3.2.2 *Sprinkler system as a control system*

Sprinkler control systems are designed to suppress a fire or control the heat release rate by considerably reducing the fire size and thereby reducing the generation of hot combustion gases immediately upon operation of the sprinkler system. The reduced fire size is therefore prevented from growing or spreading by maintaining it at a much reduced steady rate until either the combustibles have burnt out and/ or manual fire fighting arrangements have been implemented (see Figure 5a)). In such cases, a specified sprinkler activation area should control the fire growth by pre-wetting the fuel surrounding the active fuel region. The minimum design density designated for the system should be maintained for the activation area and quick response sprinklers, being highly sensitive, but having reliable integrity, can be used where appropriate.



Q_{vc} is the rate of heat release under ventilation-controlled conditions
Q_{sup} is the rate of heat release at which suppression activates conditions
$Q_{control}$ is the maximum rate of heat release at which the fire can be controlled

a) Effect of suppression



Q_{vc} is the rate of heat release under ventilation-controlled conditions
Q_{sup} is the rate of heat release at which suppression activates conditions
$Q_{control}$ is the maximum rate of heat release at which the fire can be controlled

b) Effect of partial suppression

Figure 5 — Effect of suppression on rate of heat release

9.3.2.3 *Sprinkler system as an extinguishing system*

When designed to extinguish a fire, the sprinkler system must operate at a stage of the heat release rate where suppression can be assured. Early Suppression Fast Response (ESFR) sprinklers have been developed to achieve this by using sprinkler heads with a quicker sensitivity combined with special water discharge characteristics ensuring that greater delivered densities can be achieved, which are designed to deliver water directly to the seat of the fire and thus extinguish the fire. In this case, the system design is more critical as is the management of the hazard and extinguishment is absolutely necessary to prevent failure of the system.

Sprinkler systems are normally categorized on the anticipated "hazards" or fire loads. To ensure reliability, the system design, required discharge rates and the density of water discharge from sprinklers, will be based upon the hazard classification. The following are key considerations when developing a sprinkler system design.

a) *Water supplies*: Water supplies will need to be able to provide the required pressure and flow rates for the sprinkler system in operation. Furthermore, the supplies should be sufficiently reliable and available. Water supply arrangements based on hazard category are normally prescribed by the relevant code of practice BS 5306-2.

b) *Valve/Control arrangement*: Sprinkler valve sets will comprise a set of valves and components based on their intended mode of operation:

— wet mode; where the sprinkler pipework is normally filled with water;

— dry mode; where the sprinkler pipework is normally filled with pressurized air. When the heat sensitive element within a head operates, the air is expelled and the pipework is filled with water and discharged through the operated heads;

— alternate mode; where the sprinkler system can be converted from a wet system to a dry system and vice versa.

c) *Pipework installation*: In order for the correct flows to be delivered to each of the sprinkler heads, the pipework installation will need to be partly hydraulically calculated using pre-calculated tables, or fully hydraulically calculated. Proprietary computer programmes are available to assist with this task taking into account pipe friction losses using the Hazen-Williams formula (see BS 5306-2).

d) *Sprinkler head*: The sprinkler head contains a glass bulb or fusible link that triggers at a pre-determined temperature, typically around 57 °C or 68 °C or in excess of 100 °C thus allowing the flow of water. This operating temperature can be chosen to maintain an appropriate temperature differential with the ambient temperature (typically around 40 °C). Sprinkler heads have response characteristics indicated by their RTI value and cooling factor as shown in Table 7.

Table 7 — Response time indices for sprinklers

Sprinkler sensitivity	RTI range $m^{\frac{1}{2}} s^{\frac{1}{2}}$
Fast Response	≤ 50
Special Response	>50, ≤ 80
Standard Response A	>80, ≤ 200
Standard Response B	>200, ≤ 350

The siting and spacing of sprinklers has largely been based upon the results of empirical correlations of full-scale test data, engineering interpretations of generic test data or the results from a validated mathematical model. A fire safety engineering approach to this problem will be to determine the required density and envelope of the water discharge pattern, the required speed of response, and an assessment of the likely fire growth after the opening of the first sprinkler head.

Where wet systems are used (i.e. the sprinkler pipes are filled with water), activation of the sprinkler head (see Clause **6**) will simultaneously lead to start of the discharge sequence. Where dry or pre-action systems are utilized, the system will not discharge water until the air within the pipework is expelled. This period is represented as t_{predis} in the time formula equations and has an impact on the fire safety engineered strategy. The following relationship can be used to determine this figure:

$$t = 0.0352\left(\frac{V_T}{A_n T_0^{\frac{1}{2}}}\right)1n\left(\frac{p_{a,0}}{p_a}\right) \quad [18]\ (16)$$

where

t is the time in seconds

V_T is the dry volume of sprinkler system in cubic feet

A_n is the flow area of open sprinklers in square feet

T_0 is the air temperature in Rankine degrees

$p_{a,0}$ is the initial air pressure (absolute)

p_a is the trip pressure (absolute)

Note that for pre-action systems, where fire detection is used to initiate the sprinkler system, two other factors may be included in the overall calculation of t_{predis}. These will be:

— the additional time introduced by the use of coincidence detection (see **7.5.6**);

— the additional time introduced by the pre-action control system processing (this may be established by the equipment supplier).

Impact on fire growth

Operation of the sprinkler system will impact on the fire growth by providing the following:

— cooling of the flame due to vaporized water within the flame. Sufficient vapour in this case can take the flame temperature below the critical flame temperature and thus could lead to extinguishment;

— cooling of burning surfaces, where the system is designed to reach these surfaces. Again, this will cool the fire fuel to a point where the fire cannot be sustained;

— pre-wetting of non-burning fuels around the source of the fire. This is part of the fire control properties of the system and may be the main purpose of the system in designated cases.

