Building Research Establishment Report

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External fire spread: building separation and boundary distances

Fire Research Station

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Foreword

This Report describes different methods for calculating adequate space separation between buildings. It has been prepared in support of Approved Document B4 to the Building Regulations for England and Wales.

Part 1 describes the Enclosing Rectangle and Aggregate Notional Area methods from Approved Document B2/3/4 (HMSO, 1985). Both methods have been expanded to include additional information from the original Geometric and Protractor methods in Appendix II of Fire Note No 8 ‘Fire and the external wall’ by G J Langdon-Thomas and Margaret Law (HMSO, 1966).

The basis of the methods described in Part 1 is set out in Fire Research Technical Paper No 5 ‘Heat radiation from fires and building separation’ by Margaret Law (HMSO, 1963) which is reproduced as Part 2.

Note: In relation to Part 1, reference should be made to Approved Document B* for the meaning of the Purpose groups quoted and for the terms 'Boundary', 'External wall', 'Notional boundary', 'Protected shaft', 'Relevant boundary' and 'Unprotected area'.

In Part 2, the term 'opening' has the same meaning as 'unprotected area'.

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* If the building under consideration is not in England or Wales, then reference should be made to the appropriate Building Regulations/Standards or supporting technical document.

Part 1: Methods for determining boundary distance

Introduction

The two methods described in this part give distances which are sufficiently accurate for most purposes. However, they have been designed so that any inaccuracy tends to overestimate the distances. Where this is considered undesirable, then the more refined calculations described in Part 2 may be undertaken.

The boundary distance is based on the assumption that the more openings or other unprotected areas in the external enclosure of the building, the further the building (or side of the building) should be from the boundary.

Certain features of the design process are common to both methods:

1 The first consideration is to determine what constitutes an 'unprotected area' in relation to space separation. Any part of a wall which may contribute radiation at any time during the fire must be taken into account, namely windows, doors and any parts of the external wall not possessing the required fire resistance. Combustible cladding must also be taken into account, as at some stage of the fire it may well ignite and so contribute radiation.

2 The second consideration is to decide how much of the elevation of the building must be included in the calculations. If the building is not divided into compartments, then all the unprotected areas must be taken into account. Whereas if the building is divided into compartments, then it is assumed that the fire will not spread beyond the compartment in which it started. Therefore as each compartment may be treated for calculation purposes as a separate radiator, the area of wall in the largest compartment must be taken into account.

Openings in the external enclosures of stairways may be ignored for the purpose of these calculations if the stairway forms a 'protected shaft'.

3 If the building has a low fire load density it is assumed that the unprotected areas will radiate with a lower intensity than normal, so the boundary distance can be reduced. Therefore two sets of figures are given in the table used with the Enclosing Rectangle method (Table l), the figures in brackets being for those occupancies with low fire loads (ie a fire load density less than 25 kg/m^2). Correspondingly for the Protractor method the permitted effective area of unprotected areas is larger for the low fire load occupancies, and in Appendix A different values are given in Tables 3 and 4 according to the purpose group of the building or compartment.

Note: The boundary under consideration may not necessarily be the site boundary. For example, requirements made in connection with Building Regulations may necessitate a 'notional' boundary being drawn between certain buildings on the same site.

Enclosing Rectangles (Geometric method)

In this method, the elevation is viewed and a rectangle drawn around the 'unprotected areas'; a table then gives the minimum boundary distance for this size of rectangle and this proportion of unprotected area. The process is repeated for the other elevations of the building so that a trace on plan is obtained. If the boundary falls outside the trace then no further calculation is needed; but if it falls inside the trace at any point, then before considering any alterations to the plan or elevation it is worth examining the problem in more detail. The basic method assumes that the external enclosure is in one plane, whereas if large parts of it are set back or recessed the distance calculated will be an overestimate. The method can be modified to a certain extent to allow for this, but with complicated plan shapes it may be more satisfactory to use the Protractor method.

This method may be sub-divided into the following stages:

1 determine what part(s) of the side of the building (termed 'unprotected areas') must be taken into account,

2 determine the 'plane of reference' from which boundary distance is measured,

3 determine the extent of the exposure hazard due to the unprotected areas in the side of the building,

4 determine a minimum boundary distance based on the assessment of the risk determined by Stage 3, and

5 locate any special area of exposure hazard which may call for a greater or lesser boundary distance than has been obtained from Stage 4, and to determine the final distance of the building from the 'relevant boundary'.

Stage 1 Unprotected areas

The appropriate Building Regulations or supporting technical document should be consulted regarding which parts of the building are considered 'unprotected areas' and which of these areas may be disregarded in the calculations.

Stage 2 Plane of reference

This stage is considered in two parts:

(a) Establish a **plane of reference** (Diagram 1) which is the most favourable for the side of the building under consideration and which complies with (i), (ii) and (iii) below. (Where the boundary distance has not been set, an assumed relationship with the **relevant boundary** should be made):

i it touches all or part of the side, and

ii however far extended, it does not pass within the building (but may pass through projections such as a balcony or coping), and

iii it does not cross the relevant boundary.

Normally it will be best for the plane of reference to be roughly parallel to the relevant boundary. Where the side of the building is all in one plane then this side is itself the plane of reference.

For simplification any part of an elevation which is set back behind the plane of reference a distance not greater than 1.5 m may be assumed not to be set back for calculation purposes. For parts of an elevation which are set back as a break in the elevation or as a recess more than 1.5 m behind the plane of reference, see Stage 5.

(b) On the **plane of reference**, and at right angles to it, project lines marking those **unprotected areas** which are 80° or less to the plane of reference (Diagram 2).

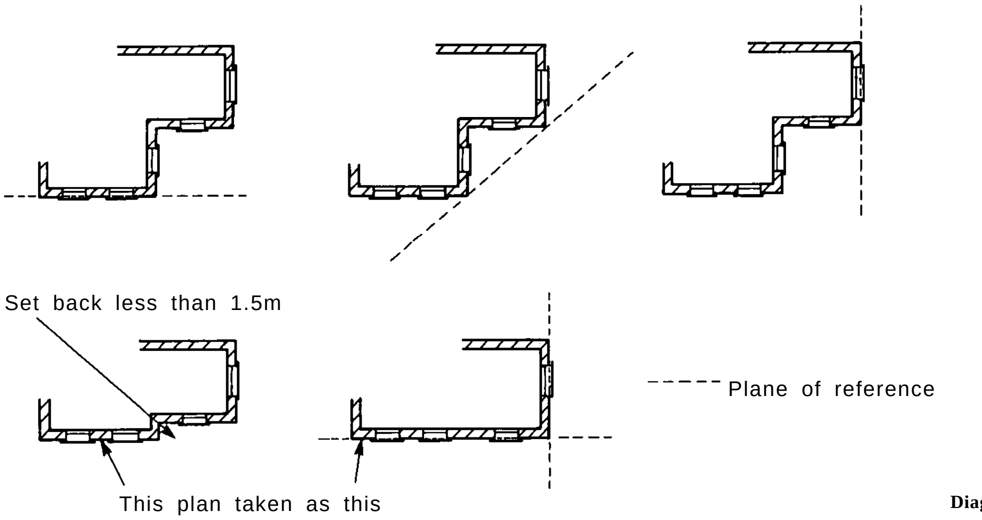
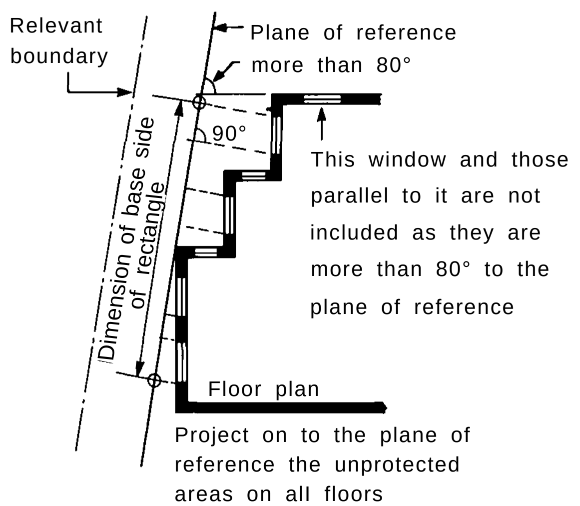


Diagram 1 Planes of reference (on plan)



Note: The relevant boundary could be a notional boundary depending on the use of the building and the circumstances

Diagram 2 Unprotected areas projected onto plane of reference

Stage 3 Determination of the area of exposure hazard

This stage is considered in two parts:

(a) The area of exposure hazard is taken as the smallest rectangle from Table 1 which (on elevation) is equal, or next greater in both height and width, to a rectangle which encloses all relevant **unprotected areas** in the side of the building or compartment projected onto the **plane of reference.** This is known as the **enclosing rectangle** (Diagram 3).

