bre

Second edition

External fire spread

Building separation and boundary distances

Richard Chitty

IHS

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BR 187

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Contents

Preface to the second edition

The first edition of BR 187 *External fire spread: building separation and boundary distances*[1], published in 1991, was divided into two parts: Part 1: *Methods for determining boundary distance* described the application of several methods of determining boundary distance with a few examples, while Part 2 was a reproduction of Technical paper 5 *Heat radiation from fires and building separation*[2], which gave some of the technical background to the calculation methods. While it was expedient to reuse Technical paper 5 in the first edition, after almost 50 years it is showing its age. Imperial units are used for calculations and some of the graphs justifying assumptions needed to be updated with additional modern data (to confirm that they are still valid). In addition it was not especially clear how the methods used in Part 1 were derived from the theory in Part 2 – this is especially important to those who wish to develop software tools (for example spreadsheets) to perform the calculations. It was also felt that further examples and explanations would be useful to newcomers or those who only occasionally have to calculate boundary distances.

For the reasons stated above, a major revision of BR 187 was needed. The revision allows more recent data to be included to investigate the validity of the assumptions in the methods for current building materials and techniques.

Some people will use this second edition as a reference document, others will use it as a textbook. The working tables A to J (called Table 1 in the first edition) can be found in **Tables for calculations** on pages 46 to 56 – they are easier to locate than in the first edition. They can be copied, annotated and added to other calculation sheets relating to a particular project.

The terminology associated with thermal radiation can be difficult as some words or phrases have a very specific technical meaning, as well as a more general colloquial usage. In this edition we have attempted to be rigorous and the definitions used here are given in the glossary of terms – readers should find this consistent with technical reference books and scientific papers. The definitions in ISO 13943 *Fire safety – Vocabulary*[3] and in BS 7974 *Application of fire safety engineering principles to the design of buildings – Code of practice*[4] do not include many items relevant to radiation.

Who is the guide for?

- Those who know what they are doing and need to solve a boundary distance problem. They may want to go directly to one of the methods as a reference or access the tables for the enclosing rectangles method.
- People who have a tricky problem or are new to the topic (or revisiting it after a long interval) and need to revise how to do things and look at, or work through, some examples.
- Those who want to fully understand the methods and their limitations:
  - because they are studying fire safety science/ engineering
  - they wish to adapt the methods and develop a fire engineering solution to a problem
  - they are developing tools (software, eg spreadsheets) to perform the calculations
  - they have a problem that is not covered by the ‘standard’ methods and need to work around something
  - they wish to use the tools to perform similar radiation calculations
  - they are fire investigators ‘reverse engineering’ the design process.

Acknowledgements

BRE would like to acknowledge the authors (R E H Read, M Law and S Melinek) the authors of the first edition of BR 187, which has been used successfully for many years, and is the basis for this second edition.

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- Building Control Alliance
- Chartered Institute of Architectural Technologists
- Chief Fire Officers Association
- Chief Fire Officers Association (Scotland)
- Fire Brigades Union
- Institution of Fire Engineers
- Local Authority Building Control
- Royal Incorporation of Architects in Scotland
- Royal Institute of British Architects (RIBA)
- Royal Institute of Chartered Surveyors
- Scottish Association of Building Standards Managers
- Scottish Fire Engineering Network
- The Welsh Government.

National building regulation guidance

Throughout this guide, reference is made to national building regulation guidance. Guidance can be found in the following publications which relate to a specific UK region.

Scotland

The Building (Scottish) Regulations 2013. *Technical handbook – Domestic, and Technical handbook – Non-domestic*. 2013 edition[5].

Northern Ireland

The Building Regulations (Northern Ireland) 2000. *Technical booklet E*. 2012 edition[6].

England

The Building Regulations 2010. Approved Document B *Fire safety*. Volumes 1 and 2. 2006 edition with 2010 and 2013 amendments[7].

Wales

The Building Regulations 2006. Approved Document B *Fire safety*. Volumes 1 and 2. 2006 edition[8].

This guidance is updated from time to time. Readers should ensure that they are using the most current edition and that the guidance is relevant for their region of the UK.

Glossary of terms and symbols

Term	Definition	Notes
ASET	Available safe egress time	Time taken for hazardous conditions to occur in a building
RSET	Required safe egress time	Time taken to evacuate a building
Boundary distance	Distance from a building elevation to the boundary	See Figure 1
Fire compartment	A space in a building bound by fire-resisting barriers	See national building regulation guidance on page vii
Separation distance	Distance from a building elevation to an adjacent building	See Figure 1
Unprotected area	Area of a building elevation considered for calculating boundary distance	See national building regulation guidance on page vii
View factor	Fraction of the field of view occupied by the radiating surface (see Appendix A)	Also called configuration factor

Symbol	Description	Units
A	Unprotected area	m^2
H	Height of an opening or radiating surface	m
I	Radiation intensity	kW/m^2
T	Absolute temperature	K
S	Separation distance	m
W	Width of an opening or radiating surface	m
h	Heat transfer coefficient	$kW/m^2/K$
k	Thermal conductivity	kW/m/K
x	Distance into a solid	m
σ	Stefan Boltzmann constant	5.67×10^{-11} $kW/m^2/K^4$
ε	Emissivity	–
ϕ	View factor (also configuration factor)	–

Executive summary

Following a large fire in London an ordinance was issued by King John in 1212[9] requiring new or restored roofs to be made tiled, shingled, boarded or covered with lead and not covered with reeds or rush. The Great Fire of London in 1666 resulted in a number of regulations to classify buildings based on their construction and to control the width of streets each class of building could be built on.

The experience gained from large fires in cities during World War II led to systematic investigation of fire damage and detailed research into how fires could develop in one building and cause ignition of an adjacent one. By the early 1960s The Building Standards (Scotland) Regulations[10], and shortly afterwards The Building (First Amendment) Regulations for England and Wales[11], included methods for calculating the spacing between buildings and requirements to control the use of combustible materials on the external surfaces of a building. This was probably the first practical application of what is now referred to as fire safety engineering.

In 1991 BRE published BR 187 *External fire spread: building separation and boundary distances*[1]. BR 187 described a number of methods for calculating building separation distances that were previously described in the Building Regulations (up to 1976)[12, 13], and in Approved Document B *Fire safety* (1985 edition)[14]. In addition, BR 187 included a reproduction of a technical report that described the underlying principles of the calculation methods. Referencing BR 187 in Approved Document B *Fire safety* (1992 edition)[15] allowed Approved Document B to be simplified.

BR 187 continues to be referenced in the various national building regulation guidance publications used in the UK.

Since 1991 the way people expect to perform calculations has changed. In the first edition of BR 187, the calculations relied on the use of tables or graphs and one of the methods (notional aggregate area) involved constructing a 'protractor' that could be used on scale (paper) drawings to estimate if a boundary was located within the required limits. Now computer software is used by most people to perform these calculations.

There have also been changes to the style of buildings. In Part 2 of BR 187 (reproduced from Technical paper 5 *Heat radiation from fires and building separation*[2]) it is mentioned that there was 'a trend towards designing buildings with larger windows and combustible cladding'. Now smaller windows are more desirable (to conserve energy) and the external surface of a building may include a complex cladding system (for thermal and sound insulation, weather protection, decorative effects or even energy generation) which may, or may not, be combustible.

These and other issues do not change the underlying technical content of BR 187 but do change the emphasis and create a need to go back to basics for some problems.

While it was prudent in 1991 to write the original version of BR 187 in two parts (including Technical paper 5 *Heat radiation from fires and building separation* in Part 2[2]) to provide the technical background, Part 2 after almost 50 years is now dated. Calculations used Imperial units and some of the graphs justifying assumptions used data from experiments conducted between 1955 and 1960. A major revision of BR 187 has allowed more recent data to be included to investigate the validity of the assumptions in the methods for current building materials and techniques.

The objectives of this revision of BR 187 have been to:

- merge the two parts into a single narrative
- improve the presentation of the methods with further examples
- clarify and update (converting to SI units) the theoretical background
- present detailed analysis to the methods so that users can create their own fire engineering software
- include more recent experimental data to confirm the assumptions used in the methods are valid for modern buildings
- provide the background of methods 1 and 2 used in national building regulation guidance.

The methods outlined in the first edition in 1991 are included in this second edition, together with graphs and formulae to calculate view factors. The experimental determination of a view factor using a photo-cell is not discussed.

In addition the sections on several topics, such as flame projection from windows, have been expanded.

This second edition draws on some concepts and definitions from national building regulation guidance notably the meanings of:

- purpose groups/building use
- boundaries
- external wall
- notional boundary
- relevant boundary
- unprotected areas.

Readers should refer to the relevant national building regulation guidance publications for these definitions.

Introduction

Most accidental fires start as small fires which initially present a very small hazard to adjacent buildings. However, as a fire grows, windows in the burning building will break and other openings in the external envelope may develop; this provides the potential for fire to spread to adjacent buildings by contact with flames and hot gases from the openings, thermal radiation or by burning brands (burning debris from the fire) drifting in the wind.

Buildings are not normally close enough together for fire to spread by direct contact from flames, although a fire could propagate across combustible materials between buildings such as stored materials, wooden sheds, fences, garden debris, rubbish and even cars or caravans parked between buildings. These factors are beyond the scope of building separation and boundary distances and are more relevant to the use of the building which, in England and Wales, is controlled by the Regulatory Reform (Fire Safety) Order 2005[16] and in Scotland under Part 3 of the Fire Safety (Scotland) Amendment Regulations 2006, as amended in 2010[17].

The presence of fire brands from a burning building will be dependent on the materials that are burning. They are, by their nature, small and have the potential to travel a significant distance, maybe several hundred metres. This is an important mechanism of fire spread in wildfires and needs to be considered when, for example selecting roof materials for a building located in woodland. Burning debris from a fire at high level in a tall building also has the potential to spread fire to lower parts of the building if the material falls onto balconies or is blown into a room through open windows. Burning debris may also ignite items such as vehicles at ground level. The main concern here is that a brand could provide a pilot ignition source for materials on an adjacent building that has been heated by thermal radiation from the fire.

If a fire is allowed to develop, as windows in the compartment break, more air can enter the compartment allowing the fire to grow until it is limited either by the amount of fuel, availability of air or the extent of the compartment. Thermal radiation from the external openings in the burning compartment, and from flames leaving the compartment, will then heat surfaces on adjacent buildings. This has the potential, especially if burning brands are present, to ignite the surface(s) of an adjacent building. If left unchecked the fire could then propagate from building to building and develop into a large urban fire. These have occurred many times in history either as the result of accidental fires, for example in London, UK in 1666[9], Oaklands, USA, 1993[18], during warfare in German and Japanese cities during WWII[19] or as a consequence of natural disasters such as volcanoes in Montserrat, The Caribbean, 1997[20], and earthquakes in Kobe, Japan, 1995[21].

It has been known for a long time that fire spread due to thermal radiation can be controlled by adjusting the size of buildings and openings, and the distance between buildings. For example, the Building Act of 1667[22] following the Great Fire of London had requirements relating the height of buildings to the width of streets and for the use of non-combustible materials. The scientific basis of this approach was explored through the 1950s following post-war building studies and resulted in calculation methods which were first made a requirement in the Building Standards (Scotland) Regulations 1963[10] and was shortly followed by similar requirements being introduced in legislation for England and Wales[11]. Technical paper 5 *Heat radiation from fires and building separation*[2] summarised the background to these calculations.

This guide will allow the reader to trace the development of boundary distance requirements in the building regulations since World War II which is of practical relevance today. Existing buildings will have been built to the building regulations and requirements of the time of their construction. The redevelopment of a site or refurbishment of an existing building will need to consider, and may be constrained, by the location of previous and surrounding buildings.

A glossary of terms and symbols is provided on page viii.

It should be noted that ISO 13943:2000 *Fire safety – Vocabulary*[3] and definitions sections of BS 7974 *Application of fire safety engineering to the design of buildings – Code of practice*[4] contain very few terms relating to heat transfer by thermal radiation that could be used here as definitive definitions.

To be consistent with the national building regulation guidance the term 'radiation intensity' is used here to mean the amount of energy per unit time per unit area or radiant power per unit area. Values of radiation intensity are usually given in units of kiloWatts per square metre (kW/m^2). Care needs to be taken with the terminology as scientific textbooks on heat transfer and illumination use very similar terms (such as radiant intensity, $W\ sr^{1}$, for power per solid angle) for other quantities.

The terms 'heat flux' or 'heat flux density' are often used to refer to radiation intensity.

1 Principles

1.1 Calculation of boundary and separation distances

The approach that was developed in Technical paper 5[2] to calculate boundary and separation distances between buildings assumes that:

- a fire totally involves the whole of a fire compartment in a building
- all the weaker areas in the external walls of the compartment that have failed (for example usually windows breaking) can be assumed to be equivalent to hot surfaces that emit thermal radiation into the environment outside the burning building.

Adjoining buildings may be exposed to this radiation, this will lead to windows breaking and exposing the contents of rooms to the hazard. In addition, materials of the external surface of the building may soften and fall away (for example plastic gutters, down pipes and soil pipes) or be heated to the point where they may be ignited by a flying brand.

The objective of the calculation methods described here is to determine the distance between pairs of buildings (the separation distance) so that in the event of one of them having a fire, the other is not exposed to a value of radiation intensity above a specified level. This level has been taken to be the intensity required for the pilot ignition of wood.

It is not practical to specify separation distances as a legal requirement. It may not be known where a building is to be placed on a site and specifying a separation distance from one building could impose limitations on the future use of an adjacent site. The solution that has been adopted is to base the requirements on the location of the site boundary (boundary distance) and not the separation distance.

Specifying a boundary distance requires making an assumption about any building that is already in existence, or may be built, on the adjacent site. The assumption used has been that the two adjacent buildings would be identical and be mirror images of each other across the site boundary. The distance to the site boundary is the boundary distance which is half the separation distance; this is illustrated in Figure 1.

When determining the boundary distance for a building, two scenarios need to be considered: the case where the building has a fire and presents a hazard to its neighbours and the case where a fire in an adjacent building threatens the building. This leads to an 'offensive' minimum boundary distance (fire spread from the building being considered) and a 'defensive' minimum boundary distance (fire spread to the building being considered), these are usually the same. However, in some cases, notably when a building has or is designed to have an automatic suppression system, they may be different.

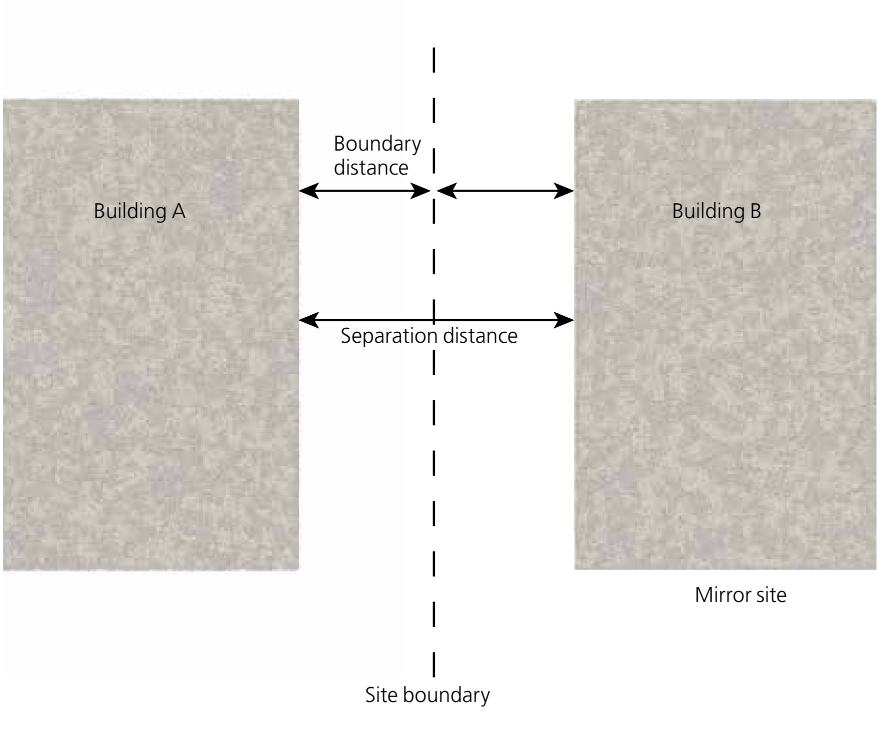


Figure 1: The relationship between boundary distance and separation distance

To calculate a minimum safe distance between buildings requires:

- values of compartment temperature in a burning building for different occupancies and ventilation conditions
- methods to calculate the transport of heat by radiation between buildings
- criteria for the maximum radiation intensity at an exposed building.

In practice consideration also needs to be given to:

- very small openings in the wall of a building that can be disregarded (such as air bricks)
- the influence of suppression systems
- combustible cladding on a building surface
- unprotected areas that are not in line with the boundary or building elevation.

In general, the assumptions used in the calculation methods will overestimate the radiation intensity on a building adjacent to a burning building providing a (unquantified) margin of safety. This should be considered if more precise calculations are used as part of a fire engineering approach.

1.2 Fires in compartments

1.2.1 Building use and fire loads

Table 1 (using data from BS PD 7974-1 Table A19[23]) shows typical fire load densities for different occupancies.

The data in Table 1 is derived from a *Conseil International Du Batiment* (CIB)[24] work programme published in 1986 and is consistent with a more recent Canadian survey[25].

In the original building separation work[2], a 'low fire load density' was taken to be below 25 kg/m^2 which, from Table 1, would place residential occupancies today in the high fire load category. However, many residential compartments will have a ventilation factor above 20 m$^{1/2}$ and will be ventilation controlled so the use of lower compartment temperature and radiation intensity can be justified. Increasing the fuel load of a ventilation controlled fire will increase the fire duration.

Table 1: Fire load densities for different occupancies (BS PD 7974-1)[23]

Occupancy	Fire load (MJ/m^2)	Wood equivalent (kg/m^2)
Dwelling	780	45.9
Hospital	230	13.5
Hospital storage	2000	117.6
Hotel bedroom	310	18.2
Libraries	1500	88.2
Manufacturing	300	17.6
Manufacturing and storage	1180	69.4
Offices	420	24.7
Schools	285	16.8
Shops	600	35.3

1.2.2 Fire development

At ignition a fire is typically small unless ignition is due to a catastrophic event such as an explosion because of a gas leak, or a deliberate ignition involving flammable liquids, possibly at multiple locations. Once established, the fire will grow at a rate depending on the nature and distribution of the available fuel. As the fire grows the temperature in the compartment increases, heating objects adjacent to the original burning item which may also ignite. When the temperature in the compartment reaches about 550°C, the thermal radiation from the flames and hot gases will be high enough to ignite any exposed combustible surfaces and is characterised by rapid fire growth which continues until the fire is restricted by the availability of air. This sudden development of a fire is known as flashover[26, 27]. The fire then remains in an almost steady condition until the fuel starts to become exhausted and the fire burns out. These stages of the fire are shown in Figure 2.

As the compartment temperature rises, windows may break and other unprotected areas may experience integrity failures increasing the ventilation to the compartment. This increases the supply of air allowing the fire to reach the fully developed phase.

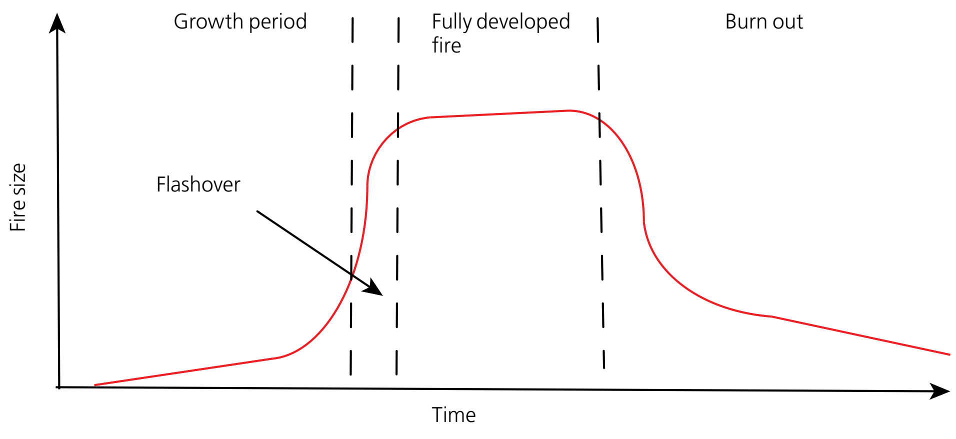


Figure 2: Compartment fire development

The temperature of the hot gases in a compartment during a fire depends on a balance between the heat that can be generated in the compartment (by burning) and the heat that leaves the compartment by:

- thermal radiation at the openings
- convection in the smoke and hot gases flowing out of the openings
- conduction through the compartment boundaries (walls and ceilings).

Ventilation is a key factor as it controls the rate that hot gases can leave the compartment and the rate at which oxygen (required to burn the fuel in the compartment) can enter the compartment. Fires in compartments may be divided into two types[28]:

- fires where ventilation is restricted and the rate of burning depends on the size of the openings (ventilation control)
- fires in which the opening area or compartment volume is sufficiently large so that the rate of burning depends on the fire load, its surface area and arrangement (fully ventilated or fuel controlled) where the fire load is the total amount of combustible material in the compartment.

The degree of ventilation in a compartment is typically characterised using the factor $AH^{1/2}$ where A is the area of, and H is the height of, an opening in a compartment. This factor can be used to distinguish between the two types of fire as shown in Figure 3.

The original analysis of compartment fires, to establish compartment temperatures that could be used in building separation calculations, was based on data from small scale experiments with compartment of dimensions between 0.3 m and 1.0 m in addition to a small number of larger fires in a 3 m by 3 m brick building. It was found that fully ventilated fires with a fire load density in excess of 25 kg/m² could achieve a maximum compartment temperature of 1040°C corresponding to a value of radiation intensity at the openings of 168 kW/m². However, if there was a lower fire load density (less than 25 kg/m²) then a maximum temperature of 830°C (radiation intensity 84 kW/m²) was more appropriate. Selection of the appropriate value is given in the national building regulation guidance depending on the purpose group or class of the occupancy.

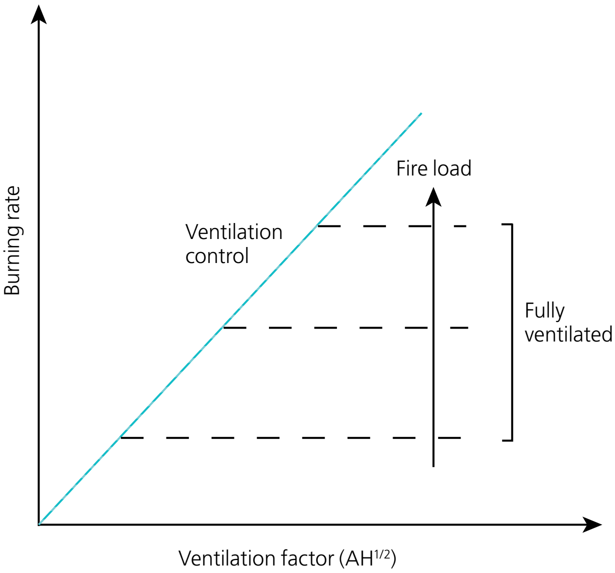


Figure 3: Compartment temperature versus ventilation and fire load

The limitations of the experimental data were recognised[29] and at the time that the building separation calculations were being developed (1960) a large international experimental programme commenced to study the behaviour of fully developed compartment fires. This study, organised by the CIB, investigated a number of different compartment shapes and scales with different ventilation conditions and fire loads[30]. Measurements provided data for the development of the concepts of fire resistance as well as data directly relevant to building separation calculations (maximum compartment temperature and radiation intensity from an opening).

Results from the CIB programme together with more recent experiments on large insulated compartments have been compiled here. The sources of the experimental data considered here are listed in Table 2. Series I, II, III, 'Small scale', '4 Storey Tower' and Large fires are included in the original development of the boundary distance calculation methods.

Table 2: Compartment temperature data

Name	Description	Reference
Series I, II, III	Small boxes (1 ft square, 2 ft square, 3 ft square). Various opening and fire loads. One data set included 38 mm thick mineral wool insulation around the compartment	FR note 412 (1960)[31]
'Small scale'	1 ft, 2 ft, 3 ft boxes (constructed from asbestos wood)	FR note 398 (1959)[32]
'4 Storey Tower'	3 m by 3 m compartment at base of external brickwork tower	FR note 436 (1960)[33]
Large fires	Kawagoe's and Swedish data	FR note 413 (1960)[34]
CIB	International programme of over 400 tests	FR note 923 (1972)[35]
'British Steel'	23 m by 6 m compartment (50 mm thick mineral wool insulation)	Kirby et al 1994[36]
'Natural fire safety concept'	12 m by 12 m compartment (25 mm sprayed insulation)	Moore and Lennon 2002[37]
British Iron and Steel Federation	7.1 m by 3.7 m compartment (25 mm thick mineral wool insulation)	FR note 646 (1966)[38]

Figure 4 shows a plot of the maximum compartment temperature data against a ventilation factor, O, from the sources given in Table 2. The ventilation factor is calculated from:

$$O = \frac{A_s}{A\sqrt{H}} m^{-1/2} \qquad \text{(Eqn 1)}$$

Where:

A_s Surface area of the compartment (less the areas of the opening and floor) (m^2)

A Area of the ventilation opening (m^2)

H Height of the ventilation opening (m).

The ventilation factor increases with larger compartments and smaller openings. As a guide a small, 4 m by 4 m by 2.4 m high, room with a 1 m by 1 m window has a ventilation factor of approximately 50 $m^{-1/2}$.

Figure 4 also shows the temperatures corresponding to low and high fire loads (830°C and 1040°C) from Technical paper 5 *Heat radiation from fires and building separation*[2].

In Figure 5 and Figure 6 the data has been selected to show the compartment temperatures from experiments with fire loads below and above 25 kg/m^2.

In the low fire load experiments (Figure 5) some of the data with low ventilation factors (where the openings are large in relation to the compartments) indicate that the fire may not have flashed over (temperature less than 550°C). In general the temperatures are clustered around the 830°C falling as the ventilation factor increases.

In the higher fire load cases (Figure 6) the data tend to be centred on a temperature of 1040°C and, the trend indicates as the ventilation increases that the temperature falls. However, it can be seen that maximum temperatures that are significantly above 1040°C have been measured.

Much of the experimental data was obtained from experiments carried out in compartments constructed from asbestos board which had a U value (thermal conductivity/thickness) in the range 5 to 10 W/m^2/°C. Some of the data relates to more recent experiments[36, 37, 38] that were carried out in well insulated compartments with a U value in the range U 0.8 to 3 W/m^2/°C. These data are plotted separately in Figure 7 where it can be seen that maximum temperatures significantly above 1040°C were measured.

Figures 5 and Figure 6 show that the values of 830°C and 1040°C can still be justified for low and high fire loads respectively. The lower value is also appropriate where the ventilation factor is greater than about 30 $m^{-1/2}$. Further work is required to investigate whether a higher temperature should be used for building separation calculations for some buildings with

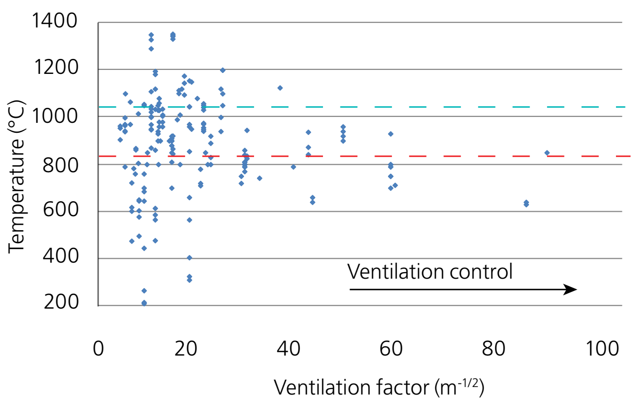


Figure 4: Maximum compartment temperatures versus ventilation factor

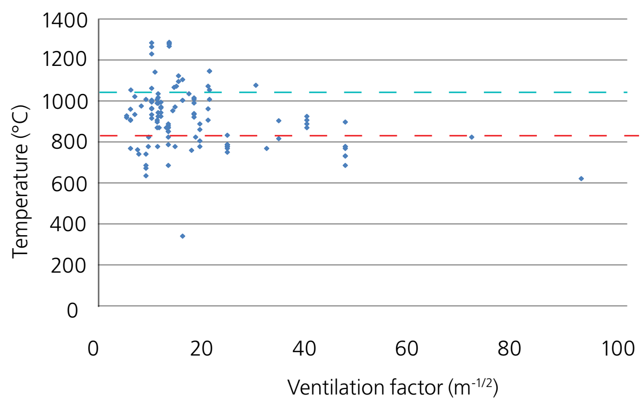


Figure 6: Data from experiments with a high fire load

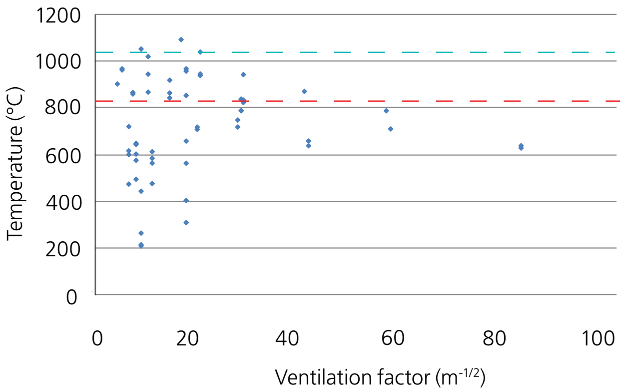


Figure 5: Data from experiments with a low fire load

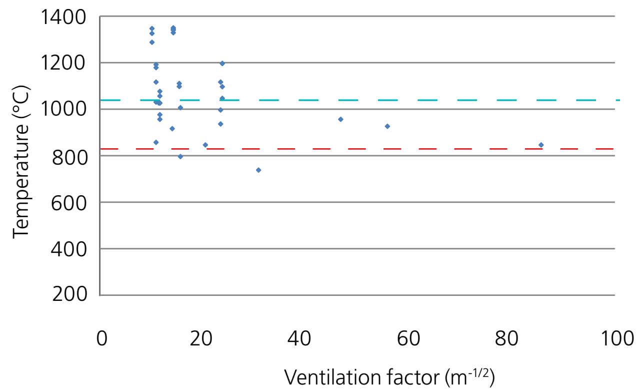


Figure 7: Insulated compartments

higher levels of insulation in line with the requirements in the national building regulation guidance at the time of drafting this publication (for example U values in the range 0.16 to 0.28 W/m²/°C in Approved Document L for England).

