Introduction

This Published Document provides a framework for developing a rational methodology for design of buildings using a fire safety engineering approach. It applies scientific and engineering principles to the protection of people, property and the environment from fire.

The Published Documents (PDs) in this series contain guidance and information on how to undertake quantitative and detailed analysis of specific aspects of the design. They are a summary of the state of the art and it is intended that they be updated as new theories, calculation methods and/or data become available. They do not preclude the use of appropriate methods and data from other sources. Figure 1 shows the structure of BS 7974 and the associated Published Documents.

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

This Published Document includes no specific analysis of some aspects of fire spread beyond the enclosure of origin other than the performance of products based upon a fire resistance furnace test. In due time, as the knowledge and understanding is improved, these areas of uncertainty will be addressed. However, in the meantime, a commentary is given on the particular issues that need to be considered and how these should be treated.

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

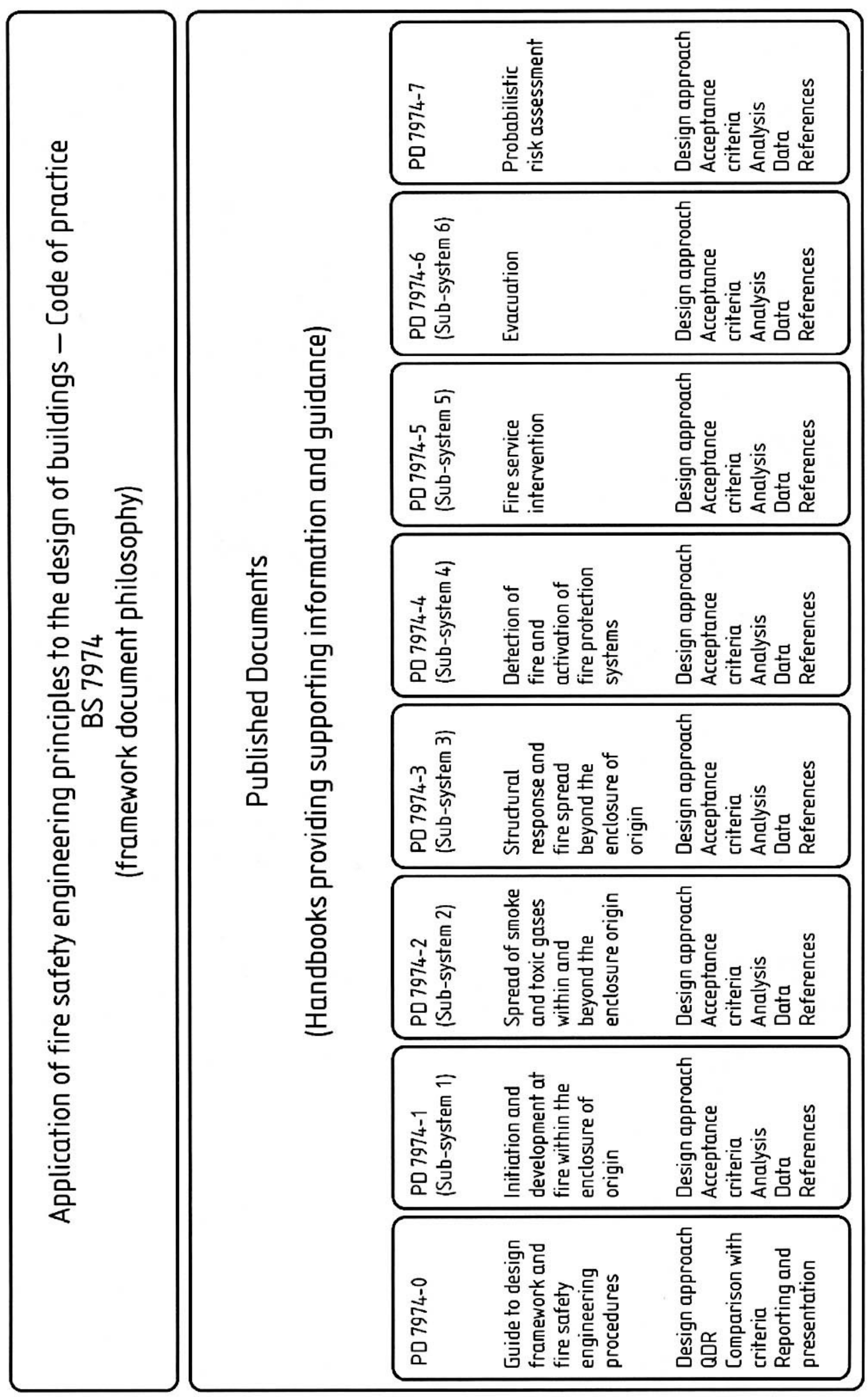

Figure 1 — Overview of the PD 7974 series of Published Documents

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1 Scope

This Published Document considers the following issues:

a) the conditions within a fire enclosure and their potential to cause fire spread by way of recognized mechanisms and routes;

b) the thermal and mechanical responses of the enclosure boundaries and its structure to the fire conditions;

c) the impact of these anticipated thermal and mechanical responses on adjacent enclosures and spaces;

d) the structural responses of load-bearing elements and their effect on structural stability, load transfer and acceptable damage.

2 Normative references

The following referenced documents are indispensible for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN ISO 13943:2000, *Fire Safety — Vocabulary.*

3 Terms and definitions

For the purposes of this Published Document, the terms and definitions given in BS EN ISO 13943:2000 and the following apply.