The height of the enclosing rectangle should be taken for the compartment which gives the greatest exposure hazard. If the building is not sub-divided horizontally by compartment floors, the height of the rectangle enclosing all the unprotected areas must be taken into account. Similarly if the building is not sub-divided vertically by compartment walls, it is necessary to take into account the whole width of the overall enclosing rectangle. (Diagram 4 shows how to construct an enclosing rectangle and Diagram 5 shows the effect of compartmentation).

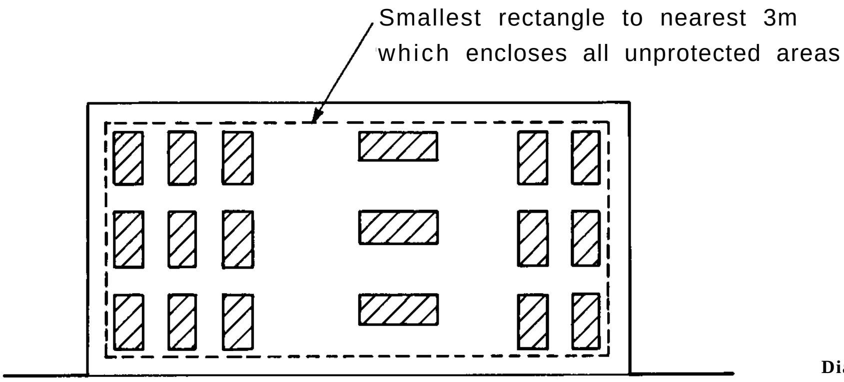
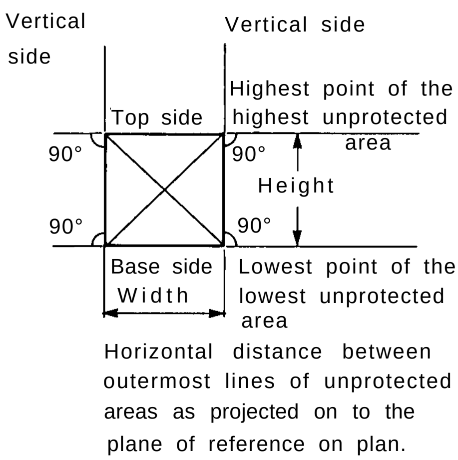


Diagram 3 Enclosing rectangle

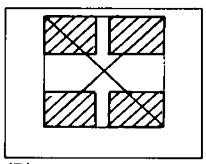
Diagram A shows the essentials in constructing the rectangle (shown by diagonal lines) enclosing the unprotected areas

Diagrams B-D show how the wall construction determines the size of the rectangle

In the diagrams the relevant boundary is assumed as parallel with the wall face, and the plane of reference to coincide with the wall face. But this will not always be so

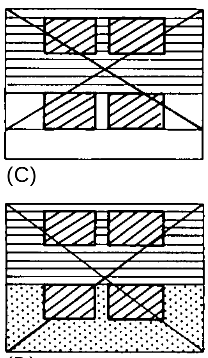


(A) setting rectangle



(B)

the whole of the solid wall area has the approved fire resistance



(C)

combustible cladding on wall which does not have the approved fire resistance. Unclad wall area has approved fire resistance

(D)

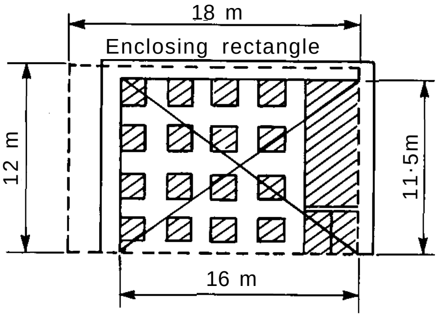
whole of wall area behind and below the combustible cladding does not have the approved fire resistance

Diagram 4 Constructing an enclosing rectangle

(b) The total **unprotected area** (excluding any areas which may be disregarded under Stage 1) is then expressed as a percentage of the enclosing rectangle which contains them. This gives the **unprotected percentage.**

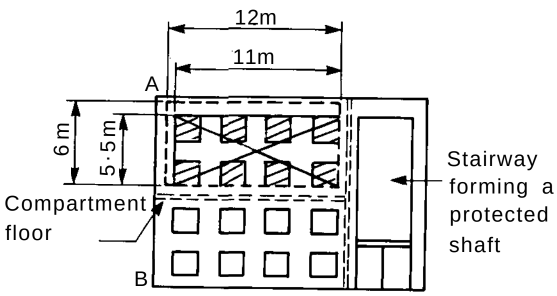
All unprotected areas in a recess are included *unless* they exceed the area of the front of the recess, when the area of the front of the recess is taken instead. (See also Stage 5).

The effect of compartmentation is explained in the following diagrams which assume a Residential, Office or Assembly/Recreation use.



(a) Uncompartmented

1 assume rectangle (enclosing unprotected areas) = 11.5m × 16m
2 from Table 1 enclosing rectangle = 12m × 18m = 216m^2
3 assume unprotected areas (shaded) = 105m^2
4 unprotected percentage (unprotected areas as percentage of enclosing rectangle) = 105m^2 as percentage of 216m^2 = 48.6%. Use 50% column in Table 1
5 from Table 1 distance from boundary = 6m (minimum)

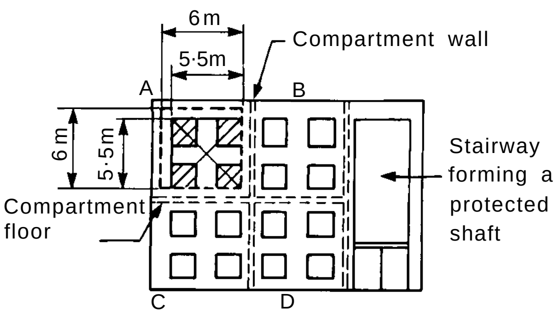


(b) Compartmented

(assume compartmentation as shown)

(a) as the entrance and stairways are now isolated the area becomes a protected shaft and the glazed area does not now count as part of the unprotected area
(b) the remainder of the building is divided by the compartment floor into compartments A and B. In this example the compartments have the same unprotected area. But where there are two (or more) compartments with different unprotected areas, take the compartment with the greatest unprotected area

1 assume rectangle = 5.5m × 11m
2 from Table 1 enclosing rectangle = 6m × 12m = 72m^2
3 assume unprotected areas = 26m^2
4 unprotected percentage = 26m^2 as percentage of 72m^2 = 36%. Use 40 % column in Table 1
5 from Table 1 distance from boundary = 3m (minimum)



(c) Compartmented

(assume compartmentation as shown)

With the inclusion of a compartment wall, the building is now divided into compartments A, B, C and D, each having the same unprotected area for the purpose of this example.

1 assume rectangle = 5.5m × 5.5m
2 from Table 1 enclosing rectangle = 6m × 6m = 36m^2
3 assume unprotected areas = 13m^2
4 unprotected percentage = 36%. Use 40% column in Table 1
5 from Table 1 distance from boundary = 2m (minimum)

Note

In the above diagrams the relevant boundary is assumed as parallel with the wall face, and the plane of reference to coincide with the wall face. But this will not always be so.

Diagram 5 Effect of compartmentation on distance from boundary

Stage 4 Determination of boundary distance

Having determined what parts of the elevation must be taken into account it is now possible, by the use of Table 1, to find the minimum distance from its **relevant boundary** for a building with a plane elevation (or to find the maximum **unprotected area** for a given boundary position).

Note: An alternative to using Table 1 is given in Appendix A.

It will be seen that Table 1 sets out the boundary distance for various heights and widths of rectangles, and the percentage of unprotected areas within them. In this connection it should be noted that:

(a) different distances are given according to whether the fire load density of the building or compartment under consideration is 'normal' or 'low',

(b) the distances relate to the **plane of reference** *not* the side of the building unless the two are coincident: and

(c) where the **unprotected percentage** falls between the figures shown, they can be interpolated.

For example, the enclosing rectangle shown in Diagram 6 (6 m high and 12 m wide with an unprotected percentage of 50%) would require a space separation from the relevant boundary of 5.5 m if the building is used for Shop and commercial, Industrial, Storage or Other non-residential purposes (or 3.5 m if it is used for Residential, Office or Assembly and recreation purposes).

To find the maximum unprotected area for a given boundary position

From Table 1 (according to the use of the building or compartment and the size of the **enclosing rectangle**) find the **unprotected percentage** allowed for the distance from the **relevant boundary**.

If the proposed total area of unprotected area relative to the size of the enclosing rectangle exceeds the allowable unprotected percentage for that distance, the design should be modified accordingly until an enclosing rectangle and allowable unprotected percentage is established for the boundary distance.

Repeat the process for all sides of the building situated not less than 1 m from any point on the relevant boundary.

To find the nearest position of boundary for a given building design

From Table 1 (according to the use of the building or compartment and the size of the **enclosing rectangle**) find the minimum allowable distance for the **unprotected percentage**.