1.2.3 Fire growth rates and fire duration

A fire engineering approach to calculating building separation distances may require an estimate of the duration of a fire, so that a timeline or an illustration similar to Figure 2 can be constructed. For example, this could be based on fire growth rates from design fire data[23, 39], and times for the failure of unprotected areas on an adjacent building (an approach similar to an ASET/RSET analysis[40] for occupant evacuation).

1.2.4 Compartment fires with suppression systems

The temperature of fire gases in a compartment when a suppression system has operated will be much lower than those shown in Figures 5 and 6. The operation of appropriately designed and installed suppression systems should:

- control the burning rate of the fire
- cool materials surrounding the fire limiting the growth rate of the fire
- cool hot smoke and fire gases in the compartment
- reduce thermal radiation through absorption by the water droplets.

Gaseous suppression systems are usually associated with specific hazards (for example standby generators and electrical equipment) in a building, are typically installed in relatively small, well-sealed compartments. It is unlikely that these types of compartments would have large unprotected areas on external boundaries of a building and therefore are unlikely to have a significant role in determining boundary distances. If they are relevant, a fire engineering approach should be applied for the specific situation under consideration.

Figure 8 shows the development of a fire in a compartment with and without suppression.

An appropriately designed, installed and maintained suppression system will prevent the further development of the fire, and ideally start to extinguish it (controlled or suppressed shown in Figure 8). However, if the fire growth is unusually rapid then the suppression system may only be able to reduce the growth rate (uncontrolled in Figure 8).

For a sprinkler system, a simple estimate of the compartment temperature can be based on the operation temperature of the sprinkler heads; if the gas temperature exceeds the operation temperature, further heads will operate increasing the cooling of the compartment.

The BRE design fire data base[41] includes temperature data for 13 sprinklered fires, with the exception of one of the luggage fires. The temperature of the gases measured in the test compartment was below 100°C (in most cases less than 50°C) within 1 min of the sprinklers operating. Other experimental programmes using large (30 m × 30 m) compartments show similar values[42]. This observation from the experimental data needs to be treated with some caution as there may be direct wetting of the temperature measurement sensors (thermocouples) by the water spray leading to an error in the gas temperature measurement.

Some experiments with water mist systems in small compartments (simulated prison cells) also show the compartment temperature rapidly falling below 100°C after operation of the suppression system[43].

A compartment temperature of 100°C or less would not normally result in windows breaking unless the fire originated directly adjacent to a window.

For a building with an approved, well designed, installed and maintained suppression system the separation distance required to control the hazard of fire spread to an adjacent building may not be significant. However, this does not consider the protection the building requires from a fire in the adjacent building. The current practice in England, Wales and Northern Ireland is to reduce the minimum boundary distance for buildings with a suppression system to 50% of the distance calculated for a building without a suppression system. In Scotland, the minimum boundary distance for a building with a suppression system may be based on calculations using the reduced fire load tables. Both these approaches provide some protection to a building with a suppression system from a fire in an unprotected neighbouring building.

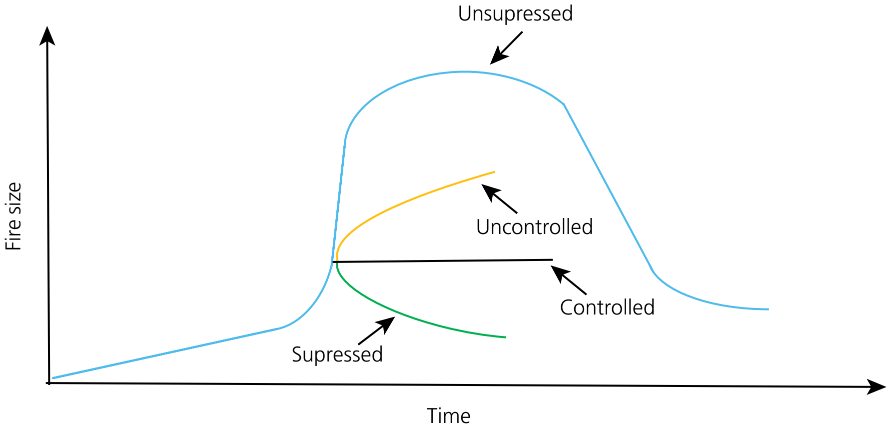


Figure 8: Compartment fire with suppression operation

The reduction of the boundary distance between buildings, based on the successful operation of a suppression system allowed in the national building regulation guidance, assumes that the probability of successful system operation (maximum of 95% for sprinkler systems from BS PD 7974-7, Table A 17[44]) and thereby the probability of preventing building to building fire spread, is acceptable.

1.3 Intensity of radiation from compartment fires

The radiation intensity from a compartment fire can be estimated by assuming that the unprotected areas of the compartment can be approximated as hot surfaces at the same temperature as the compartment. This implies total involvement of the compartment.

A small opening to a uniformly heated enclosure will radiate with an emissivity approaching 1.0. Thus a room or compartment fully involved in fire may be considered as approximating to this condition. For a large opening, this assumption is not strictly correct but the hazard is only overestimated to a slight extent.

Using the compartment temperatures of 830°C and 1040°C the radiation intensity, Is at each unprotected area in a building can be calculated using:

$$I_S = \sigma \varepsilon T^4 \text{ kW/m}^2 \qquad \text{(Eqn 2)}$$

Where:

σ Stefan Boltzmann constant (5.67×10^{-11} kW/m²/K⁴)

ε Emissivity of the radiating object (taken to 1.0)

T Absolute temperature of the radiating object (K)

The results of the calculations for temperatures related to high and low fire loads are summarised in Table 3.

Table 3: Radiation intensity and compartment temperature

	Compartment temperature (°C)	**Radiation intensity at unprotected area (kW/m²)**
Reduced fire load	830	84
Standard fire load	1040	168

The values of radiation intensity in Table 3 were the basis for the original work on building separation and in the first edition of BR 187[1].

Note: In Technical paper 5[2] *the radiation intensities were given as 2 cal/cm²/s and 4 cal/cm²/s which convert to 83.6 kW/m² and 167.2 kW/m² respectively. These values have been rounded up to the next integer value in Table 3. However,* Technical paper 5 *gives the corresponding compartment temperatures as 800°C and 1100°C which does not agree with the values derived from Equation 2 given in Table 3.*

1.3.1 External flaming

Calculating the intensity of thermal radiation from a burning building by representing the building openings by hot surfaces located on the building elevation, does not include the effect of any external flaming that is often seen from fully developed compartment fires. This is discussed in Appendix B and provided there is no forced or through draught in the burning compartment, it is shown that the thermal radiation intensity from the 'single surface' approximation would result in a conservative building separation distance compared with a more complex representation including external flaming.

Where there is a through draught in the burning building, due to a combination of wind effects and several openings in the building envelope, flames may extend several metres from an opening and could envelop an adjacent building. If this occurs, the calculation methods for fire exposure of an external structure in Eurocode 1[45] or BS PD 7974-3[46] should be followed.

1.3.2 External burning surfaces (cladding and paint)

In addition to flaming from an opening, the radiation intensity from an elevation of a burning building would be enhanced if the surface material of the elevation was combustible and ignited.

Surfaces finishes, such as paints, that are less than 1 mm thick would not contain enough fuel for a fire with any significant duration and may delaminate and fall away from the building before ignition. These are not considered in building separation calculations.

The national building regulation guidance describes building configurations where combustible materials are permitted on the elevations of buildings. BR 135 *Fire performance of external thermal insulation for walls of multistorey buildings*[47] describes fire protection features and a test method to restrict the external spread of fire over a building elevation.

For building separation distance calculations, an area of combustible cladding on a building elevation is considered as an unprotected area. The Building (Scottish) Regulations 2013 *Technical handbook – Domestic, and Technical handbook – Non-domestic*[5] require that the actual area of cladding is used for the separation calculation. Other national building regulation guidance allows the value in the calculation to be half the actual value of the cladding area; these are an engineering judgement that considers the reduced duration of a cladding fire compared to the duration of a compartment fire.

1.4 Effect of thermal radiation on a building

Figure 9 indicates some of the features in a building that may be vulnerable in the event of a fire in an adjacent building and need to be considered in the context of building separation. These are:

- ignition of combustible materials on the exterior of the building
- ignition of the building contents due to:
  - radiation through an open window
  - radiation through an unprotected area after integrity failure
  - fire penetration from burning external materials to the inside of the building.
- ignition of materials between the buildings providing a bridge for fire spread.

In each case materials may be heated by thermal radiation and ignited by a pilot flame, possibly a burning brand from the original fire.

Some of these routes for fire spread are out of the scope of establishing boundary or separation distances but may need to be included as a building management requirement in a fire engineering approach. For example, ensuring significant quantities of combustible materials are not kept in the space between buildings.

The mechanisms involved in ignition are complex and detailed descriptions of the current understanding of the process can be found in books such as *An introduction to fire dynamics*[26] or the *Ignition handbook*[48].

1.4.1 Effect of thermal radiation on a solid

If a solid object is exposed to thermal radiation, some of the energy will be absorbed into the object and some will be released back into the surrounding environment as shown schematically in Figure 10.

For most building materials, reflection of thermal radiation is not significant and even surfaces that visibly appear to be shiny may not reflect much of the electromagnetic spectrum at the wavelengths of the incident thermal energy[49]. As such, no further discussion of reflection is included here.

A proportion of the incident energy will be conducted into the object and raise its temperature. Initially the temperature rise will be confined to the region near the surface; as the duration of the exposure increases, the heated region will become deeper and at some time raise the temperature of the unexposed surface.

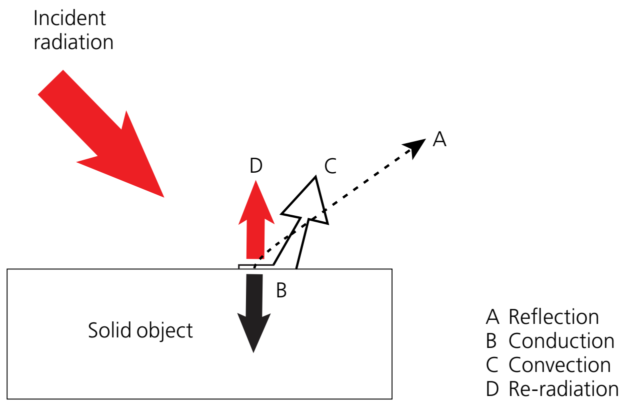


Figure 10: Object heated by radiation

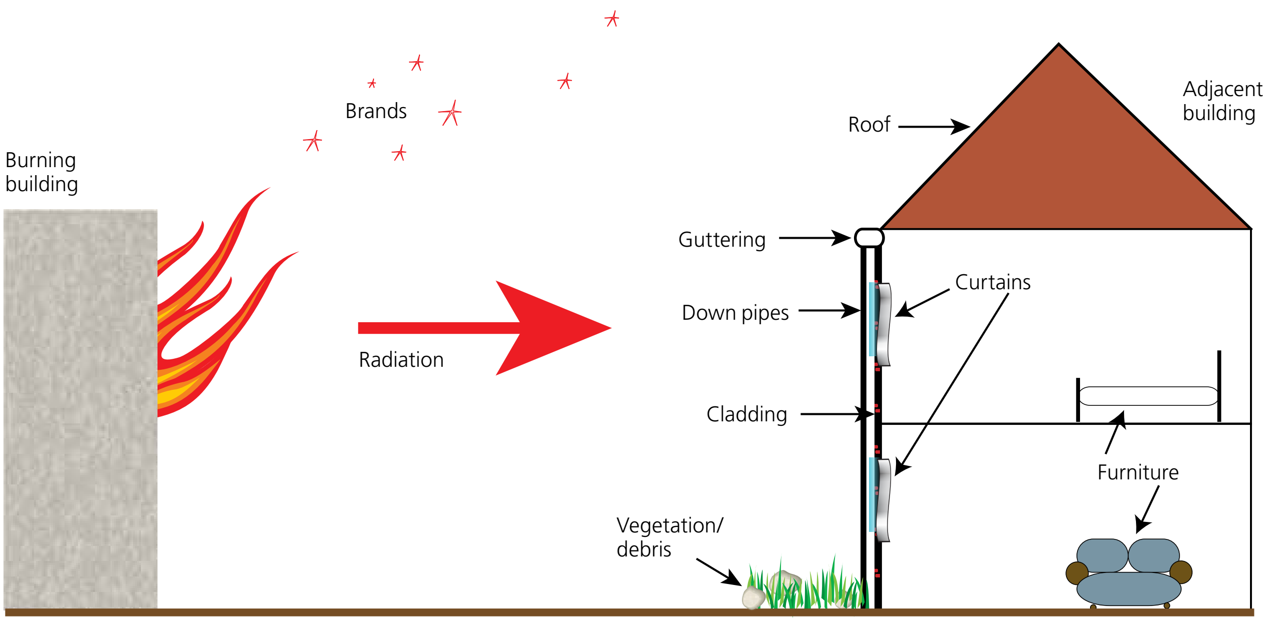


Figure 9: Ignition of a building adjacent to a fire

The time taken for the heat to be conducted through the thickness of the object depends on the thickness of the object and material properties. As the surface temperature of the object rises, heat will be lost from that surface by convection and radiation. If the unexposed face of the object does not rise in temperature during the period of interest, the object can be considered to be 'thermally thick' and conditions on the unexposed face do not need to be considered. If the temperature of the unexposed face increases, the material is 'thermally thin' and heat losses from the unexposed face may become significant. A fire is of short duration, relative to the time taken for incident energy to be conducted through the thickness of an aerated concrete blockwork wall – this means that the blockwork wall may be considered to be thermally thick; however, a steel bulkhead would be thermally thin.

When the temperature of the surface rises, heat will be transferred to air on the surface of the object, this air will then become buoyant and convect heat away from the surface. In addition, the temperature rise of the surface will cause the surface to radiate removing more heat from the object. Assuming no energy is generated in the object (ie it has not begun to burn, decompose or pyrolyse) then an energy balance at the surface can be written:

Incident radiation = conduction into object + convection from surface + re-radiation from surface

or

$$I_R = k\left(\frac{dT_s}{dx}\right)_{x=0} + h_c\left(T_s - T_o\right) + \sigma\varepsilon_s T_S^4 \qquad \text{(Eqn 3)}$$

Where:

I_R Incident radiation intensity [kW/m^2]

k Thermal conductivity of the object[kW/m/K]

T_s Surface temperature [K]

x Distance into the object [m]

h_c Convective heat transfer coefficient at the surface (kW/m^2/K)

T_0 Ambient temperature [K]

σ Stefan Boltzmann constant [5.67 × 10^{-11} kW/m^2/K^4]

ε_s Surface emissivity [-].

In principle, Equation 3 can be solved to calculate the surface temperature (or more generally the temperature at any depth in the solid) as a function of the time of the exposure to the radiation. However, in practice solving Equation 3 can be very difficult requiring a number of assumptions to represent different boundary conditions[26, 48]. In some cases the use of numerical methods and computer software are required.

If the object exposed to thermal radiation is made of a combustible material, then as the surface temperature increases, the material will begin to melt or decompose; it will then release flammable vapour and gases and heat may also be generated in the solid material that will accelerate the process. These vapours and gases will mix with air above the surface of the material and may form a flammable mixture which can ignite if the temperature is high enough (or in contact with a hot surface or pilot flame). The flames from the burning vapour will increase the radiation to the surface of the material which will increase the production rate of flammable vapour (a positive feedback loop). At some point there is enough heat returned from the flame to the solid to create a sustained ignition.

In the 1950s the critical radiation intensity for the pilot ignition of wood used in the building separation calculations was determined by exposing vertical samples of wood to radiant heat from a gas-fired radiant panel with a pilot flame located above the sample[50] (Table 4). Times to ignition were measured at different incident radiation intensities and the results analysed using a simple thermal model based on a solution of Equation 3.

Table 4: Pilot ignition of wood

Wood	Spontaneous ignition (kW/m^2)	Pilot ignition (kW/m^2)
African Mahogany	23.8	12.6
American White wood	25.5	14.6
Fibre board	23.8	6.5
Freijo	26.3	15.0
Iroko	33.4	15.0
Oak	27.6	15.0
Western red cedar	26.7	14.6

The samples were 50 mm × 50 mm × 19 mm thick, cut so that the exposed face was parallel to the grain of the wood and dried in an oven before testing.

The theoretical model[51] showed that for a semi-infinite cellulose solid, ignition occurred at 525°C which is why all the species of wood ignite under similar conditions.

These data gave an average value of 12.54 kW/m^2 (taken as 12.6 kW/m^2) for unprotected dry wood (several species were included in the average). Other studies have shown that the presence of paint and moisture would increase the critical radiation intensity required to cause ignition. The value of 12.6 kW/m^2 was used to provide a safety margin for practical applications. Wood exposed to a above radiation intensity of 12.6 kW/m^2 should take at least 10 min to reach the conditions where pilot ignition may occur[52].

The *Ignition handbook*[48] provides ignition conditions for an extensive range of materials.

In 2006 Hare and Burrell[53] conducted and reviewed the ignition criteria for the Health and Safety Executive and concluded that 12.6 kW/m^2 accurately represented the pilot ignition of wood and recommended a value of 10 kW/m^2 for plastic and composite skinned building materials.

1.4.2 Ignition of materials in a compartment

If the windows of a compartment facing a burning building are open, the contents of the room will be directly exposed to radiant heating. There is a possibility that burning brands could be blown into the room to provide a pilot ignition (open flames, such as gas fires, may also provide a pilot ignition). The contents of a room will usually contain items that may ignite easily and in turn ignite more substantial items.

If the compartment windows are closed then the glass will absorb or reflect a significant part of any incident thermal radiation protecting the contents of the building. One design solution that can be considered is to use fire-resisting glazing which may be able to provide the required level of fire resistance so that a window does not need to be considered as an unprotected area. It is important to make sure that the insulation criterion is met to reduce the risk of transmitted heat igniting light weight furnishings inside the building close to the window such as curtains[54].

Predicting the behaviour of glazing in fires is difficult due to the number of random factors[55]. Glass will crack when temperature gradients are created across the material, however the location where cracking starts and the shape of the crack depends on surface defects. The cracks may, or may not, create isolated 'islands' of glass that will fall out. A pessimistic assumption that glazing will immediately crack and fall out was used in previous work. This is supported, for plate glass, by experimental studies where a single pane (or the exposed pane of a double pane unit) cracked within 2 min when exposed to a radiation intensity of ~9 kW/m^2 and within 5 min for a radiation intensity of 5 kW/m^2. Other work suggests that the protected pane of a double pane unit will break about 1 min after the exposed pane. Tempered and toughened glass will behave differently and may survive exposures up to 40 kW/m^2. Despite several programmes of research it is not yet possible to identify a simple, general criterion for glass breaking in a fire or by exposure to radiant heat.

In addition a window exposed to radiant heat may fail, not because of the glass breaking, but because of expansion and distortion of the window frame allowing the glazing unit/pane to fall out of place.

Observations, supported by a theoretical analysis, of the 1993 fire in Oaklands, California indicated the buildings at the edge of the fire (where they would only be exposed to radiation and not to flame impingement) with double glazing survived better than single-glazed buildings[56].

For the purposes of calculating building separation we need to assume that if a building has openable windows then they may be open when a fire occurs. The compartment contents would then be exposed to thermal radiation from a fire in an adjacent building. If the windows are not openable, then it may be possible to account for the protection provided by some forms of glazing when determining building separation.

If objects are inside a compartment when they are exposed to thermal radiation then ignition of the objects may occur at lower radiation intensities than for an object outside a compartment. This is because volatile gases and vapours released as the object is heated may accumulate in a compartment. Some experiments were conducted when the building separation methods were developed where scale models of furnished rooms were exposed to radiant heating[57] (scale furniture was constructed from fibreboard and the room had a small gas flame to provide a pilot ignition). These experiments showed that ignition of a room exposed to approximately 9 kW/m^2 with a fully open elevation occurred after about 25 min. Further experiments[58] reported ignition of a room after 20 min exposure to a radiation intensity of 12.5 kW/m^2. It was suggested that ignition times for larger compartments (ie full scale) would be longer as convective cooling of the compartment would become more significant.

This may still (in 2014) be regarded as a pessimistic scenario but with additional factors that may introduce further confidence in the margins of safety:

- early detection of the original fire alerting Fire and Rescue Service and occupants of adjacent buildings
- improved performance of glazing slowing break out of fire from the original building
- improved performance of glazing protecting compartments in adjacent buildings
- fire-resisting furnishings delaying ignition of furnishings in an adjacent building.

1.4.3 Materials of the external surface of a building

For thermoplastics typically used for (uPVC) gutters, waste pipes and soil pipes, on the exterior of a building, the softening temperature (60°C to 130°C) is much less than the temperature required for ignition (270°C+ for pilot ignition). Therefore many items present on the exterior of building may fall away before they can be ignited and will not directly contribute to the fire hazard. However, this can result in routes being created for fire entry into, for example roofs. Additionally, the loss of services may result in the occupancy (with otherwise superficial damage) being uninhabitable until they are replaced.

Combustible materials on the surface of a building (for example cladding) may be heated by a fire in an adjacent building so that a large area of material reaches the point where a pilot ignition can occur and fire may rapidly spread over the heated area. This is a different scenario to the case of cladding being on the building that is ignited by a flashed-over fire breaking out of a compartment within the building, as described in BR 135[47].

The fire-resisting characteristics of the wall should prevent a fire from a burning façade spreading into the building, however there may be unprotected areas (windows) which could fail quickly. Timber cladding could be expected to ignite (from a pilot flame) after 10 min exposure to a radiation intensity of 12.6 kW/m^2 (the traditional criteria). Wooden window frames will also ignite after 10 min exposure to a radiation intensity of 12.6 kW/m^2 for pilot ignition.

1.4.4 Buildings with a suppression system

The presence of a suppression system in a building will not affect the response of the building exterior to thermal radiation from an adjacent building. However, if the unprotected areas on the exposed face of the building fail then sprinklers will control the spread of fire into the compartment. This is illustrated in Figure 11 where an external fire broke the windows and ignited items near the window (curtains and pelmet) but the operation of sprinklers prevented further items igniting.

National building regulation guidance permits the reduction of the boundary distance if a building has a suppression system. This assumes that the probability of successful sprinkler operation (maximum of 95% from BS PD 7974-7, Table A 17[44]) and thereby the probability of preventing building to building fire spread, is acceptable.

Figure 11: Fire spread from broken windows controlled by sprinklers (© Avon Fire and Rescue Service)

1.5 Boundary and separation distances

1.5.1 Fire spread between buildings

To maintain consistency with existing buildings the current 'mirror boundary' concept[2] should be retained. Existing buildings should not be exposed to an increased hazard as the result of construction of a new adjacent building.

Many of the factors that apparently conflict between the 'offensive' and 'defensive' requirements for building separation compensate for each other. For example, a building elevation with a high proportion of unprotected areas would be more vulnerable to exposure from a fire in an adjacent building than one with a smaller proportion. However, the building with a larger unprotected area would be further from the boundary to reduce exposure to its neighbour in the event of a fire. Ideally adjacent buildings should be similar as shown in Figure 1.

1.5.2 Adjacent large and small buildings

Figure 12 shows two dissimilar buildings adjacent to each other.

In this case the smaller building (building A) may be exposed to a greater hazard than it would have been if it was next to an identical building. Building A would be located at boundary distance B_A in the expectation that the adjacent building (building B) would be located a distance of S_A from building A. Building A could then receive a radiation intensity of 12.6 kW/m^2 in the event of a fire in building B. However, building B is much larger than building A and would be at a boundary distance B_B so that the radiation intensity at a distance S_B would be 12.6 kW/m^2. Building A is closer to building B (as shown in Figure 12) than S_B and could receive a radiation intensity greater than 12.6 kW/m^2 in the event of a fire in building B.

Conversely building B is at a distance greater than S_A from building A and would receive a radiation intensity less than 12.6 kW/m^2 in the event of a fire in building A.

If there is a significant difference in the size of two adjacent buildings, then a fire engineering approach should be considered to determine the boundary distance to the smaller building.

In some cases compartmentation will resolve this issue. If the buildings have similar-sized compartments, for example blocks of flats, and the boundary distance calculation is based on the largest compartment/unprotected area, then each building will have a similar boundary distance.

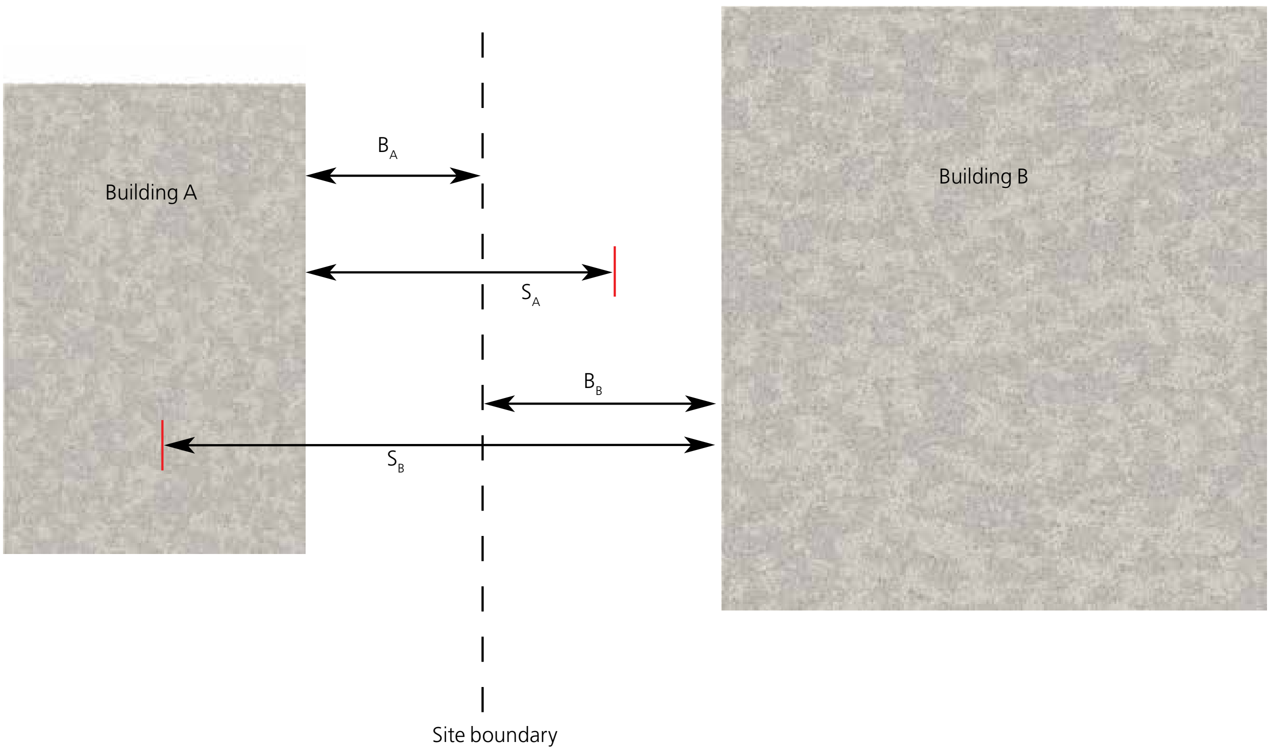


Figure 12: Site boundary and separation distance for dissimilar buildings

1.5.3 Summary

The key factors used to determine and design boundary distances are summarised below:

- The extent of a fire in a building should be limited by compartmentation.
- Unprotected areas on a burning building are taken to fail immediately.
- Unprotected areas on an exposed building fail when the fire in the adjacent building reaches its peak intensity.
- Thermal radiation from a burning building is based on:
  - total unprotected area on the elevation of a compartment
  - compartment temperature which is dependent on fire load (purpose group), ventilation, insulation and presence of a suppression system.
- Limiting the radiation intensity on an exposed building to 12.6 kW/m^2 unless:
  - the exposed building has a sprinkler system to control internal fire spread
  - the two buildings are of dissimilar size – a fire engineering analysis should be performed.