Figure 5a) and Figure 5b) illustrate the reduction in the heat release rate over time. The following equation has been produced for determining the effectiveness of sprinkler systems in reducing the heat release rate of furnishing fires. The model is based upon tests carried out with wood cribs (which simulate deep seated fires) and thus could be regarded as conservative in providing results:

$$Q_{(t - t_{act})} = Q_{t_{act}} e^{-(t - t_{act})/3.0(w'')^{-1.85}} \quad [19]\ (17)$$

where

Q is the heat release rate (kW)

t is any time following t_{act} of the sprinklers (s)

w'' is the water spray density (mm/s)

Until detailed design guidance for sprinkler systems using a fire safety engineered approach is available, BS 5306-2 should be consulted.

9.3.3 *Open head water sprinkler systems*

Open head water sprinkler systems or deluge systems are specially designed water suppression systems for specific risks. The pipework is thus kept dry back to the point of activation (either by a multiple jet controller or motorized valve arrangement).

These systems may be activated by manual means or via a fire detection system. One benefit that such a system has over the closed head sprinkler system is that the location and type of fire detector used to initiate water discharge may be independent of the location of nozzles. Consequently some of the adverse affects preventing the operation of individual sprinkler heads, or those causing a greater number of sprinkler heads to operate than that designed for, can be avoided.

In other respects, the design principles and hydraulic calculations will be as described for sprinkler systems.

9.3.4 *Water fog/mist systems*

Water fog/mist systems are systems designed for specific risks or sometimes as an alternative to sprinkler systems, where there is limited water supply. The systems are treated as fire suppression/control systems.

Commercially available fog or mist systems fall into several types and, while certain system types can perform more efficiently for some risks, the general use of a single mist system across all types of risks is not advisable.

Variations in systems are based upon a number of factors including water droplet size, velocity or momentum of the spray plume, system operating pressure and whether or not a *single* or *twin* fluid principle is utilized to deliver water to the nozzles.

The water supply may be either:

— self contained and pressurized; or

— pumped, drawing from a towns main supply or water storage tank.

The operating pressure ranges for the mist systems fall into the following categories:

— Low pressure (12 bar or less);

— Medium pressure (12 to 34.5 bar); and

— High pressure (greater than 34.5 bar).

Owing to the high surface tension of water, the atomization to produce fine mist is a function of the operating pressure and nozzle design. For this reason, intermediate or high pressure and twin fluid mist systems tend to produce finer mists than low pressure systems. Generally, the finer mists have proven to be a more efficient suppressant in three-dimensional situations. However, they rely heavily on entrainment into the fire plume and hence their performance under fire conditions can vary.

The design type for the risk may be Local Application, Total Flood or Zoned application systems. Total Flood systems, as a replacement for gaseous systems, would tend to be those that generate a fine mist using open single or cluster nozzle type, while systems for general light or ordinary hazard application, would be of the low pressure zoned or local application type. The systems are most effective when used within a defined enclosure with minimal openings.

Basing the formulae on the system operating as a fire control system, t_{predis} can be evaluated as incorporating the following:

— the time for the heat sensitive element on the head to operate (note that this could be assumed to be similar as that for a sprinkler head. The detection time is not applicable in this case);

— the additional time introduced by the use of coincidence detection of a fire detection system (see **7.5.6**);

— the additional time introduced by control system processing, if used (10s may be appropriate in many cases).

Impact on fire growth

The principle mechanisms involved in fire suppression by water mist include:

— gas phase cooling of the flame reaction zone below the limiting flame temperature;

— oxygen depletion by steam expansion; and

— radiant heat obstruction by wetting of fuel surfaces.

The rate at which water is discharged (l/min) is dependant on system type.

As the systems are predominantly used for protection of enclosures, the output of any assessment should be used for further analysis in Sub-system 1.

NFPA 750 should be consulted for detailed design guidance for water mist and fog systems.

9.3.5 *Gaseous fire suppression systems*

Gaseous extinguishing systems are often used where water as an extinguishing medium is not desirable, or where the particular properties of an extinguishing gas are more appropriate. The systems are normally designed as fire extinguishing systems, i.e they should completely extinguish the fire, although follow up are be recommended to ensure that there is no re-emergence of the fire once the enclosure is opened up, allowing fresh air into the area. Gaseous extinguishing systems are available in one of two forms:

— *Halocarbon based systems* using the chemical inhibition of flame to extinguish a fire. A range of agents have been introduced since the demise of Halons. Each has its own set of properties and thus an investigation of the different types should be undertaken prior to choice. Due to the principles of extinguishment, the systems are likely to be effective prior to a certain stage in the fire growth, thus the choice of automatic fire detection and the chosen layout can be more critical than for other forms of suppression;

— *Inert gas based systems* designed to smother the fire until it is extinguished. There is also some cooling effect during the initial discharge phase. A range of agents are available predominantly making use of carbon dioxide, argon and nitrogen. These systems tend to be regarded as more environmentally friendly than even the current range of halocarbon agents. There are, however, practical considerations such as the additional storage requirement for the agent when compared to halocarbon agents, and the additional storage pressures necessary.

For Total Flooding systems, the extinguishing medium should be contained within a defined enclosure with minimal openings for a defined hold time. There may be cases where direct application of a gas is required (often referred to as a local application system). Note that only some gaseous agents will be suitable for the latter.