Repeat the process for all sides of the building.

If these minimum distances are superimposed upon a plan of the building, a zone around the building is established upon which a boundary should not encroach (Diagram 7).

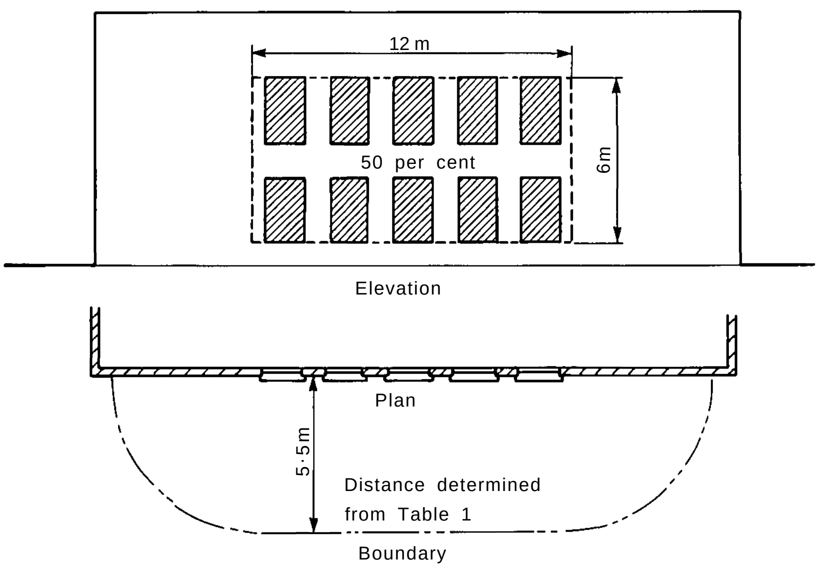


Diagram 6 Determination of boundary distance (plane elevation)