The design objectives are:

- to prevent fire spread to external combustible material on the exposed building occurring less than 10 min after the original fire reaches its peak
- to prevent ignition of the interior of an exposed building until 20 min after the original fire reaches its peak.

2 Calculation methods

2.1 General considerations

2.1.1 Accuracy and precision

The calculation methods presented here contain a number of assumptions (for example complete involvement of a whole compartment, failure of all unprotected areas and the radiant intensity from unprotected areas) and unknowns such as wind conditions. These factors mean that the calculated values should not be expected to be reproduced precisely in the event of a fire.

It is possible to calculate some of the components very accurately (for example configuration factors), but other factors have more uncertainty. Consequently the methods have been prepared so that any inaccuracies will tend towards giving an overestimation of the minimum boundary distance.

As a general principle, the boundary distance should not be presented to more than one decimal place. For some cases, boundary distance is not critical and all that may be required is an approximate calculation to confirm that it is adequate and not an issue. In such cases rounding values up to the nearest metre would be appropriate.

In other instances, demonstrating an acceptable boundary distance may determine the viability of a project. In inner cities there is a requirement to make effective use of available land and to build large, prestigious buildings. This results in a requirement to exploit small available boundary distances. This can always be achieved by introducing compartmentation within the building and reducing unprotected areas. However, this approach is likely to conflict with the function and aesthetics of a building. Problems may arise when there are very small differences (maybe less the 0.5 m) between the available and calculated boundary distances. Such cases require a risk-based fire engineering approach.

2.1.2 Process outline

The process of determining the minimum boundary distance for a building has many steps that are common to all the available calculation methods:

- Identifying a plane of reference for each elevation from where the boundary distance needs to be calculated.
- Determining the 'unprotected areas' on each elevation. This includes any combustible cladding.
- Identification of internal compartmentation that can be used to subdivide areas on an elevation. The compartment with the largest amount of unprotected areas on an elevation would normally be the only area that would need to be considered.
- Establishing the purpose group for the building so that the appropriate compartment temperature (and thereby radiation intensity at the unprotected areas) can be selected.
- The presence or not of a suppression system.

The next step would be to calculate the minimum boundary distance from each elevation using the 'enclosing rectangles' method. This may require refinement if there are local concentrations of unprotected areas that would cause 'hot spots'. If the resulting minimum boundary is within the relevant boundary then the process is complete.

If there are areas where the calculated minimum boundary distance exceeds the relevant boundary then the initial calculations can be refined. Firstly by considering any areas such as recesses in the building elevation where the initial estimate may be excessive and secondly by using the aggregate notional area method (protractor method) which will give a more detailed calculation along sections of the boundary. The aggregate notional area method does not average the contribution of each unprotected area and is more accurate near corners of the building. This method will also identify specific unprotected areas that 'cause problems' by requiring a larger boundary distances at specific points.

2.1.3 Plane of reference

The plane of reference is a line from which the boundary distance is calculated, in many cases this will be the building elevation, however in some cases it may be more convenient if this is parallel to the actual boundary or cuts across setbacks at the corner of buildings. The plane of reference should:

- touch all or part of the building elevation
- not pass through the building (although it may pass through balconies or other external features of the building)
- not cross the relevant boundary.

Setbacks in the building elevation which are less than 1.5 m can be neglected for the initial calculations; however, it may be necessary to account for these later if the calculations prove to be marginal.

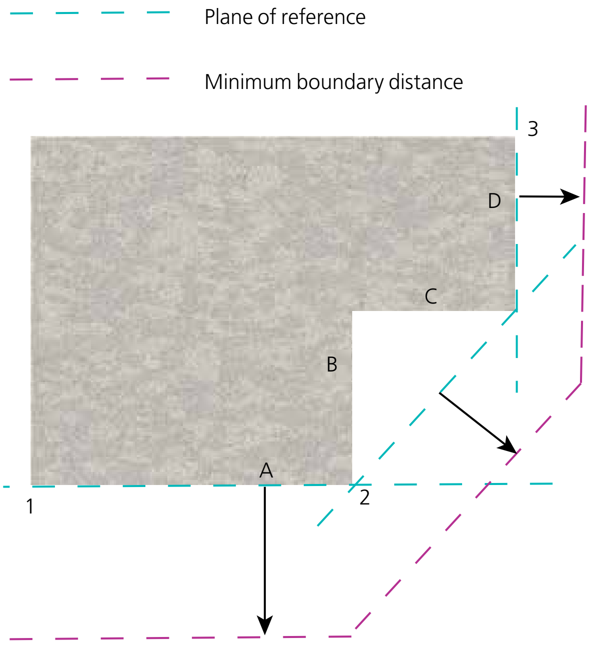


Figure 13: Plane of reference

Figure 13 shows the location of the plane of reference and the calculated minimum boundary distances.

The planes of reference 1 and 3 in Figure 13 coincide with the building elevations A and D, while plane 2 refers to elevations B and C. The unprotected areas on elevations B and C need to be projected onto the plane of reference if the enclosing rectangles method is being used. This is shown in Figure 14.

Figure 15 shows a case where the plane of reference is parallel to the relevant boundary. This illustrates where some of the unprotected areas can be discounted (for the boundary being considered) because they are at an angle of more than 80° to the plane of reference.

2.1.4 Unprotected areas

Unprotected areas are parts of the building elevation that do not have the fire resistance required by the compartmentation of the building, these are usually windows. As shown in Figure 15 it may be possible to discount some of these because they are at an angle to the plane of reference and will not make a significant contribution to thermal radiation for the boundary being considered.

It may also be possible to discount some small unprotected areas (for example air bricks and small windows) and unprotected areas on the elevations of some internal spaces such as protected shafts. Details of these will be found in the appropriate national guidance.

Combustible surface materials more than 1 mm thick are also considered to be unprotected areas. However, the fire duration of a burning area of surface material would usually be much less than a compartment, therefore the effective area of the surface material is reduced by a half for the purposes for boundary distance calculations.

Items such as plastic gutters and waste pipes will soften and fall away from a building at temperatures that are significantly below the temperature required for ignition consequently these items can be disregarded in the context of building separation calculations.

For the enclosing rectangles method the total unprotected area is found and divided by the area of a rectangle that encloses all the unprotected areas, this is expressed as a percentage. Tables A to J can then be used to find the minimum boundary distance for the elevation. This is illustrated in **Section 2.1.5 Compartmentation** and discussed in detail in subsequent sections.

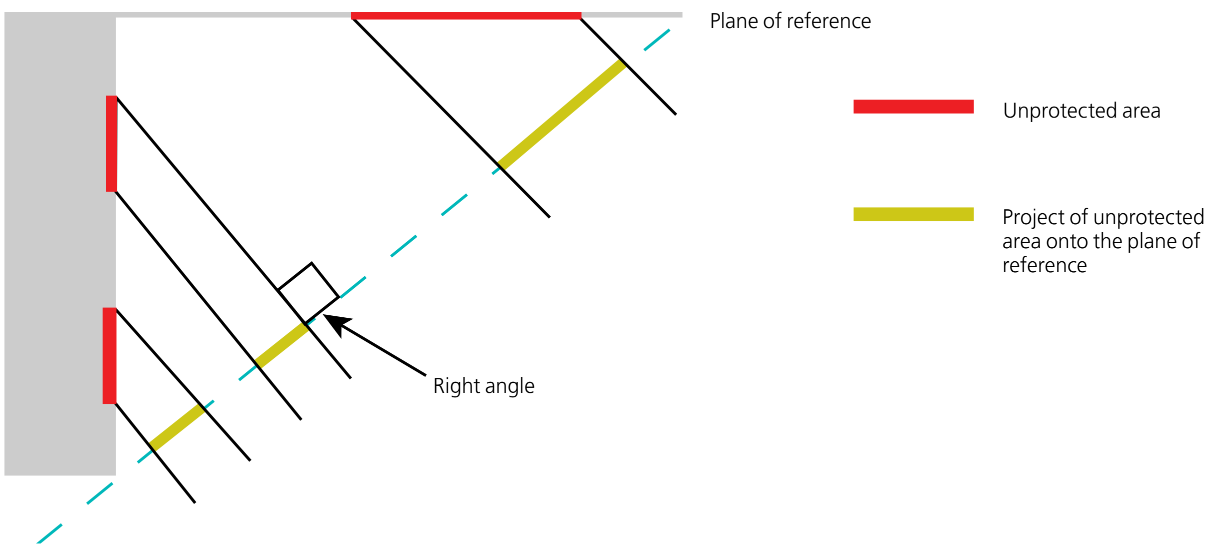


Figure 14: Projecting unprotected areas on to the plane of reference

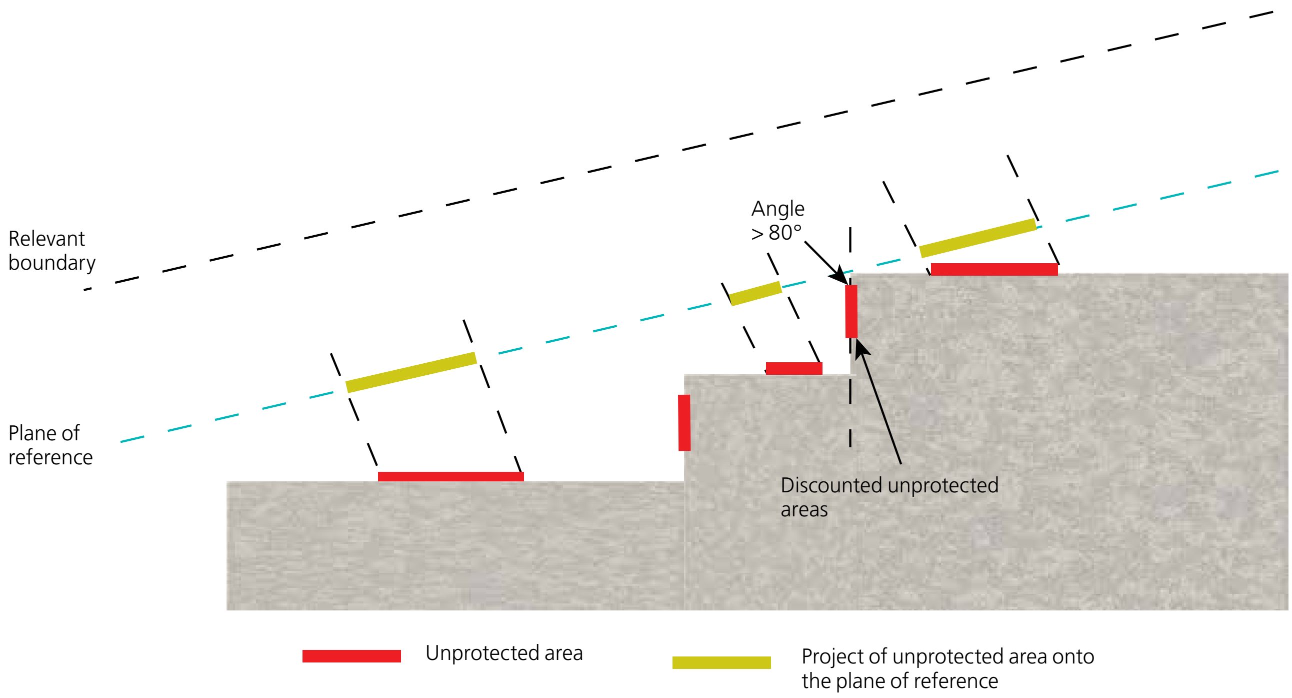


Figure 15: Plane of reference parallel to boundary

2.1.5 Compartmentation

For the purposes of boundary distance calculations it is assumed that the fire is confined to one compartment in a building and that the fire has developed to involve the whole of that compartment. This provides the designer with a method of reducing boundary distances by introducing additional compartmentation into the building. Compartments which are protected shafts can be discounted as they will not have any fire load.

2.1.6 Purpose group/building use

The enclosing rectangles and aggregate notional area methods are based on the temperature in a compartment reaching a specified value depending on the fire load and ventilation conditions, these are given in Table 3. The lower values are usually applied to building occupancies for residential, office and assembly/recreational uses. This should be confirmed from the relevant national building regulation guidance.

2.1.7 Suppression systems

The presence of a suppression system will, if correctly designed and maintained, significantly limit the development of the fire so that the fire will not develop to involve the whole of a compartment. This will reduce the hazard of fire spread from a building with the suppression system to an adjacent building. The building will also be exposed to the hazard of a fire in the adjacent building, which may cause the unprotected areas to fail and allow a fire to develop inside the building; however, the suppression system should prevent this fire spreading beyond the area around the exposed edge of the building. The vulnerability of a building to thermal radiation from an adjacent building will be related to the total unprotected area on the elevation facing the burning building.

Halving the boundary distance if sprinklers are installed acknowledges the beneficial effects of a functioning sprinkler system, however, this assumes that the reliability of the system is acceptable (maximum of 95% from BS PD 7974-7, Table A 17[44]). In some cases a probabilistic risk assessment may be required.

2.2 Determining the boundary distance

2.2.1 Enclosing rectangles

For most elevations with a number of unprotected areas, the scenario can be approximated to a single area that will provide an equivalent intensity of radiation. This equivalent radiator is the rectangle which totally encloses all the openings in the elevation (termed the overall enclosing rectangle) that radiates at a reduced intensity, the reduction factor being the ratio of the total area of all the openings to the area of the enclosing rectangle. Thus, if the area of the openings were 60% of the enclosing rectangle (the unprotected percentage) and the building contained a normal fire load, then the intensity 168 kW/m^2 would be reduced by a factor 60/100 and the effective radiating intensity of the rectangle would be taken as 101 kW/m^2. The appropriate configuration factor would then be calculated to find the required separation distance. The equation to calculate ϕ can be found in Appendix A.

Consider the elevation in Figure 16; the rectangle ABCD encloses all the unprotected areas and their total area is 50% of the area of ABCD. Using the radiation intensity for the reduced fire load (I_o = 84 kW/m^2) the equivalent radiation intensity from the enclosing rectangle is 0.5 × 84 = 42 kW/m^2 and the view factor at the location where the radiant intensity has fallen to 12.6 kW/m^2 is:

$$\phi=\frac{12.6}{42}=0.3 \qquad \text{(Eqn 4)}$$

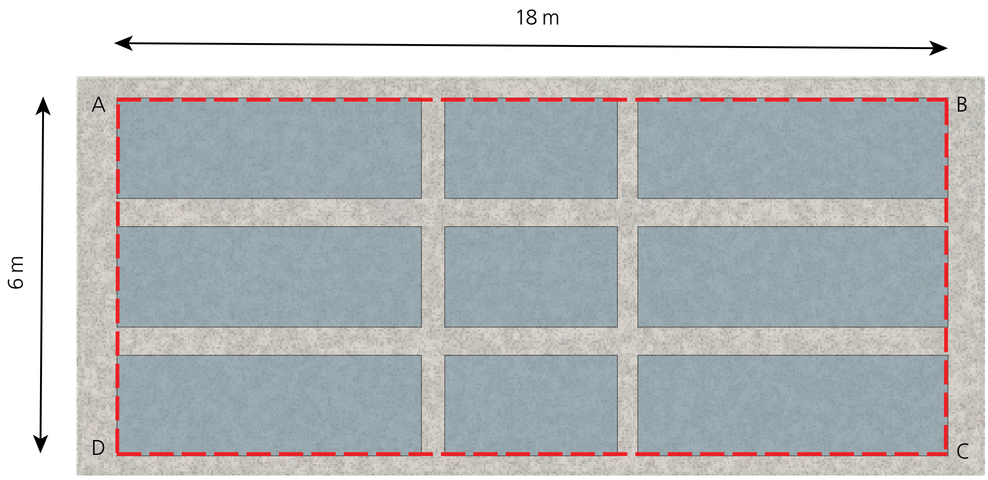


Figure 16: Building elevation

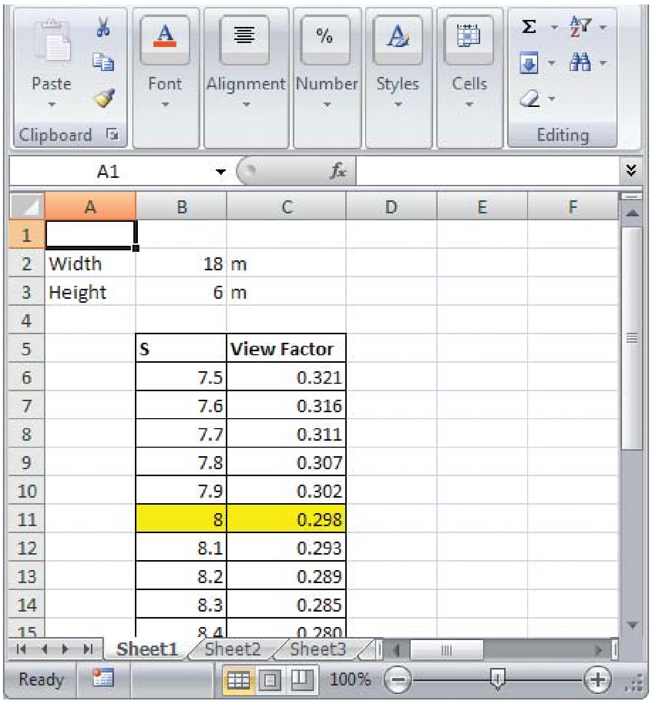


Figure 17: Calculation of view factor

The distance from the elevation where the configuration factor is equal to 0.3 can be found by evaluating Equation A3 in Appendix A for different values ϕ until a sufficiently close value is found (techniques such as successive approximation allow this to be done efficiently). Alternatively the view factor can be calculated for a range of distances and the appropriate value selected. Figure 17 shows a spreadsheet that has been used to find the distance, S, from a 18 m wide, 6 m high rectangle where the view factor is 0.3. This occurs at a distance of 8 m which would be the separation distance. The boundary distance is therefore 4 m.

Sets of tables (Table A to J) have been provided in **Tables for calculations** on pages 46 to 56, so that boundary distances for enclosing rectangles of various sizes and unprotected percentages can be found directly. In this example (shown in Figure 18) the height of the enclosing rectangle is 6 m, the width is 18 m and the unprotected percentage of 50%.

The value in brackets should be used for the reduced fire load which gives a minimum boundary distance of 4 m.

This approach assumes that the unprotected areas are uniformly distributed over the enclosing rectangle and the separation distance is based on the maximum radiation intensity calculated at the centre of the rectangle. The radiation intensity reduces away from the centre so the separation distance may be overestimated at the ends of the elevation. If the unprotected areas are not uniformly distributed then there may be hot spots which should be treated independently.

Table B: Enclosing rectangle 6 m high

Distance from relevant boundary for unprotected percentage not exceeding

Width	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100**
Minimum boundary distance (m) *Figures in brackets for residential, office and assembly uses*									
3.0	1.5 (1.0)	2.0 (1.0)	2.5 (1.5)	3.0 (1.5)	3.0 (2.0)	3.5 (2.0)	3.5 (2.5)	4.	
6.0	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.0 (2.5)	4.5 (3.0)	5.0 (3.0	5 (3.5)		
9.0	2.5 (1.0)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	5.5 (3.5)				
12.0	3.0 (1.0)	4.0 (2.0)	5.0 (3.0)	5.5 (3.5)	6				
15.0	3.0 (1.5)	4.5 (2.5)	5.5 (3.0)	6.0 (4.0)					
18.0	3.5 (1.5)	4.5 (2.5)	5.5 (3.5)	6.5 (4.0)					

Figure 18: In this example, Table B (on page 48) has been used to find the boundary distance for the elevation shown in Figure 16

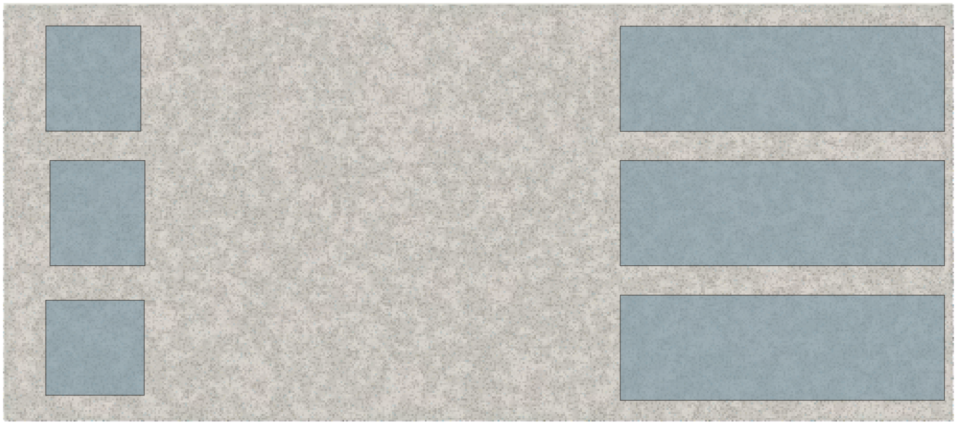


Figure 19: Elevation with widely space unprotected areas

Widely spaced unprotected areas

Sometimes an elevation may include widely spaced distinct groups of unprotected areas such as that shown in Figure 19.

In many cases it is likely that the two sets of unprotected areas will be associated with different compartments and the groups can be treated individually. If the elevation is to a single compartment then a fire could involve all the unprotected areas simultaneously. Constructing an enclosing rectangle around all the unprotected areas will average the radiation intensity from each unprotected area over the whole of the enclosing rectangle. As a result, the radiation intensity will be underestimated near the unprotected areas and over predicted near the centre of the enclosing rectangle.

If the two groups are sufficiently far apart then radiation from one group will not add significantly to the radiation intensity near the other group. Figure 20 shows two groups of unprotected areas separated along the elevation by a distance X. The boundary distance for each group can be calculated independently (B_1, B_2). If the distance between the groups, X, is greater than four times the largest of B_1 and B_2 then the groups of unprotected areas can be considered independently, as shown in Figure 20. This is based on the separation distances from each unprotected area (where the radiation intensity would be 12.6 kW/m²), not overlapping along the boundary.

If the separation distance is less than 4 times the greater of B_1 and B2 then the boundary distance for the whole elevation should be found (B_0), and the minimum boundary distance line constructed as shown in Figure 21.

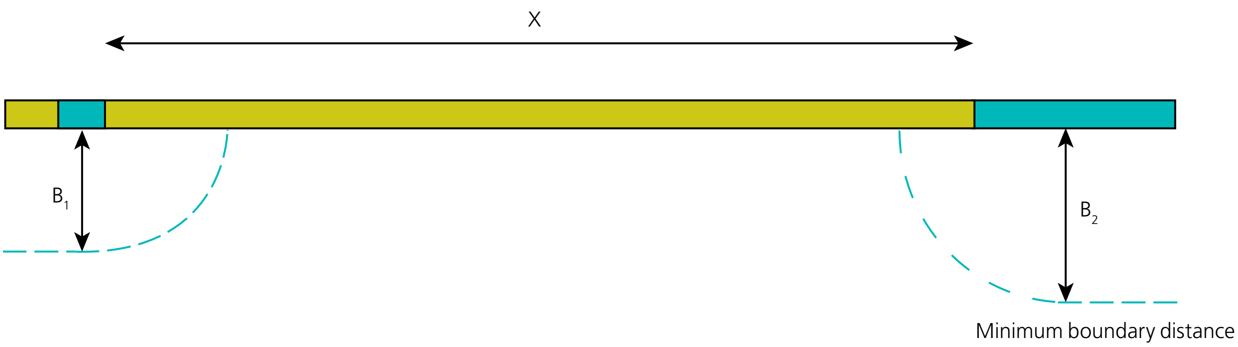


Figure 20: Independent unprotected areas ($X > 4B_2$)

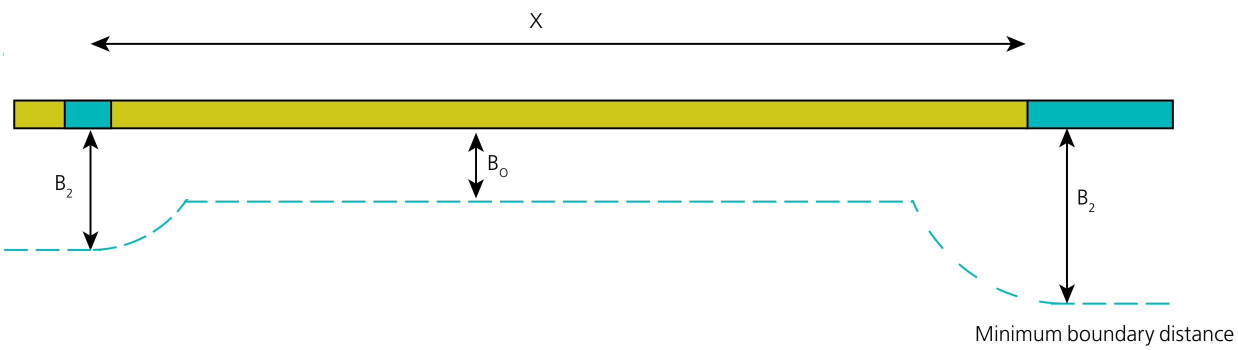


Figure 21: Dependent unprotected areas ($X < 4B_2$)

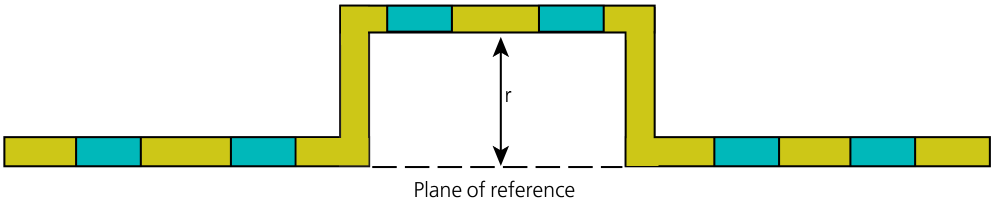


Figure 22: Elevation with recess

Elevations with recesses

The enclosed rectangles method may also prove to be onerous if the elevation contains a recess and some of the unprotected areas are behind the plane of reference as shown in Figure 22.

If it is assumed that all the openings are on the plane of reference, this will give an overestimate of the required boundary distance. If this is used as a first estimate of the boundary distance, B_0, a reduction factor, r, can be calculated that can be applied to the areas of the unprotected areas in the recess[2]. The boundary distance can be recalculated accounting for the unprotected areas setback from the plane of reference.

The value of the reduction factor, r, based on similar triangles, is found using:

$$R=\left[\frac{2B_o}{2B_o+r}\right]^2 \qquad \text{(Eqn 5)}$$

An example of using Equation 5 is given in Case 7 (see **Section 3 Case studies**). If the recess is less than 1.5 m the reduction factor is not significant, this is demonstrated in Case 6.

If the recess has unprotected areas on all three sides, the total of all unprotected areas in the recess should be found and these should be considered to be distributed over the area of the recess in line with the front of the elevation. This should be limited so that the total unprotected area does not exceed 100% of the recess opening. An example of this scenario is given in Case 8.

2.2.2 Aggregate notional area method

To consider the variation of minimum separation distance along an elevation, more detailed calculations are required. The contribution of radiation intensity from each unprotected area to a point away from the building can be calculated by finding the individual view factors. This can become a very intensive task and a method was developed to provide a reasonable approximation to calculating individual view factors. This is referred to as the aggregate notional areas or protractor method. For each point on a boundary, each relevant unprotected area is identified and its area multiplied by a factor that is related to the distance between the point and the area. The sum of these areas is the aggregate area, and if this less than a specified value (90 m^2 or 210 m^2 for the reduced fire load occupancies) the boundary distance would be acceptable.

Table 5 gives the factors at various distances from the point. It can be used to construct a protractor by drawing semicircles with the radii of the values at the scale of the drawings to be used. This can be on a transparent plastic sheet to be used with paper drawings or a graphical object that can be moved and rotated over an electronic drawing. Figure 23 shows a sample protractor. Note it is easier to use if the extent of the protractor is limited to the range of distances that will be found on the drawing.

To use the protractor the datum on the protractor (the red dot on Figure 23) is placed on a point on the boundary and the protractor rotated so that the green line touches the building elevation at the nearest point. The area of each unprotected area on the elevation is then multiplied by the factor shown by the protractor and added to a total. Some unprotected areas can be discounted:

- those that face away from the datum
- where there is a section of the building with the appropriate fire resistance between the datum and the unprotected area
- where the angle between a line passing through the unprotected area and the datum forms an angle of less than 10° to the base of the protractor(the blue line on Figure 23).