Gaseous extinguishing systems are normally activated by the fire detection system, although some systems may be activated via mechanical means. Basing the formulae on the system operating as a fire control system, t_{predis} can be evaluated as incorporating the following:

— the time introduced by the use of coincidence detection of a fire detection system which is often the case for such systems (see Clause **6**);

— the additional time introduced by control system processing, if used (10 s might be appropriate in many cases).

Dependant on the system type and gaseous medium used, both the discharge time and hold time will be defined by the system supplier. With regard to the latter, consideration should also be given to local follow up procedures such that the hold time will be contained for the required period.

The design concentration for gaseous extinguishing systems is normally determined by the results of testing and the introduction of safety factors. Recommended design concentrations, for different risk types will be provided by the system supplier.

BS ISO 14520 should be referred to for detailed design guidance.

Impact on fire growth

The principal mechanisms involved in fire extinguishing are based upon the type of system used. As the method of extinguishment is designed for specific enclosed area, and that fire barriers are normally activated to contain the extinguishing agent, it should be assumed that smoke and heat movement will be curtailed for at least the duration of the discharge and hold time.

There is however, a need to consider from a fire safety engineering perspective, the impact of the release of the extinguishment and the effects on evacuation and human behaviour. The HAG Report should be referred to for more information.

Specific guidance should be obtained from the system supplier.

9.3.6 *Foam and wet chemical systems*

Fire-fighting foam is an aggregate of air-filled bubbles formed from aqueous solutions and is lower in density than flammable liquids. It is used principally to form a cohesive floating blanket that prevents or extinguishes fire by excluding air and cooling the burning fuel. It also prevents re-ignition by suppressing formation of flammable vapours. It has the property of adhering to surfaces, which provides a degree of exposure protection from adjacent fires.

— *Aqueous film-forming foam* (AFFF) is a type of low expansion foam that produces a highly stable aqueous film that spreads rapidly over a liquid hydrocarbon surface;

— *Wet chemical solutions* in extinguishing systems are generally potassium carbonate and/or potassium acetate based, mixed with water to form an alkaline solution capable of being discharged through piping. The effect of such solutions applied to flammable liquid fires is to create a rapidly spreading vapour-suppressing foam on the fuel surface that extinguishes the flame by forming a barrier between the liquid fuel and oxygen and by cooling the flammable fuel;

— *High-expansion foam* is an agent for control and extinguishment of solid-fuel and flammable liquid fires and is particularly suited as a flooding agent for use in confined spaces;

— *Medium-expansion foam* was developed to meet the need for a foam that was more wind resistant than high-expansion foam for outdoor applications.

Medium- and high-expansion foams are mechanically generated by the passage of air or other gases through a net, screen or other porous medium that is wetted by an aqueous solution of surface active foaming agents. (Note that gases for foam generation should not be taken from the fire area as smoke can contaminate the foam, causing it to break down). Under proper conditions, fire-fighting foams of expansion ratios from 20:1 to 1 000:1 can be generated. These foams provide a unique agent for transporting water to inaccessible places, for total flooding of confined spaces, and for volumetric displacement of vapour, heat and smoke.

Medium- and high-expansion foam have the following effects on fires:

— where generated in sufficient volume, foam can prevent movement of air to the fire;

— water in the foam is converted to steam, inerting the flame and cooling the environment;

— the solution from the foams that is not converted to steam will tend to penetrate solid fuel materials because of their relatively low surface tension;

— where accumulated in depth, foam can provide an insulating barrier for protection of exposed materials or structures not involved in a fire and can thus prevent fire spread;

— solid fuel fires are controlled when the foam completely covers the fire and burning material. If the foam is sufficiently wet and is maintained long enough, the fire can be extinguished;

— flammable liquid fires involving high flash point liquids can be extinguished when the surface is cooled below the flash point. Liquid fuel fires involving low flash point liquids can be extinguished when a foam blanket of sufficient depth is established over the liquid surface.

The systems may be activated either manually or via the fire detection system. It should also be noted that some foam systems rely on manual fire fighting by, for example, hosereels.

Impact on fire growth

The principle mechanisms involved in fire extinguishing are based upon the smothering of the fire and thus full extinguishment of a fire. Should the foam fail to cover the fire completely, it is likely to re-emerge.

The fire control time is related to the solution application rate and the type of foam used. Data is available [20] enabling the fire control time to be determined.

10 Activation of fire barrier systems

10.1 General considerations

There are a number of types of systems that can be used to provide a smoke and/or fire barrier when required. These systems are designed to complete the integrity of passive fire protection in the event of a fire, whilst allowing access, ventilation, etc. through the structures at other times.

Sub-system 3 covers issues with regard to passive fire protection. In this section, consideration is given to the activation of such systems when a fire has been detected. In this case, the following time formula can be used:

$$t_{barrier} = t_{det} + t_{proc} + t_{closure} \qquad (18)$$

where

$t_{barrier}$ is the time taken for the fire barrier system to complete its function

t_{det} is the calculated detection time

t_{proc} is the processing time of the barrier system

$t_{closure}$ is the time taken for the barrier to complete its function after activation

10.2 Types of barrier system

The use of barrier systems is covered in Sub-system 3. The following types are commonly used when controlled by the fire detection system.

— *Door or shutter release systems*. These systems will hold open the door or shutter in normal circumstances and release them when an alarm has been activated. The system itself will normally be operated on a default to closure basis, so that power failure will also lead to closure. Note that the operation will be programmed into the fire detection system using logic so that a specific group or groups of fire detectors will need to operate before activation is achieved. This should be taken into account when evaluating t_{det}.