3.1
enclosure
space defined by boundary elements (on all sides) around the point of origin of the fire

3.2
fire safety engineering
FSE
use of engineering principles for the achievement of fire safety

3.3
time equivalent
duration of exposure to fire test conditions specified in BS 476-20:1987 or ISO 834-1

NOTE This is equivalent (in terms of some designated effect) to exposure to the full duration of real enclosure fire conditions.

3.4
sensitivity analysis
calculation of changes in outputs for variations of an input parameter of interest

3.5
structural frames
arrangement of structural materials and/or elements combined to form a building or a part thereof which has been designed to fulfil a loadbearing function

3.6
duration of steady burning
Interval between onset of flashover and commencement of decay

NOTE It is often characterized as the period over which the fire load within the enclosure is reduced from 80 % to 30 % of its initial value.

4 Symbols and abbreviated terms

A	is the cross-section area of a steel member (m^2)
A_c	is the area of concrete core (mm^2)
A_e	is the area of exposed surface (m^2)
A_f	is the floor area of enclosure (m^2)
A_h	is the area of ventilation in the horizontal plane (m^2)
A_i	is the cross section area of an insulated element (m^2)
A^*_i	is the surface area of element i, (wall, floor, roof) (m^2)
A_r	is the cross-section of steel reinforcement (mm^2)
A_{rad}	is the area of radiating surface (m^2)
A_T	is the internal solid area of the enclosure (m^2)
A_t	is the total internal area, including openings, of the enclosure (m^2)
A_v	is the area of ventilation in the vertical plane (m^2)
A_w	is the area of the openings (m^2)
A_w%	is percentage of window area (%)
a	is the distance between the edge of opening and external steel column (m)
b	is the thermal inertia ($J/m^2 \cdot s^{½} \cdot K$)
b_e	is the exposed height of an external beam (m)
b_c	is the width of a reinforced concrete slab (mm)
b_i	is the thermal inertia of an element ($W/m^2 \cdot s^{½}$)
b_p	is the thermally induced movement of a partition at mid-height (mm)
b_s	is the additional bow of partition due to self weight (mm)
b_t	is the width of a timber beam (m)
C	is the specific heat capacity ($J/kg \cdot K$)
C_a	is the specific heat capacity of steel ($J/kg \cdot K$)
C_{al}	is the specific heat capacity of aluminium alloys ($J/kg \cdot K$)
C_c	is the specific heat capacity of concrete ($J/kg \cdot K$)
C_{com}	is the specific heat capacity of a fibre reinforced polymer ($J/kg \cdot K$)
C_f	is the specific heat capacity of fibre reinforcement ($J/kg \cdot K$)
C_g	is the specific heat capacity of the gases ($J/kg \cdot K$)
C_i	is the specific heat capacity of insulation layer i ($J/kg \cdot K$)
C_m	is the specific heat capacity of metal ($J/kg \cdot K$)
C_t	is the specific heat capacity of uncharred timber ($J/kg \cdot K$)
C_x	is the specific heat capacity of a composite matrix ($J/kg \cdot K$)
D	is the depth of enclosure (m)
d	is the characteristic dimension perpendicular to the direction of heat flow (m)
d_{char}	is the depth of char (mm)
d_{door}	is the thickness of a door leaf (mm)
d_i	is the thickness of insulating material i (m)
d_r	is the depth of reinforcement in a concrete slab (m)
d_s	is the thickness of the stud partition (m)
d_t	is the depth of a timber beam (mm)
d_w	is the thickness of a wall (m)
d_x	is the concrete depth normal to major axis (m)

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d_y	is the concrete depth normal to minor axis (m)
E	is the Young's modulus for metal at the relevant temperature (kN/mm^2)
E_a	is the Young's modulus for steel at the relevant temperature (kN/mm^2)
E_{al}	is the Young's modulus for aluminium alloys (kN/mm^2)
$E_{d,t}$	is the design load created by the fire situation at time t
E_t	is the tangent modulus (kN/mm^2)
e_{rfc}	is the complex error function
F	is the axial load applied in fire (N)
F_d	is the design value of indirect loads created by the effect of fire
F_R	is the fire resistance time (h)
F_{wi}	is the strength of wrought iron at ambient temperature (N/mm^2)
$F_{e\text{-}R}$	is the configuration factor describing the spatial relationship between the emitting and receiving surfaces
F_o	is the strength of reinforcement at ambient temperature (N/mm^2)
F_s	is the strength of reinforcement at the relevant temperature (N/mm^2)
F_t	is the tensile strength of steel at the relevant temperature (N/mm^2)
F_{wo}	is the strength of wrought iron at ambient temperature (N/mm^2)
F_{wi}	is the strength of wrought iron at the relevant temperature (N/mm^2)
f	is an empirical factor (min/mm)
f_c	is the compressive strength of concrete at the relevant temperature (N/mm^2)
f_{ap}	is the stress at the proportional limit for steel at the relevant temperature (N/mm^2)
f_{au}	is the ultimate stress for steel at the relevant temperature (N/mm^2)
$f_{au,\theta}$	is the tensile strength at elevated temperatures (N/mm^2)
f_{ay}	is the yield strength of steel at temperature T_a (N/mm^2)
f_{cu}	is the cube strength of concrete (N/mm^2)
f_k	is a modification factor for ventilation
$f_{a,max}$	is the maximum stress for steel at the relevant temperature (N/mm^2)
f_o	is the concrete strength at ambient (298 K) temperature (N/mm^2)
f_s	is the steel stress (N/mm^2)
f_y	is the yield strength of steel (N/mm^2)
$f_{0.2}$	is the 0.2 % proof stress of steel (N/mm^2)
G_k	is the characteristic value of the permanent dead load
H	is the height of the enclosure (m)
ΔH	is the heat of combustion of a fire load material (kJ/kg)
H_{door}	is the key linear dimension of the door leaf (mm)
H_p	is the heated perimeter of a section (m)
H_{roof}	is the difference in height between the plane of the horizontal opening and the neutral axis of the gas in the vertical opening (m)
H_w	is the opening height (m)
H_{wall}	is the height of wall (mm)
h_p	is the partition height (mm)
I	is the second moment of area (mm^4)
$K_{0,1,2}$	are constants relating to the fire protection material
K	is the thermal diffusivity (m^2/s)