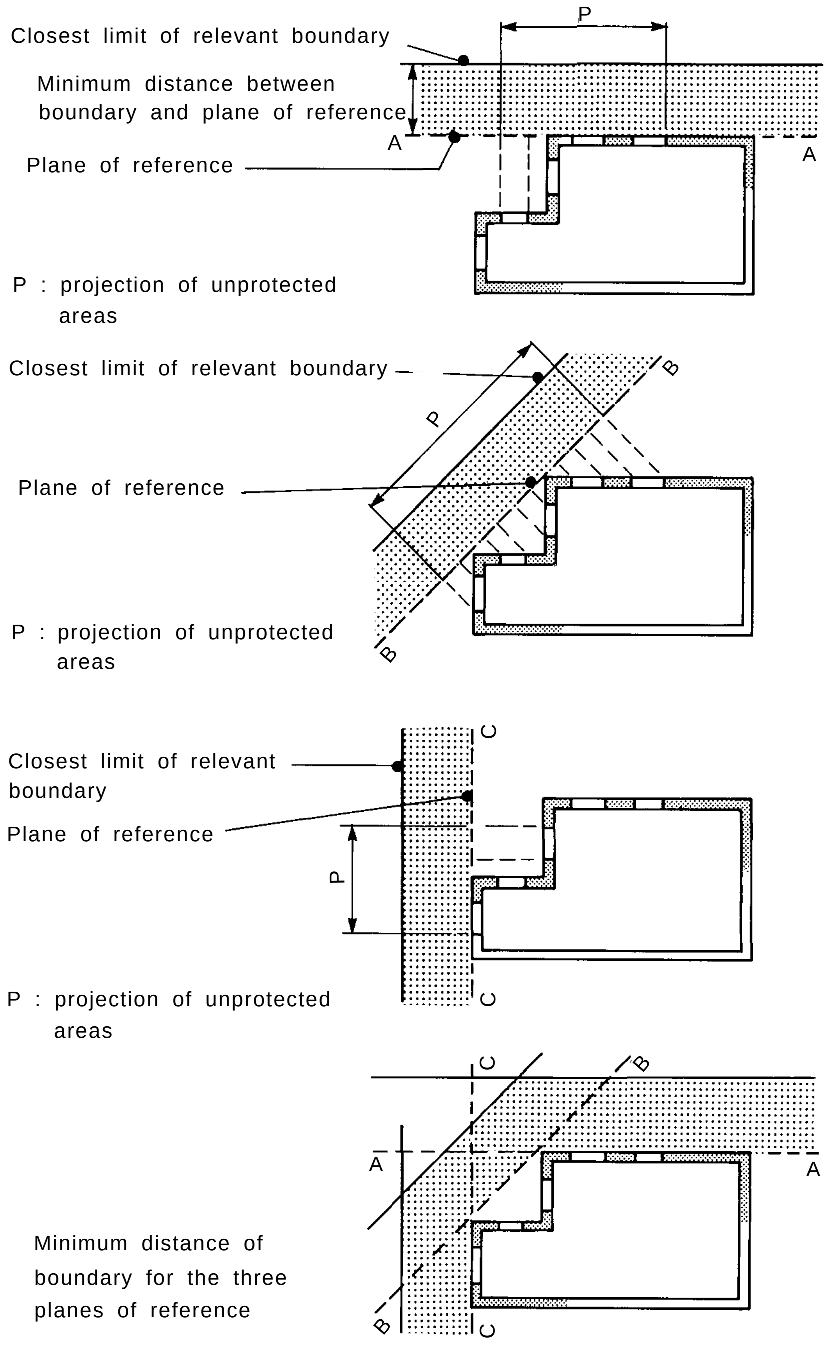


Diagram 7 Zone formed around building

Table 1 Permitted unprotected percentages in relation to enclosing rectangles

Width of enclosing rectangle (m)	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 are for Residential, Office and Assembly/recreation uses								
Enclosing rectangle 3m high									
3	1.0 *(1.0)*	1.5 *(1.0)*	2.0 *(1.0)*	2.0 *(1.5)*	2.5 *(1.5)*	2.5 *(1.5)*	2.5 *(2.0)*	3.0 *(2.0)*	3.0 *(2.0)*
6	1.5 *(1.0)*	2.0 *(1.0)*	2.5 *(1.5)*	3.0 *(2.0)*	3.0 *(2.0)*	3.5 *(2.0)*	3.5 *(2.5)*	4.0 *(2.5)*	4.0 *(3.0)*
9	1.5 *(1.0)*	2.5 *(1.0)*	3.0 *(1.5)*	3.5 *(2.0)*	4.0 *(2.5)*	4.0 *(2.5)*	4.5 *(3.0)*	5.0 *(3.0)*	5.0 *(3.5)*
12	2.0 *(1.0)*	2.5 *(1.5)*	3.0 *(2.0)*	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	2.0 *(1.0)*	2.5 *(1.5)*	3.5 *(2.0)*	4.0 *(2.5)*	4.5 *(2.5)*	5.0 *(3.0)*	5.5 *(3.5)*	6.0 *(3.5)*	6.0 *(4.0)*
18	2.0 *(1.0)*	2.5 *(1.5)*	3.5 *(2.0)*	4.0 *(2.5)*	5.0 *(2.5)*	5.0 *(3.0)*	6.0 *(3.5)*	6.5 *(4.0)*	6.5 *(4.0)*
21	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	2.0 *(1.0)*	3.0 *(1.5)*	3.5 *(2.0)*	4.5 *(2.5)*	5.0 *(3.0)*	5.5 *(3.5)*	6.0 *(3.5)*	7.0 *(4.0)*	7.5 *(4.5)*
27	2.0 *(1.0)*	3.0 *(1.5)*	4.0 *(2.0)*	4.5 *(2.5)*	5.5 *(3.0)*	6.0 *(3.5)*	6.5 *(4.0)*	7.0 *(4.0)*	7.5 *(4.5)*
30	2.0 *(1.0)*	3.0 *(1.5)*	4.0 *(2.0)*	4.5 *(2.5)*	5.5 *(3.0)*	6.0 *(3.5)*	6.5 *(4.0)*	7.5 *(4.0)*	8.0 *(4.5)*
40	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 *(4.0)*	8.5 *(5.0)*
50	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)*	8.0 *(4.0)*	9.0 *(5.0)*
60	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 *(4.0)*	9.5 *(5.0)*
80	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 *(4.0)*	9.5 *(5.0)*
no limit	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 *(4.0)*	10.0 *(5.0)*
Enclosing rectangle 6m high									
3	1.5 *(1.0)*	2.0 *(1.0)*	2.5 *(1.5)*	3.0 *(2.0)*	3.0 *(2.0)*	3.5 *(2.0)*	3.5 *(2.5)*	4.0 *(2.5)*	4.0 *(3.0)*
6	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	2.5 *(1.0)*	3.5 *(2.0)*	4.5 *(2.5)*	5.0 *(3.0)*	5.5 *(3.5)*	6.0 *(4.0)*	6.0 *(4.5)*	7.0 *(4.5)*	7.0 *(5.0)*
12	3.0 *(1.5)*	4.0 *(2.5)*	5.0 *(3.0)*	5.5 *(3.5)*	6.5 *(4.0)*	7.0 *(4.5)*	7.5 *(5.0)*	8.0 *(5.0)*	8.5 *(5.5)*
15	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)*	9.0 *(5.5)*	9.0 *(6.0)*
18	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	3.5 *(1.5)*	5.0 *(2.5)*	6.0 *(3.5)*	7.0 *(4.0)*	8.0 *(5.0)*	9.0 *(5.5)*	9.5 *(6.0)*	10.0 *(6.5)*	10.5 *(7.0)*
24	3.5 *(1.5)*	5.0 *(2.5)*	6.0 *(3.5)*	7.0 *(4.5)*	8.5 *(5.0)*	9.5 *(5.5)*	10.0 *(6.0)*	10.5 *(7.0)*	11.0 *(7.0)*
27	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	3.5 *(1.5)*	5.0 *(2.5)*	6.5 *(3.5)*	8.0 *(4.5)*	9.0 *(5.0)*	10.0 *(6.0)*	11.0 *(6.5)*	12.0 *(7.0)*	12.5 *(8.0)*
40	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	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	3.5 *(1.5)*	5.5 *(2.5)*	7.5 *(3.5)*	9.5 *(5.0)*	11.0 *(5.5)*	12.0 *(6.5)*	13.5 *(7.5)*	15.0 *(8.5)*	16.0 *(9.5)*
80	3.5 *(1.5)*	6.0 *(2.5)*	7.5 *(3.5)*	9.5 *(5.0)*	11.5 *(6.0)*	13.0 *(7.0)*	14.5 *(7.5)*	16.0 *(8.5)*	17.5 *(9.5)*
100	3.5 *(1.5)*	6.0 *(2.5)*	8.0 *(3.5)*	10.0 *(5.0)*	12.0 *(6.0)*	13.5 *(7.0)*	15.0 *(8.0)*	16.5 *(8.5)*	18.0 *(10.0)*
120	3.5 *(1.5)*	6.0 *(2.5)*	8.0 *(3.5)*	10.0 *(5.0)*	12.0 *(6.0)*	14.0 *(7.0)*	15.5 *(8.0)*	17.0 *(8.5)*	19.0 *(10.0)*
no limit	3.5 *(1.5)*	6.0 *(2.5)*	8.0 *(3.5)*	10.0 *(5.0)*	12.0 *(6.0)*	14.0 *(7.0)*	16.0 *(8.0)*	18.0 *(8.5)*	19.0 *(10.0)*
Enclosing rectangle 9m high									
3	1.5 *(1.0)*	2.5 *(1.0)*	3.0 *(1.5)*	3.5 *(2.0)*	4.0 *(2.5)*	4.0 *(2.5)*	4.5 *(3.0)*	5.0 *(3.0)*	5.0 *(3.5)*
6	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)*	7.0 *(5.0)*
9	3.5 *(1.5)*	4.5 *(2.5)*	5.5 *(3.5)*	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	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	4.0 *(2.0)*	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	4.5 *(2.0)*	6.0 *(3.5)*	7.0 *(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	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)*	13.0 *(8.5)*	13.5 *(9.0)*
24	5.0 *(2.0)*	6.5 *(3.5)*	8.0 *(5.0)*	9.5 *(5.5)*	11.0 *(6.5)*	12.0 *(7.5)*	13.0 *(8.0)*	13.5 *(9.0)*	14.5 *(9.5)*
27	5.0 *(2.0)*	7.0 *(3.5)*	8.5 *(5.0)*	10.0 *(6.0)*	11.5 *(7.0)*	12.5 *(7.5)*	13.5 *(8.5)*	14.5 *(9.5)*	15.0 *(10.0)*
30	5.0 *(2.0)*	7.0 *(3.5)*	9.0 *(5.0)*	10.5 *(6.0)*	12.0 *(7.0)*	13.0 *(8.0)*	14.0 *(9.0)*	15.0 *(9.5)*	16.0 *(10.5)*
40	5.5 *(2.0)*	7.5 *(3.5)*	9.5 *(5.5)*	11.5 *(6.5)*	13.0 *(7.5)*	14.5 *(8.5)*	15.5 *(9.5)*	17.0 *(10.5)*	17.5 *(11.5)*
50	5.5 *(2.0)*	8.0 *(4.0)*	10.0 *(5.5)*	12.5 *(6.5)*	14.0 *(8.0)*	15.5 *(9.0)*	17.0 *(10.0)*	18.5 *(11.5)*	19.5 *(12.5)*
60	5.5 *(2.0)*	8.0 *(4.0)*	11.0 *(5.5)*	13.0 *(7.0)*	15.0 *(8.0)*	16.5 *(9.5)*	18.0 *(11.0)*	19.5 *(11.5)*	21.0 *(13.0)*
80	5.5 *(2.0)*	8.5 *(4.0)*	11.5 *(5.5)*	13.5 *(7.0)*	16.0 *(8.5)*	17.5 *(10.0)*	19.5 *(11.5)*	21.5 *(12.5)*	23.0 *(13.5)*
100	5.5 *(2.0)*	8.5 *(4.0)*	11.5 *(5.5)*	14.5 *(7.0)*	16.5 *(8.5)*	18.5 *(10.0)*	21.0 *(11.5)*	22.5 *(12.5)*	24.5 *(14.5)*
120	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)*	23.5 *(12.5)*	26.0 *(14.5)*
no limit	5.5 *(2.0)*	8.5 *(4.0)*	11.5 *(5.5)*	15.0 *(7.0)*	17.5 *(8.5)*	20.0 *(10.5)*	22.5 *(12.0)*	24.5 *(12.5)*	27.0 *(15.0)*

Table 1 (continued)