Activation of the door or shutter may be made via a loop interface unit installed directly into the fire detection system circuitry. Consequently, the value for t_{proc} can be evaluated from the detection system supplier. $t_{closure}$ will be provided by the supplier of the door release mechanism.

NOTE Consideration should be given to ensuring that the means of escape is maintained until the building has been evacuated.

— *Fire damper systems*. Fire dampers are either installed into ventilation ductwork at the fire separation line, or within fire rated walls to provide ventilation. Once activated, the damper blades will quickly close. The system will normally be operated on a default to closure basis, so that power failure will also lead to closure.

— Note that the operation will be programmed into the fire detection system using logic so that a specific group or groups of fire detectors will need to operate before activation is achieved. This should be taken into account when evaluating t_{det}.

— Activation of the damper may be made via a loop interface unit installed directly into the fire detection system circuitry. Consequently, the value for t_{proc} can be evaluated from the detection system supplier. $t_{closure}$ will be provided by the supplier of the damper.

10.3 Impact on fire growth

If the system is correct configured, operation of the barrier systems will quickly lead to closure of all ventilation to the growing fire. As the speed of closure is normally fast, this assessment could be assumed to be a step function. This can then be fed back into the formulae of Sub-systems 1 and 2.

10.4 Failure modes

The modes of failure for barrier systems can be divided into two categories.

— *Failure to be activated*: This may be due to the fire detection system failing to detect a fire or the activating mechanism to operate. Where this is all controlled by the fire detection system, the supplier of that system should be consulted.

— *Failure to close*: This may be due to an inherent mechanical problem within the equipment or due to closure being prevented by obstructions. In either case, a proper maintenance regime combined with general good housekeeping should assist in reducing the probability of this failure occurring. Note that partial closure should be regarded as a failure.

11 Activation of smoke control systems

11.1 General considerations

Smoke control systems are provided in many larger buildings as part of a fire engineering design:

— to aid the evacuation of persons from a building;

— to allow fire fighting teams to enter the building.

There may also be a number of other indirect benefits of smoke, heat and exhaust control such as for property protection, where fire effluents are redirected away from designated parts of the building fabric, equipment or processes. Smoke Heat and Exhaust Ventilation Systems (SHEVs) use the thermal buoyancy of the fire effluent allow the smoky gases to float above higher-density clear air, thus achieving a separation between fire effluent and who/what is being protected.

The systems are designed to either:

— channel effluents from a fire to a designated part of the building (e.g smoke reservoir) and/or discharged from the building via vents;

— set up conditions whereby effluents are prevented from entering specific areas of the building;

— operate barriers to physically prevent the effluents from moving to other areas.

In many cases, the systems are active systems and thus require a signal to initiate their operation. This signal may normally derive from the fire detection and alarm system.

The system is to be activated as soon as possible after detection of smoke or other effluents, to bring the operation to a stage where the control conditions have been met, and to maintain its function for longer than the period of evacuation (where the system is designed for life safety purposes) and/or for the benefit of fire fighting teams (for both life safety and property protection).

In this case, the following time formula can be used from the activation of the system:

$$t_{\text{sm-cont}} = t_{\text{act}} + t_{\text{proc}} + t_{\text{maint}} \quad (19)$$

where

$t_{\text{sm-cont}}$ is the total time required for the smoke control system to maintain its function;

t_{act} is the time from the detected fire to the activation of the smoke control system;

t_{proc} is the processing time of the control system to bring it to a stage where it meets the design criteria;

t_{maint} is the maintenance time whereby the system is required to continue its function.

Note that for life safety protection, the value of $t_{\text{sm-cont}}$ must be *greater* than the total evacuation time from detection of the fire condition. Where the system is designed to allow fire fighters to enter the building, for both property protection and life safety objectives, this value must be greater than the time from detection of the alarm condition to mobilization of the fire fighting teams. Clause **8** should be consulted for determination of these periods.

11.2 Types of system

There are a number of different types of smoke control system. Each type has certain aspects beneficial to specific building types and occupancies. Note that, where smoke and other control systems are specified, they should be designed and installed to the relevant standards as detailed below.

a) *Smoke and heat exhaust ventilation.*

The objective for smoke exhaust ventilation is to maintain a smoke free layer in designated areas of a building to allow the evacuation of persons from the building and to allow fire fighters to enter the building to fight the fire and aid evacuation. A typical smoke ventilation system will incorporate the following:

— ventilators at high level to allow the fire effluent to escape. These may be natural smoke ventilators or may be powered;

— a smoke collection reservoir that collects the smoke for further extraction. This should be of a size that does not promote unwanted cooling of the fire effluent;

— inlet air sources, either at low level or via ventilators in adjacent zones, that will allow the replacement of the exhausted fire effluent with clean air.

Typically, smoke exhaust ventilation is used in large open areas such as atria and shopping malls where evacuation may be via the atria areas. In such cases, the building may be zoned into a series of smoke reservoirs.

Note that the operation will, in nearly all cases, be initiated by the fire detection system. It may be preferred that a specific group or groups of fire detector must operate before a signal is used to activate the system. Furthermore, coincidence detection of fire detectors may be required. These aspects may all have an affect on the calculated detection time.

When evaluating the value for t_{proc} an assessment of the fire growth parameters, including perimeter, smoke production and heat output, will be required. Calculations will then need to be made to ensure that the volumetric rate of smoke exhaustion from the protected area is equal or greater to the quantity of smoke produced, to ensure that a sufficient smoke free layer of specified height is maintained for the required period t_{maint}. However, consideration should also be given to the use of zoned reservoirs using smoke barriers such that the clear height may need to be greater.

b) *Pressurization.*

These systems are commonly used to prevent the ingress of smoke into a protected escape routes and fire fighting shafts. The system works by charging the protected space with additional air, thus creating an overpressure (typically not less than 50 Pa in the design condition. This causes a pressure differential between the enclosed escape route areas and other areas, thus preventing smoke from entering the escape routes.