K_b	is the buckling factor
K_c	is the thermal diffusivity of concrete (m^2/s)
k	is the thermal conductivity (W/m·K)
k_a	is the thermal conductivity of steel (W/m·K)
k_{al}	is the thermal conductivity of aluminium alloys (W/m·K)
k_b	is the factor describing the thermal properties of the enclosure
$k_{bolt,\theta}$	is the reduction factor for bolts (tension and shear)
k_c	is the thermal conductivity of concrete (W/m·K)
k_{comp}	is the thermal conductivity of a composite (W/m·K)
k_f	is the thermal conductivity of fibre reinforcement (W/m·K)
k_i	is the thermal conductivity of an insulation layer i (W/m·K)
k_t	is the thermal conductivity of uncharred timber (W/m·K)
k_x	is the thermal conductivity of a composite matrix (W/m·K)
l	is the distance along a flame (m)
L	is the total fire load in enclosure either in wood equivalent (kg) or heat content (MJ)
ΔL	is the expansion of a door leaf (mm)
L_0	is the linear dimension at ambient temperature (mm)
L_R	is the load ratio
L_T	is the linear dimension at temperature T (mm)
ΔL_T	is the temperature induced expansion (mm)
M	is the mass outflow rate of hot gases (kg/s)
M_b	is the moment resistance to lateral torsional buckling (N·m)
M_c	is the moment capacity of section about appropriate axis of bending (N·m)
M_f	is the applied moment in fire (N·m)
M_{fx}	is the moment about major axis in fire (N·m)
M_{fy}	is the moment about minor axis in fire (N·m)
$M_{opening}$	is the mass flow rate in plume, at height Z_w (kg/s)
M_{px}	is the plastic moment capacity of reinforcement about major axis (N·m)
M_{py}	is the plastic moment capacity of reinforcement about minor axis (N·m)
M_{stud}	is the moment in the stud due to thermal induced eccentricity (N·m)
m	is the equivalent uniform moment factor
m_s	is the stud spacing (mm)
$N_{pl,fi,Rd}$	is the compressive resistance in fire
$N_{pl,Rd}$	is the compressive resistance in normal design
n	is the weight of the partition per metre height (kN)
n_s	is the ratio between the gas and surface temperatures of a concrete member
n_x	is the ratio between surface temperature and the temperature at depth x in a concrete member
n_y	is the ratio between surface temperature and the temperature at depth y in a concrete member
O	is the opening factor ($m^{½}$)
P	is the % of moisture (by mass)
P_b	is the buckling load (kN)
p_c	is the compressive strength of concrete (N/mm^2)
p_y	is the characteristic design stress for steel (N/mm^2)

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p_{yr}	is the characteristic yield strength for steel reinforcement (N/mm^2)
Q	is total heat release
Q_c	is the rate of heat loss by convection (kW)
Q_g	is the rate of accumulation of heat in the hot gases (kW)
Q_k	is the characteristic value of the imposed load
$Q_{k,i}$	are the characteristic values of the other variable live loads, e.g. wind
$Q_{k,1}$	is the characteristic value of the dominant load
Q_r	is the rate of heat loss by radiation through the openings (kW)
Q_{total}	is the total rate of heat release in the enclosure (kW)
Q_w	is the rate of heat flow to enclosing construction (kW)
q	is the fire load density per unit area of enclosure surface or floor area (MJ/m^2)
q_c	is the convective heat flux (kW/m^2)
q_{cond}	is the conductive heat flow (kW)
q_{conv}	is the convective heat flow (kW)
q_{net}	is the net incident heat flux (kW/m^2)
q_r	is the radiative heat flux (kW/m^2)
q_{rad}	is the radiative heat flow (kW)
q_{rec}	is the radiative heat flux received by the surface outside the fire enclosure (kW/m^2)
q_{total}	is the total heat flux (kW/m^2)
R	is the burning rate (kg/s)
$R_{d,t}$	is the design resistance of the member or structure to the fire created situation at time t
S_i	is the thickness of layer i (m)
S_{limit}	is the limiting depth of boundary (m)
T	is temperature (°C or K)
ΔT	is a temperature interval (°C or K)
ΔT_{stud}	is the temperature difference between the hot and cold faces of a stud partition (°C)
T_a	is the steel temperature (K)
T_{al}	is the aluminium alloy temperature (K)
T_c	is the concrete temperature (K)
T_{door}	is the temperature of the door leaf (K)
T_{exp}	is the exposed wall surface temperature (°C)
T_g	is the gas temperature in the enclosure or furnace (K)
T_g^{max}	is the maximum gas temperature in fire enclosure (K)
T_m	is the metal temperature (K)
T_o	is ambient temperature (293 K)
$T_{opening}$	is the gas temperature in the plane of the opening (K)
$T_{surface}$	is the material surface temperature (K)
ΔT_{stud}	is the temperature difference between the hot and cold faces of a stud partition (°C)
T_t	is the temperature of uncharred timber (K)
T_{unexp}	is the unexposed wall surface temperature (°C)
T_{wi}	is the wrought iron temperature (°C)
$T_{x,t}$	is the temperature at location x and time t (K)
T_z	is the temperature at any point along the flame (K)
t	is time (s, min or h)