It is beneficial to record these values in a simple table.

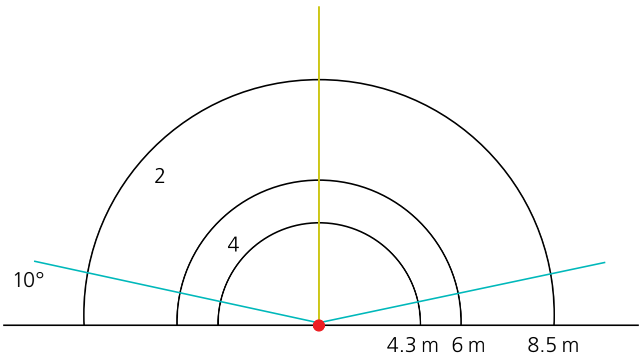


Figure 23: Relevant boundary requiring detailed calculations

Table 5: The factors for aggregate notional area method

From (not less than) (m)	To (less than) (m)	Factor
1	1.2	80
1.2	1.8	40
1.8	2.7	20
2.7	4.3	10
4.3	6.0	4
6.0	8.5	2
8.5	12.0	1
12.0	18.5	0.5
18.5	27.5	0.25
27.5	50	0.1
50	No limit	0

If the total is less than 210 m^2 for the 'low fire load' occupancies or 90 m^2 for other occupancies then the point can be accepted. A series of points at 3 m intervals along the boundary should be tested.

Figure 24 shows a situation where the relevant boundary falls inside the calculated minimum boundary distance and the aggregate notional area method can be used to give a more detailed analysis.

The aggregate notional area method is divided into four steps:

- determine which parts of the elevations need to be considered
- identify points on the boundary (at 3 m intervals) that need to be tested
- for each point determine which unprotected areas need to be taken into account
- calculate the 'aggregate notional area' (sum of unprotected areas multiplied by the factor found from the protractor) at each point.

The boundary distance is satisfactory if the aggregate notional area is less than the limiting value for the appropriate purpose group.

2.2.3 An alternative approach to using tables

Before the wide availability of computers evaluating equations, such as those in Appendix A, using the tables was not a trivial task and also prone to errors. The first edition of BR 187[1] included a simplified method for determining the boundary distance where a graph could be used in place of the enclosing rectangles tables. This alternative method is based on an estimate of the view factor derived by Willams-Leir[59] at the National Research Council (Canada) and revised by Melinek in Appendix A of the first edition of BR 187.

The method has two forms:

- calculating the maximum percentage unprotected area for a given boundary distance and building elevation
- calculating the minimum boundary distance for given building elevation and percentage unprotected area.

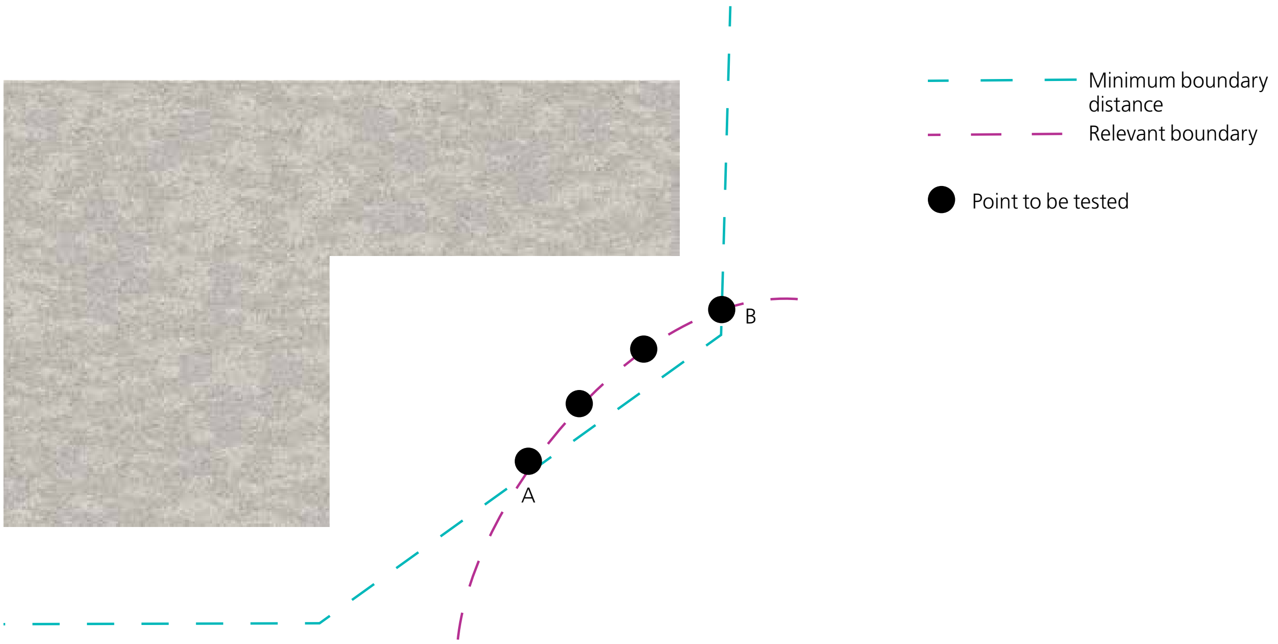


Figure 24 : Relevant boundary requiring detailed calculations

2.2.4 Calculating the maximum percentage area

The maximum percentage area, u, is found from:

Where:

$$u=100\frac{(d/F)^2}{wh}\% \qquad \text{(Eqn 6)}$$

F Is a factor from Figure 25

d Boundary distance (m)

w Width of the elevation (m)

h Height of the elevation (m)

To find the factor F, the largest value of h/d and w/d should be used with Figure 25. The maximum percentage area cannot exceed 100%.

For values of h/d or w/d that are greater than 10 the unprotected percentage should be taken as:

60 maximum (d/w, d/h) for the reduced fire load

30 maximum (d/w, d/h) for the standard fire load.

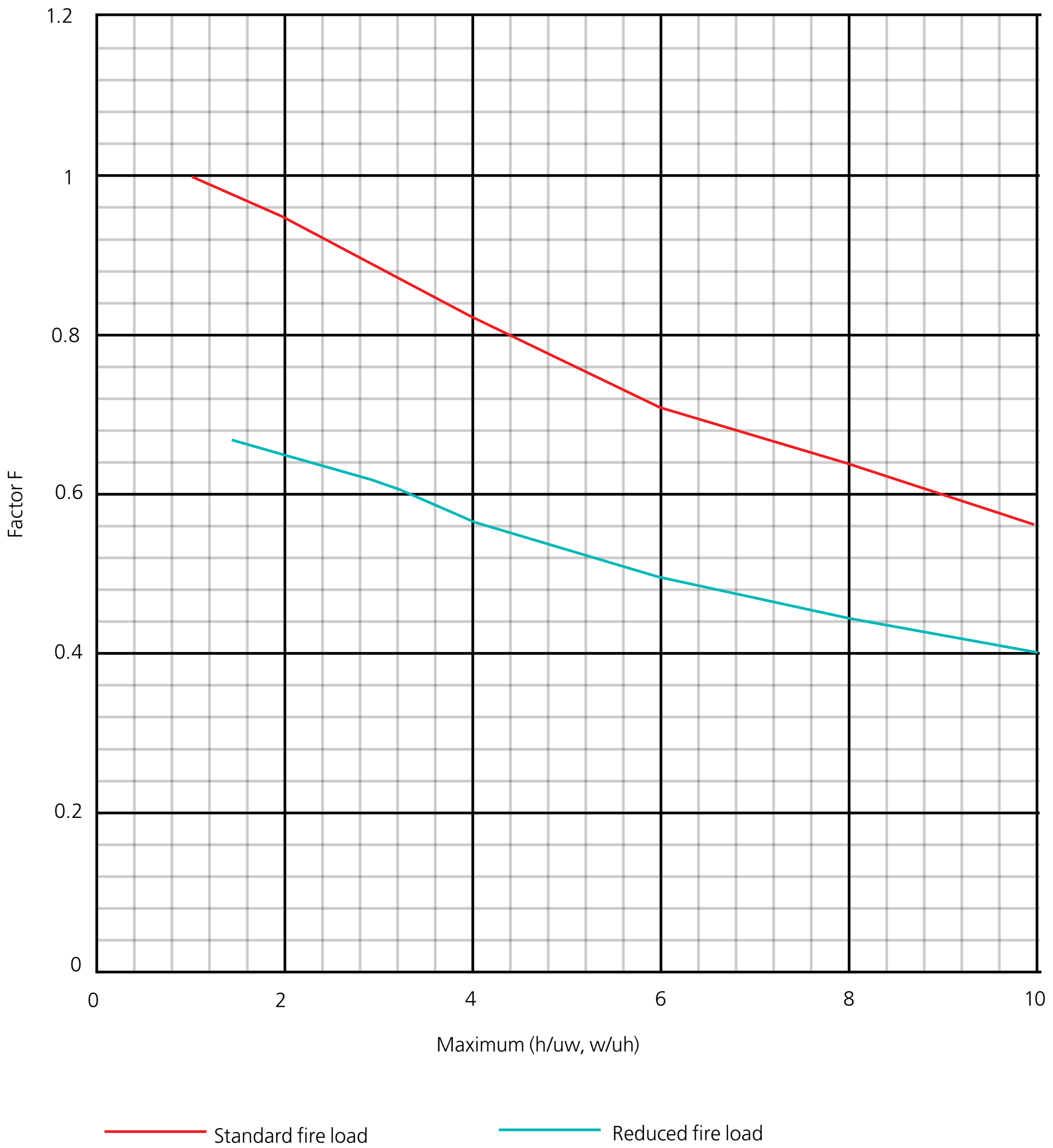


Figure 25: Factor F for use with Equation 6

2.2.5 Calculating the minimum boundary distance

The minimum boundary distance, d, is found from where:

$$d = G\sqrt{\frac{uwh}{100}}\ m \qquad \text{(Eqn 7)}$$

G Is a factor found from Figure 26

u Unprotected percentage area (%)

w Width of the elevation (m)

h Height of the elevation (m)

To find the value of G the largest value of 100 w/(uh) and 100 h/(uw) should be used with Figure 26. If the value of 100 w/(hu) (or 100 h/(uw) is greater than 30 then the boundary distance can be taken as 1.67 minimum (uw, uh) for the reduced fire load 3.33 minimum (uw, hw) for the standard fire load.

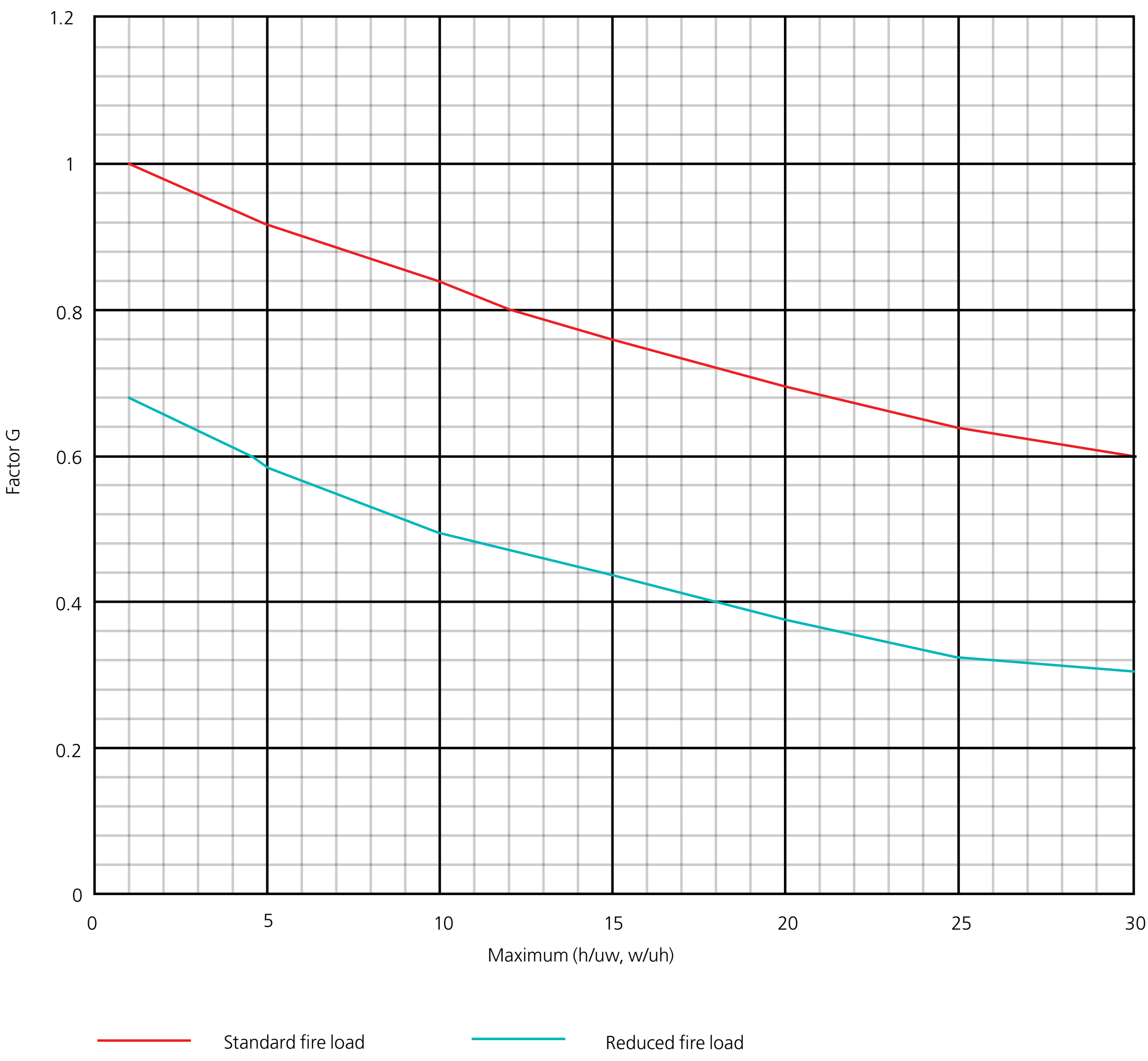


Figure 26: Factor G for use with Equation 7

3 Case studies

This section illustrates the use of the various methods to calculate separation and boundary distances for a number of cases.

Some of the examples show variations in the procedure to accommodate building features such as elevations with recesses.

The following cases are considered:

- compartmentation
- simple elevation (shop front)
- elevation with several unprotected areas (office floor)
- elevation with non-uniform distribution of unprotected areas (factory)
- widely spaced unprotected areas
- shallow recess
- deep recess
- recess with openings on all sides
- setback.

In some cases the results are compared with more detailed calculations shown in Appendix A to illustrate the accuracy that can be expected from the methods, and where a problem may benefit from a fire engineering approach.

Tables A to J, referred to in the case studies, can be found in the section **Tables for calculations** on pages 46 to 56.

Case 1 Compartmentation

Description

The effect of compartmentation is explained in the following example which assumes a residential, office or assembly/recreation use. The shaded areas in Figures 27 to 29 are unprotected areas and the enclosing rectangle is shown as a dashed red box. The plane of reference in these examples coincides with the building elevation.

No compartmentation

Figure 27 shows an elevation of a building with no compartmentation. The total unprotected area is the total area of the windows (16 × 1.8 m × 1.8 m = 52 m^2) and the area of the unprotected entrance/door way (4.6 m × 11.5 m = 53 m^2) giving a total of 105 m^2.

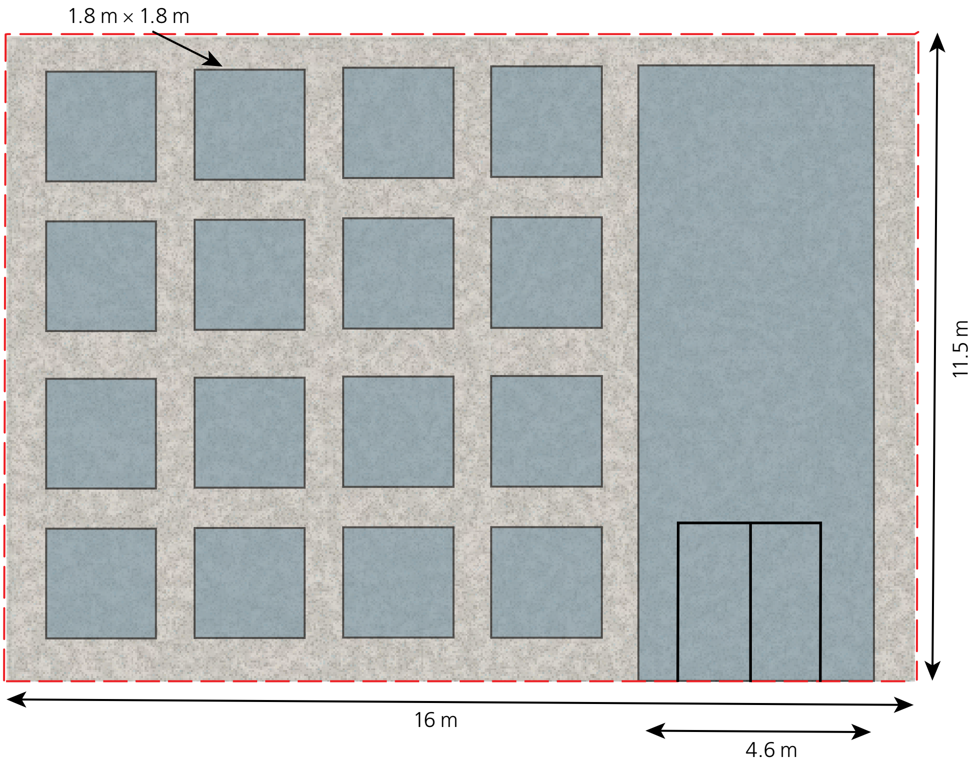


Figure 27: Building elevation: No compartmentation

These are enclosed by an enclosing rectangle 18 m wide and 12 m high, this is the smallest rectangle from Tables A to J that encloses all the unprotected areas. The unprotected percentage is then:

$$\text{Unprotected percentage} = 100\frac{\text{Total unprotected area}}{\text{Area of enclosing rectangle}} = 100\frac{105}{18 \times 12} = 48\%$$

This is rounded up to 50% in Table D (for a 12 m high enclosing rectangle) gives a minimum boundary distance of 6 m.

Compartmentation (1)

Adding a compartment wall to create a protected shaft for the entrance and stairwell, and providing a compartment floor half way up the building, allows a smaller unprotected area to be considered (Figure 28).

The side of the protected shaft is not considered as an unprotected area and the two levels can be considered independently. Usually the compartment with the larger area of openings would be considered, however in this case the compartments on both levels are the identical.

The total unprotected area is now 8 × 1.8 m × 1.8 m = 26 m^2 which can be enclosed in a 12 m wide by 6 m high enclosing rectangle, this gives an unprotected percentage of 36%. This is rounded up to 40% – Table B gives a minimum boundary distance of 3 m.

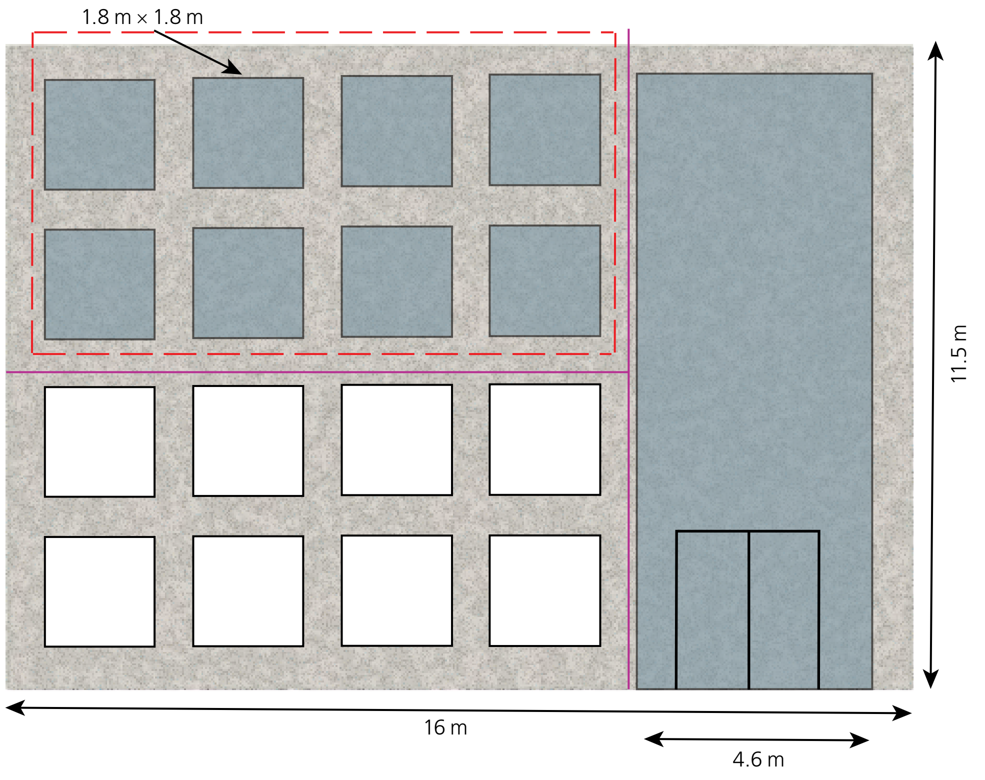


Figure 28: Building elevation with compartmentation

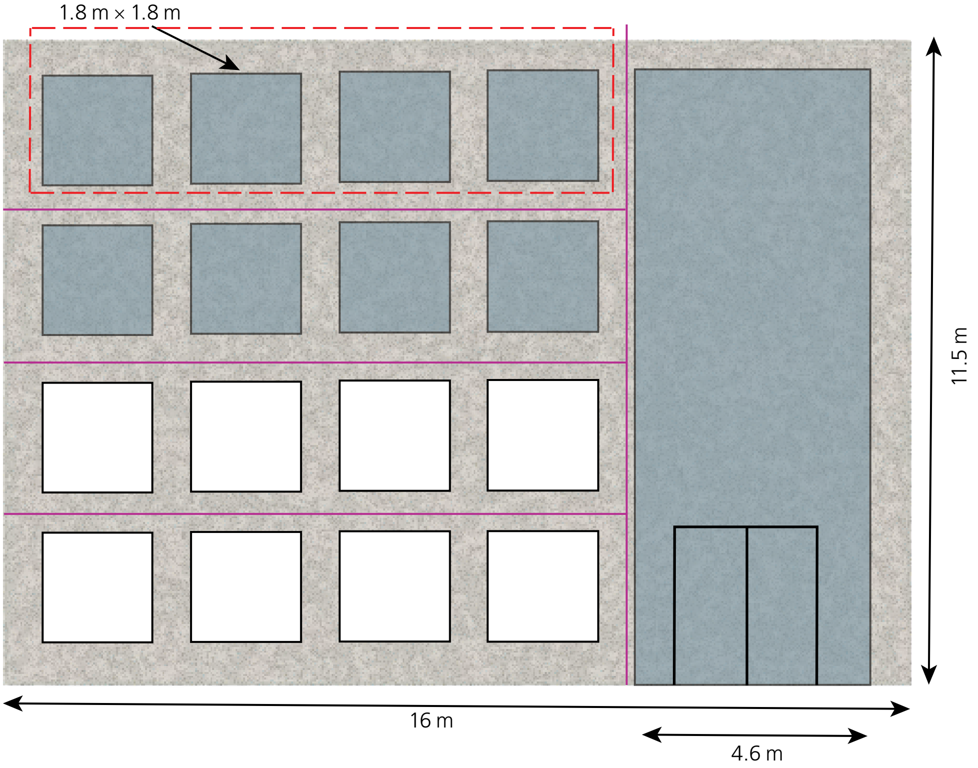


Figure 29: Building elevation with smaller compartments

Compartmentation (2)

Adding compartment floors at all levels results in a further reduction of the boundary distance (Figure 29).

The unprotected area is now 13 m² with a 12 m wide, 3 m high enclosing rectangle giving an unprotected percentage of 36%. This is rounded up to 40% and Table A gives a minimum boundary distance of 1.5 m.

Case 2 Simple elevation (shop front)

Description

Consider a shop front 6 m wide and 2.4 m high with a large glazed window (Figure 30).

Enclosing rectangle and unprotected percentage

The nearest enclosing rectangle from Table 1 is 3 m high and 6 m wide the unprotected percentage is therefore:

$U = 100 \times (2.4 \times 6) / (3 \times 6) = 80\%$

Boundary and separation distances

From Table A, the boundary distance for the shop would be 3.5 m corresponding to a separation distance of 7 m.

Using configuration factor

Calculating the factor using the equations in Appendix A gives a radiation intensity in line with the centre of the window at the separation distance calculated above of 13.8 kW/m². The critical value of 12.6 kW/m² occurs at a separation distance of 7.35 m (boundary distance 3.67 m) indicating that in this example the error in calculating the configuration factor using the enclosing rectangles method is 0.35 m or 5%. This error is partly due to rounding the boundary distance to the nearest 0.5 m in Tables A to J.

It should be noted that the enclosing rectangle method gives the boundary distance perpendicular to the centre of the enclosing rectangle and that the radiation intensity will fall off towards the edges of the unprotected areas. Figure 31 shows the radiation intensity across the width of the shop front at the mid-height of the window and Figure 32 the radiation intensity perpendicular to the centre of the window.

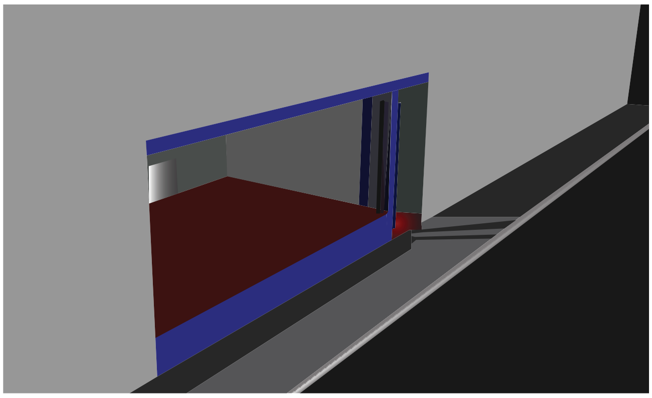


Figure 30: Simple shop front

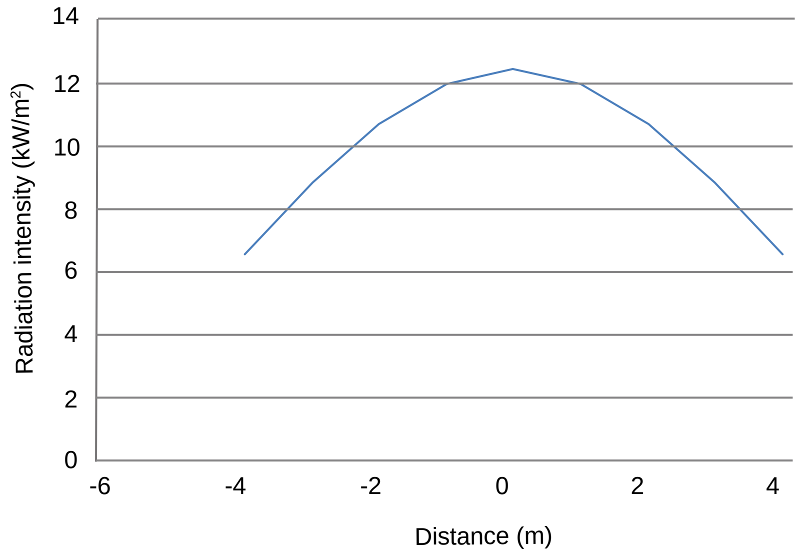


Figure 31: Radiation intensity across a shop front

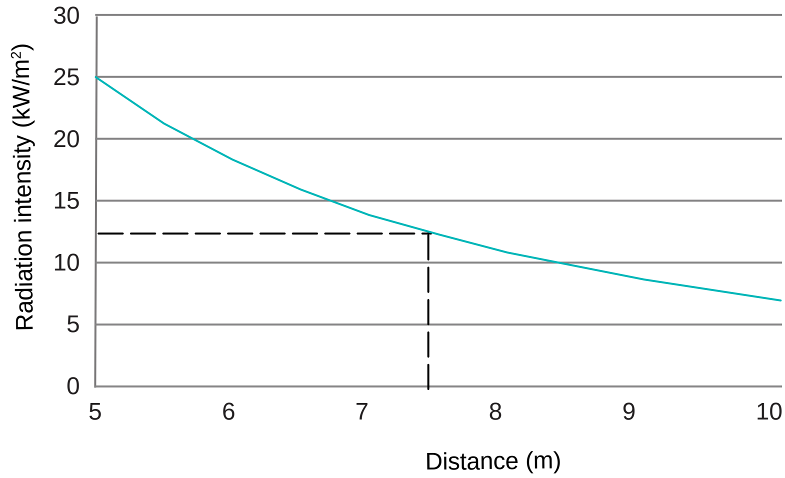


Figure 32: Radiation intensity away from a shop front

The fall off of radiation intensity at the edges of the unprotected area is one of the margins of safety inherent in the calculations since the peak value at the centre of the opening is used to determine the boundary distance.