Width of enclosing rectangle (m)	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 are for Residential, Office and Assembly/recreation uses								
Enclosing rectangle 12m high									
3	2.0 *(1.0)*	2.5 *(1.5)*	3.0 *(2.0)*	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	3.0 *(1.5)*	4.0 *(2.5)*	5.0 *(3.0)*	5.5 *(3.5)*	6.5 *(4.0)*	7.0 *(4.5)*	7.5 *(5.0)*	8.0 *(5.0)*	8.5 *(5.5)*
9	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	4.5 *(1.5)*	6.0 *(3.5)*	7.0 *(4.5)*	8.0 *(5.0)*	9.0 *(6.0)*	9.5 *(6.5)*	11.0 *(7.0)*	11.5 *(7.5)*	12.0 *(8.0)*
15	5.0 *(2.0)*	6.5 *(3.5)*	8.0 *(5.0)*	9.0 *(5.5)*	10.0 *(6.5)*	11.0 *(7.0)*	12.0 *(8.0)*	13.0 *(8.5)*	13.5 *(9.0)*
18	5.0 *(2.5)*	7.0 *(4.0)*	8.5 *(5.0)*	10.0 *(6.0)*	11.0 *(7.0)*	12.0 *(7.5)*	13.0 *(8.5)*	14.0 *(9.0)*	14.5 *(10.0)*
21	5.5 *(2.5)*	7.5 *(4.0)*	9.0 *(5.5)*	10.5 *(6.5)*	12.0 *(7.5)*	13.0 *(8.5)*	14.0 *(9.0)*	15.0 *(10.0)*	16.0 *(10.5)*
24	6.0 *(2.5)*	8.0 *(4.5)*	9.5 *(6.0)*	11.5 *(7.0)*	12.5 *(8.0)*	14.0 *(8.5)*	15.0 *(9.5)*	16.0 *(10.5)*	16.5 *(11.5)*
27	6.0 *(2.5)*	8.0 *(4.5)*	10.5 *(6.0)*	12.0 *(7.0)*	13.5 *(8.0)*	14.5 *(9.0)*	16.0 *(10.5)*	17.0 *(11.0)*	17.5 *(12.0)*
30	6.5 *(2.5)*	8.5 *(4.5)*	10.5 *(6.5)*	12.5 *(7.5)*	14.0 *(8.5)*	15.0 *(9.5)*	16.5 *(10.5)*	17.5 *(11.5)*	18.5 *(12.5)*
40	6.5 *(2.5)*	9.5 *(5.0)*	12.0 *(6.5)*	14.0 *(8.0)*	15.5 *(9.5)*	17.5 *(10.5)*	18.5 *(12.0)*	20.0 *(13.0)*	21.0 *(14.0)*
50	7.0 *(2.5)*	10.0 *(5.0)*	13.0 *(7.0)*	15.0 *(8.5)*	17.0 *(10.0)*	19.0 *(11.0)*	20.5 *(13.0)*	23.0 *(14.0)*	23.0 *(15.0)*
60	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 *(16.0)*
80	7.0 *(2.5)*	11.0 *(5.0)*	14.5 *(7.0)*	17.0 *(9.0)*	19.5 *(11.0)*	21.5 *(13.0)*	23.5 *(14.5)*	26.0 *(16.0)*	27.5 *(17.0)*
100	7.5 *(2.5)*	11.5 *(5.0)*	15.0 *(7.5)*	18.0 *(9.5)*	21.0 *(11.5)*	23.0 *(13.5)*	25.5 *(15.0)*	28.0 *(16.5)*	30.0 *(18.0)*
120	7.5 *(2.5)*	11.5 *(5.0)*	15.0 *(7.5)*	18.5 *(9.5)*	22.0 *(11.5)*	24.0 *(13.5)*	27.0 *(15.0)*	29.5 *(17.0)*	31.5 *(18.5)*
no limit	7.5 *(2.5)*	12.0 *(5.0)*	15.5 *(7.5)*	19.0 *(9.5)*	22.5 *(12.0)*	25.0 *(14.0)*	28.0 *(15.5)*	30.5 *(17.0)*	34.0 *(19.0)*
Enclosing rectangle 15m high									
3	2.0 *(1.0)*	2.5 *(1.5)*	3.5 *(2.0)*	4.0 *(2.5)*	4.5 *(2.5)*	5.0 *(3.0)*	5.5 *(3.5)*	6.0 *(3.5)*	6.0 *(4.0)*
6	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)*	9.0 *(5.5)*	9.0 *(6.0)*
9	4.0 *(2.0)*	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	5.0 *(2.0)*	6.5 *(3.5)*	8.0 *(5.0)*	9.0 *(5.5)*	10.0 *(6.5)*	11.0 *(7.0)*	12.0 *(8.0)*	13.0 *(8.5)*	13.5 *(9.0)*
15	5.5 *(2.0)*	7.0 *(4.0)*	9.0 *(5.5)*	10.0 *(6.5)*	11.5 *(7.0)*	12.5 *(8.0)*	13.5 *(9.0)*	14.5 *(9.5)*	15.0 *(10.0)*
18	6.0 *(2.5)*	8.0 *(4.5)*	9.5 *(6.0)*	11.0 *(7.0)*	12.5 *(8.0)*	13.5 *(8.5)*	14.5 *(9.5)*	15.5 *(10.5)*	16.5 *(11.0)*
21	6.5 *(2.5)*	8.5 *(5.0)*	10.5 *(6.5)*	12.0 *(7.5)*	13.5 *(8.5)*	14.5 *(9.5)*	16.0 *(10.5)*	16.5 *(11.0)*	17.5 *(12.0)*
24	6.5 *(3.0)*	9.0 *(5.0)*	11.0 *(6.5)*	13.0 *(8.0)*	14.5 *(9.0)*	15.5 *(10.0)*	17.0 *(11.0)*	18.0 *(12.0)*	19.0 *(13.0)*
27	7.0 *(3.0)*	9.5 *(5.5)*	11.5 *(7.0)*	13.5 *(8.5)*	15.0 *(9.5)*	16.5 *(10.5)*	18.0 *(11.5)*	19.0 *(12.5)*	20.0 *(13.5)*
30	7.5 *(3.0)*	10.0 *(5.5)*	12.0 *(7.5)*	14.0 *(8.5)*	16.0 *(10.0)*	17.0 *(11.0)*	18.5 *(12.0)*	20.0 *(13.5)*	21.0 *(14.0)*
40	8.0 *(3.0)*	11.0 *(6.0)*	13.5 *(8.0)*	16.0 *(9.5)*	18.0 *(11.0)*	19.5 *(12.5)*	21.0 *(13.5)*	22.5 *(15.0)*	23.5 *(16.0)*
50	8.5 *(3.5)*	12.0 *(6.0)*	15.0 *(8.5)*	17.5 *(10.0)*	19.5 *(12.0)*	21.5 *(13.5)*	23.0 *(15.0)*	25.0 *(16.5)*	26.0 *(17.5)*
60	8.5 *(3.5)*	12.5 *(6.5)*	15.5 *(8.5)*	18.0 *(10.5)*	21.0 *(12.5)*	23.5 *(14.0)*	25.0 *(15.5)*	27.0 *(17.0)*	28.0 *(18.0)*
80	9.0 *(3.5)*	13.5 *(6.5)*	17.0 *(9.0)*	20.0 *(11.0)*	23.0 *(13.5)*	25.5 *(15.0)*	28.0 *(17.0)*	30.0 *(18.5)*	31.5 *(20.0)*
100	9.0 *(3.5)*	14.0 *(6.5)*	18.0 *(9.0)*	21.5 *(11.5)*	24.5 *(14.0)*	27.5 *(16.0)*	30.0 *(18.0)*	32.5 *(19.5)*	34.5 *(21.5)*
120	9.0 *(3.5)*	14.0 *(6.5)*	18.5 *(9.0)*	22.5 *(11.5)*	25.5 *(14.0)*	28.5 *(16.5)*	31.5 *(18.5)*	34.5 *(20.5)*	37.0 *(22.5)*
no limit	9.0 *(3.5)*	14.5 *(6.5)*	19.0 *(9.0)*	23.0 *(12.0)*	27.0 *(14.5)*	30.0 *(17.0)*	34.0 *(19.0)*	36.0 *(21.0)*	39.0 *(23.0)*
Enclosing rectangle 18m high									
3	2.0 *(1.0)*	2.5 *(1.5)*	3.5 *(2.0)*	4.0 *(2.5)*	5.0 *(2.5)*	5.0 *(3.0)*	6.0 *(3.5)*	6.5 *(4.0)*	6.5 *(4.0)*
6	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	4.5 *(2.0)*	6.0 *(3.5)*	7.0 *(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	5.0 *(2.5)*	7.0 *(4.0)*	8.5 *(5.0)*	10.0 *(6.0)*	11.0 *(7.0)*	12.0 *(7.5)*	13.0 *(8.5)*	14.0 *(9.0)*	14.5 *(10.0)*
15	6.0 *(2.5)*	8.0 *(4.5)*	9.5 *(6.0)*	11.0 *(7.0)*	12.5 *(8.0)*	13.5 *(8.5)*	14.5 *(9.5)*	15.5 *(10.5)*	16.5 *(11.0)*
18	6.5 *(2.5)*	8.5 *(5.0)*	11.0 *(6.5)*	12.0 *(7.5)*	13.5 *(8.5)*	14.5 *(9.5)*	16.0 *(11.0)*	17.0 *(11.5)*	18.0 *(13.0)*
21	7.0 *(3.0)*	9.5 *(5.5)*	11.5 *(7.0)*	13.0 *(8.0)*	14.5 *(9.5)*	16.0 *(10.5)*	17.0 *(11.5)*	18.0 *(12.5)*	19.5 *(13.0)*
24	7.5 *(3.0)*	10.0 *(5.5)*	12.0 *(7.5)*	14.0 *(8.5)*	15.5 *(10.0)*	16.5 *(11.0)*	18.5 *(12.0)*	19.5 *(13.0)*	20.5 *(14.0)*
27	8.0 *(3.5)*	10.5 *(6.0)*	12.5 *(8.0)*	14.5 *(9.0)*	16.5 *(10.5)*	17.5 *(11.5)*	19.5 *(12.5)*	20.5 *(13.5)*	21.5 *(14.5)*
30	8.0 *(3.5)*	11.0 *(6.5)*	13.5 *(8.0)*	15.5 *(9.5)*	17.0 *(11.0)*	18.5 *(12.0)*	20.5 *(13.5)*	21.5 *(14.5)*	22.5 *(15.5)*
40	9.0 *(4.0)*	12.0 *(7.0)*	15.0 *(9.0)*	17.5 *(11.0)*	19.5 *(12.0)*	21.5 *(13.5)*	23.5 *(15.0)*	25.0 *(16.5)*	26.0 *(17.5)*
50	9.5 *(4.0)*	13.0 *(7.0)*	16.5 *(9.5)*	19.0 *(11.5)*	21.5 *(13.0)*	23.5 *(15.0)*	26.0 *(16.5)*	27.5 *(18.0)*	29.0 *(19.0)*
60	10.0 *(4.0)*	14.0 *(7.5)*	17.5 *(10.0)*	20.5 *(12.0)*	23.0 *(14.0)*	26.0 *(16.0)*	27.5 *(17.5)*	29.5 *(19.5)*	31.0 *(20.5)*
80	10.0 *(4.0)*	15.0 *(7.5)*	19.0 *(10.0)*	22.5 *(13.0)*	26.0 *(15.0)*	28.5 *(17.0)*	31.0 *(19.0)*	33.5 *(21.0)*	35.0 *(22.5)*
100	10.0 *(4.0)*	16.0 *(7.5)*	20.5 *(10.0)*	24.0 *(13.5)*	28.0 *(16.0)*	31.0 *(18.0)*	33.5 *(20.5)*	36.0 *(22.5)*	38.5 *(24.0)*
120	10.0 *(4.0)*	16.5 *(7.5)*	21.0 *(10.0)*	25.5 *(14.0)*	29.5 *(16.5)*	32.5 *(19.0)*	35.5 *(21.0)*	39.0 *(23.5)*	41.5 *(25.5)*
no limit	10.0 *(4.0)*	17.0 *(8.0)*	22.0 *(10.0)*	26.5 *(14.0)*	30.5 *(17.0)*	34.0 *(19.5)*	37.0 *(22.0)*	41.0 *(24.0)*	43.5 *(26.5)*