Δt is a time interval (s)
t_{char} is the charring rate (mm/min)
t_{char}^{max} is the maximum charring rate (mm/min)
t_d is the dwell time (min)
t_e is the time equivalent (min)
t_{ed} is the design time for an equivalent duration of heating in the standard furnace test (min)
t_{fr} is the fire resistance time (min)
t_s is scaled time (h)
t^* is the modified time (h) ($t^* = \Gamma.t$)
t^*_{max} is the time to reach maximum temperature (h)
u is the wind speed (m/s) (generally taken as 6 m/s)
V is the steel volume (m^3)
V_f is the fibre volume fraction of a composite
V_i is the volume per unit length of an insulated element (m^3)
V_x is the matrix volume fraction of a composite
W is the width of enclosure (m)
w is the width of the opening (m)
w_f is the width of the flame front (m)
w_v is a ventilation factor (dimensionless)
X is the flame length along axis (m)
x is the horizontal projection of the flame (m)
x_a is the depth of the neutral axis (m)
x_s is the distance from exposed surface (m)
Z is the flame height above opening (m)
Z_y is the elastic modulus about the minor axis (cm^4)
Z_w is the height above the top of the opening (m)
z is the vertical projection of the flame above the window (m)
z_c is the lever arm between the centroid of the effective stress block and the neutral axis
α is the coefficient of thermal expansion
α_c is the coefficient of heat transfer by convection ($W/m^2 \cdot K$)
Γ is the compartment time factor
γ_1 is the safety factor reflecting the consequences of failure by the enclosure
γ_2 is the safety factor reflecting the risk of a fully developed fire taking place in the enclosure
γ_3 is the safety factor reflecting the benefits of installing an automatic sprinkler system to BS 5306-2 within enclosure
γ_c is the material strength partial safety factor for concrete (1.3)
γ_{conv} is a coefficient for heat transfer by convection
γ_G is the partial safety factor for permanent loads to be assigned a value of 1.0
γ_{rad} is a coefficient for heat transfer by radiation
γ_s is the material strength partial safety factor for steel (1.0)
Δ_{bow} is the lateral deflection of a wall (mm)
Δ_{dis} is the displacement (mm)
Δ_{head} is the deflection of head of wall away from the heat source (mm)
ε is strain
ε_a is strain at the relevant temperature

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$\varepsilon_{a,max}$	is the strain at the maximum stress corresponding to 2.0 % strain
ε_{ap}	is the strain at the proportional limit at the relevant temperature
ε_{au}	is the strain at the ultimate stress at the relevant temperature
ε_{c}	is strain corresponding to 0.2 % proof stress at the relevant temperature
ε_{f}	is the emissivity of the fire
ε_{fl}	is the emissivity of the flames
ε_{g}	is the emissivity of the fire gases
ε_{rec}	is the emissivity of the receiving surface
ε_{res}	is the resultant emmisivity
ε_{s}	is the emissivity at the surface of a material
$\varepsilon_{surface}$	is the emissivity of the surface
η	is the load ratio of a concrete filled hollow section
$\eta_{fi,t}$	is the strength ratio at temperature ($\gamma_{1,2,3}$ are safety factors)
θ	is temperature (°C or K)
λ	is the thickness of the flame (m)
ϕ	is the configuration factor
ρ	is density (kg/m^3)
ρ_a	is the density of steel (kg/m^3)
ρ_{al}	is the density of aluminium alloys (kg/m^3)
ρ_c	is the density of concrete (kg/m^3)
ρ_f	is the density of fibre reinforcement (kg/m^3)
ρ_i	is the density of the insulation layer i (kg/m^3)
ρ_m	is the density of metal (kg/m^3)
ρ_t	is the density of timber (kg/m^3)
ρ_x	is the density of a composite matrix (kg/m^3)
ρ_w	is the density of water (kg/m^3)
σ	is the Stefan Boltzman constant (5.67×10^{-8} $W/m^2 \cdot K^4$)
σ_a	is the applied stress at the relevant temperature (N/mm^2)
ψ	is $L/(A_w A_T)^{0.5}$ (kg/m^2)
$\psi_{i,j}$	are partial safety factors for variable loads
$\psi_{1,1}$	is a partial safety factor for the primary variable load
$\psi_{2,i}$	are the partial safety factors for the secondary variable loads

5 Design approach

5.1 Design principles

5.1.1 *Experience and qualifications*

The complexity of the interactions between people, buildings and fire is such that no single set of calculation procedures can be applied to all types of buildings in all circumstances. Therefore, FSE requires a greater degree of care and responsibility by the designer than does the application of prescriptive codes. It is therefore essential that the application of FSE be entrusted to suitably qualified and experienced personnel.

5.1.2 *Methodology for design — General*

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

The quantitative analysis necessary as part of the design process is divided into a number of separate parts or sub-systems. Each sub-system may be used in isolation when analysing a particular aspect of design or they may be used in combination as part of an overall fire evaluation of a building. A representation of the concept is shown in Figure 2. Some of the potential interactions between sub-systems are illustrated. The parameters are often both inputs into one sub-system and outputs from another.