Using the alternative approach to the enclosing rectangles tables

Equation 7 and Figure 26 are used here to find the minimum separation distance.

Taking the values from above:

Width of enclosing rectangle (w) = 6 m

Height of enclosing rectangle (h) = 3 m

Unprotected percentage (u) = 80%

To find the factor G used in Equation 7 the value of 100 w/(uh) needs to be calculated using the values above. This gives a result of 2.5 which is used with Figure 26 to find the factor G. For the standard fire load (red line) G = 0.97.

Equation 7 can then be used to find the boundary distance:

$$0.97\sqrt{\frac{uhw}{100}}=3.7m$$

Case 3 Elevation with several unprotected areas (office)

Description

Consider an elevation with a line of five windows each 0.8 m wide and 1 m high with a space of 0.2 m between each window (Figure 33).

Enclosing rectangle and unprotected percentage

The total unprotected area is 5 × 0.8 m × 1 m = 4 m^2 which can be contained in an enclosing rectangle 6 m wide and 3 m high.

This gives an unprotected percentage of 100 × 4 / (6 × 3) = 22%.

Boundary and separation distances

Using an unprotected percentage of 20%, Table A gives a minimum boundary distance of 1 m. The separation distance is therefore 2 m.

Case 4 Non-uniform unprotected areas

Description

This example is a factory/industrial unit with a glazed showroom area at one end of the elevation (Figure 34).

The seven small windows are 2 m wide and 1 m high with a 1 m gap between them, the glazed area is 8 m by 8 m.

Enclosing rectangle and unprotected percentage

The total unprotected area is (7 × 2 m × 1 m) + (8 m × 8 m) = 78 m^2.

The enclosing rectangle is 9 m high and 30 m wide, so the unprotected percentage is 100 × 78 m^2 / 9 m × 30 m = 28% (30%).

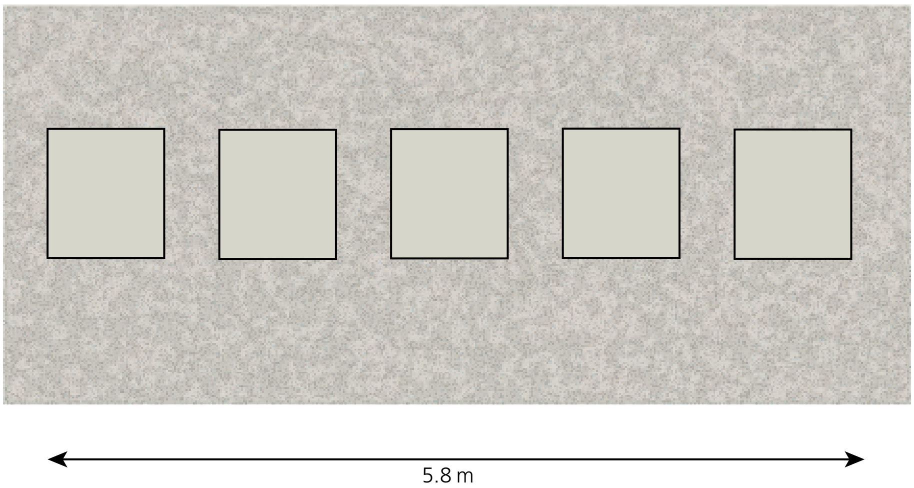


Figure 33: Elevation with several unprotected areas

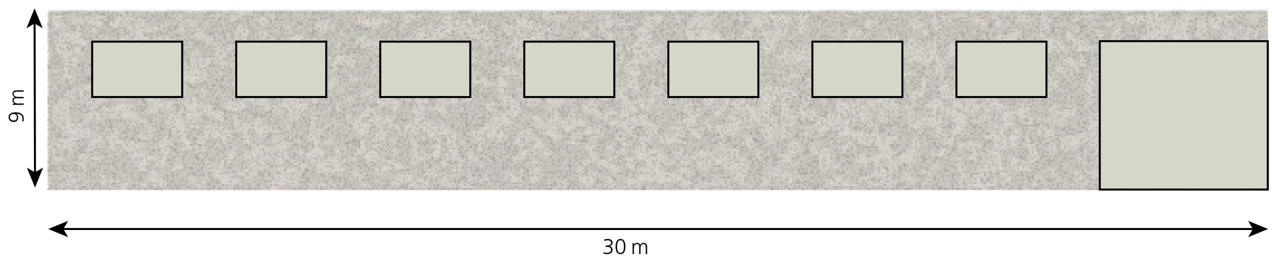


Figure 34: Elevation with non-uniform distribution of unprotected areas

Boundary and separation distances

Table C gives a 'first limiting position' for the boundary of 7 m. However, this does not take into account the local effect of the large glazed area.

The large area will fit into a 9 m by 9 m enclosing rectangle giving an unprotected percentage of 100 × 64 m² / 81 m² = 79% (80%).

Using data in Table C this requires a minimum boundary distance of 8 m, this is the final limiting value that should be used near the large glazed area. Figure 35 shows a plan view of the elevation indicating the calculated distances and the final minimum boundary location.

Case 5 Widely spaced unprotected areas

Description

Figure 36 shows an industrial building with unprotected areas (office windows) at each end.

At one end there are three unprotected areas 6 m wide and 2 m high, at the other end there are three areas, 2 m wide and 2 m high. There is a gap of 22 m between the unprotected areas.

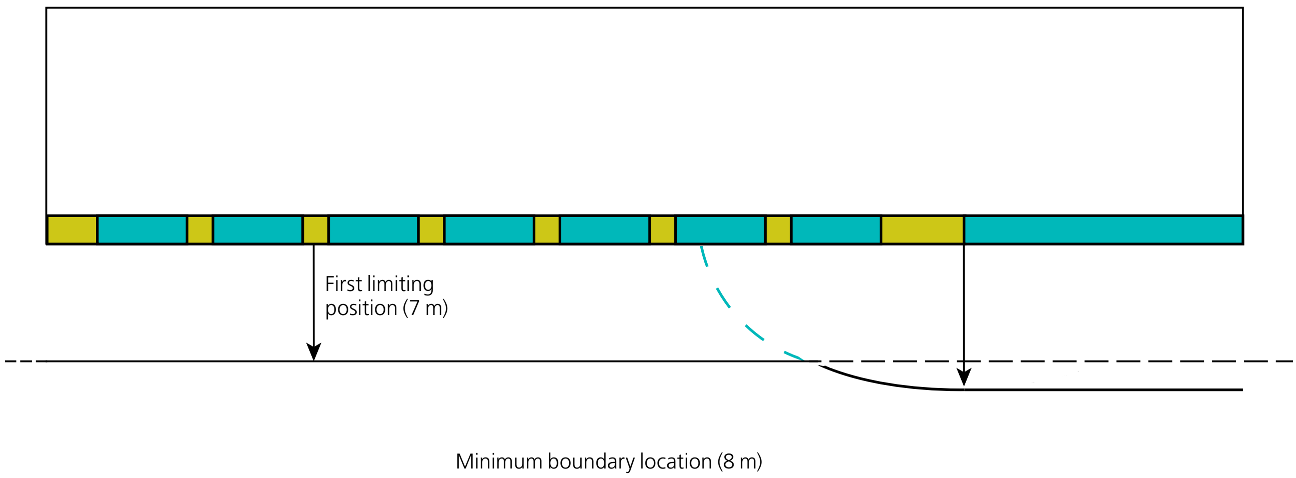


Figure 35: Calculated boundary distances

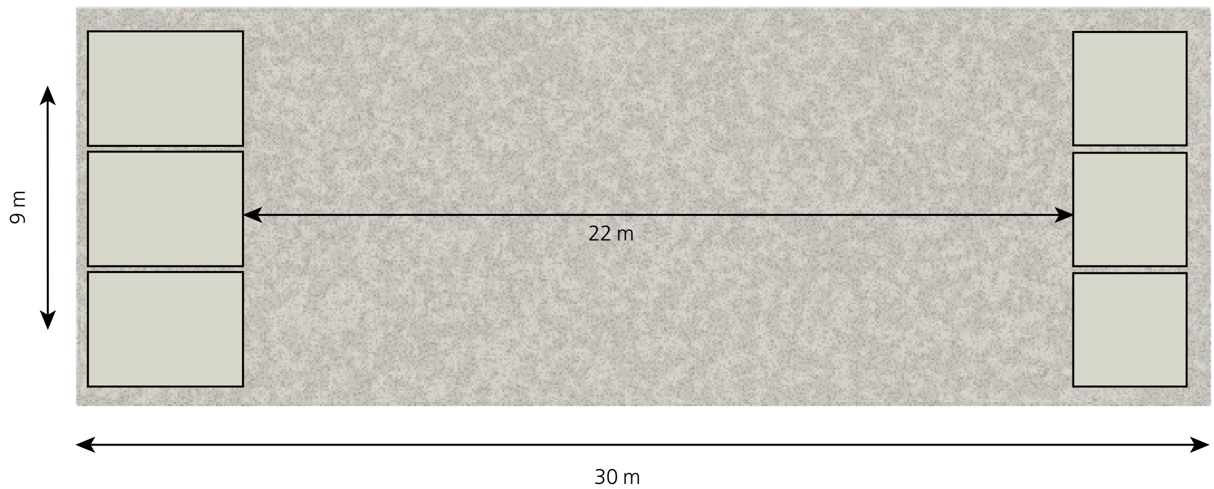


Figure 36: Widely space unprotected areas

Enclosing rectangle and unprotected percentage

The first set is to calculate the first limiting position of the boundary. If the space between the unprotected areas is more than four times the distance to the first limiting position then the areas can be considered separately.

The total unprotected area is 3 × (2 m × 6 m) + 3 × (2 m × 2 m) = 48 m². These can be contained in an enclosing rectangle 9 m high and 30 m wide. This gives an unprotected percentage of (100 × 48 m²) / (9 m × 30 m) = 18% (rounded up to 20%). For an industrial purpose group this gives a first limiting boundary distance of 5 m.

The gap between the unprotected areas (22 m) is therefore greater than four times the first limiting distance (4 × 5 m) and the unprotected areas can be considered as two groups.

The larger group has an area of 36 m² and can be contained in an enclosing rectangle 9 m high and 6 m wide giving an unprotected percentage of (100 × 36 m²) / (9 m × 6 m) = 66% (use 70%). This gives a minimum boundary distance of 6 m.

The smaller group has an area of 12 m² and can be contained in an enclosing rectangle 3 m wide and 9 m high giving an unprotected percentage of (100 × 12 m²) / (3 m × 9 m) = 44%. Table C gives boundary distances of 3 m for 40% and 3.5 m for 50%. A conservative approach is to take the higher value, however if the distance is critical in this case the values can be interpolated (using Equation 9) giving a minimum separation distance of 3.2 m.

A plan showing the final limiting boundary can then be drawn (Figure 37).

Case 6 Shallow recess

Description

Not all building elevations will be on one plane, recesses or bay windows can result in an elevation with a 'square wave' pattern. To simplify boundary distance calculations, recesses or setbacks of less than 1.5 m may be ignored (this gives a conservative result as some unprotected areas may be further from the boundary than the calculated position). An example is included here so that the more detailed calculation can justify this simplification (Figure 38).

The example uses an elevation with three identical unprotected areas 3 m wide and 2 m high spaced 1 m apart (horizontally) with the centre area recessed by 1.5 m.

Enclosing rectangle and unprotected percentage

Neglecting the recess, the total unprotected area is 3 × (2 m × 3 m) = 18 m² which can be contained in an enclosing rectangle 3 m high and 12 m wide giving an unprotected percentage of 18 m² / (3 m × 12 m) = 50%.

Boundary and separation distances

This gives a minimum boundary distance for a domestic or office purpose group of 2 m.

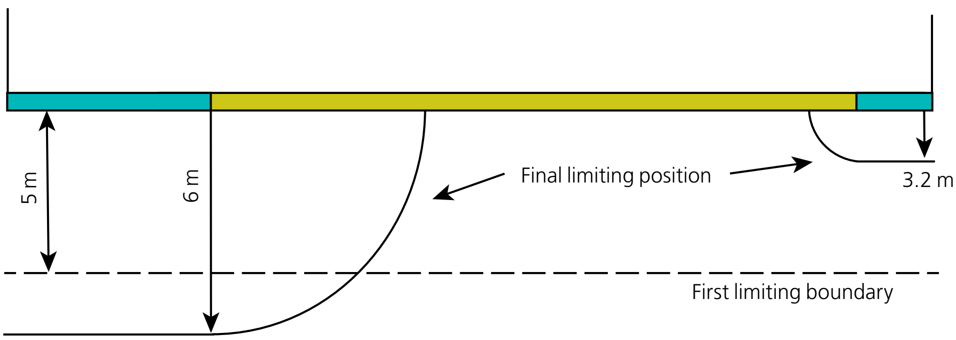


Figure 37: Minimum boundary location

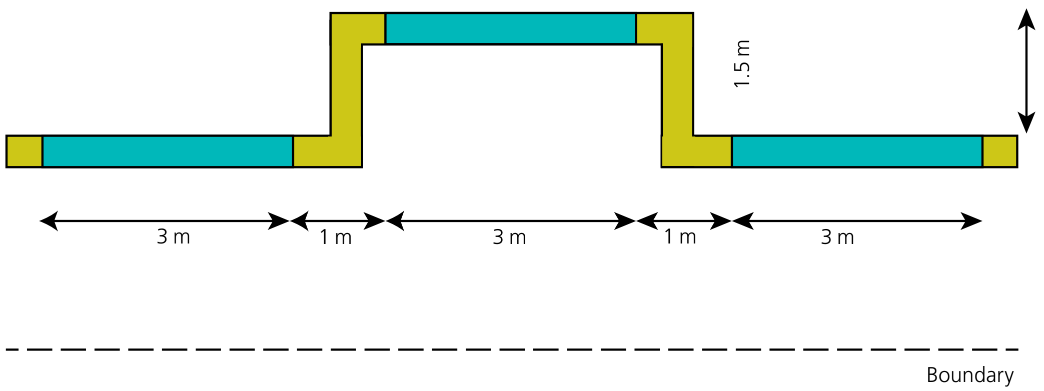


Figure 38: Shallow recess

Using configuration factor

The radiation intensity has been calculated across the elevation with and without a recess (Figure 39). This shows that ignoring the recess, for the purposes of calculating the minimum boundary distance, would result in a maximum radiation intensity of 10.8 kW/m^2 on an adjacent building located at the minimum boundary distance.

This demonstrates that assuming recesses or setbacks of up to 1.5 m in depth results in a slight overestimate of the minimum boundary distance, but the differences are within the variations of the calculation methods.

Case 7 Deep recess

Description

Case 6 showed that a shallow recess may not, in many cases, significantly affect the required boundary distance. However, for a large elevation with a deep recess the simple approach of neglecting the recess may not be unduly onerous (Figure 40).

If there are only unprotected areas in the rear wall of a recess then the calculation of the boundary distance can assume all the unprotected areas are on the same plane. A reduction factor (Equation 5) can be applied to the unprotected areas in the recess and the boundary distance recalculated so that the effect of the recess is included.

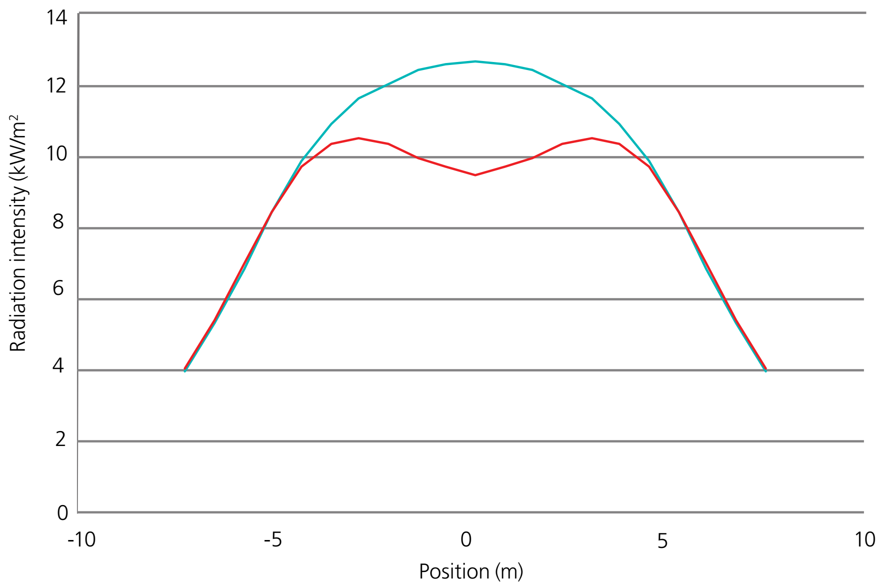


Figure 39: Radiation intensity across elevation with a shallow recess

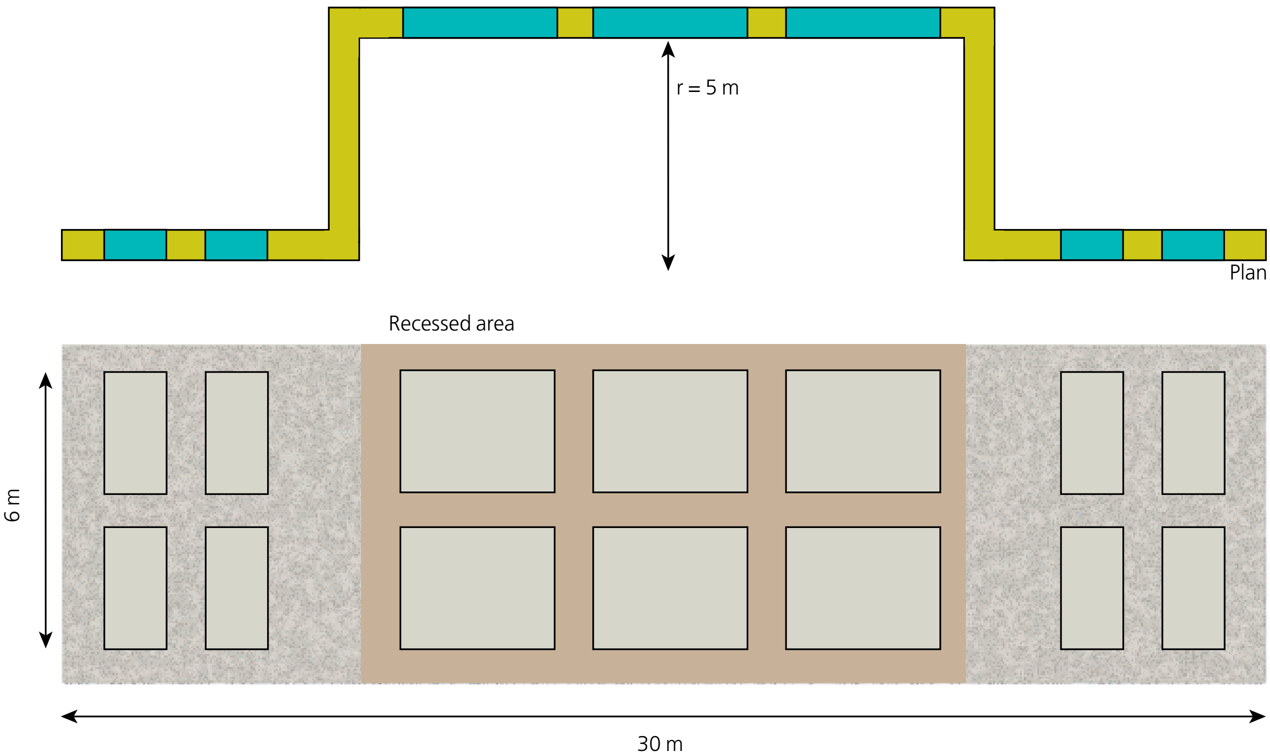


Figure 40: Elevation with a deep recess

The unprotected areas on each wing have an area of 14 m^2 and the unprotected areas on the recessed wall have an area of 44 m^2.

Enclosing rectangle and unprotected percentage

The total unprotected area on the elevation (wings plus recess) is (2 × 14 m^2) + 44 m^2 = 72 m^2. These can be enclosed in a rectangle 6 m high by 30 m wide. The unprotected percentage is therefore (100 × 72 m^2) / (6 m × 30 m) = 40%.

Boundary and separation distances

From data in Table B, this gives a boundary distance of 3.5 m before any consideration of the recess. The correction factor, R, to reduce the influence of the areas at the back of the recess can be found using Equation 5.

In this example:

$$R = \left[\frac{2\times3.5}{2\times3.5+5}\right]^2 = 0.34$$

The total unprotected area can now be modified to (2 × 14 m^2) + (0.34 × 44 m) = 43 m^2 and the unprotected percentage becomes (100 × 43 m^2) / (6 m × 30 m) = 23%.

And the corrected minimum boundary distance for the residential and office purpose group is 2.5 m (conservatively using the 30% column in Table B).

Case 8 Recess with unprotected areas on sides

Description

A deep recess is likely to have unprotected areas on three sides (Figure 41). In this case the radiation intensity is likely to be increased requiring a higher boundary distance. In this case the unprotected areas at the sides of the recess are not discounted and all the unprotected areas are considered to be on the plane of the front of the building.

The unprotected area on each wing and the rear of the recess is 26 m^2. The unprotected area on each side of the recess is 15 m^2.

Enclosing rectangle and unprotected percentage

The total unprotected area is therefore (3 × 26 m^2) + (2 × 15 m^2) = 108 m^2. The enclosing rectangle for the elevation is 9 m high by 30 m wide. The unprotected percentage is therefore (100 × 108 m^2) / (9 m × 30 m) = 40%.

Boundary and separation distances

Table C gives a boundary distance of 5 m for residential and office purpose groups or 9 m for other groups.

As the total unprotected area including those on the sides of the recess may be greater than the area of the building elevation, the unprotected percentage may be calculated to be greater than 100%. If this occurs the unprotected percentage should be limited to 100%.

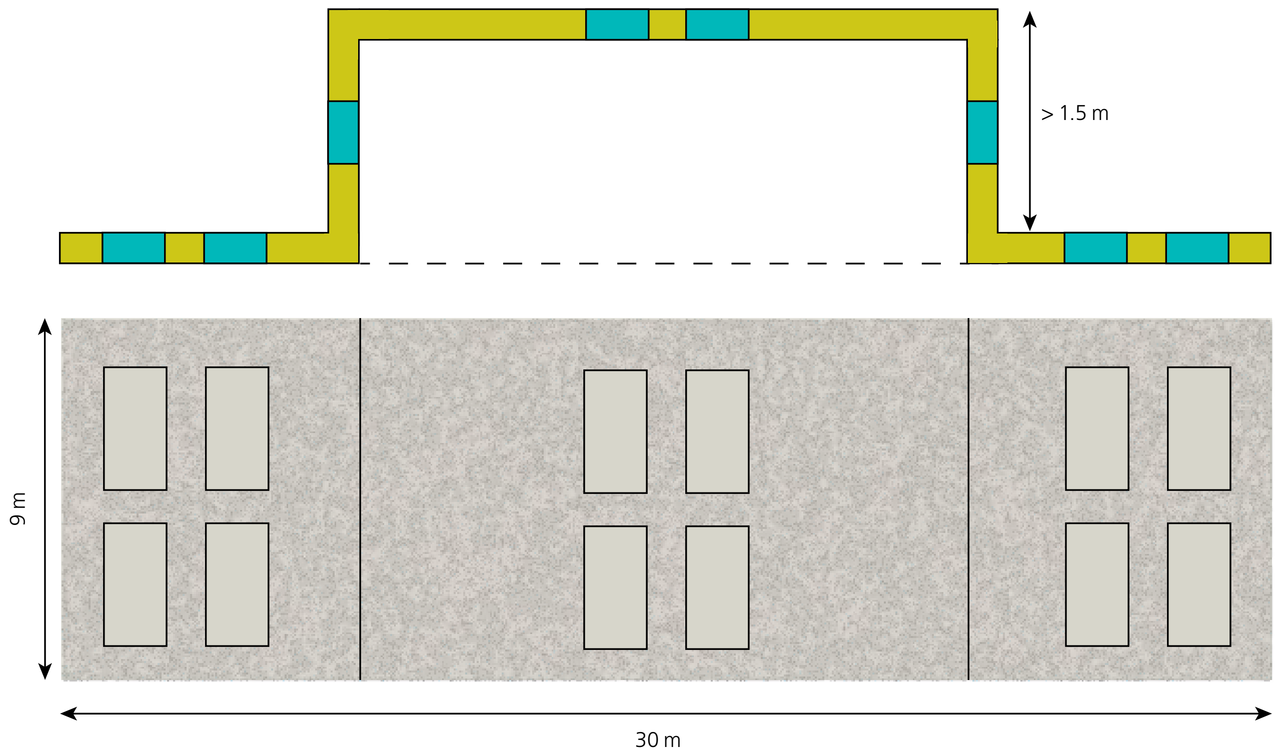


Figure 41: Recess with openings on the sides

Case 9 Setback

Description

Figure 42 shows an image of part of building elevation with a setback. The unprotected areas are shown in red.

Each unprotected area on the forward facing elevations is 2 m high and 4 m wide. The unprotected areas on the side elevation are 2 m wide by 2 m high. The vertical distance between the unprotected areas is 2 m. A plane and elevation are shown in Figure 43.

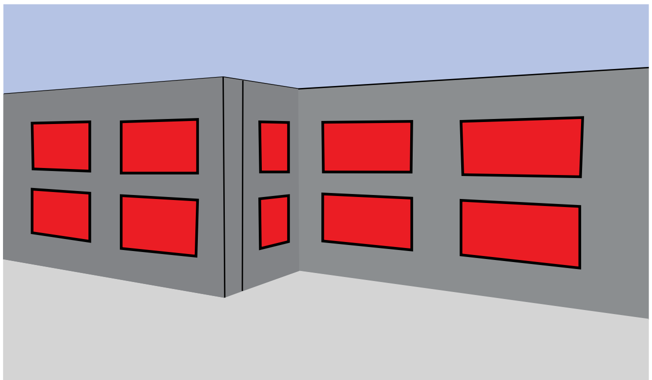


Figure 42: Building with a setback

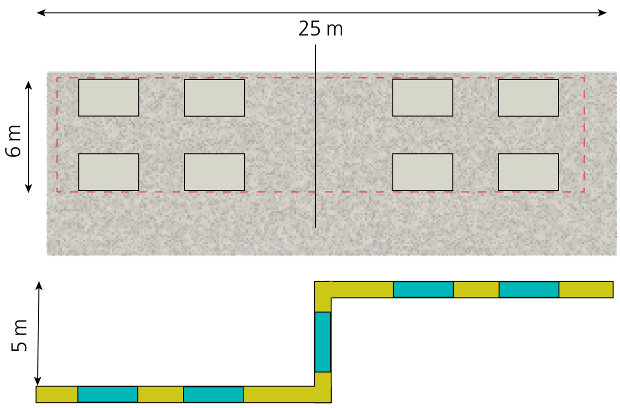


Figure 43: Building with a setback (plane and elevation)

Enclosing rectangle and unprotected percentage

The first step is to assume all the forward facing unprotected areas are on a plane of reference that is in line with the front of the elevation. The total unprotected area is 8 × 2 m × 4 m = 64 m^2. The enclosing rectangle (shown as a dotted red line in Figure 44) is 6 m high by 27 m wide giving an unprotected percentage of 40%, for residential or office purpose groups this gives a minimum boundary distance of 3.5 m.

The second step is to construct a second plane of reference across the diagonal of the setback.

The unprotected percentage of the 'line' BCDE is then assumed to lie along AE. The total unprotected area is (8 × 2 m × 4 m) + (2 × 2 m × 2 m) = 72 m^2. The length along AE is 25 m using Pythagoras's theorem. Therefore the enclosing rectangle is 6 m high by 27 m wide and the unprotected percentage is (100 × 72 m^2) / (6 m × 27 m) = 44%. From data in Table B this gives a boundary distance of 3.9 m by interpolation.

Boundary and separation distances

The green line on Figure 45 shows the location of the minimum boundary position across the corner of the setback.