Table 1 (continued)

Width of enclosing rectangle (m)	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 are for Residential, Office and Assembly/recreation uses								
Enclosing rectangle 21m high									
3	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	3.5 *(1.5)*	5.0 *(2.5)*	6.0 *(3.5)*	7.0 *(4.0)*	8.0 *(5.0)*	9.0 *(5.5)*	9.5 *(6.0)*	10.0 *(6.5)*	10.5 *(7.0)*
9	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)*	13.0 *(8.5)*	13.5 *(9.0)*
12	5.5 *(2.5)*	7.5 *(4.0)*	9.0 *(5.5)*	10.5 *(6.5)*	12.0 *(7.5)*	13.0 *(8.5)*	14.0 *(9.0)*	15.0 *(10.0)*	16.0 *(10.5)*
15	6.5 *(2.5)*	8.5 *(5.0)*	10.5 *(6.5)*	12.0 *(7.5)*	13.5 *(8.5)*	14.5 *(9.5)*	16.0 *(10.5)*	16.5 *(11.0)*	17.5 *(12.0)*
18	7.0 *(3.0)*	9.5 *(5.5)*	11.5 *(7.0)*	13.0 *(8.0)*	14.5 *(9.5)*	16.0 *(10.5)*	17.0 *(11.5)*	18.0 *(12.5)*	19.5 *(13.0)*
21	7.5 *(3.0)*	10.0 *(6.0)*	12.5 *(7.5)*	14.0 *(9.0)*	15.5 *(10.0)*	17.0 *(11.0)*	18.5 *(12.5)*	20.0 *(13.5)*	21.0 *(14.0)*
24	8.0 *(3.5)*	10.5 *(6.0)*	13.0 *(8.0)*	15.0 *(9.5)*	16.5 *(10.5)*	18.0 *(12.0)*	20.0 *(13.0)*	21.0 *(14.0)*	22.0 *(15.0)*
27	8.5 *(3.5)*	11.5 *(6.5)*	14.0 *(8.5)*	16.0 *(10.0)*	18.0 *(11.5)*	19.0 *(13.0)*	21.0 *(14.0)*	22.5 *(15.0)*	23.5 *(16.0)*
30	9.0 *(4.0)*	12.0 *(7.0)*	14.5 *(9.0)*	16.5 *(10.5)*	18.5 *(12.0)*	20.5 *(13.0)*	22.0 *(14.5)*	23.5 *(16.0)*	25.0 *(16.5)*
40	10.0 *(4.5)*	13.5 *(7.5)*	16.5 *(10.0)*	19.0 *(12.0)*	21.5 *(13.5)*	23.0 *(15.0)*	25.5 *(16.5)*	27.0 *(18.0)*	28.5 *(19.0)*
50	11.0 *(4.5)*	14.5 *(8.0)*	18.0 *(11.0)*	21.0 *(13.0)*	23.5 *(14.5)*	25.5 *(16.5)*	28.0 *(18.0)*	30.0 *(20.0)*	31.5 *(21.0)*
60	11.5 *(4.5)*	15.5 *(8.5)*	19.5 *(11.5)*	22.5 *(13.5)*	25.5 *(15.5)*	28.0 *(17.5)*	30.5 *(19.5)*	32.5 *(21.0)*	33.5 *(22.5)*
80	12.0 *(4.5)*	17.0 *(8.5)*	21.0 *(12.0)*	25.0 *(14.5)*	28.5 *(17.0)*	31.5 *(19.0)*	34.0 *(21.0)*	36.5 *(23.5)*	38.5 *(25.0)*
100	12.0 *(4.5)*	18.0 *(9.0)*	22.5 *(12.0)*	27.0 *(15.5)*	31.0 *(18.0)*	34.5 *(20.5)*	37.0 *(22.5)*	40.0 *(25.0)*	42.0 *(27.0)*
120	12.0 *(4.5)*	18.5 *(9.0)*	23.5 *(12.0)*	28.5 *(16.0)*	32.5 *(18.5)*	36.5 *(21.5)*	39.5 *(23.5)*	43.0 *(26.5)*	45.5 *(28.5)*
no limit	12.0 *(4.5)*	19.0 *(9.0)*	25.0 *(12.0)*	29.5 *(16.0)*	34.5 *(19.0)*	38.0 *(22.0)*	41.5 *(25.0)*	45.5 *(26.5)*	48.0 *(29.5)*
Enclosing rectangle 24m high									
3	2.0 *(1.0)*	3.0 *(1.5)*	3.5 *(2.0)*	4.5 *(2.5)*	5.0 *(3.0)*	5.5 *(3.5)*	6.0 *(3.5)*	7.0 *(4.0)*	7.5 *(4.5)*
6	3.5 *(1.5)*	5.0 *(2.5)*	6.0 *(3.5)*	7.0 *(4.5)*	8.5 *(5.0)*	9.5 *(5.5)*	10.0 *(6.0)*	10.5 *(7.0)*	11.0 *(7.0)*
9	5.0 *(2.0)*	6.5 *(3.5)*	8.0 *(5.0)*	9.5 *(5.5)*	11.0 *(6.5)*	12.0 *(7.5)*	13.0 *(8.0)*	13.5 *(9.0)*	14.5 *(9.5)*
12	6.0 *(2.5)*	8.0 *(4.5)*	9.5 *(6.0)*	11.5 *(7.0)*	12.5 *(8.0)*	14.0 *(8.5)*	15.0 *(9.5)*	16.0 *(10.5)*	16.5 *(11.5)*
15	6.5 *(3.0)*	9.0 *(5.0)*	11.0 *(6.5)*	13.0 *(8.0)*	14.5 *(9.0)*	15.5 *(10.0)*	17.0 *(11.0)*	18.0 *(12.0)*	19.0 *(13.0)*
18	7.5 *(3.0)*	10.0 *(5.5)*	12.0 *(7.5)*	14.0 *(8.5)*	15.5 *(10.0)*	16.5 *(11.0)*	18.5 *(12.0)*	19.5 *(13.0)*	20.5 *(14.0)*
21	8.0 *(3.5)*	10.5 *(6.0)*	13.0 *(8.0)*	15.0 *(9.5)*	16.5 *(10.5)*	18.0 *(12.0)*	20.0 *(13.0)*	21.0 *(14.0)*	22.0 *(15.0)*
24	8.5 *(3.5)*	11.5 *(6.5)*	14.0 *(8.5)*	16.0 *(10.0)*	18.0 *(11.5)*	19.5 *(12.5)*	21.0 *(14.0)*	22.5 *(15.0)*	24.0 *(16.0)*
27	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)*	25.5 *(17.0)*
30	9.5 *(4.0)*	13.0 *(7.5)*	15.5 *(9.5)*	18.0 *(11.5)*	20.0 *(13.0)*	21.5 *(14.0)*	23.5 *(15.5)*	25.0 *(17.0)*	26.5 *(18.0)*
40	11.0 *(4.5)*	14.5 *(8.5)*	18.0 *(11.0)*	20.5 *(13.0)*	23.0 *(14.5)*	25.0 *(16.0)*	27.5 *(18.0)*	29.0 *(19.0)*	30.5 *(20.5)*
50	12.0 *(5.0)*	16.0 *(9.0)*	19.5 *(12.0)*	22.5 *(14.0)*	25.5 *(16.0)*	27.5 *(17.5)*	30.0 *(19.5)*	32.0 *(21.0)*	33.5 *(22.5)*
60	12.5 *(5.0)*	17.0 *(9.5)*	21.0 *(12.5)*	24.5 *(15.0)*	27.5 *(17.0)*	30.0 *(19.0)*	32.5 *(21.0)*	35.0 *(23.0)*	36.5 *(24.5)*
80	13.5 *(5.0)*	18.5 *(10.0)*	23.5 *(13.5)*	27.5 *(16.5)*	31.0 *(18.5)*	34.5 *(21.0)*	37.0 *(23.5)*	39.5 *(25.5)*	41.5 *(27.5)*
100	13.5 *(5.0)*	20.0 *(10.0)*	25.0 *(13.5)*	29.5 *(17.0)*	33.5 *(20.0)*	37.0 *(22.5)*	40.0 *(25.0)*	43.0 *(27.5)*	45.5 *(29.5)*
120	13.5 *(5.5)*	20.5 *(10.0)*	26.5 *(13.5)*	31.0 *(17.5)*	36.0 *(20.5)*	39.5 *(22.5)*	43.0 *(26.5)*	46.5 *(29.0)*	49.0 *(31.0)*
no limit	13.5 *(5.5)*	21.0 *(10.0)*	27.5 *(13.5)*	32.5 *(18.0)*	37.5 *(21.0)*	42.0 *(24.0)*	45.5 *(27.5)*	49.5 *(30.0)*	52.0 *(32.5)*
Enclosing rectangle 27m high									
3	2.0 *(1.0)*	3.0 *(1.5)*	4.0 *(2.0)*	4.5 *(2.5)*	5.5 *(3.0)*	6.0 *(3.5)*	6.5 *(4.0)*	7.0 *(4.0)*	7.5 *(4.5)*
6	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	5.0 *(2.0)*	7.0 *(3.5)*	8.5 *(5.0)*	10.0 *(6.0)*	11.5 *(7.0)*	12.5 *(7.5)*	13.5 *(8.5)*	14.5 *(9.5)*	15.0 *(10.0)*
12	6.0 *(2.5)*	8.0 *(4.5)*	10.5 *(6.0)*	12.0 *(7.0)*	13.5 *(8.0)*	14.5 *(9.0)*	16.0 *(10.5)*	17.0 *(11.0)*	17.5 *(12.0)*
15	7.0 *(3.0)*	9.5 *(5.5)*	11.5 *(7.0)*	13.5 *(8.5)*	15.0 *(9.5)*	16.5 *(10.5)*	18.0 *(11.5)*	19.0 *(12.5)*	20.0 *(13.5)*
18	8.0 *(3.5)*	10.5 *(6.0)*	12.5 *(8.0)*	14.5 *(9.0)*	16.5 *(10.5)*	17.5 *(11.5)*	19.5 *(12.5)*	20.5 *(13.5)*	21.5 *(14.5)*
21	8.5 *(3.5)*	11.5 *(6.5)*	14.0 *(8.5)*	16.0 *(10.0)*	18.0 *(11.5)*	19.0 *(13.0)*	21.0 *(14.0)*	22.5 *(15.0)*	23.5 *(16.0)*
24	9.0 *(3.5)*	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)*	25.5 *(17.0)*
27	10.0 *(4.0)*	13.0 *(7.5)*	16.0 *(10.0)*	18.0 *(11.5)*	20.0 *(13.0)*	22.0 *(14.0)*	24.0 *(16.0)*	25.5 *(17.0)*	27.0 *(18.0)*
30	10.0 *(4.0)*	13.5 *(8.0)*	17.0 *(10.0)*	19.0 *(12.0)*	21.0 *(13.5)*	23.0 *(15.0)*	25.0 *(17.0)*	26.5 *(18.0)*	28.0 *(19.0)*
40	11.5 *(5.0)*	15.5 *(9.0)*	19.0 *(11.5)*	22.0 *(14.0)*	24.5 *(15.5)*	26.5 *(17.5)*	29.0 *(19.0)*	30.5 *(20.5)*	32.5 *(22.0)*
50	12.5 *(5.5)*	17.0 *(9.5)*	21.0 *(12.5)*	24.0 *(15.0)*	27.0 *(17.0)*	29.5 *(19.0)*	32.0 *(21.0)*	34.5 (22.5)	36.0 *(24.0)*
60	13.5 *(5.5)*	18.5 *(10.5)*	22.5 *(13.5)*	26.5 *(16.0)*	29.5 *(18.5)*	32.0 *(20.5)*	35.0 *(22.5)*	37.0 *(24.5)*	39.0 *(26.5)*
80	14.5 *(6.0)*	20.5 *(11.0)*	25.0 *(14.5)*	29.5 *(17.5)*	33.0 *(20.5)*	36.5 *(22.5)*	39.5 *(25.0)*	42.0 *(27.5)*	44.0 *(29.5)*
100	15.5 *(6.0)*	21.5 *(11.0)*	27.0 *(15.5)*	32.0 *(19.0)*	36.5 *(21.5)*	40.5 *(24.5)*	43.0 *(27.0)*	46.5 *(30.0)*	48.5 *(32.0)*
120	15.5 *(6.0)*	22.5 *(11.5)*	28.5 *(15.5)*	34.0 *(19.5)*	39.0 *(22.5)*	43.0 *(26.0)*	46.5 *(28.5)*	50.5 *(32.0)*	53.0 *(34.0)*
no limit	15.5 *(6.0)*	23.5 *(11.5)*	29.5 *(15.5)*	35.0 *(20.0)*	40.5 *(23.5)*	44.5 *(27.0)*	48.5 *(29.5)*	52.0 *(33.0)*	55.5 *(35.0)*