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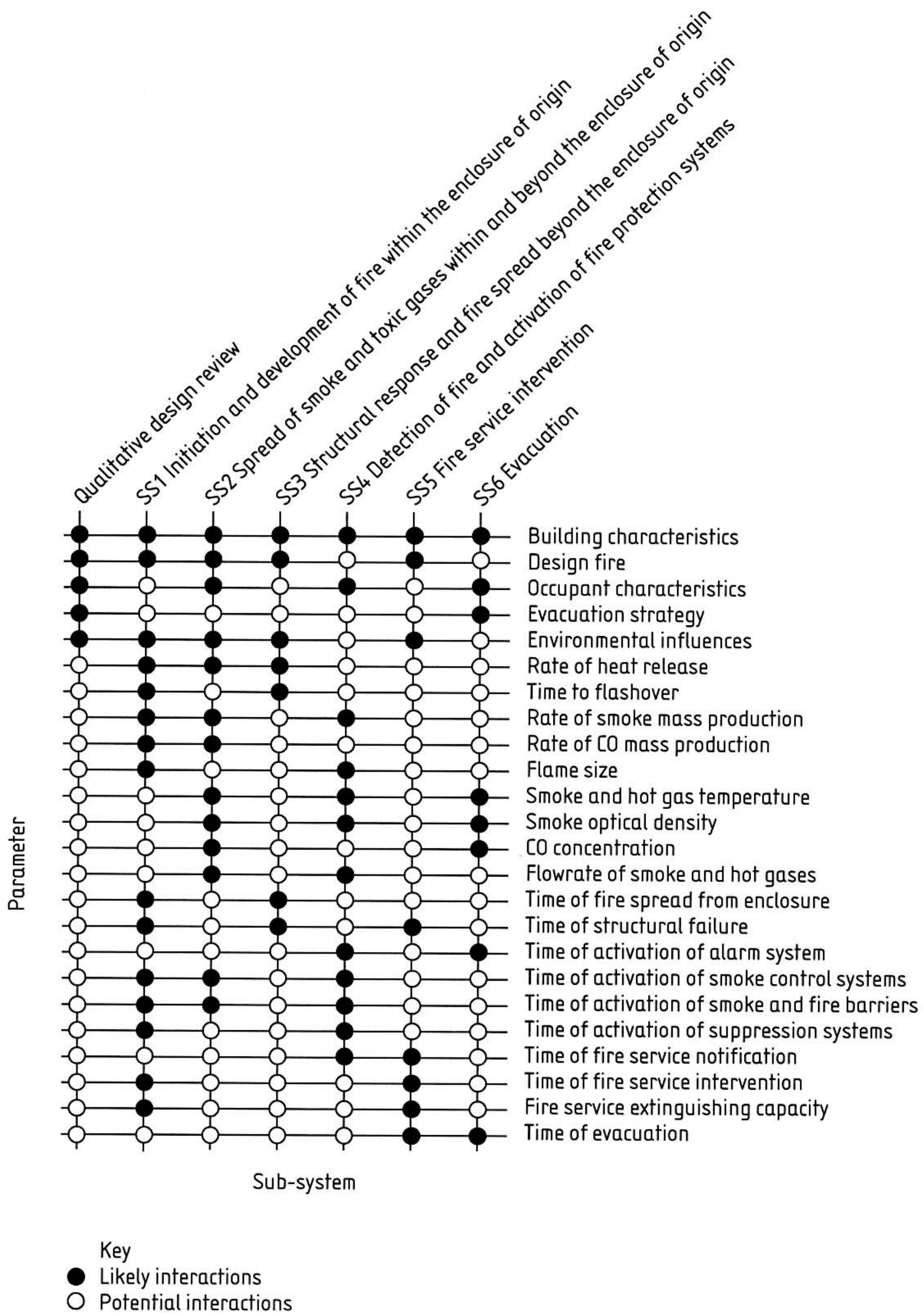

Figure 2 — Methodology for design of all sub-systems in the PD 7974 series

5.1.3 ***Methodology for design with respect to sub-system 3***

The methodology for design of sub-system 3 is outlined in Figure 3.