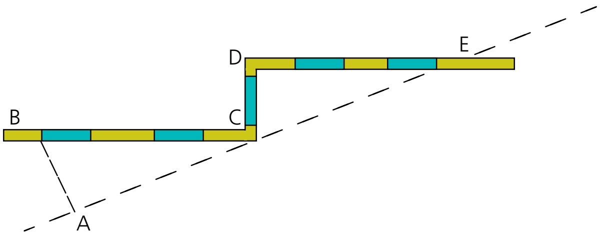


Figure 44: Plane of reference

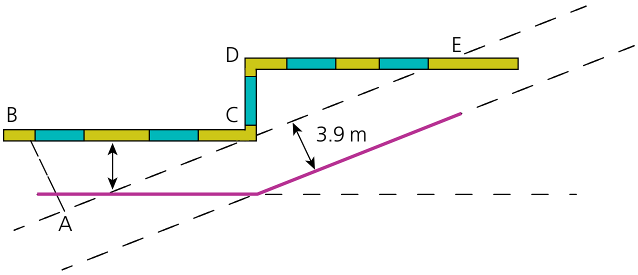


Figure 45: Setback showing minimum boundary location

4 Fire engineering approaches

4.1 Simple calculations

These calculations are referred to as being 'simple' because they can be evaluated using a calculator or spreadsheet, or maybe with reference to tables or charts. Publications such as BS 7974:2001 *Application of fire safety engineering principles to the design of buildings – Code of practice*[4] and the SFPE *Handbook of fire protection engineering*[60] include several equations for calculating compartment temperatures, for example flame shapes and temperatures and view factors, which can be used to analyse specific scenarios.

A particularly useful approach is to calculate the radiation intensity from a number of unprotected areas and plot the results, often as contours, where the critical radiation intensity for ignition (for example 12.6 kW/m²) occurs in the space around a building.

These are usually based on equations such as those in Appendix A. If the radiation intensity from a hot surface is calculated at a number of points then contour maps of radiation intensity around an object can be plotted. Figure 46 shows a plan view of two buildings; one of the elevations on the right-hand 'L-shaped' building has a number of unprotected areas. The radiation intensity from these unprotected areas has been calculated in the space between the buildings and a contour map created indicating the intensity of radiation. From the scale it can be seen that the adjacent building is on the edge of the 12.5 kW showing an acceptable building separation distance.

In some cases the radiation intensities for 'standard' and 'reduced' fire loads may not be considered to be appropriate. Correlations developed from the CIB data[30] are included in BS PD 7974-1[23] and provide a calculation for maximum compartment temperature that could be attained for different compartment sizes, ventilation conditions and fire loads (the correlation does not include the effect of compartment insulation).

$$T_{max}=6000\left(\frac{1-e^{-0.1\eta}}{\sqrt{\eta}}\right)\left(1-e^{-0.05\phi}\right) \quad \text{(Eqn 8)}$$

$$\eta=\frac{A_T}{A_w\sqrt{H_w}} = \text{Ventilation factor}$$

$$\phi=\frac{L}{\sqrt{A_wA_T}}=\text{Fire load factor}$$

Where:

A_T is the surface area of the compartment (less the floor and the openings), A_w the area of the opening, H_w the height of the opening and L the fire load.

There may also be situations where alternative critical radiation intensities, other than 12.6 kW/m², would be relevant and the calculation aids included here (Tables A to J) cannot be used.

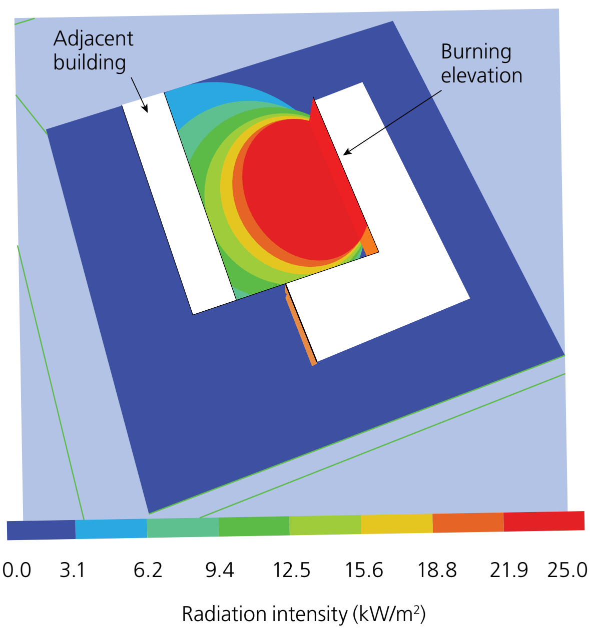


Figure 46: Setback showing minimum boundary location

4.2 Computer models

Computer fire simulation models may include predictions of radiation intensity. These may be useful for building separation calculations, however, the methods and assumptions used need to be understood.

4.2.1 Zone models

Zone model used for smoke control calculations often consider thermal radiation very simply by assuming a fraction of the total heat release of the fire is lost by radiation. This ensures the calculations of smoke temperature are not overestimated, but does not provide information for building separation calculations. Some computer zone models, such as CFAST[61], provide a calculation of the energy leaving a compartment at a window; further calculations would be required to use this to estimate its effect on an adjacent building.

4.2.2 Computational fluid dynamics models

Computational fluid dynamic (CFD) models may contain a number of options to calculate heat transfer by thermal radiation which range from simple approximations at the boundaries, such as the P1 model, to complex methods where radiation transfer is calculated along a number of paths from each cell face. This is an advanced area of fire safety engineering beyond the scope of this guide. However, it should be noted that CFD simulations usually provide a very detailed analysis of specific scenarios which may be used to quantify a particular hazard.

Appendix A: Transfer of heat by thermal radiation

Thermal radiation is the mechanism that causes energy from a hot surface to heat another surface at a distance, for example the heating of the Earth by energy from the sun. If the radiating surface is hot enough (over 550°C) then some of the radiation may be present as visible light and the surface will be seen to glow. The light emitted by a fire is part of the thermal radiation from hot, glowing soot particles in the flames.

Detailed explanations of the nature of thermal radiation can be found in most physics text books and Drysdale[26] gives an account in the context of fires.

The intensity of radiation, I_s, from a heated surface can be calculated from:

$$I_S = \sigma \varepsilon T^4 \text{ kW/m}^2 \qquad \text{(Eqn A1)}$$

Where:

σ Stefan Boltzmann constant (5.67×10^{-11} kW/m²/K⁴)

ε Emissivity of the radiating object

T Absolute temperature of the radiating object (K).

The emissivity (a value between 0 and 1) characterises how efficiently the surface behaves as a radiator. A surface blackened with soot or flames more than 1 m deep will have a high (approaching 1.0) emissivity, and flames from methanol fires are almost invisible, radiate little heat and have a very low emissivity.

The radiant energy travels away from the source (at the speed of light) in all directions and some may fall on other surfaces which will be heated. This is illustrated in Figure A1.

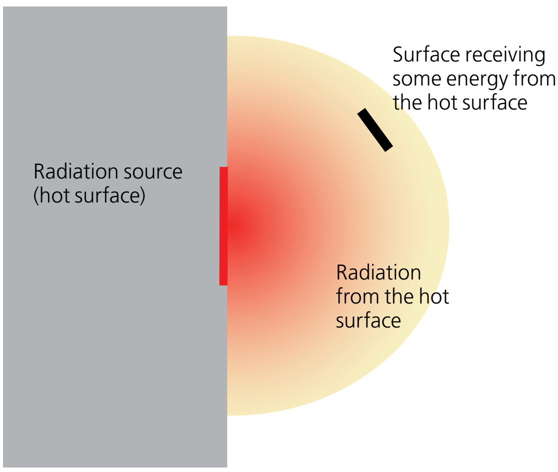


Figure A1: Radiation from a surface

The amount of energy received by a point on receiving surface depends on the area of the radiating surface, the relative position of the source and receiver and the direction the receiving surface is facing.

The radiation intensity at the receiving surface, I_S, can be written in terms of the intensity at the source, I_R, and a view (or configuration) factor:

$$I_R = \phi I_S \qquad \text{(Eqn A2)}$$

If the receiving surface is a very large distance from the source then the view factor will be a function of the square of the distance between the source and the receiver (the inverse square law). However, if the distance is similar to, or less than, the size of the source then the calculation of ϕ can be more complex. Expressions for some geometries can be found in text books[26], standards[45] and papers[62, 63]. Two geometries are considered here:

- parallel source and receiver: Separation distance calculations
- perpendicular source and receiver: Calculations involving roofs or return walls.

Parallel source and receiver: Separation distance calculations

For calculation of radiation transfer between buildings one of the most common scenarios is of a radiant surface with a parallel receiver (Figure A2). This is representative of thermal radiation from a window opening in a burning building being received on a facing wall of an adjacent building.

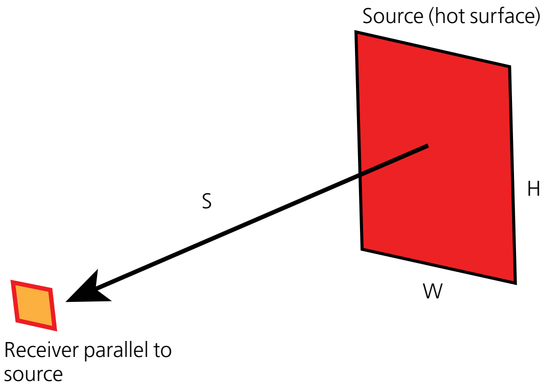


Figure A2: Parallel source and receiver: Centre

Setting:

$X=\frac{W}{2s}$ and $Y=\frac{H}{2s}$

The view factor ϕ is found from:

$$\phi=\frac{2}{\pi}\left(\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left(\frac{Y}{\sqrt{1+X^2}}\right)+\frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left(\frac{X}{\sqrt{1+Y^2}}\right)\right) \qquad \text{(Eqn A3)}$$

Equations A1, A2 and A3 can be used to calculate the maximum radiation intensity on a surface facing a radiating surface with a specified size, width (W) and height (H), and temperature T at a distance S.

It is important to note the temperature is the **absolute temperature** (°Kelvin ie °C + 273) and the inverse tangent function **MUST** be calculated in radians.

To calculate the radiation intensity at points which are not aligned with the centre of the source or to consider more complex shapes for the radiating surface, the calculation of a view factor for a point aligned with the corner of a rectangular source, Figure A3 can be used as a building block.

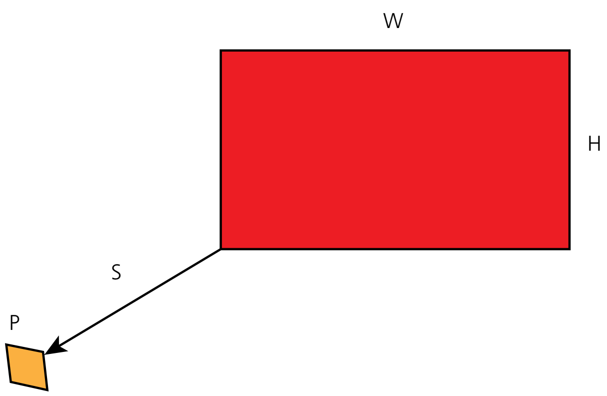


Figure A3: Parallel source and receiver: Corner

The view factor for a rectangle as seen from the corner (Figure 3 on page 4) can be found from:

$$\phi=\frac{1}{2\pi}\left(\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left(\frac{Y}{\sqrt{1+X^2}}\right)+\frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left(\frac{X}{\sqrt{1+Y^2}}\right)\right) \qquad \text{(Eqn A4)}$$

Where:

$X = W / S$ and $Y = H / S$

To find the configuration factor for a point facing the radiating surface, but not aligned with the centre, the radiator can be divided into four as shown in Figure A4 and Equation A4 used to calculate the view factor for each quarter (ϕABIH, ϕBCDI, ϕHIFG and ϕIDEF). The view factor, ϕ, for the whole shape can then be found from:

$$\phi = \phi_{ABIH} + \phi_{BCDI} - \phi_{HIFG} - \phi_{DEF}$$

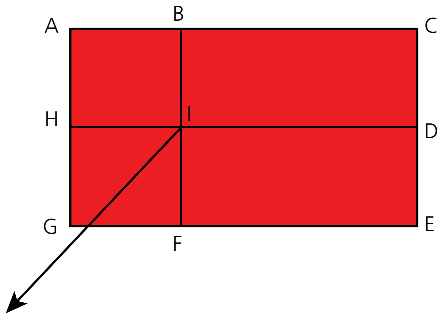


Figure A4: Parallel source and receiver: Off centre

The receiving point does not have to be directly opposite the radiating surface as the view factors may be subtracted as well as added. Figure A5 shows a radiating surface (in red) and dashed dummy shape to include the offset. The total view factor, ϕ is found from:

$$\phi = \phi_{ACDH} + \phi_{HDEG} - \phi_{ABIH} - \phi_{HIFG}$$

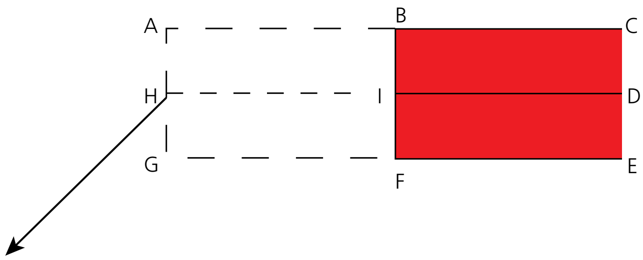


Figure A5: Parallel source and receiver: Not aligned

More complex shapes can be constructed and the view factors calculated by dividing the radiating surface into rectangles as shown in Figure A6.

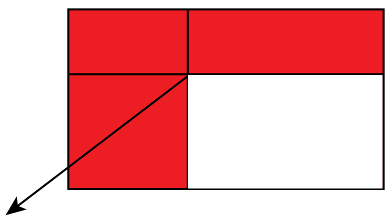


Figure A6: Parallel source and receiver: Complex shape

As an alternative to evaluating Equation A4, the view factor for a point aligned with the corner of a rectangular source can be estimated graphically from Figure A7.

From Figure A3, the ratio of the width (W) to height (H), N is found from N = W/H. The value of NH/S is then calculated and the view factor found from Equation A7.

Example

Consider a shop front 6 m wide and 3 m high. An estimate of the maximum radiation intensity on an adjacent building 7.5 m from the front of the shop is required assuming a temperature in the shop of 830°C. The view factor required in Equation A2 could be found directly from Equation A3, alternatively Figure A7 can be used by dividing the shop front into four (W = 3 m, H = 1.5 m) finding the ratio, N of the width to height (N = 3 m/1.5 m = 2) and then NH/S (2 × 1.5 m / 7.5 m = 0.4). From Figure A7 the view factor for a quarter of the radiator is approximately 0.022. Therefore the total view factor is 0.088 (considering the accuracy from reading values from the graph, it would be appropriate to round this value up to 0.09). Assuming thick flaming in the shop then ε = 1.0 and Equation A1 can be evaluated (T = 830 + 273 K) to give the radiation intensity at the shop front (84 kW/m²). Using Equation A2 gives the maximum radiation intensity at the adjacent building, 0.09 × 84 = 7.6 kW/m².

Perpendicular source and receiver: Roofs and return walls

It is also useful to be able to calculate the view factor for a receiving surface that is perpendicular to the radiating surface (Figure A8). This could be used to find the radiation intensity on a flat roof or a return wall. This would be relevant when considering, for example, a tall building next to a low building with a flat roof or some external fire spread issues such as ignition of cladding on a building adjacent to an unprotected area in a recess.

$$\phi = \frac{1}{2\pi}\left(\tan^{-1}(X) - \frac{1}{\sqrt{Y^2+1}}\tan^{-1}\left(\frac{X}{\sqrt{Y^2+1}}\right)\right) \quad \text{(Eqn A5)}$$

Where:

X = W / S and Y = H / S

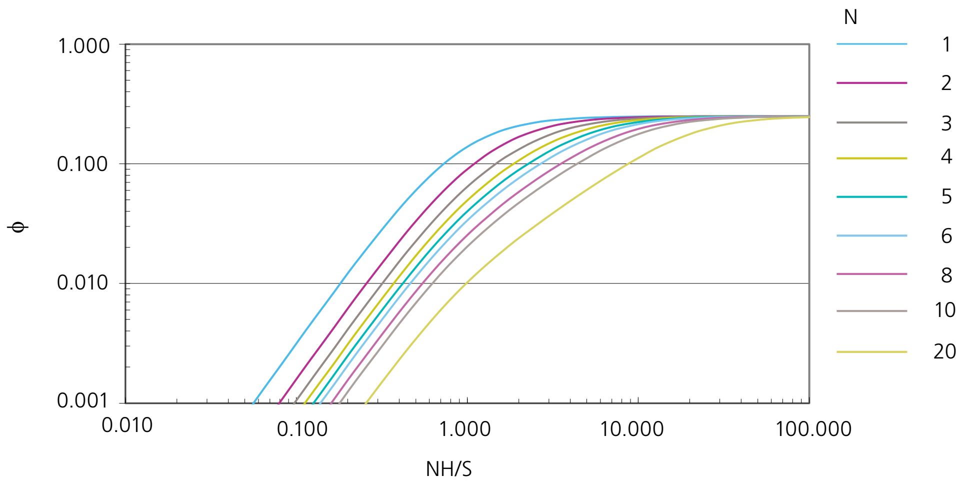


Figure A7: Calculation of configuration factor

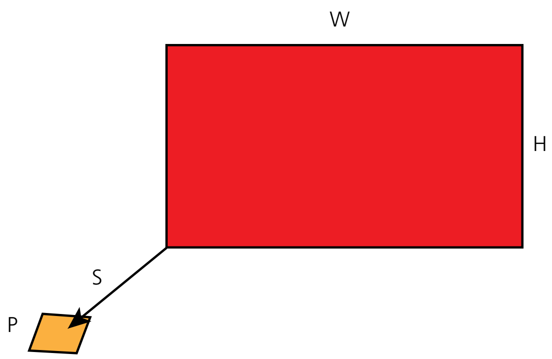


Figure A8: Perpendicular source and receiver: Corner

As an alternative to evaluating Equation A5 the view factor for a point aligned with the corner of a rectangular source can be estimated graphically using Figure A9. The ratio of the width (W) to height (H), N is found from N = W/H. The value of NH/S is then calculated and the view factor found from Figure A9.

Example

Figure A10 shows two office buildings, thermal radiation from a fire in a compartment in the taller building is received on the roof of the lower building.

The unprotected area, shown in red in Figure A10, in the tall building is 2.5 m high and 6 m wide and the distance between the buildings is 5 m. The view factor for half the area is found from Figure A8 with W = 3.0, H = 2.5 and S = 5.0. This gives N = W/H = 3.0 m/2.5 m = 1.5 and NH/S = 1.5*2.5 m/5 m = 0.75. Figure A9 gives a value of ~0.03 for half the view factor and therefore 0.06 for the whole unprotected area. If it is assumed that the flames in the office are thick then $\varepsilon = 1.0$ and Equation A1 can be evaluated (T = 830 + 273 K) to give the radiation intensity at the office front (84 kW/m^2). Equation A2 gives the maximum radiation intensity at the adjacent building, $0.06 \times 84 = 5.0$ kW/m^2.

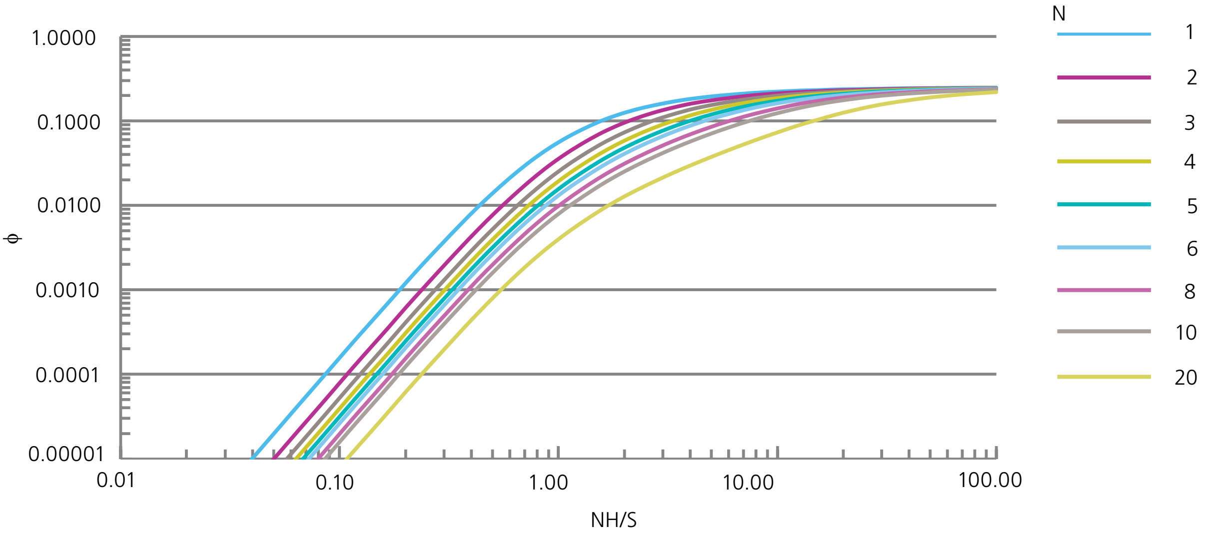


Figure A9: Calculation of configuration factor for perpendicular source and receiver

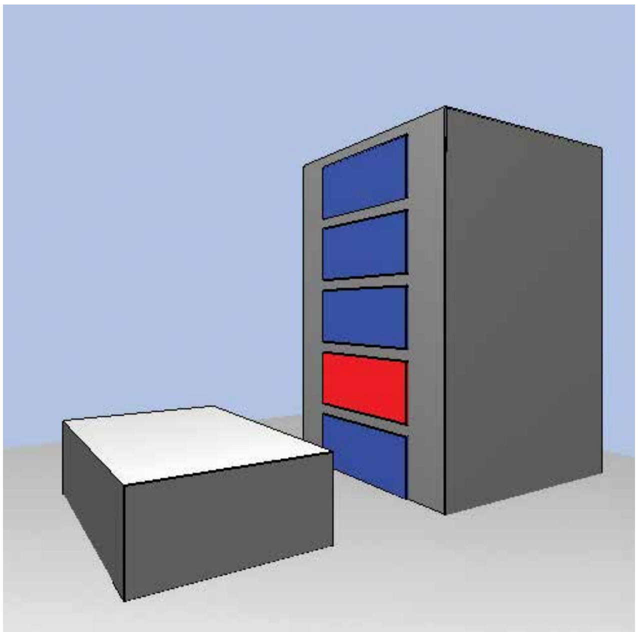


Figure A10: Radiation intensity on a roof from an adjacent tall building

Appendix B: External flaming

Flame projection from compartment openings

When the integrity of an unprotected area on the elevation of a building has failed there may be external flaming which could have an impact on the possibility of spread of fire between buildings. The extent of external flaming will depend on whether the combination of wind and the internal air paths in the burning building create a through, or forced, draught. In addition there will be some cases when the opening only provides an air inlet to the compartment. These cases are illustrated in Figure B1.

Calculation methods to estimate the extent of external flaming for these cases have been developed from work by Law and Kirby and are presented in Eurocode 1: *Actions and structures* BS EN 1991-1-2[45]. For many fire scenarios the 'no through or forced draught' case will apply as this represents a fire in a compartment with openings on only one elevation and the airflow required to create a through draught to another opening in the building is prevented (or restricted) by internal walls and partitions. The through draught scenarios will require at least two openings to the compartment in the building containing the fire; this may result from two integrity failures or a structure such as an open sided car park where there are openings to a single space on different building elevations. A through draft scenario can also be created by openings in a compartment at different heights such as a maisonette where a single (fire) compartment is divided into two levels.

In addition to the ventilation conditions in the compartment containing the fire, the extent of external flaming will depend on the presence of a wall and/or balcony/awning above the opening.

Flames from a compartment with no through or forced draught

Considering Figure B1, the thermal radiation from a compartment with a single opening and no through draft can be estimated by considering two radiating surfaces, one representing the opening to the compartment and the other representing the external flames. The radiation to any point can then be calculated using the method described in Appendix A.

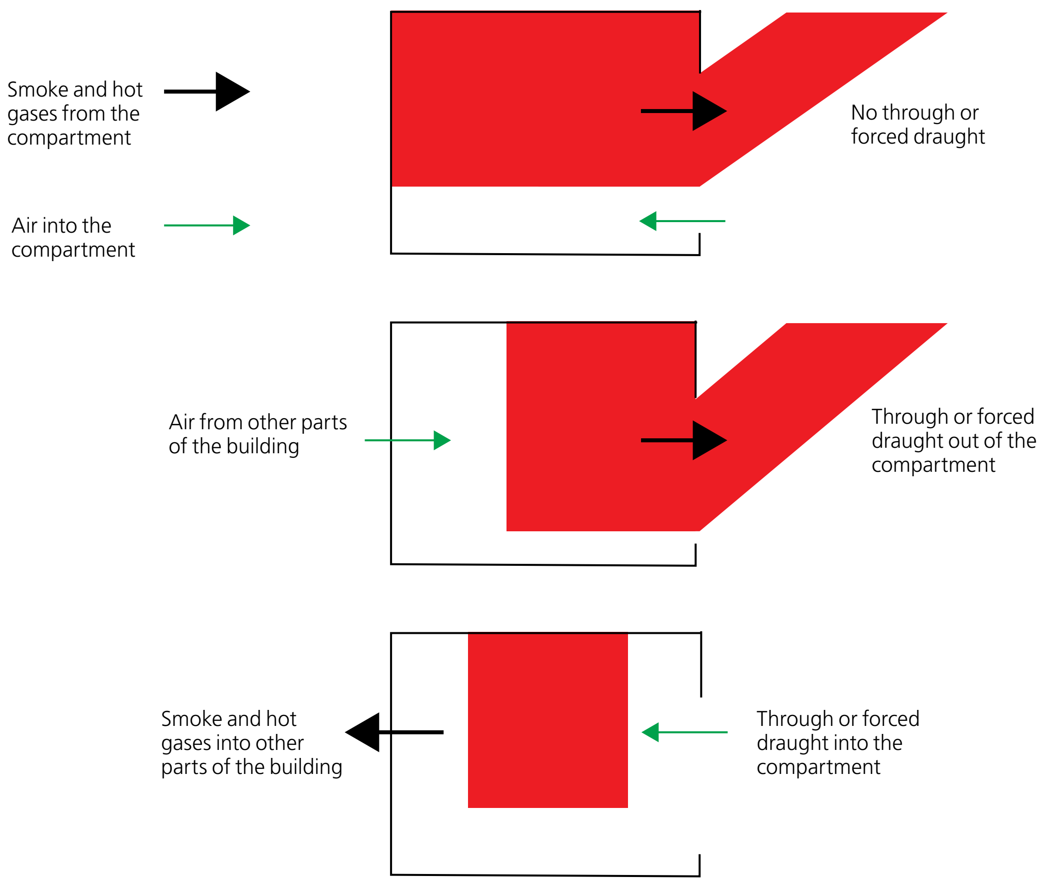


Figure B1: Conditions for external flaming

Figure B2 shows a vertical cross section of a schematic representation of flaming from an opening in a compartment containing a fire with no through draught and a wall above the opening. Figure B3 shows the equivalent radiating surfaces that can be used for building separation calculations.

For an opening with a width (W) and height (H), the distances on Figures B2 and B3 can be found using the expressions (from Eurocode 1[45]) given in Table B1.

Table B1 assumes that the height of the opening is less than 1.25 w. If the calculated value for H_{ef} is negative this indicates that there are no external flames.

The radiation intensity, I_R, at any point at a distance greater than X_{ef} from the opening can then be calculated using:

$$I_R = \varepsilon_o \phi_o I_S + \varepsilon_f \phi_f I_S \qquad \text{(Eqn B1)}$$

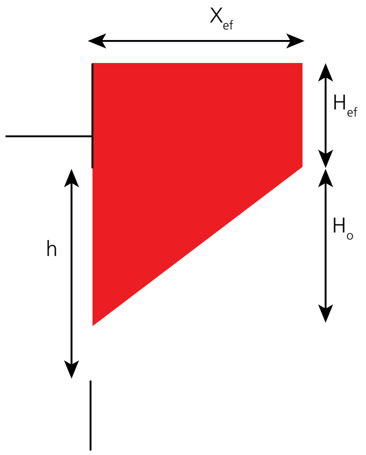


Figure B2: Flames from an opening

Table B1: Flame dimensions (no through draught)

Symbol	Description	Value
H_{ef}	Height of external flames above opening soffit (m)	$=1.9\left(\frac{Q}{w}\right)^{2/3}-h$
X_{ef}	Thickness of external flaming (m)	$=\frac{2}{3}h$
H_o	Height of flaming in opening (m)	$=\frac{2}{3}h$
Q	Fire heat release rate (MW)	$=\min\left(\frac{A_F L}{\tau}, 3.15\left(1-\exp\left(\frac{-0.036}{O}\right)\right)A_V\left(\frac{h}{D/W}\right)^{1/2}\right)$
A_F	Fire area (m²)	–
L	Fire load density (MJ/m²)	–
τ	Fire duration (s)	1200 s
O	Opening factor ($m^{1/2}$)	$=\frac{wh\sqrt{h}}{A_T}$
A_V	Opening area (m²)	=wh
D	Depth of compartment (m)	–
W	Width of compartment (m)	–
H	Height of compartment (m)	–
A_T	Surface area of enclosure including walls, floor, ceiling and openings (m²)	=2DW+2H(D+W)
ε_o	Emissivity of flames in opening	1.0
ε_f	Emissivity of external flames	$=1-\exp(-0.3X_{ef})$

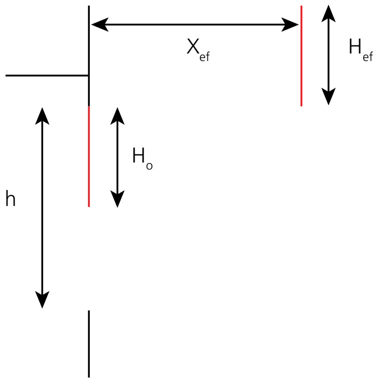


Figure B3: Radiating surfaces to represent external flaming

Where ϕ_o and ϕ_f are the view factors for the opening and the external flaming region from the adjacent building. I_s is the radiation intensity at the opening based on the fire load in the compartment (see Table 3 on page 7). It should be noted that applying the same value of I_s to the external flames and the compartment implies that the temperature of the external flaming region will be the same as inside the compartment; this will be an overestimate of the radiation intensity from the external flame as the external flame temperature will fall with the distance from the opening.