Stage 5 Special areas of exposure hazard

Often the boundary distances may be determined quite simply by the use of Stages 1-4. In practice, however, instances will occur where the elevation is not uniform or the plan shape is more complex.

Local concentration of exposure hazard
An elevation may be of such character that at one point the amount of unprotected area presents a greater radiation hazard than the remainder of the elevation. Diagram 8 shows a building where the total area of unprotected areas in the overall enclosing rectangle ABCD (6 m high and 24 m wide) is 30% and from Table 1 the required distance to the boundary is 5 m for a building of 'normal' fire load density. This distance is termed the 'first limiting position' of the boundary. Rectangle EBCF however should be considered separately. Reference to Table 1 shows that a rectangle 6 m high and 6 m wide with 100% of unprotected area would require a boundary distance of 6 m, an increase of 1 m which must be maintained on either side of the area EBCF. This position is known as the 'final limiting position' of the boundary.

It will be mainly found that unless the area of unprotected areas in the remainder of the overall enclosing rectangle is small in comparison with the local concentration, no change in the boundary distance will be necessary.

Widely spaced groups of unprotected areas
Sometimes groups of unprotected areas may be spaced a considerable distance apart; so far apart, in fact, that a point opposite one group may receive a negligible amount of radiation from the next group. Here, each unprotected area or group of unprotected areas may be treated as a separate radiator.

To assess whether or not the unprotected areas are spaced sufficiently far apart that they may be treated as separate radiators, it is necessary to determine first the boundary distance by taking the percentage of all unprotected areas within the overall enclosing rectangle and from the table obtain the 'first limiting position' of the boundary. If the spacing of the unprotected areas or groups of unprotected areas is not less than four times the boundary distance determined from the table, then each group of unprotected areas may be taken as acting as a separate radiator and the boundary distance may be adjusted accordingly (Diagram 9).

Elevations with set-backs more than 1.5 m behind the plane of reference
When parts of an elevation are set back more than 1.5 m a reduction in the boundary distance is possible to allow for the reduced radiation exposure. This is achieved by considering the elevation in two stages (Diagram 10).

1 The elevation is assumed to be on the plane of reference. For a building used for Residential, Office or Assembly and recreation purposes Table 1 gives a boundary distance of 3.5 m.

2 An 'equivalent radiator' is set on line D′C′ from the external angle of the extreme opening of the set-back, for which Table 1 gives a boundary distance of 4.1 m by interpolation.

The new limiting position of the boundary is taken to be at a distance of 4.1 m from the 'equivalent radiator' or at the original position whichever is the nearer.

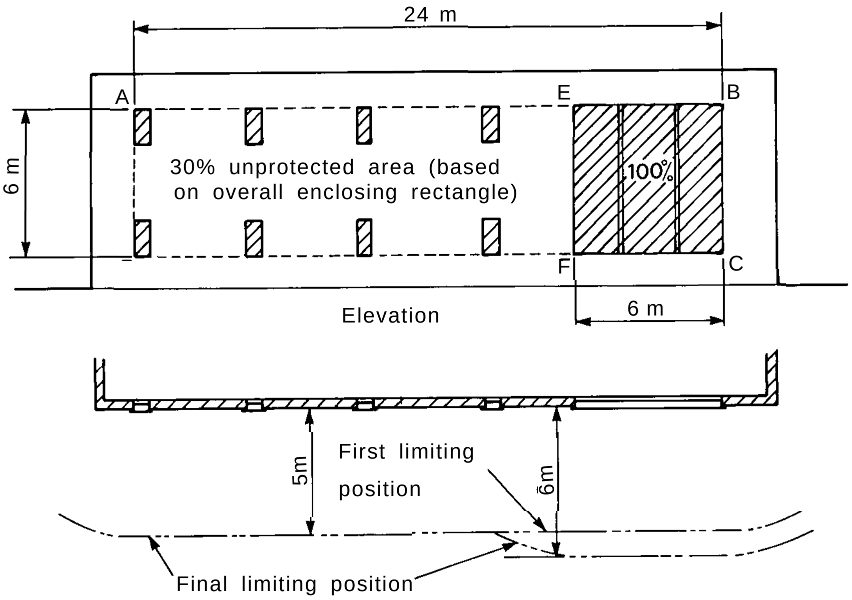


Diagram 8 Concentration of unprotected areas

Recesses with unprotected areas on three sides

A recess containing unprotected areas on all three sides will appear on elevation as a radiating enclosure. To determine the boundary position, all the unprotected areas in the elevation, including those in the sides of the recess, should be added together and expressed as a percentage of the overall enclosing rectangle. Where the total area of unprotected areas in the recess is greater than the area of the front of the recess, then the front should be considered as a radiator with 100% unprotected area.