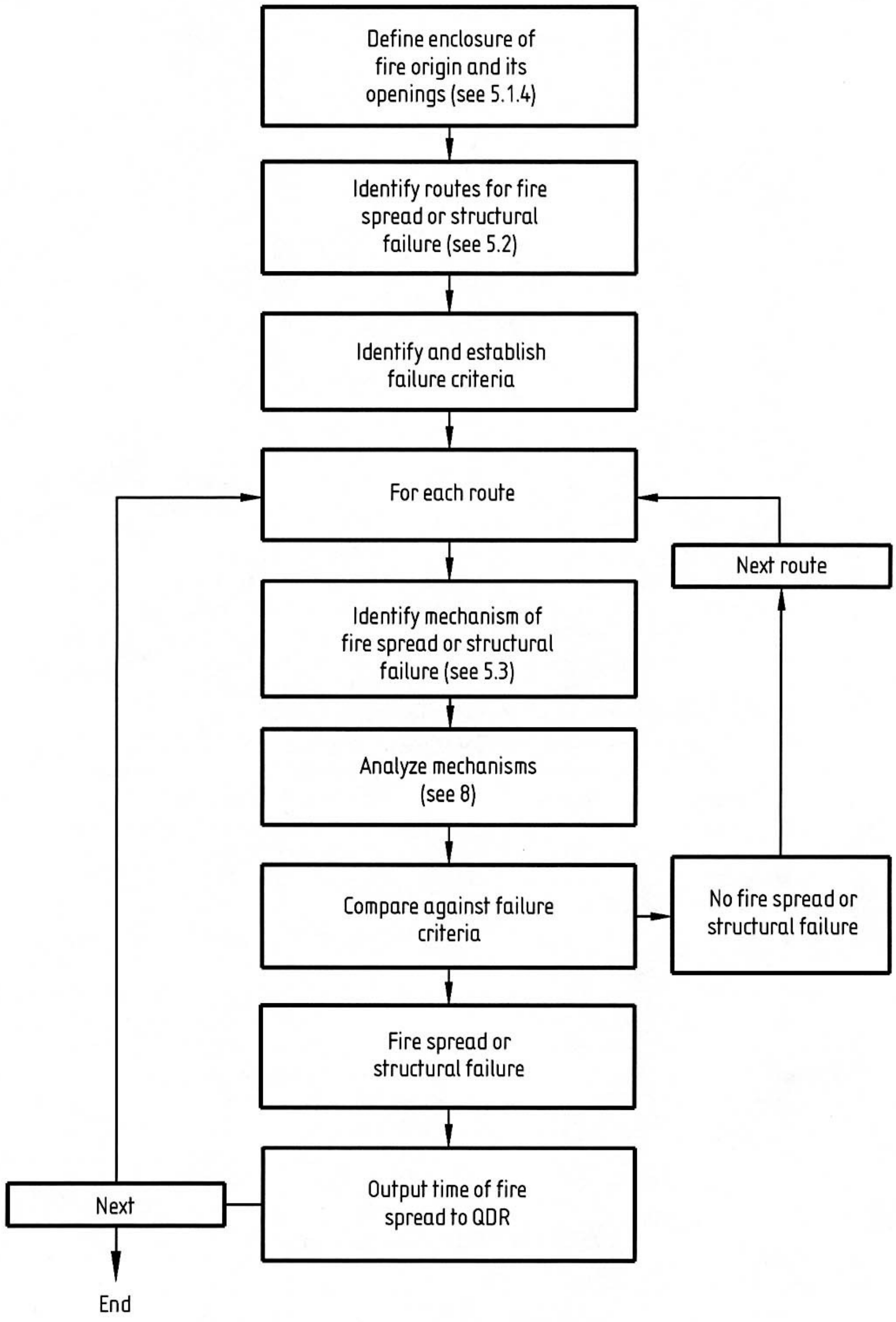

Figure 3 — Methodology for design of sub-system 3

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5.1.4 *Description of the fire enclosure*

All solid boundaries in a building will inhibit the spread of fire to some extent. Certain boundaries in a building are purpose designed to prevent fire spread and are generally tested in a standard furnace to assure their fire-resisting performance. The fire safety strategy [established in the Qualitative Design Review (QDR); see PD 7974-0] will designate those boundaries required to resist fire spread. Nonetheless, any surface bounding a space in which a fire can occur will enclose the fire to some extent. This is particularly important in terms of the rate of growth of the fire and the development of temperatures within the space. The ongoing capacity of these initial enclosing surfaces to remain imperforate to the spread of fire will be a function of their construction and the fire condition, which can be changing. Accordingly, the nature of the fire enclosure should be viewed as being time-dependent and will need ongoing analysis as described in this sub-system.

When characterizing the enclosure of fire origin, the following guidance is offered.

— In the context of predicting pre-flashover fire conditions, the horizontal and vertical surfaces immediately surrounding the fire should be considered as the enclosure.

— The enclosure can also contain openings (see **5.1.5**) which, although immediately and directly open to the passage of fire and heat, may be characterized as part of the enclosing boundaries.

— After flashover has occurred, solid boundaries may be assumed to remain imperforate to fire for that duration when no openings are created in the surfaces due to their mechanical response on exposure to fire. Guidance on the prediction of fire created openings is given in Clause **8** and Clause **13**.

— As the definition of the enclosing surfaces is changed by the creation of openings, the fire conditions might need to be re-examined and fire spread routes re-evaluated.

— Design may be simplified by assuming the enclosure is bounded only by those surfaces that have a determinate fire resistance rating. Enclosures viewed in this manner are often described as fire compartments. Intermediate boundaries without determinate fire resistance ratings are ignored. The compartment may be evaluated to ascertain the fire conditions and the consequent potential for fire spread. The possibility of more severe conditions developing locally within the compartment need not be considered. For example, whilst it may be that a fire occurring in a small enclosure within a large compartment can be more severe than the fire in the entirety of the larger compartment, the definition of the larger space as a single compartment during the QDR will have taken this into consideration.

5.1.5 *Characterization of openings (doors, windows, vents, etc.) under non-fire conditions*

The fire conditions within an enclosure depend on the size, shape and extent of openings, which permit airflow to the fire, and ventilation of heat. Where a combination of fixed opening conditions is possible for the fire enclosure (e.g. some doors open, some doors closed), options which are most conducive to fire spread should be considered, i.e. a worst case scenario. The assumption that all openings are initially open might not necessarily be the worst case. The following guidance is offered.

— Doors should be assumed open if the enclosure has no other openings.

— Doors should be assumed closed if the enclosure has other openings.

— All enclosure surfaces (including glazed openings) may be assumed to be imperforate for the duration of the fire provided analysis has shown that the conditions have not created openings; see Clause **8** and Clause **13**.

— Large numbers of combinations of opening condition may be simulated using Monte Carlo type modelling techniques, allowing the designer to evaluate the robustness of the design solution.

5.2 Routes for fire spread

Once the enclosure of fire origin has been characterized, the designer should identify all of the possible routes of fire transmission through the boundary surfaces. Figure 4a) illustrates some of the more common direct routes for potential fire spread. In many instances, designers also need to consider the potential for fire spread between two adjoining enclosures via independent spaces as illustrated in Figure 4b). These routes of fire spread represent a combination of direct spread routes and should be examined as a series of direct spread mechanisms.