Figure B4 shows the calculated radiation intensity at distances from the centre of a 4 m wide by 2 m high window (for example a shop unit) calculated using:

- a single surface based on the window size (using equations from Appendix A)
- external flaming using surfaces as shown in Figure B2.

Both calculations show that the separation distance (ie the distance where the radiation intensity has fallen to 12.6 kW/m^2) is approximately 5 m; however, the calculation base on external flaming gives a lower radiation intensity indicating that a calculation based on the window size only would give a conservative result.

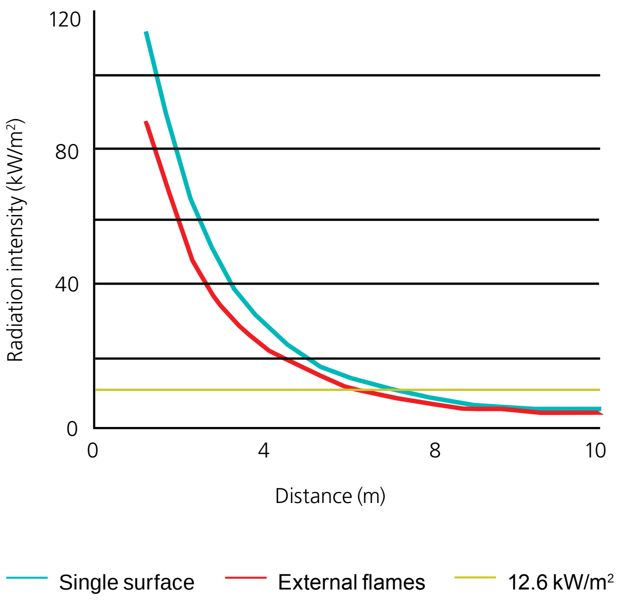


Figure B4: Corporating single radiator and external flaming (no through draft)

Flames from a compartment with a through draught

Figure B5 shows a schematic representation of flames projecting from a compartment with a through draught.

For an opening with a width (W) and height (H), the distances on Figure B5 can be found using the expressions (taken from Eurocode 1[45]) given in Table B2.

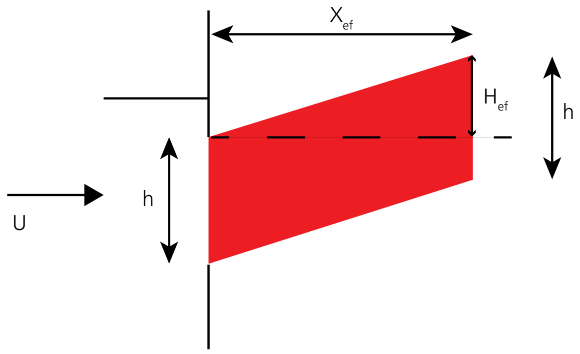


Figure B5: Flames from an opening with a through draught

For a 4 m (w) by 2 m (h) opening to a compartment with a fire having a heat release rate of 10 MW and a through draft of 6 m/s, the extent of the external flaming is:

- height of flames above soffit = 2.3 m
- projection from building elevation = 5.3 m.

This example shows that where a through draught is likely in a burning building, the resulting flame projection from an opening may reach an adjacent building if the separation distance was determined without considering external flaming.

For the case of a fire in a compartment with a through or forced draught heating an adjacent building, consideration should be given to radiated heat from the compartment opening and radiated and convected heat from the external flames. The height of the external flames and the flame projection from the building elevation will indicate if these factors are significant to the separation of buildings under consideration and in which case the adjacent building could be considered as an external structural element and the procedures in Eurocode 1[45] or BS PD 7974-3[45] followed.

Table B2: Flame dimensions (with through draught)

Symbol	Description	Value
h_{ef}	Height of external flames above opening soffit (m)	
X_{ef}	Flame projection from building elevation (m)	$=0.605\left(\frac{U^2}{h}\right)^{0.22}(h_{ef}+h)$
U	Velocity of through or forced draught (m/s)	Taken as 6 m/s unless otherwise known
ε_o	Emissivity of flames in opening	1.0
A_v	Opening area (m^2)	=wh
Q	Fire heat release rate (MW)	$\frac{A_F L}{\tau}$
A_F	Fire area (m^2)	–
L	Fire load density (MJ/m^2)	–
τ	Fire duration (s)	1200 s

Appendix C: Evolution of ‘simple’ methods in Approved Document B

Section 2.6.3 of the *Technical handbook – Domestic*[5] describes the ‘simple geometry method’ which is equivalent to Method 1 in Approved Document B:

> *Where the external wall of a building is more than 1m from the boundary the amount of unprotected area (in square metres) may be equivalent to six times the distance (in metres) to the boundary. Therefore if the distance to the boundary is at least 1m, the unprotected area should not exceed 6m², if the distance to the boundary is at least 2m the unprotected area is 12m², and so on.*
>
> *Where the external wall of a building is more than 6m from the boundary the amount of unprotected area is unlimited.*
>
> *The use of the simple geometry method described above is limited to buildings which are more than 1m from the boundary, not more than 9m in height and the length of the side of the building facing the boundary is not more than 24m.*

The Building Regulations 2010. Approved Document B *Fire safety*, 2013 edition[7]

Note: There are further considerations if the building is not parallel to the boundary.

In summary the simple geometry method could be written as follows:

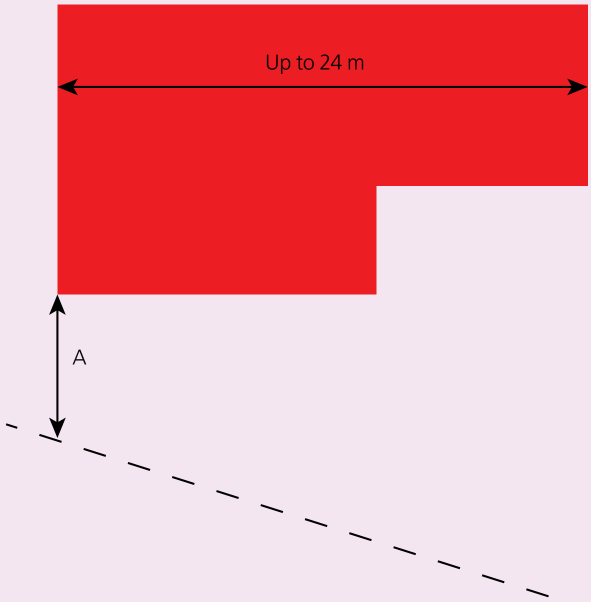
For buildings with elevations up to 9 m high and 24 m wide, the total of the unprotected areas, U, on the building elevations should be:

IF $(A > 1 \text{ and } A < 6)\ U = 6 \times A\ m^2$

IF $(A > 6)$ U = unlimited unprotected area

Where:

A is the minimum distance between the building and the boundary.



Minimum distance (A) between side of building and relevant boundary (m)	Maximum total area of unprotected areas, U (m^2)
1	5.6
2	12
3	18
4	24
5	30
6	No limit

Figure C1: The simple geometry method

Origins of the method

The 2013 edition of Approved Document B *Fire safety*. Volume 1 *Dwellinghouses*[7] of the Building Regulations 2010 (England and Wales) presents the same calculation in the form of a diagram (diagram 22); this is referred to as Method 1 and applies to buildings up to three stories (9 m) (Figure C1).

This method first appeared in the *Technical standards for compliance with the Building Standards (Scotland) Regulations 1990* (D6.3)[64] and in the 1992 edition of Approved Document B[15] as diagram 41.

In the 1985 edition of Approved Document B[14] and 1972 edition of The Building Regulations[12], the table of values was slightly different to that shown in Table C1.

Table C1 appeared in the 1972 edition of The Building Regulations (Schedule 9, Part IV)[12] where the simple geometry method seems to have been presented for the first time.

No description or analysis of the simple geometry method in the *Technical handbook – Domestic*[5] or the equivalent Method 1 in Approved Document B[7] has been found in any research report or paper, although the figure of 5.6 m^2 used in early versions of the method suggest it could have been linked to experimental work conducted at the Fire Research Station in 1968 which included tests with a window of that size.

Table C1: Method 1 Approved Document B (1985 edition)[14] and The Building Regulations 1972[12]

Minimum distance (A) between side of building and relevant boundary (m)	Maximum length of side (m)	Maximum total area of unprotected areas, U (m^2)
1	24	5.6
2.5	24	15
5	12	No limit
6.0	24	No limit

Evolution of the method

Figures C2a to C2c illustrate the development of the table (see Table C1) used with Method 1 from the version presented in the 1972 edition of the Building Regulations[12], to the table in the 2006 edition of Approved Document B[8].

Figure C2a shows the original two values in the Method 1 version of the 1972 Building Regulations[12]. For the 1992 edition of Approved Document B[15] the number of values in the table was increased by interpolating between the original values (Figure C2b) and then extrapolating (Figure C2c).

Figure C2c shows the values used in the 2006 edition of Approved Document B[8]. The simple geometry method, described in the *Technical handbook – Domestic*[5], has rounded up the maximum unprotected area corresponding to a boundary distance of 1 m from 5.6 m^2 to 6 m^2 and now specifies that the maximum unprotected area should be six times the boundary distance up to 6 m after which there is no limit.

Checking the methods

In Table C2 the accuracy of the simple geometry method has been checked by using the distances and areas from Figure C1 to calculate the configuration factor, ϕ, which should not be greater than 0.15 for domestic premises (assuming the radiation intensity at each unprotected area is 84 kW/m^2). The calculations have used Equation A3 from Appendix A and assumed a square unprotected area.

Table C2 shows that the simple geometry method in the *Technical handbook – Domestic*[5] and Method 1 in the 1972 edition of Approved Document B[12] is not based on a critical view factor of 0.15 and may not therefore be consistent with other methods such as the enclosing rectangles method.

Table C2: Configuration factors for current version of the simple method

Boundary distance (m)	Maximum total unprotected area (m^2)	Separation distance (m)	View factor (ϕ)
1	5.6	2	0.305
2	12	4	0.191
3	18	6	0.136
4	24	8	0.106
5	30	10	0.087

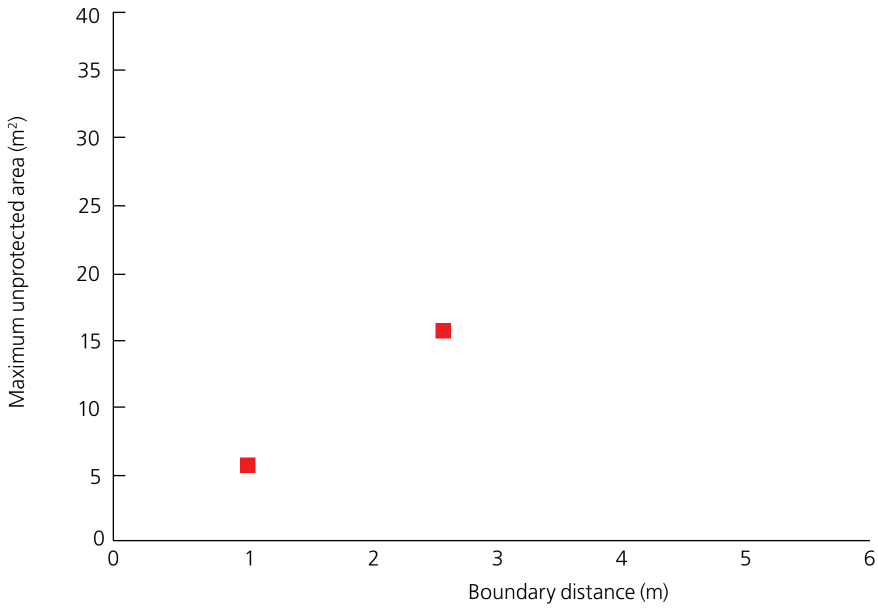


Figure C2a: Original 1972 values

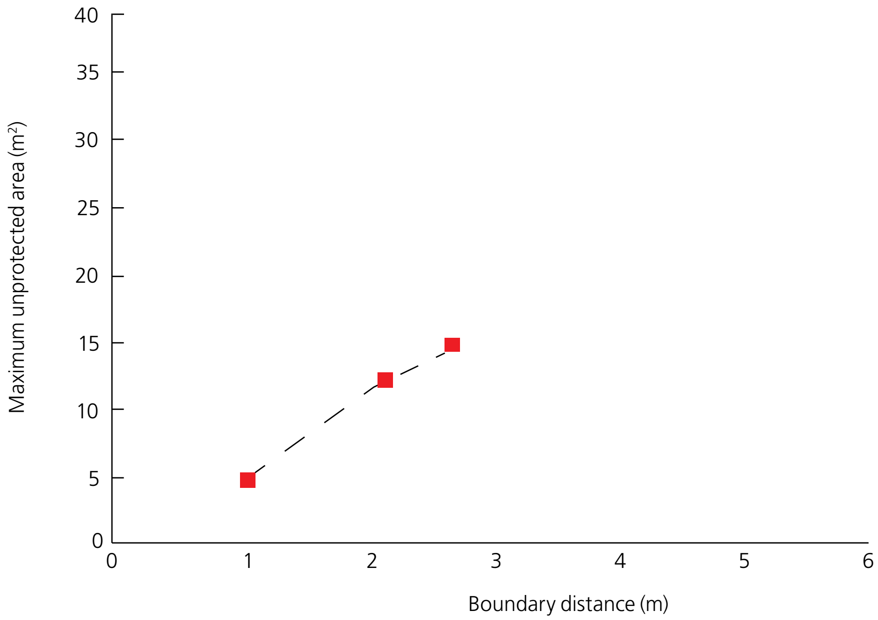


Figure C2b: Interpolation to obtain unprotected area for boundary distance of 2 m

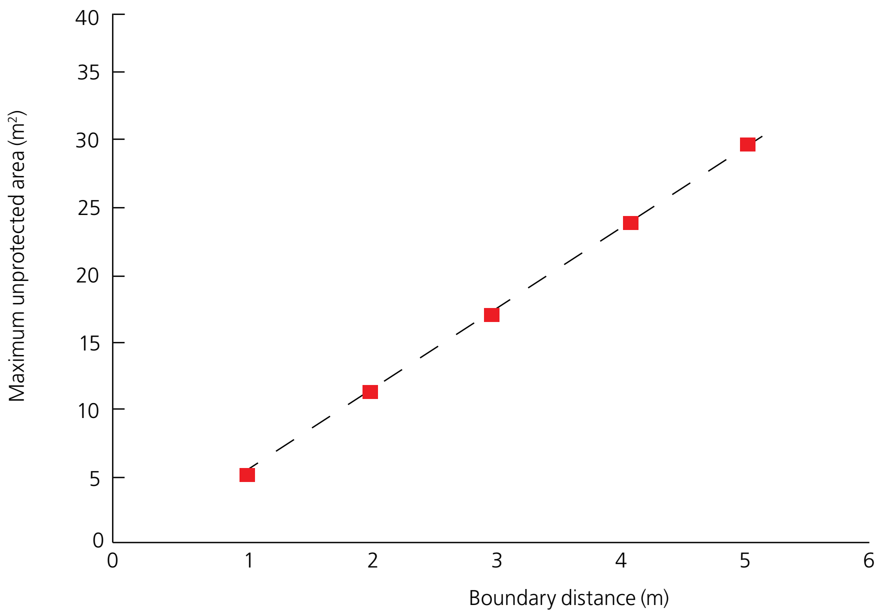


Figure C2c: Extrapolation to obtain unprotected areas for boundary distances greater than 3 m

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Tables for calculations

Interpolation

In most cases, the calculated unprotected area will not be an exact value that is given in a selected table (for example 40%). As a safe, first approximation the value can be rounded up to the next value on the table (for example if the calculated value is 46%, the 50% column should be used). However, this is a cautious approach; intermediate values can be found by interpolation using.

Where:

$$D=D_l+\frac{(U-U_L)}{10}(D_H-D_L) \quad \text{(Eqn 9)}$$

U is the calculated unprotected percentage, U_L the column value below U, D_L the distance from the table corresponding to U_L and D_H the distance from the table of the unprotected percentage column above U. The resulting value D is the intermediate distance.

For example, for an enclosing rectangle 9 m high and 27 m wide an unprotected percentage of 54% has been calculated. Rounding up to 60% for an industrial purpose group gives a separation distance of 11 m. The distance for an unprotected area of 50% is 10 m. Using the equation above to interpolate gives:

$$D=10.0+\frac{54-50}{10}(11.0-10.0)=10.4\ \text{m}$$

Unprotected areas less than 20% should be rounded up to 20%. For an elevation to have an unprotected percentage this low it may be more accurate to consider each unprotected area as a local concentration of exposure hazard.

The tables

Table 1 from the first edition of BR 187[1] has been split into 10 pages (on pages 47 to 56) as Tables A to J, so that each enclosing rectangle height is on a separate page. This allows the relevant page to be copied, annotated and added to other calculation sheets relating to a project.

Tables A to J on the following pages show the permitted unprotected percentages in relation to enclosing rectangles.

Table A: Enclosing rectangle 3 m high

	Distance from relevant boundary for unprotected percentage not exceeding								
Width	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)	Figures in brackets for residential, office and assembly uses								
3.0	1.0 (1.0)	1.5 (1.0)	2.0 (1.0)	2.0 (1.5)	2.0 (1.5)	2.5 (1.5)	2.5 (2.0)	3.0 (2.0)	3.0 (2.0)
6.0	1.5 (1.0)	2.0 (1.0)	2.5 (1.5)	3.0 (1.5)	3.0 (2.0)	3.5 (2.0)	3.5 (2.5)	4.0 (2.5)	4.0 (3.0)
9.0	1.5 (1.0)	2.5 (1.0)	3.0 (1.5)	3.5 (2.0)	3.5 (2.5)	4.0 (2.5)	4.5 (3.0)	4.5 (3.0)	5.0 (3.5)
12.0	1.5 (1.0)	2.5 (1.0)	3.0 (1.5)	3.5 (2.0)	4.0 (2.5)	4.5 (3.0)	5.0 (3.0)	5.5 (3.5)	5.5 (3.5)
15.0	2.0 (1.0)	2.5 (1.5)	3.5 (2.0)	4.0 (2.0)	4.5 (2.5)	5.0(3.0)	5.5 (3.5)	6.0 (3.5)	6.0 (4.0)
18.0	2.0 (1.0)	2.5 (1.5)	3.5 (2.0)	4.0 (2.5)	5.0 (2.5)	5.5 (3.0)	6.0 (3.5)	6.5 (4.0)	6.5 (4.0)
21.0	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	5.5 (3.0)	6.0 (3.5)	6.5 (4.0)	7.0 (4.5)
24.0	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	6.0 (3.0)	6.5 (3.5)	7.0 (4.0)	7.5 (4.5)
27.0	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.5 (2.5)	5.5 (3.0)	6.0 (3.5)	6.5 (3.5)	7.0 (4.0)	7.5 (4.5)
30.0	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	4.5 (2.5)	5.5 (3.0)	6.0 (3.5)	7.0 (4.0)	7.5 (4.0)	8.0 (4.5)
40.0	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	5.5 (3.0)	6.5 (3.5)	7.0 (4.0)	8.0 (4.5)	8.5 (5.0)
50.0	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	6.5 (3.5)	7.5 (4.0)	8.5 (4.5)	9.0 (5.0)
60.0	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	7.0 (3.5)	7.5 (4.0)	8.5 (4.5)	9.5 (5.0)
80.0	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	7.0 (3.5)	8.0 (4.0)	8.5 (4.5)	9.5 (5.0)
100.0	2.0 (1.0)	3.0(1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	7.0 (3.5)	8.0 (4.0)	9.0 (4.5)	10.0 (5.0)
120.0	2.0(1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	7.0 (3.5)	8.0 (4.0)	9.0 (4.5)	10.0 (5.0)
130.0	2.0(1.0)	3.0 (1.5)	4.0 (2.0)	5.0 (2.5)	6.0 (3.0)	7.0 (3.5)	8.0 (4.0)	9.0 (4.5)	10.0 (5.0)

Notes

Table B: Enclosing rectangle 6 m high

	Distance from relevant boundary for unprotected percentage not exceeding								
Width	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)	Figures in brackets for residential, office and assembly uses								
3.0	1.5 (1.0)	2.0 (1.0)	2.5 (1.5)	3.0 (1.5)	3.0 (2.0)	3.5 (2.0)	3.5 (2.5)	4.0 (2.5)	4.0 (3.0)
6.0	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.0 (2.5)	4.5 (3.0)	5.0 (3.0)	5.5 (3.5)	5.5 (4.0)	6.0 (4.0)
9.0	2.5 (1.0)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	5.5 (3.5)	6.0(4.0)	6.5 (4.5)	7.0 (4.5)	7.5 (5.0)
12.0	3.0 (1.0)	4.0 (2.0)	5.0 (3.0)	5.5 (3.5)	6.0 (4.0)	7.0 (4.5)	7.5 (5.0)	8.0 (5.0)	8.5 (5.5)
15.0	3.0 (1.5)	4.5 (2.5)	5.5 (3.0)	6.0 (4.0)	7.0 (4.5)	7.5 (5.0)	8.0 (5.5)	8.5 (5.5)	9.0 (6.0)
18.0	3.5 (1.5)	4.5 (2.5)	5.5 (3.5)	6.5 (4.0)	7.5 (4.5)	8.0 (5.0)	9.0 (5.5)	9.5 (6.0)	10.0 (6.5)
21.0	3.5 (1.5)	5.0 (2.5)	6.0 (3.5)	7.0 (4.0)	8.0 (5.0)	8.5 (5.5)	9.5 (6.0)	10.0 (6.5)	10.5 (7.0)
24.0	3.5 (1.5)	5.0 (2.5)	6.5 (3.5)	7.5 (4.5)	8.5 (5.0)	9.0 (5.5)	10.0 (6.0)	10.5 (7.0)	11.5 (7.5)
27.0	3.5 (1.5)	5.0 (2.5)	6.5 (3.5)	7.5 (4.5)	8.5 (5.0)	9.5 (6.0)	10.5 (6.5)	11.0 (7.0)	12.0 (7.5)
30.0	3.5 (1.5)	5.5 (2.5)	6.5 (3.5)	8.0 (4.5)	9.0 (5.0)	10.0 (6.0)	11.0 (6.5)	11.5 (7.5)	12.5 (8.0)
40.0	3.5 (1.5)	5.5 (2.5)	7.0 (3.5)	8.5 (4.5)	10.0 (5.5)	11.0 (6.5)	12.0 (7.0)	13.0 (8.0)	14.0 (8.5)
50.0	3.5 (1.5)	5.5 (2.5)	7.5 (3.5)	9.0 (4.5)	10.5 (5.5)	11.5 (6.5)	13.0 (7.5)	14.0 (8.0)	15.0 (9.0)
60.0	3.5 (1.5)	5.5 (2.5)	7.5 (3.5)	9.0 (4.5)	11.0 (5.5)	12.0 (6.5)	13.5 (7.5)	15.0 (8.5)	16.0 (9.0)
80.0	3.5 (1.5)	6.0 (2.5)	7.5 (3.5)	9.5 (4.5)	11.5 (5.5)	13.0 (6.5)	14.5 (7.5)	16.0 (8.5)	17.0 (9.5)
100.0	3.5(1.5)	6.0 (2.5)	8.0 (3.5)	9.5 (4.5)	11.5 (6.0)	13.5 (7.0)	15.0 (8.0)	16.5 (8.5)	18.0 (9.5)
120.0	3.5 (1.5)	6.0 (2.5)	8.0 (3.5)	10.0 (5.0)	11.5 (6.0)	13.5 (7.0)	15.5 (8.0)	17.0 (9.0)	18.5 (9.5)
130.0	3.5 (1.5)	6.0 (2.5)	8.0 (3.5)	10.0 (5.0)	11.5 (6.0)	13.5 (7.0)	15.5 (8.0)	17.0 (9.0)	19.0 (10.0)

Notes

Table C: Enclosing rectangle 9 m high

	Distance from relevant boundary for unprotected percentage not exceeding								
Width	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)	Figures in brackets for residential, office and assembly uses								
3.0	1.5 (1.0)	2.5 (1.0)	3.0 (1.5)	3.5 (2.0)	3.5 (2.5)	4.0 (2.5)	4.5 (3.0)	4.5 (3.0)	5.0 (3.5)
6.0	2.5 (1.0)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	5.5 (3.5)	6.0 (4.0)	6.5 (4.5)	7.0 (4.5)	7.5 (5.0)
9.0	3.5 (1.5)	4.5 (2.5)	5.5 (3.0)	6.0 (4.0)	6.5 (4.5)	7.5 (5.0)	8.0 (5.5)	8.5 (5.5)	9.0 (6.0)
12.0	3.5 (1.5)	5.0 (3.0)	6.0 (3.5)	7.0 (4.5)	7.5 (5.0)	8.5 (5.5)	9.0 (6.0)	9.5 (6.5)	10.5 (7.0)
15.0	4.0 (1.5)	5.5 (3.0)	6.5 (4.0)	7.5 (5.0)	8.5 (5.5)	9.5 (6.0)	10.0 (6.5)	11.0 (7.0)	11.5 (7.5)
18.0	4.5 (2.0)	6.0 (3.5)	7.5 (4.5)	8.5 (5.0)	9.5 (6.0)	10.0 (6.5)	11.0 (7.0)	12.0 (8.0)	12.5 (8.5)
21.0	4.5 (2.0)	6.5 (3.5)	7.5 (4.5)	9.0 (5.5)	10.0 (6.5)	11.0 (7.0)	12.0 (7.5)	12.5 (8.5)	13.5 (9.0)
24.0	5.0 (2.0)	6.5 (3.5)	8.0 (4.5)	9.5 (6.0)	10.5 (6.5)	11.5 (7.5)	12.5 (8.0)	13.5 (9.0)	14.5 (9.5)
27.0	5.0 (2.0)	7.0 (3.5)	8.5 (5.0)	10.0 (6.0)	11.0 (7.0)	12.0 (7.5)	13.0 (8.5)	14.0 (9.0)	15.0 (10.0)
30.0	5.0 (2.0)	7.0 (3.5)	9.0 (5.0)	10.5 (6.0)	11.5 (7.0)	12.5 (8.0)	14.0 (9.0)	15.0 (9.5)	15.5 (10.5)
40.0	5.5 (2.0)	7.5 (4.0)	9.5 (5.0)	11.5 (6.5)	13.0 (7.5)	14.5 (8.5)	15.5 (9.5)	16.5 (10.5)	18.0 (11.5)
50.0	5.5 (2.0)	8.0 (4.0)	10.5 (5.5)	12.0 (6.5)	14.0 (8.0)	15.5 (9.0)	17.0 (10.0)	18.0 (11.0)	19.5 (12.0)
60.0	5.5 (2.0)	8.0 (4.0)	10.5 (5.5)	13.0 (7.0)	14.5 (8.0)	16.5 (9.5)	18.0 (10.5)	19.5 (11.5)	21.0 (13.0)
80.0	5.5 (2.0)	8.5 (4.0)	11.0 (5.5)	13.5 (7.0)	16.0 (8.5)	18.0 (10.0)	19.5 (11.0)	21.5 (12.5)	23.0 (13.5)
100.0	5.5 (2.0)	8.5 (4.0)	11.5 (5.5)	14.0 (7.0)	16.5 (8.5)	18.5 (10.0)	21.0 (11.5)	23.0 (12.5)	24.5 (14.0)
120.0	5.5 (2.0)	8.5 (4.0)	11.5 (5.5)	14.5 (7.0)	17.0 (8.5)	19.5 (10.0)	21.5 (11.5)	24.0 (13.0)	26.0 (14.5)
130.0	5.5 (2.0)	8.5 (4.0)	11.5 (5.5)	14.5 (7.0)	17.0 (8.5)	19.5 (10.0)	22.0 (11.5)	24.0 (13.0)	26.5 (14.5)