The system comprises a mechanical system used to inject air into the protected space, usually by a ductwork distribution system with inlets to the space. One or more fan units provide the forced air. The system also requires a leakage path from the building fabric to prevent the pressure from equalizing, and to cater for open door conditions.

c) *Dispersal ventilation.*

This technique is where clean air is brought into part or parts of the protected building such that any smoke is diluted to an acceptable level. Note that this form of smoke control is not widely favoured within the UK.

Detailed design guidance is given in BS 5588-4.

Note that the operation will, in many cases, be initiated by the fire detection system. It may be preferred that a specific group or groups of fire detectors must operate before a signal is used to activate the system. Furthermore, coincidence detection of fire detectors may be required. These aspects may all have an affect on the calculated detection time.

The activation time t_{act} of the system should normally be established by the system supplier and will also be based on the detection system output parameters (such as operation of loop interface units on the detection system).

The value for t_{proc}, should be relatively small once the doors are closed and the open door velocity caters for open door cases.

The value of t_{maint} can be assessed by first determining the evacuation and fire fighting times, (see Clause **7**), together with an additional time safety factor.

11.3 Impact on fire growth

Smoke control systems will have an impact on fire growth as follows:

— for pressurization systems, smoke and heat may be re-directed to other parts of the building;

— for smoke exhaust systems, the additional distance created between a fire and the smoke layer should be designed to prevent the onset of flashover by allowing continued entrainment of air into the smoke plume and keeping the plume temperature controlled.

Due to the potentially complex analysis in some cases, suitable computer based models may need to be used. These may be either zone based models, involving the solution of a simplified set of equations, or may use computational fluid dynamics (CFD) where an enclosure is sub-divided into a large number of sub-volumes where mass momentum and energy conservation parameters are applied to each of these sub-volumes.

11.4 Failure modes

Smoke control systems are complex and variable, designed around specific risks. Consequently the failure modes will also be complex, but can be divided into the following:

— *failure to be activated*: This will depend on the form of activation system used. Where this is controlled by the fire detection system, an analysis of the failure modes of the detection system will assist;

— *failure to properly operate*: This may be due to a system design or installation failure or maintenance failure. The supplier of the smoke control systems should be able to provide suitable data;

— *failure to control smoke (and heat) as designed*: The likely cause of the failure mode is impact by external elements. This may include ambient or local conditions not taken into consideration during the design phase, the fire growth not acting as envisaged, or the operation of other fire safety and protection systems adversely affecting the operation of the smoke control system (see Clause **12**).

Computer based modelling can assist in determining how failure will affect the overall fire safety engineered design.

12 Interactions of smoke control and suppression systems

NOTE The conclusions reached in this clause are under constant review in the light of recent, current and future research by BRE, NISTIR, VdS and other bodies.

BS 5588-4 should be consulted for more details on the operation of systems.

The QDR should ensure that systems installed as part of the fire safety engineering strategy will be compatible. However, there are recognised concerns that the needs of different forms of system require operating parameters that conflict. Particular concerns have emanated from the use of SHEVS and water sprinkler systems in the same area.

There are three types of interaction between sprinklers and natural or powered ventilation systems designed to exhaust or vent smoke an heat during a fire. These are as follows.

a) *Influence of smoke exhaust on sprinkler operations or opening patterns*.

Where smoke curtains are used as part of a smoke control system, and the ceiling area is divided into zones, the following adverse reactions are possible.

— The spray pattern and envelope from sprinkler heads located within the same area can be distorted;

— The heat from a fire, directed by the zoning arrangement, can lead to excess sprinkler heads opening, causing reduced flow pressures. This effect will be most critical in the cases of sprinkler systems designed to respond at an early stage.

b) *Influence of smoke exhaust or smoke vents on the effectiveness of sprinklers*.

When smoke vents operate automatically, there is the inevitability of fresh air being introduced into the enclosure during the critical period when sprinklers are in the process of activation, control or suppression of fire growth. Smoke venting during this sprinkler control process may lead to an increase in the number of sprinklers activated and hence an increase in the total water flow requirements. Therefore, where suppression systems and smoke control systems are both present, care must be taken to ensure optimum performance of the combined system and that the activation of these systems is designed to fulfil the requirements of the fire safety design.

c) *Influence of sprinklers on the effectiveness of smoke control systems*.

At some distance from the fire, the sprinkler spray will interact with a slowly moving ceiling jet (layer) that, with time, is submerged within a thickening hot gas layer. In many cases, the spray will cool this hot gas layer and reduce its buoyancy. Therefore, where suppression systems and smoke control systems are both present, care must be taken to ensure optimum performance of the combined system and that the activation of these systems is designed to fulfil the requirements of the fire safety design.

Where forms of fire suppression other than sprinkler systems are installed, the operation of smoke control systems in conjunction with these systems may have adverse reactions. Such examples are where extinguishing systems rely on the integrity of an enclosure. However, it is not normally considered a practical strategy to combine smoke extraction within the same area as a gaseous extinguishing system.