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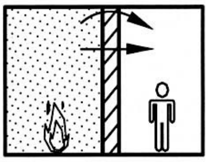
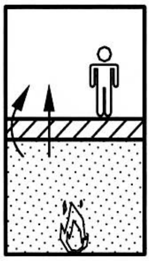
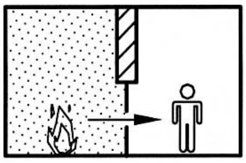
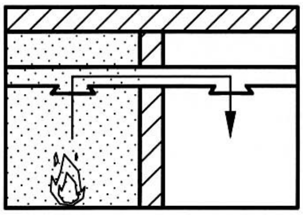
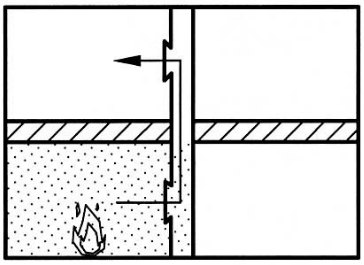
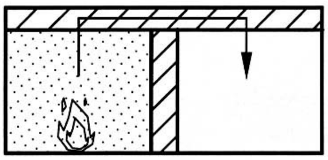
Ideally, all of the potential routes for fire spread from the enclosure should be investigated and the minimum time for fire spread determined. However, design effort may be reduced in situations where expert judgement can identify those routes susceptible to the most rapid fire spread. The minimum fire spread time is necessary for the QDR. It should be remembered that the determination as to whether or not fire spread takes place will be influenced by conditions both within the fire enclosure and within the adjacent enclosures/spaces.

 Through wall or openings created in wall Spread mechanism: conduction, convection, direct pyrolysis (collapse)	 Through floor Spread mechanism: conduction, convection, direct pyrolysis (collapse)
 Through fixed opening Spread mechanism: convection, radiation, direct pyrolysis, mass transfer	 Along or through horizontal duct Spread mechanism: conduction, convection
 Along or through vertical duct Spread mechanism: conduction, convection	 Within roof Spread mechanism: direct pyrolysis

a) Direct routes of fire transmission through enclosed boundaries

Figure 4 — Routes of fire transmission

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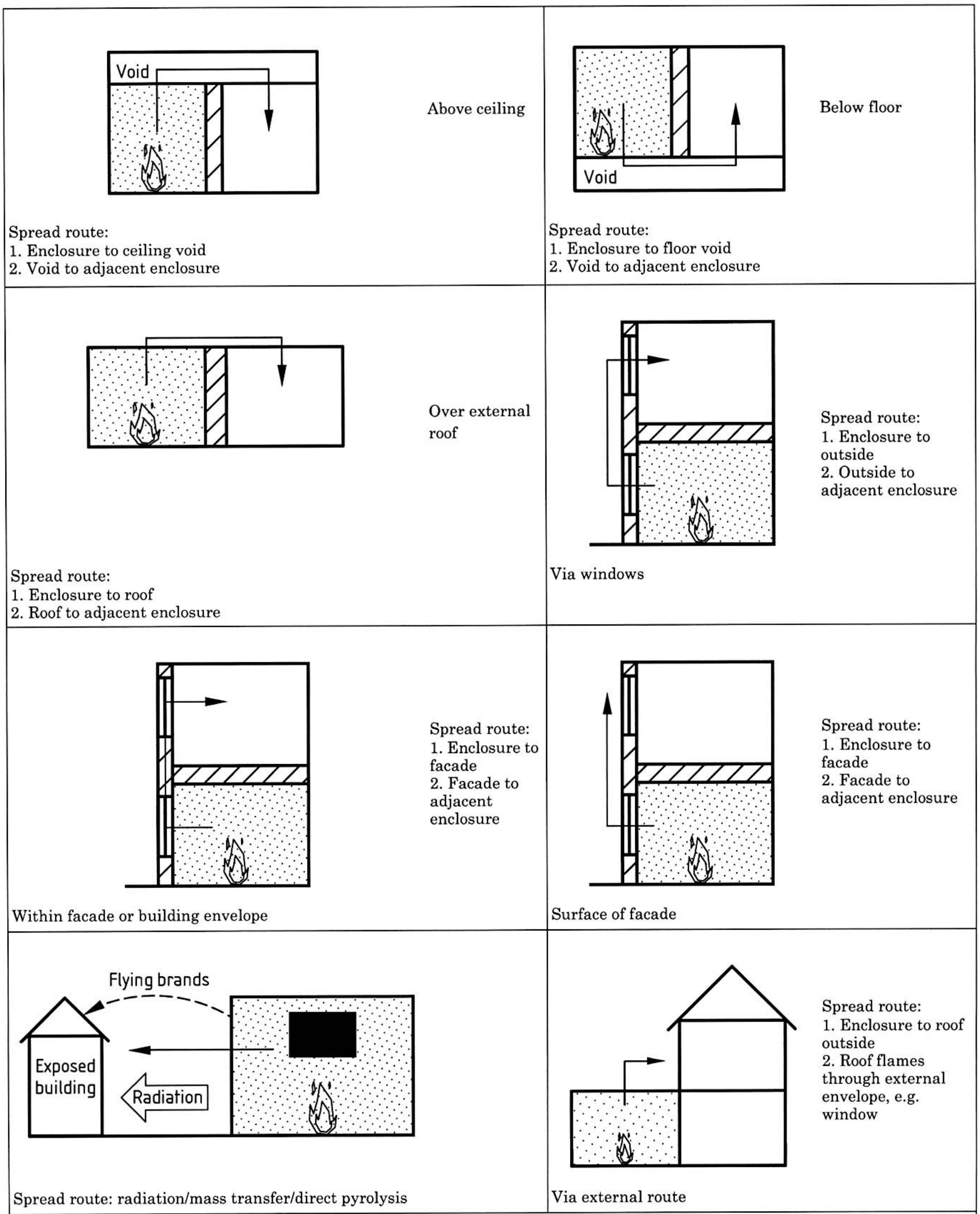

b) Combined routes of fire transmission from enclosure potentially leading to fire spread

Figure 4 — Routes of fire transmission (*continued*)

5.3 Mechanisms for fire spread

5.3.1 *Introduction*

Assuming that fire starts within an enclosure, fire could potentially spread to adjacent enclosures or spaces as the individual or combined result of heat transmitted by:

a) conduction;

b) convection;

c) radiation;

d) mass transfer;

e) direct pyrolysis.