Notes

Table D: Enclosing rectangle 12.0m high

	Distance from relevant boundary for unprotected percentage not exceeding								
Width	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)	Figures in brackets for residential, office and assembly uses								
3.0	1.5 (1.0)	2.5 (1.0)	3.0 (1.5)	3.5 (2.0)	4.0 (2.5)	4.5 (3.0)	5.0 (3.0)	5.5 (3.5)	5.5 (3.5)
6.0	3.0 (1.0)	4.0 (2.0)	5.0 (3.0)	5.5 (3.5)	6.0 (4.0)	7.0 (4.5)	7.5 (5.0)	8.0 (5.0)	8.5 (5.5)
9.0	3.5 (1.5)	5.0 (3.0)	6.0 (3.5)	7.0 (4.5)	7.5 (5.0)	8.5 (5.5)	9.0 (6.0)	9.5 (6.5)	10.5 (7.0)
12.0	4.5 (2.0)	6.0 (3.5)	7.0 (4.5)	8.0 (5.0)	9.0 (6.0)	10.0 (6.5)	10.5 (7.0)	11.0 (7.5)	12.0 (8.0)
15.0	5.0 (2.0)	6.5 (3.5)	8.0 (5.0)	9.0 (5.5)	10.0 (6.5)	11.0 (7.0)	11.5 (8.0)	12.5 (8.5)	13.5 (9.0)
18.0	5.0 (2.5)	7.0 (4.0)	8.5 (5.0)	10.0 (6.0)	11.0 (7.0)	12.0 (8.0)	13.0 (8.5)	13.5 (9.0)	14.5 (10.0)
21.0	5.5 (2.5)	7.5 (4.0)	9.0 (5.5)	10.5 (6.5)	11.5 (7.5)	13.0 (8.5)	14.0 (9.0)	14.5 (10.0)	15.5 (10.5)
24.0	6.0 (2.5)	8.0 (4.5)	9.5 (6.0)	11.0 (7.0)	12.5 (8.0)	13.5 (9.0)	14.5 (9.5)	15.5 (10.5)	16.5 (11.0)
27.0	6.0 (2.5)	8.5 (4.5)	10.0 (6.0)	11.5 (7.5)	13.0 (8.5)	14.5 (9.5)	15.5 (10.0)	16.5 (11.0)	17.5 (11.5)
30.0	6.0 (2.5)	8.5 (4.5)	10.5 (6.0)	12.5 (7.5)	13.5 (8.5)	15.0 (9.5)	16.5 (10.5)	17.5 (11.5)	18.5 (12.0)
40.0	6.5 (2.5)	9.5 (5.0)	12.0 (6.5)	13.5 (8.0)	15.5 (9.5)	17.0 (10.5)	18.5 (12.0)	20.0 (13.0)	21.0 (13.5)
50.0	7.0 (2.5)	10.0 (5.0)	12.5 (7.0)	15.0 (8.5)	17.0 (10.0)	18.5 (11.5)	20.0 (12.5)	21.5 (14.0)	23.0 (15.0)
60.0	7.0 (2.5)	10.5 (5.0)	13.5 (7.0)	16.0 (9.0)	18.0 (10.5)	20.0 (12.0)	21.5 (13.5)	23.5 (14.5)	25.0 (15.5)
80.0	7.5 (2.5)	11.0 (5.0)	14.0 (7.0)	17.0 (9.0)	19.5 (11.0)	22.0 (12.5)	24.0 (14.0)	26.0 (15.5)	28.0 (17.0)
100.0	7.5 (2.5)	11.5 (5.0)	15.0 (7.5)	18.0 (9.5)	21.0 (11.0)	23.5 (13.0)	26.0 (14.5)	28.0 (16.5)	30.0 (18.0)
120.0	7.5 (2.5)	11.5 (5.0)	15.0 (7.5)	18.5 (9.5)	21.5 (11.5)	24.5 (13.0)	27.0 (15.0)	29.5 (16.5)	32.0 (18.5)
130.0	7.5 (2.5)	11.5 (5.0)	15.0 (7.5)	18.5 (9.5)	22.0 (11.5)	25.0 (13.5)	27.5 (15.0)	30.0 (17.0)	32.5 (18.5)

Notes

Table E: Enclosing rectangle 15 m high

	Distance from relevant boundary for unprotected percentage not exceeding								
Width	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)	Figures in brackets for residential, office and assembly uses								
3.0	2.0 (1.0)	2.5 (1.5)	3.5 (2.0)	4.0 (2.0)	4.5 (2.5)	5.0 (3.0)	5.5 (3.5)	6.0 (3.5)	6.0 (4.0)
6.0	3.0 (1.5)	4.5 (2.5)	5.5 (3.0)	6.0 (4.0)	7.0 (4.5)	7.5 (5.0)	8.0 (5.5)	8.5 (5.5)	9.0 (6.0)
9.0	4.0 (1.5)	5.5 (3.0)	6.5 (4.0)	7.5 (5.0)	8.5 (5.5)	9.5 (6.0)	10.0 (6.5)	11.0 (7.0)	11.5 (7.5)
12.0	5.0 (2.0)	6.5 (3.5)	8.0 (5.0)	9.0 (5.5)	10.0 (6.5)	11.0 (7.0)	11.5 (8.0)	12.5 (8.5)	13.5 (9.0)
15.0	5.5 (2.5)	7.5 (4.0)	9.0 (5.5)	10.0 (6.5)	11.0 (7.5)	12.0 (8.0)	13.0 (9.0)	14.0 (9.5)	15.0 (10.0)
18.0	6.0 (2.5)	8.0 (4.5)	9.5 (6.0)	11.0 (7.0)	12.0 (8.0)	13.5 (9.0)	14.5 (9.5)	15.5 (10.5)	16.5 (11.0)
21.0	6.5 (3.0)	8.5 (5.0)	10.5 (6.5)	12.0 (7.5)	13.0 (8.5)	14.5 (9.5)	15.5 (10.5)	16.5 (11.0)	17.5 (12.0)
24.0	6.5 (3.0)	9.0 (5.0)	11.0 (6.5)	12.5 (8.0)	14.0 (9.0)	15.5 (10.0)	16.5 (11.0)	17.5 (12.0)	18.5 (12.5)
27.0	7.0 (3.0)	9.5 (5.5)	11.5 (7.0)	13.5 (8.5)	15.0 (9.5)	16.0 (10.5)	17.5 (11.5)	18.5 (12.5)	20.0 (13.5)
30.0	7.5 (3.0)	10.0 (5.5)	12.0 (7.0)	14.0 (8.5)	15.5 (10.0)	17.0 (11.0)	18.5 (12.0)	19.5 (13.0)	21.0 (14.0)
40.0	8.0 (3.0)	11.0 (6.0)	13.5 (8.0)	15.5 (9.5)	17.5 (11.0)	19.5 (12.5)	21.0 (13.5)	22.5 (14.5)	24.0 (15.5)
50.0	8.5 (3.0)	12.0 (6.0)	14.5 (8.5)	17.0 (10.0)	19.5 (12.0)	21.0 (13.5)	23.0 (14.5)	24.5 (16.0)	26.0 (17.0)
60.0	8.5 (3.5)	12.5 (6.0)	15.5 (8.5)	18.5 (10.5)	20.5 (12.5)	23.0 (14.0)	25.0 (15.5)	26.5 (17.0)	28.5 (18.5)
80.0	9.0 (3.5)	13.5 (6.5)	17.0(9.0)	20.0 (11.0)	23.0 (13.0)	25.5 (15.0)	28.0 (17.0)	30.0 (18.5)	32.0 (20.0)
100.0	9.0 (3.5)	13.5 (6.5)	18.0 (9.0)	21.5 (11.5)	24.5 (13.5)	27.5 (16.0)	30.0 (17.5)	32.5 (19.5)	35.0 (21.5)
120.0	9.0 (3.5)	14.0 (6.5)	18.5 (9.0)	22.0 (11.5)	25.5 (14.0)	29.0 (16.0)	32.0 (18.5)	34.5 (20.0)	37.0 (22.0)
130.0	9.0 (3.5)	14.0 (6.5)	18.5 (9.0)	22.5 (11.5)	26.0 (14.0)	29.5 (16.5)	32.5 (18.5)	35.5 (20.5)	38.0 (22.5)

Notes

Table F: Enclosing rectangle 18 m high

	Distance from relevant boundary for unprotected percentage not exceeding								
Width	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)	Figures in brackets for residential, office and assembly uses								
3.0	2.0 (1.0)	2.5 (1.5)	3.5 (2.0)	4.0 (2.5)	5.0 (2.5)	5.5 (3.0)	6.0 (3.5)	6.5 (4.0)	6.5 (4.0)
6.0	3.5 (1.5)	4.5 (2.5)	5.5 (3.5)	6.5 (4.0)	7.5 (4.5)	8.0 (5.0)	9.0 (5.5)	9.5 (6.0)	10.0 (6.5)
9.0	4.5 (2.0)	6.0 (3.5)	7.5 (4.5)	8.5 (5.0)	9.5 (6.0)	10.0 (6.5)	11.0 (7.0)	12.0 (8.0)	12.5 (8.5)
12.0	5.0 (2.5)	7.0 (4.0)	8.5 (5.0)	10.0 (6.0)	11.0 (7.0)	12.0 (8.0)	13.0 (8.5)	13.5 (9.0)	14.5 (10.0)
15.0	6.0 (2.5)	8.0 (4.5)	9.5 (6.0)	11.0 (7.0)	12.0 (8.0)	13.5 (9.0)	14.5 (9.5)	15.5 (10.5)	16.5 (11.0)
18.0	6.5 (3.0)	9.0 (5.0)	10.5 (6.5)	12.0 (7.5)	13.5 (8.5)	14.5 (9.5)	16.0 (10.5)	17.0 (11.5)	18.0 (12.0)
21.0	7.0 (3.0)	9.5 (5.5)	11.5 (7.0)	13.0 (8.5)	14.5 (9.5)	16.0 (10.5)	17.0 (11.5)	18.0 (12.0)	19.0 (13.0)
24.0	7.5 (3.5)	10.0 (5.5)	12.0 (7.5)	14.0 (9.0)	15.5 (10.0)	17.0 (11.0)	18.0 (12.0)	19.5 (13.0)	20.5 (14.0)
27.0	8.0 (3.5)	10.5 (6.0)	13.0 (8.0)	14.5 (9.5)	16.5 (10.5)	18.0 (11.5)	19.0 (13.0)	20.5 (13.5)	22.0 (14.5)
30.0	8.0 (3.5)	11.0 (6.0)	13.5 (8.0)	15.5 (9.5)	17.0 (11.0)	19.0 (12.5)	20.0 (13.5)	21.5 (14.5)	23.0 (15.5)
40.0	9.0 (3.5)	12.5 (7.0)	15.0 (9.0)	17.5 (11.0)	19.5 (12.5)	21.5 (14.0)	23.0 (15.0)	24.5 (16.5)	26.0 (17.5)
50.0	9.5 (4.0)	13.5 (7.0)	16.5 (9.5)	19.0 (11.5)	21.5 (13.5)	23.5 (15.0)	25.5 (16.5)	27.5 (18.0)	29.0 (19.0)
60.0	10.0 (4.0)	14.5 (7.5)	17.5 (10.0)	20.5 (12.0)	23.0 (14.0)	25.5 (16.0)	27.5 (17.5)	29.5 (19.0)	31.5 (20.5)
80.0	10.5 (4.0)	15.5 (7.5)	19.5 (10.5)	23.0 (13.0)	26.0 (15.5)	28.5 (17.5)	31.0 (19.5)	33.5 (21.0)	35.5 (22.5)
100.0	11.0 (4.0)	16.0 (7.5)	20.5 (10.5)	24.5 (13.5)	28.0 (16.0)	31.0 (18.5)	34.0 (20.5)	36.5 (22.5)	39.0 (24.5)
120.0	11.0 (4.0)	16.5 (7.5)	21.5 (11.0)	25.5 (14.0)	29.5 (16.5)	33.0 (19.0)	36.0 (21.5)	39.0 (23.5)	41.5 (25.5)
130.0	11.0 (4.0)	16.5 (7.5)	21.5 (11.0)	26.0 (14.0)	30.0 (16.5)	33.5 (19.0)	37.0 (21.5)	40.0 (24.0)	43.0 (26.0)

Notes

Table G: Enclosing rectangle 21 m high

	Distance from relevant boundary for unprotected percentage not exceeding								
Width	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)	Figures in brackets for residential, office and assembly uses								
3.0	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	5.5 (3.0)	6.0 (3.5)	6.5 (4.0)	7.0 (4.5)
6.0	3.5 (1.5)	5.0 (2.5)	6.0 (3.5)	7.0 (4.0)	8.0 (5.0)	8.5 (5.5)	9.5 (6.0)	10.0 (6.5)	10.5 (7.0)
9.0	4.5 (2.0)	6.5 (3.5)	7.5 (4.5)	9.0 (5.5)	10.0 (6.5)	11.0 (7.0)	12.0 (7.5)	12.5 (8.5)	13.5 (9.0)
12.0	5.5 (2.5)	7.5 (4.0)	9.0 (5.5)	10.5 (6.5)	11.5 (7.5)	13.0 (8.5)	14.0 (9.0)	14.5 (10.0)	15.5 (10.5)
15.0	6.5 (3.0)	8.5 (5.0)	10.5 (6.5)	12.0 (7.5)	13.0 (8.5)	14.5 (9.5)	15.5 (10.5)	16.5 (11.0)	17.5 (12.0)
18.0	7.0 (3.0)	9.5 (5.5)	11.5 (7.0)	13.0 (8.5)	14.5 (9.5)	16.0 (10.5)	17.0 (11.5)	18.0 (12.0)	19.0 (13.0)
21.0	7.5 (3.5)	10.0 (6.0)	12.5 (7.5)	14.0 (9.0)	15.5 (10.0)	17.0 (11.5)	18.5 (12.5)	19.5 (13.0)	21.0 (14.0)
24.0	8.0 (3.5)	11.0 (6.0)	13.0 (8.0)	15.0 (9.5)	16.5 (11.0)	18.5 (12.0)	19.5 (13.0)	21.0 (14.0)	22.0 (15.0)
27.0	8.5 (4.0)	11.5 (6.5)	14.0 (8.5)	16.0 (10.0)	17.5 (11.5)	19.5 (12.5)	21.0 (14.0)	22.0 (15.0)	23.5 (16.0)
30.0	9.0 (4.0)	12.0 (7.0)	14.5 (9.0)	16.5 (10.5)	18.5 (12.0)	20.5 (13.5)	22.0 (14.5)	23.5 (15.5)	25.0 (16.5)
40.0	10.0 (4.0)	13.5 (7.5)	16.5 (10.0)	19.0 (12.0)	21.5 (13.5)	23.5 (15.0)	25.0 (16.5)	27.0 (18.0)	28.5 (19.0)
50.0	11.0 (4.5)	15.0 (8.0)	18.0 (10.5)	21.0 (13.0)	23.5 (15.0)	26.0 (16.5)	28.0 (18.0)	30.0 (19.5)	31.5 (21.0)
60.0	11.5 (4.5)	16.0 (8.5)	19.5 (11.5)	22.5 (13.5)	25.5 (16.0)	28.0 (17.5)	30.0 (19.5)	32.5 (21.0)	34.5 (22.5)
80.0	12.0 (4.5)	17.5 (8.5)	21.5 (12.0)	25.0 (14.5)	28.5 (17.0)	31.5 (19.5)	34.0 (21.5)	36.5 (23.5)	39.0 (25.0)
100.0	12.5 (4.5)	18.0 (9.0)	23.0 (12.5)	27.0 (15.5)	31.0 (18.0)	34.0 (20.5)	37.0 (23.0)	40.0 (25.0)	42.5 (27.0)
120.0	12.5 (4.5)	19.0 (9.0)	24.0 (12.5)	28.5 (16.0)	33.0 (19.0)	36.5 (21.5)	40.0 (24.0)	43.0 (26.5)	46.0 (28.5)
130.0	12.5 (4.5)	19.0 (9.0)	24.5 (12.5)	29.5 (16.0)	33.5 (19.0)	37.5 (22.0)	41.0 (24.5)	44.5 (27.0)	47.5 (29.0)

Notes

Table H: Enclosing rectangle 24 m high

Width	Distance from relevant boundary for unprotected percentage not exceeding								
	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)			Figures in brackets for residential, office and assembly uses						
3.0	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.5 (2.5)	5.0 (3.0)	6.0 (3.0)	6.5 (3.5)	7.0 (4.0)	7.5 (4.5)
6.0	3.5 (1.5)	5.0 (2.5)	6.5 (3.5)	7.5 (4.5)	8.5 (5.0)	9.0 (5.5)	10.0 (6.0)	10.5 (7.0)	11.5 (7.5)
9.0	5.0 (2.0)	6.5 (3.5)	8.0 (4.5)	9.5 (6.0)	10.5 (6.5)	11.5 (7.5)	12.5 (8.0)	13.5 (9.0)	14.5 (9.5)
12.0	6.0 (2.5)	8.0 (4.5)	9.5 (6.0)	11.0 (7.0)	12.5 (8.0)	13.5 (9.0)	14.5 (9.5)	15.5 (10.5)	16.5 (11.0)
15.0	6.5 (3.0)	9.0 (5.0)	11.0 (6.5)	12.5 (8.0)	14.0 (9.0)	15.5 (10.0)	16.5 (11.0)	17.5 (12.0)	18.5 (12.5)
18.0	7.5 (3.5)	10.0 (5.5)	12.0 (7.5)	14.0 (9.0)	15.5 (10.0)	17.0 (11.0)	18.0 (12.0)	19.5 (13.0)	20.5 (14.0)
21.0	8.0 (3.5)	11.0 (6.0)	13.0 (8.0)	15.0 (9.5)	16.5 (11.0)	18.5 (12.0)	19.5 (13.0)	21.0 (14.0)	22.0 (15.0)
24.0	8.5 (4.0)	11.5 (6.5)	14.0 (8.5)	16.0 (10.5)	18.0 (11.5)	19.5 (13.0)	21.0 (14.0)	22.5 (15.0)	24.0 (16.0)
27.0	9.0 (4.0)	12.5 (7.0)	15.0 (9.0)	17.0 (11.0)	19.0 (12.5)	20.5 (13.5)	22.5 (15.0)	24.0 (16.0)	25.0 (17.0)
30.0	9.5 (4.0)	13.0 (7.5)	15.5 (9.5)	18.0 (11.5)	20.0 (13.0)	22.0 (14.5)	23.5 (15.5)	25.0 (17.0)	26.5 (18.0)
40.0	11.0 (4.5)	15.0 (8.5)	18.0 (11.0)	20.5 (13.0)	23.0 (15.0)	25.0 (16.5)	27.0 (18.0)	29.0 (19.0)	30.5 (20.5)
50.0	12.0 (5.0)	16.0 (9.0)	19.5 (12.0)	22.5 (14.0)	25.5 (16.0)	27.5 (18.0)	30.0 (19.5)	32.0 (21.0)	34.0 (22.5)
60.0	12.5 (5.0)	17.5 (9.5)	21.0 (12.5)	24.5 (15.0)	27.5 (17.5)	30.0 (19.5)	32.5 (21.0)	35.0 (23.0)	37.0 (24.5)
80.0	13.5 (5.0)	19.0 (10.0)	23.5 (13.5)	27.5 (16.5)	31.0 (19.0)	34.0 (21.5)	37.0 (23.5)	39.5 (25.5)	42.0 (27.5)
100.0	14.0 (5.0)	20.0 (10.0)	25.5 (14.0)	29.5 (17.0)	33.5 (20.0)	37.0 (23.0)	40.5 (25.5)	43.5 (27.5)	46.0 (29.5)
120.0	14.0 (5.0)	21.0 (10.0)	26.5 (14.0)	31.5 (17.5)	36.0 (21.0)	40.0 (24.0)	43.5 (26.5)	46.5 (29.0)	50.0 (31.5)
130.0	14.5 (5.0)	21.5 (10.0)	27.0 (14.5)	32.5 (18.0)	37.0 (21.0)	41.0 (24.5)	44.5 (27.0)	48.0 (29.5)	51.5 (32.0)

Notes

Table I: Enclosing rectangle 27 m high

	Distance from relevant boundary for unprotected percentage not exceeding								
Width	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)			Figures in brackets for residential, office and assembly uses						
3.0	2.0 (1.0)	3.0 (1.5)	3.5 (2.0)	4.5 (2.5)	5.5 (3.0)	6.0 (3.5)	6.5 (3.5)	7.0 (4.0)	7.5 (4.5)
6.0	3.5 (1.5)	5.0 (2.5)	6.5 (3.5)	7.5 (4.5)	8.5 (5.0)	9.5 (6.0)	10.5 (6.5)	11.0 (7.0)	12.0 (7.5)
9.0	5.0 (2.0)	7.0 (3.5)	8.5 (5.0)	10.0 (6.0)	11.0 (7.0)	12.0 (7.5)	13.0 (8.5)	14.0 (9.0)	15.0 (10.0)
12.0	6.0 (2.5)	8.5 (4.5)	10.0 (6.0)	11.5 (7.5)	13.0 (8.5)	14.5 (9.5)	15.5 (10.0)	16.5 (11.0)	17.5 (11.5)
15.0	7.0 (3.0)	9.5 (5.5)	11.5 (7.0)	13.5 (8.5)	15.0 (9.5)	16.0 (10.5)	17.5 (11.5)	18.5 (12.5)	20.0 (13.5)
18.0	8.0 (3.5)	10.5 (6.0)	13.0 (8.0)	14.5 (9.5)	16.5 (10.5)	18.0 (11.5)	19.0 (13.0)	20.5 (13.5)	22.0 (14.5)
21.0	8.5 (4.0)	11.5 (6.5)	14.0 (8.5)	16.0 (10.0)	17.5 (11.5)	19.5 (12.5)	21.0 (14.0)	22.0 (15.0)	23.5 (16.0)
24.0	9.0 (4.0)	12.5 (7.0)	15.0 (9.0)	17.0 (11.0)	19.0 (12.5)	20.5 (13.5)	22.5 (15.0)	24.0 (16.0)	25.0 (17.0)
27.0	10.0 (4.5)	13.0 (7.5)	16.0 (9.5)	18.0 (11.5)	20.0 (13.0)	22.0 (14.5)	23.5 (16.0)	25.5 (17.0)	26.5 (18.0)
30.0	10.5 (4.5)	14.0 (8.0)	16.5 (10.5)	19.0 (12.0)	21.0 (14.0)	23.0 (15.5)	25.0 (16.5)	26.5 (18.0)	28.0 (19.0)
40.0	11.5 (5.0)	16.0 (9.0)	19.0 (11.5)	22.0 (14.0)	24.5 (16.0)	26.5 (17.5)	28.5 (19.0)	30.5 (20.5)	32.5 (22.0)
50.0	12.5 (5.5)	17.5 (9.5)	21.0 (12.5)	24.0 (15.0)	27.0 (17.5)	29.5 (19.5)	32.0 (21.0)	34.0 (22.5)	36.0 (24.0)
60.0	13.5 (5.5)	18.5 (10.0)	23.0 (13.5)	26.0 (16.5)	29.5 (18.5)	32.0 (21.0)	34.5 (22.5)	37.0 (24.5)	39.5 (26.0)
80.0	14.5 (6.0)	20.5 (11.0)	25.5 (14.5)	29.5 (18.0)	33.0 (20.5)	36.5 (23.0)	39.5 (25.5)	42.0 (27.5)	45.0 (29.5)
100.0	15.5 (6.0)	22.0 (11.0)	27.5 (15.5)	32.0 (19.0)	36.0 (22.0)	40.0 (25.0)	43.5 (27.5)	46.5 (30.0)	49.5 (32.0)
120.0	16.0 (6.0)	23.0 (11.5)	29.0 (15.5)	34.0 (19.5)	38.5 (23.0)	43.0 (26.0)	46.5 (29.0)	50.0 (31.5)	53.5 (34.0)
130.0	16.0 (6.0)	23.5 (11.5)	29.5 (16.0)	35.0 (20.0)	40.0 (23.5)	44.0 (26.5)	48.0 (29.5)	52.0 (32.5)	55.0 (35.0)

Notes

Table J: Enclosing rectangle 30 m high

	Distance from relevant boundary for unprotected percentage not exceeding								
Width	20%	30%	40%	50%	60%	70%	80%	90%	100%
Minimum boundary distance (m)	Figures in brackets for residential, office and assembly uses								
3.0	2.0 (1.0)	3.0 (1.5)	4.0 (2.0)	4.5 (2.5)	5.5 (3.0)	6.0 (3.5)	7.0 (4.0)	7.5 (4.0)	8.0 (4.5)
6.0	3.5 (1.5)	5.5 (2.5)	6.5 (3.5)	8.0 (4.5)	9.0 (5.0)	10.0 (6.0)	11.0 (6.5)	11.5 (7.5)	12.5 (8.0)
9.0	5.0 (2.0)	7.0 (3.5)	9.0 (5.0)	10.5 (6.0)	11.5 (7.0)	12.5 (8.0)	14.0 (9.0)	15.0 (9.5)	15.5 (10.5)
12.0	6.0 (2.5)	8.5 (4.5)	10.5 (6.0)	12.5 (7.5)	13.5 (8.5)	15.0 (9.5)	16.5 (10.5)	17.5 (11.5)	18.5 (12.0)
15.0	7.5 (3.0)	10.0 (5.5)	12.0 (7.0)	14.0 (8.5)	15.5 (10.0)	17.0 (11.0)	18.5 (12.0)	19.5 (13.0)	21.0 (14.0)
18.0	8.0 (3.5)	11.0 (6.0)	13.5 (8.0)	15.5 (9.5)	17.0 (11.0)	19.0 (12.5)	20.0 (13.5)	21.5 (14.5)	23.0 (15.5)
21.0	9.0 (4.0)	12.0 (7.0)	14.5 (9.0)	16.5 (10.5)	18.5 (12.0)	20.5 (13.5)	22.0 (14.5)	23.5 (15.5)	25.0 (16.5)
24.0	9.5 (4.0)	13.0 (7.5)	15.5 (9.5)	18.0 (11.5)	20.0 (13.0)	22.0 (14.5)	23.5 (15.5)	25.0 (17.0)	26.5 (18.0)
27.0	10.5 (4.5)	14.0 (8.0)	16.5 (10.5)	19.0 (12.0)	21.0 (14.0)	23.0 (15.5)	25.0 (16.5)	26.5 (18.0)	28.0 (19.0)
30.0	11.0 (5.0)	14.5 (8.5)	17.5 (11.0)	20.0 (13.0)	22.5 (14.5)	24.5 (16.0)	26.5 (17.5)	28.0 (19.0)	29.5 (20.0)
40.0	12.5 (5.5)	17.0 (9.5)	20.0 (12.5)	23.0 (14.5)	26.0 (16.5)	28.0 (18.5)	30.5 (20.0)	32.5 (21.5)	34.5 (23.0)
50.0	13.5 (6.0)	18.5 (10.5)	22.5 (13.5)	25.5 (16.0)	28.5 (18.5)	31.5 (20.5)	33.5 (22.5)	36.0 (24.0)	38.0 (25.5)
60.0	14.5 (6.0)	20.0 (11.0)	24.0 (14.5)	28.0 (17.5)	31.0 (20.0)	34.0 (22.0)	36.5 (24.0)	39.0 (26.0)	41.5 (28.0)
80.0	16.0 (6.5)	22.0 (12.0)	27.0 (16.0)	31.5 (19.0)	35.0 (22.0)	38.5 (24.5)	42.0 (27.0)	45.0 (29.5)	47.5 (31.5)
100.0	16.5 (6.5)	24.0 (12.0)	29.5 (16.5)	34.5 (20.5)	38.5 (23.5)	42.5 (26.5)	46.0 (29.5)	49.5 (32.0)	52.5 (34.0)
120.0	17.5 (6.5)	25.0 (12.5)	31.5 (17.0)	36.5 (21.5)	41.5 (25.0)	45.5 (28.0)	49.5 (31.0)	53.5 (34.0)	57.0 (36.5)
130.0	17.5 (6.5)	25.5 (12.5)	32.0 (17.5)	37.5 (21.5)	42.5 (25.5)	47.0 (29.0)	51.5 (32.0)	55.0 (35.0)	58.5 (37.5)

Notes

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External fire spread (second edition)

Most accidental fires start as small fires which initially present a very small hazard to adjacent buildings. While the risk of fire spread between buildings cannot be eliminated completely, the aim of calculating building separation distances is to ensure that ignition of a building adjacent to a fire is sufficiently delayed to allow the Fire and Rescue Service to arrive on site and take preventative action.

This new edition of BR 187 describes different methods for calculating adequate space separation between buildings and has been prepared in support of national building regulations. Several sections, including flame projection from windows, have been expanded.

Specifically this new edition:

- merges the two parts into a single narrative
- improves the presentation of the methods with further examples
- clarifies and updates (converting to SI units) the theoretical background
- presents detailed analysis of the methods so that users can create their own fire engineering software
- includes more recent experimental data to confirm that the assumptions used in the methods are valid for modern buildings
- provides the background to methods 1 and 2 used in national building regulation guidance.

Table 1 (as referenced in the first edition of BR 187) has been split into 10 pages and renamed Tables A to J – enclosing rectangle heights are now on separate pages. This will allow you to copy, annotate and add the tables to other calculation sheets relating to your projects.

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