The possible adverse interactions could be overcome or limited by the careful assessment of the system designs and by the relative times to activation. Typical considerations may include:

— incorporating safety factors at the design stage to allow for such worst-case scenarios;

— adapting the system components siting, spacing and layout to minimize any adverse affects;

— re-addressing the activation times to allow one system to operate at a pre-determined delay from the other. Such factors could include the choice of detectors used to activate the functions;

— adapting procedures to incorporate manual activation to operate the smoke venting system where systems are used for life safety purposes only;

— use an open head sprinkler system activated by the fire detection system, where detection devices are located in positions not adversely affected by other systems.

13 Management of fire safety

Within this Sub-system, the fire safety measures covered are predominantly active, i.e they perform one or more actions to provide for the requirements of the fire safety engineering design. Consequently the systems should be properly designed, installed, commissioned, tested and maintained in an appropriate manner to ensure that they perform as designed.

Consultation: A full list of those involved with the development of a fire safety engineering strategy needs to be established. As the design is drawn up, it is important that the views of each party are acknowledged so that a complementary strategy will be developed.

Design: Fire detection and suppression system designs based on a fire safety engineered approach, rather than a prescriptive approach, are likely to be more open to interpretation. It is therefore essential that a design format is drawn up that will enable a thorough and detailed assessment of each phase of the design approach. Assumptions made and calculations used must be fully stated. Any subsequent modification to the premises, occupancy or processes will need to be taken into consideration.

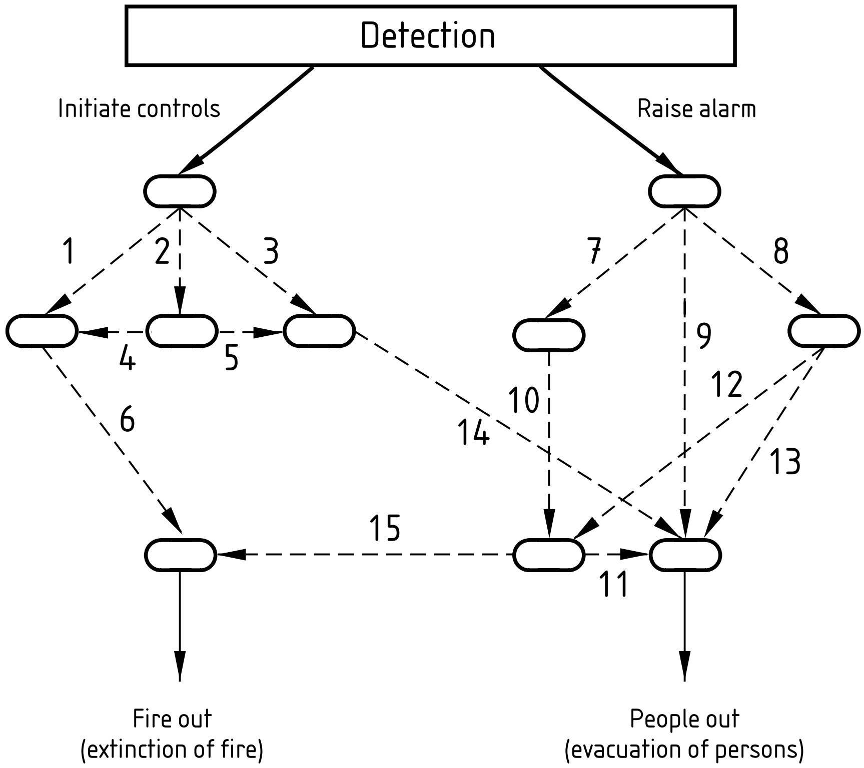
— *Installation*: All detection, activation, control and suppression systems should be installed by competent fire engineering contractors. When using this Sub-system, strategies may lead to more unusual system designs. It is therefore essential that the designs can be interpreted correctly and any practical difficulties resolved in a manner that will not adversely impact on the strategy.

— *Commissioning and testing*: All systems should be fully commissioned and tested to ensure their correct functioning. Furthermore interfaces between systems should be assessed to ensure that the cause and effect criteria meets with the requirements of the strategy. In many cases, different system types may be installed by different specialist contractors. It is therefore important that a competent person oversees the commissioning and testing stages to ensure that all parts of the protection strategy operate in a seamless manner and meet the design objectives.

— *Maintenance*: To ensure that the protection strategy continues to be effective, an integrated maintenance regime should be introduced directly after system handover. Whereas maintenance regimes for different system types can be largely based upon the scope and frequencies given in the relevant prescriptive standards, there will need to be additional requirements covering the interfaces. A maintenance plan should be drawn up prior to system completion to determine the key requirements for both planned preventive maintenance and emergency attendance. As with installation contractors, maintenance contractors should be competent in all aspects of the maintenance requirement [12].

Annex A (normative) Critical path analysis for fire control and suppression systems

Many of the more complex fire safety and protection strategies rely on the complementary actions of a number of different processes to provide for the key objectives determined by the QDR as described in PD 7974-0. This is best illustrated by Figure A.1 [21].



Key

1 Activation of automatic extinguishing systems

2 Operation of equipment to control the spread of fire (e.g. fire dampers, fire door closure)

3 Operation of functions to aid escape (e.g. escape route pressurization or smoke venting)

4 Sealing of enclosures to provide room integrity (for gaseous extinguishing systems)

5 Sealing of areas to provide fire separation from escape routes

6 Automatic suppression of fire

7 Automatic transmission of alarm to emergency services (e.g. fire brigade)

8 Alerting of in-house staff (e.g. wardens or site fire brigade)

9 Sounding of evacuation alarm sounders or Voice Alarm/Public Address

10 Mobilizing of professional fire fighting teams

11 Aiding the escape of occupants (Professional Emergency Services)

12 Trained staff using fire-fighting equipment

13 Aiding the escape of occupants (Fire Wardens)

14 Escape routes cleared of smoke and fire

15 Manual suppression of fire

Figure A.1 — Different processes to provide for the key objectives determined by the QDR

By determining the required outcome of the fire protection systems, each of the paths 1 to 15 can be separately evaluated for a number of key considerations.