5.3.2 *Conduction*

The solid boundaries of an enclosure will have one surface exposed to fire conditions whilst the other non-exposed surface will face into the adjacent enclosure/space. An excessive flow of heat from the exposed to the non-exposed surfaces of the boundary elements can lead to transmission of fire to adjacent spaces. Traditionally, fire spread by this mechanism has been referred to as insulation failure of the enclosure.

Heat can be transmitted from the enclosure by way of direct conduction to the non-exposed side of boundary elements or by indirect conduction through building components that are continuous to outside the enclosure, e.g. pipes, ducts, beams, columns.

Whether the heat conducted to the non-exposed surface causes transmission of fire will depend on the effect such heat may have on adjacent spaces. The heat conducted to the non-exposed surface from the fire enclosure may precipitate fire spread as follows:

— ignition of the non-exposed surface;

— conduction of heat from non-exposed surface to combustibles with which it has direct contact;

— convection of heat from non-exposed surface to adjacent combustibles;

— radiation of heat from non-exposed surface to adjacent combustibles.

It is possible to inhibit this fire spread mechanism through prevention of the above scenarios. However, the conductive heating of the non-exposed surface might need to be considered separately in terms of its potential effect on building occupants.

5.3.3 *Convection*

The excessive flow of hot gases or flames through openings in the enclosure can cause ignition of combustible items in adjacent spaces. The flow of hot gases from the enclosure can be by way of the fixed openings from the enclosure (as defined in **5.1.5**) or openings that have occurred as a result of fire. Traditionally, fire spread by this mechanism is termed integrity failure of the enclosure. In addition, collapse of the boundary element, e.g. due to its failure to remain sufficiently load-bearing under fire conditions, can also permit transmission of fire through excessive convection.

Heat flow through openings is one of the most difficult parameters to quantify, particularly in the stage between initial integrity failure and total collapse.

5.3.4 *Radiation*

The transmission of heat from openings in the enclosure may cause ignition of adjacent combustible items. Heat can be radiated from fixed openings (e.g. doors and windows) or openings which have occurred as a result of fire.

5.3.5 *Mass transfer*

It is possible that burning fuel items within the enclosure can be transferred from the enclosure through fixed or fire created openings. Examples include the projection of flying brands and the flowing of liquid pool fires under doors having no bund protection.

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5.3.6 *Direct pyrolysis and reaction to fire*

Where boundary elements are combustible and continuous outside the enclosure, it is possible that pyrolysis can extend beyond the enclosure. Examples include lateral fire spread within the thickness of combustible walls and roofs. Successful fire stopping of such pyrolysis routes will be influenced by the reaction to fire characteristics of the materials present as well as the mechanical stability of the overall system. For example, continuous members extending beyond the enclosure of fire origin can permit fire spread by pyrolysis via some continuous combustible component. Fire stopping may be impaired by local collapse or deformation of the non-combustible part of the system. The collapse of enclosure boundaries can also permit fire to spread by direct pyrolysis.

5.4 Factors influencing fire spread

The likelihood of fire spreading beyond its enclosure can be influenced by the following factors.

— The ability of the boundaries of the enclosure to resist the passage of fire depends on their fire resistance. For example, boundaries designed to be fire-resisting (in accordance with BS 476-20, BS 476-21 and BS 476-22) can successfully resist the passage of a fully developed fire for a known minimum period.

— The anticipated fire severity in the enclosure that can be determined by the amount of fire load and ventilation present.

— Measures to reduce the severity of a fire will similarly reduce its capacity to penetrate enclosure boundaries. Fire severity can be reduced using direct measures of fire control such as installation of an automatic sprinkler system. Control of fire severity can also be exercised indirectly through design measures such as limiting the ventilation available to the fire or limiting the amount of combustibles available to fuel it.

— The size of the enclosure can also influence the potential severity of any fire that does occur. Fires in large enclosures with high ceilings, e.g. atria or single storey commercial premises, are more likely to remain fuel controlled and less likely to reach flashover.

— Access to open vertical shafts such as stairways, lift shafts or service ducts can increase fire severity through introduction of ventilation and through draughts. Vertical routes also have the potential to permit fire spread in the absence of appropriate fire dampers.

— The presence of concealed spaces (e.g. above false ceilings, within hollow construction, under floors) can increase the potential for fire to spread undetected.

— The air pressure conditions within the enclosure and more particularly pressure differentials between enclosures will influence the potential for fire spread. Fire severity can be reduced by the release of heat through ventilation from the enclosure. Further, fire and hot gases are less likely to spread into adjacent enclosures if they are maintained at a higher pressure than the fire enclosure. This principle of positive pressurization is used to protect stair shafts.

— The extent of openings within the enclosure boundaries will influence the potential for fire spread. Casual loss of air-tightness through poor workmanship in construction and unstopped joints and service penetrations can provide easy routes for fire spread.

— The deformation of structural elements can open gaps in the enclosures' boundaries in a gradual or sudden manner, e.g. through application of load to non-loadbearing assemblies.

— The potential for fire spread through voids behind curtain walling systems will be influenced by the ongoing performance of the system under conditions of fire exposure. Some systems incorporating, for example, glazing, aluminium and steel faced composite panels, can distort or otherwise react to fire exposure in a manner that allows fire to by-pass the fire-stopping.

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