— Is this path a necessary part of the fire protection strategy?

— If required, what systems or mechanisms should be put into place to meet the objectives?

— What are the expected (or possibly worst case and/or best case) activation times?

Similarly, each of the nodes can be assessed to determine the expected output criteria provide by each path arriving at that point. In this way, a critical path to each of the objectives can be determined. This will enable the fire protection strategy to focus on the key issues and will allow the determination of the necessary activation times for the less critical paths. This can be illustrated by the following example where values of t will be determined by a full analysis of the fire safety engineered design, as shown in Table A.1 and Table A.2.

Table A.1 — Example of tabulation of completion times for single paths identified in Figure A.1

Path no.	Description	Exp. time to completion s
0	Detection System	*t*
1	Activation of gas extinguishing system	*t*
2	Activation of damper systems for room integrity	*t*
3	No venting or pressurization systems used.	
4	Operation of damper systems for 2	*t*
5	Not used	
6	Extinguishing operation (incl. hold time)	*t*
7	Alarm transmission to Emergency Services	*t*
8	In-house alarm same as main evacuation alarm	
9	Sounding of alarm system (incl. final evacuation)	*t*
10	Mobilizing of Fire Brigade (incl. attendance time)	*t*
11	Aiding escape of occupants by Fire Brigade	*t*
12	Staff fire-fighting not within strategy	
13	In-house aiding of evacuation not within strategy	
14	No automatic systems to clear evacuation routes of smoke.	
15	Fire fighting / confirmation by Fire Brigade only.	*t*

Table A.2 — Example of combining single path times to determine critical path time for Figure A.1

Path	Total duration s	Comment
1-6	*t*	
2-4-6	*t*	Dampers to operate prior to start of discharge sequence.
7-10-15	*t*	Attendance time to be before completion of hold time for gaseous systems.
7-10-11	*t*	
9	*t*	Evacuation time is likely to be before attendance by fire services.

It should be stressed that the above is a simplistic example. There are likely to be a number of factors based around, for example, different types of suppression system, each with their own characteristics.

Annex B (informative) Determination of heat detector spacing

The following method of determining the spacing for heat detectors is taken from the SFPE Handbook of Fire Protection Engineering, 2nd edition, Section 4 — Design of Detection Systems. If this is method is used, it is recommended that the section is consulted [22].

1) Determine the environmental conditions of the area being considered:

a) ambient temperature, T_a;

b) ceiling height above fuel, H.

2) Estimate the fire growth characteristics, α or t_c for the fuel expected to be burning.

3) Establish the goals of the system t_r or dQ_T/dt.

4) Select the detector type to be used. For fixed temperature units, this establishes the detector response temperature and its RTI or τ_0 or u_0.

5) Make the first estimate of the distance, r, from the fire to the detector.

6) Assume that the fire starts obeying the power-law model at time $t = 0$.

7) Set the initial temperature of the detector and its surroundings at ambient temperature.

8) Using equation (C.1), calculate the non-dimensional time, $t_{2f}*$, at which the initial heat front reaches the detector.

9) Calculate the factor A defined in equation (C.2).

10) Use the required response time along with equation (C.3) and $p = 2$ to calculate the corresponding value of t_2*.

11) If t_2* is greater than $t_{2f}*$, continue with step 12. If not, try a new detector position, r, and return to Step 8.

12) Calculate the ratio u/u_2* using equation (C.4).

13) Calculate the ratio $\Delta T/\Delta T_2*$ using equation (C.5).

14) Use equation (C.6) to calculate ΔT_2*.

15) Equation (C.7) is used to calculate the ration $u_2*/ (\Delta T_2*)^{\frac{1}{2}}$.

16) Use equations (C.8) and (C.9) to calculate Y.

17) Equation (C.10) can now be used to calculate the resulting temperature of the detector.

18) If the temperature of the detector is below its operating temperature, this procedure must be repeated using a smaller value of r. If the temperature of the detector exceeds its operating temperature, a larger value can be used.

19) Repeat this procedure until the detector temperature is equal to its operating temperature. The required spacing of detectors is $S = 1.41r$.

Note that the above procedure can be used to estimate the response of rate-of-rise heat detectors, by using equation (C.11) in Step 17. This is then compared to the rate at which the detector is designed to respond.

$$t_{2f}^* = 0.95\ (1 + r/H) \quad \text{(C.1)}$$

$$A = g/(C_p T_a \rho_0) \quad \text{(C.2)}$$

$$t_p^* = t/[A^{-1/(3+p)} \alpha^{-1/(3+p)} H^{-(5-p)/(3+p)}] \quad \text{(C.3)}$$

$$\Delta T_p^* = \Delta T/[A^{2/(3+p)} (T_a/g) \alpha^{2/(3+p)} H^{-(5-p)/(3+p)}] \quad \text{(C.4)}$$

$$u_p^* = u/[A1^{d/(3+p)} \alpha^{1/(3+p)} H^{(p-1)/(3+p)}] \quad \text{(C.5)}$$

$$\Delta T_2^* = [(t_2^* - t_{2f}^*)/(0.188 + 0.313r/H)]4/3 \text{ for } t_2^* < t_{2f}^* \quad \text{(C.6)}$$

$$u_2^*/(\Delta T_2^*)^{\frac{1}{2}} = 0.59\ (r/H)^{-0.63} \quad \text{(C.7)}$$

$$Y = (3/4)(u/u_2^*)^{\frac{1}{2}} [u_2^*/(\Delta T_2^*)^{\frac{1}{2}}]^{\frac{1}{2}}\ (\Delta T_2^*/\mathrm{RTI})(t/t_2^*)\mathrm{D} \quad \text{(C.8)}$$

$$D = 0.188 + 0.313(r/H) \quad \text{(C.9)}$$

$$T_d(t) = T_d(0) = (\Delta T/\Delta T_2^*)\Delta T_2^*[1-(1-e^{-Y})/Y] \quad \text{(C.10)}$$

$$\mathrm{d}T_d(t)/\mathrm{d}t = [(4/3)(\Delta T/\Delta T_2^*)(\Delta T_2^*)^{\frac{1}{4}}[1-(1-e^{-Y})]/[(t/t_2^*)D] \quad \text{(C.11)}$$

where

α	fire intensity coefficient (kW/s^2)
ρ_0	density of ambient air (kg/m^3)
ΔT_p^*	change in reduced gas temperature (°C)
A	area (m^2)
C_p	specific heat of air (kJ/(kg·K))
D	$0.188 + 0.313\ r/H$
g	gravitational constant, m/s^2)
H	ceiling height (m)
r	radial distance from fire plume axis (m)
RTI	response time index
t_{2f}^*	reduced arrival time of heat front (for $p = 2$ power-law fire) at a point r/H (s)
T_a	ambient temperature (°C)
$T_d(t)$	detector temperature (°C)
T_p^*	reduced time (s)
u	instantaneous velocity of fire gases (m/s)
u_p^*	reduced gas velocity (m/s)
Y	used to calculate equation (C.10)

blank

Bibliography

BSI publications

BS EN 50131-1, *Alarm systems — Intrusion systems — Part 1: General requirements*.

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

Other publications

[1] BROSOVSKY, E.L. *A preliminary approach to siting smoke detectors based on design fire size and detector aerosol entry lag time*. MS Thesis WPI Center for Fire Safety Studies, Worcester MA (1991). SFPE handbook 2nd edition.

[2] NFPA 72. Appendix B provides guidance on point heat and smoke fire detector spacing. USA: The National Fire Protection Association.

[3] EVANS, D. and STROUP, D. *Methods to calculate the response time of heat and smoke detectors installed below large unobstructed ceilings*. US Dept of Commerce, National Bureau of Standards 1985.

[4] PUCCI, W. *Modelling spot-type smoke detector response*. SFPE Fire Protection Engineering Journal. Issue 7: Summer 2000.

[5] EVANS, D. and STROUP, D. *Methods to calculate the response time of heat and smoke detectors installed below large unobstructed ceilings*. US Dept of Commerce, National Bureau of Standards 1985.

[6] Category L3 of BS 5839-1:1988.

[7] HESKESTAD, G. and BILL, R.G. *Quantification of thermal responsiveness of automatic sprinklers including conduction effects. Fire Safety Journal*, 14:113–125, 1988.

[8] QUINTIERE, J.G. BIRKY, M. MacDONALD, F. SMITH, G. An analysis of smouldering fires in closed compartments and their hazard due to carbon monoxide. Fire and Materials, Vol 6, 1982.

[9] THOMAS, P.H. *Behaviour of fires in enclosures — Some recent progress* — Combustion Institute (1973) 14th Symposium (International) on Combustion. Pittsburgh.

[10] Taken from prEN 54-12, *Smoke detectors — Line detectors using an optical light beam*. Sep 1999 (draft).

[11] SFPE Handbook of Fire Protection Engineering. 2nd edition. 4-19.

[12] More information can be obtained from NFPA 72: 1996 — *National fire alarm code*, National Fire Protection Association, USA - Annex B: Engineering Guide for automatic fire detector spacing.

[13] *Unwanted Fire Signals – National Campaign Newsletter*. BFPSA, 2001. www.bfpsa.org.uk.

[14] FORNEY, G., BUKOWSKI, R., DAVIS, W. *Field Modelling — Effect of flat beamed ceilings on detector and sprinkler response*. Oct 1993 - National Institute of Standards and Technology, USA.

[15] MATSUYYAMA, K. and WAKAMATSU, T. *Systematic experiments of room and corridor smoke filling for use in calibration of zone and CFD models*. Science University of Tokyo for the 15th Meeting of the UJNR Panel on Fire Research and Safety. March 2000, Volume 2.NIST, USA.

[16] KAHN, M.J. NBC-GCR-83-435. National Bureau of Standards (SFPE Handbook — 2nd Edition).

[17] The Building Regulations: Approved Document B. 2000 Edition.

[18] HECKSTEAD, G. and KUNG, H, FMRC Serial No. 15918. Factory Mutual Research Corp. Norwood (1973).

[19] EVANS, D.D. *Sprinkler fire suppression algorithm for HAZARD*. NISTIR 5254, National Institute of Standards and Technology, Gaithersburg, MD (1993).

[20] SCHEFFEY, J. *Foam agents and AFF system design considerations*. SFPE Handbook of Fire Protection Engineering. 2nd edition. Section 4. Chapter 4.

[21] BRYANT, P. Kingfell Fire Protection Ltd. Published in Fire Safety Engineering Journal, UK.1996.

[22] SCHIFILITI R. *et al*. SFPE Handbook of Fire Protection Engineering. 2nd edition. Section 4. Design of Detection Systems. If this is method is used, it is recommended that the section is consulted.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.
Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001.
Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre.
Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.
Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001.
Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

BSI
389 Chiswick High Road
London
W4 4AL