It may be found that where this occurs, a local concentration of exposure hazard is produced necessitating an increase in the boundary distance. The increased distance must be maintained in all radial directions from the plane of reference.

Diagram 11 shows the boundary distance for an elevation with a recess having windows on three sides.

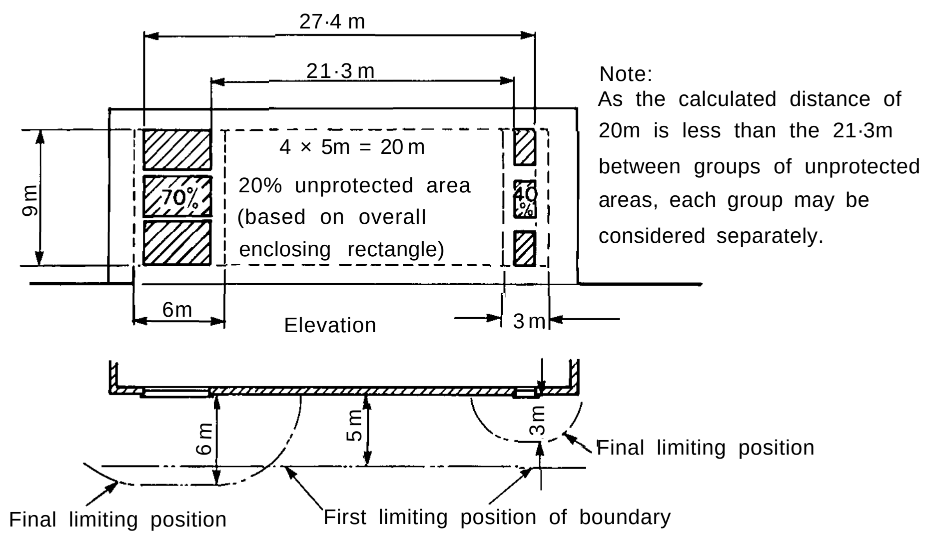


Diagram 9 Widely spaced groups of unprotected areas

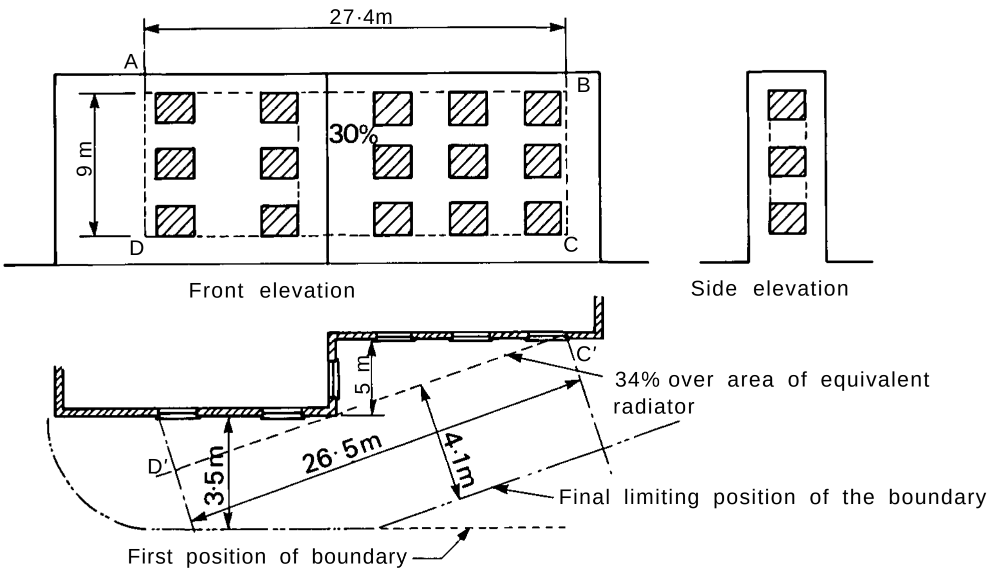


Diagram 10 Set-backs on plan

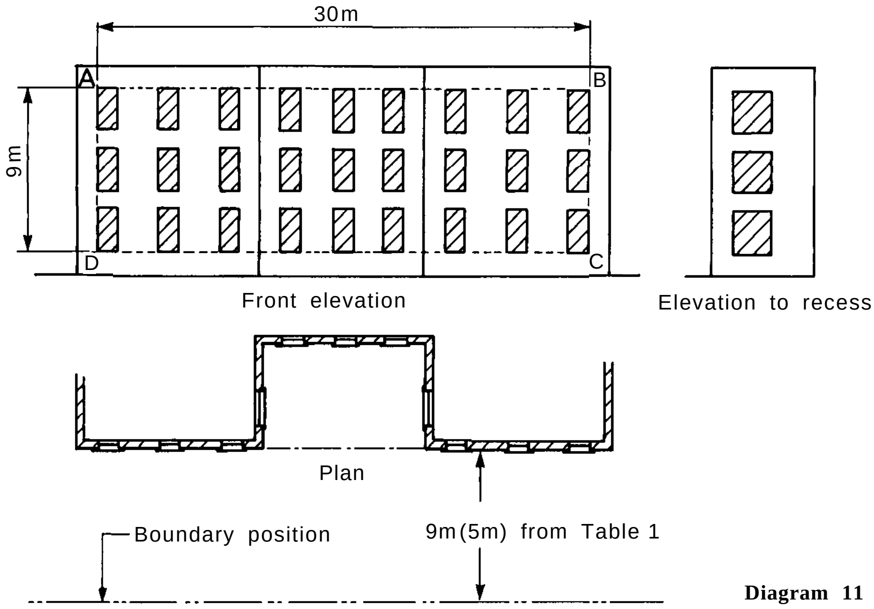


Diagram 11 Recesses with windows on three sides

Area ABCD (overall rectangle) = 30 m × 9 m = 270 m^2

Area of unprotected areas (on elevation) = 78 m^2

Area of unprotected areas (sides of recess) = 30 m^2

Total unprotected area = 108 m^2

Percentage of all unprotected areas in ABCD = $\frac{108}{270} \times 100 = 40\%$

From Table 1, for an enclosing rectangle 9 m high × 30 m wide, with an unprotected percentage not exceeding 40%, the minimum boundary distance is given as 9 m or 5 m according to the purpose group of the building.

Recesses with unprotected areas only in the rear wall

The first limiting position of the boundary must be obtained assuming all the unprotected areas in the recess are radiating at the aperture. The fact that some of the unprotected areas are set back behind the face of the building (the plane of reference) will reduce the intensity of radiation from the elevation as a whole. It is necessary, therefore, to assess what this reduction will be. This may be done by the use of the formula:

$$R = \left[\frac{2b_1}{2b_1 + r}\right]^2$$

where : b_1 = first limiting position of the boundary

r = depth of the recess

R = reduction factor for the unprotected areas in the recess

If the recess is narrow in relation to the length of the overall enclosing rectangle, it is unlikely that within the range of Table 1 any significant reduction from the first limiting position of the boundary will be possible.

Diagram 12 shows the adjusted boundary distance for a recess 5 m deep and 18 m wide with windows only in the rear wall.

Area ABCD (overall rectangle) = 30 m × 6 m = 180 m^2

Area of unprotected areas in (1) = 14 m^2
(2) = 44 m^2
(3) = 14 m^2

Total unprotected area = 72 m^2

Percentage of all unprotected areas in ABCD = $\frac{72}{180} \times 100 = 40\%$

From Table 1, for an enclosing rectangle 6 m high × 30 m wide, with an unprotected percentage not exceeding 40%, the minimum boundary distance is given as 6.5 m or 3.5 m according to the purpose group of the building.

Assuming the building has a Residential, Office or Assembly/recreation use, the area of the unprotected areas (2) in the recess may be reduced as follows:

$$R = \left[\frac{2b_1}{2b_1 + r}\right]^2 = \left[\frac{7}{7 + 5}\right]^2 = 0.34$$

Therefore the area in (2) is taken as 44 × 0.34 = 14.96 m^2.

Reduced area of unprotected areas in ABCD = (14 + 14.96 + 14) = 42.96 m^2.

Adjusted percentage of unprotected areas in ABCD =

$$\frac{42.96}{180} \times 100 = 23.87\%$$

From Table 1, for an enclosing rectangle 6 m high × 30 m wide, with an unprotected percentage not exceeding 30%, the minimum boundary distance is now given as 2.5 m.

Note: The examples which have been illustrated are basic plan forms but the principles can be applied to a wide variety of plan shapes and elevational treatment.

Stage 5 does, however, require a more detailed analysis than Stages 1 to 4 and the Aggregate Notional Area method may be used instead.

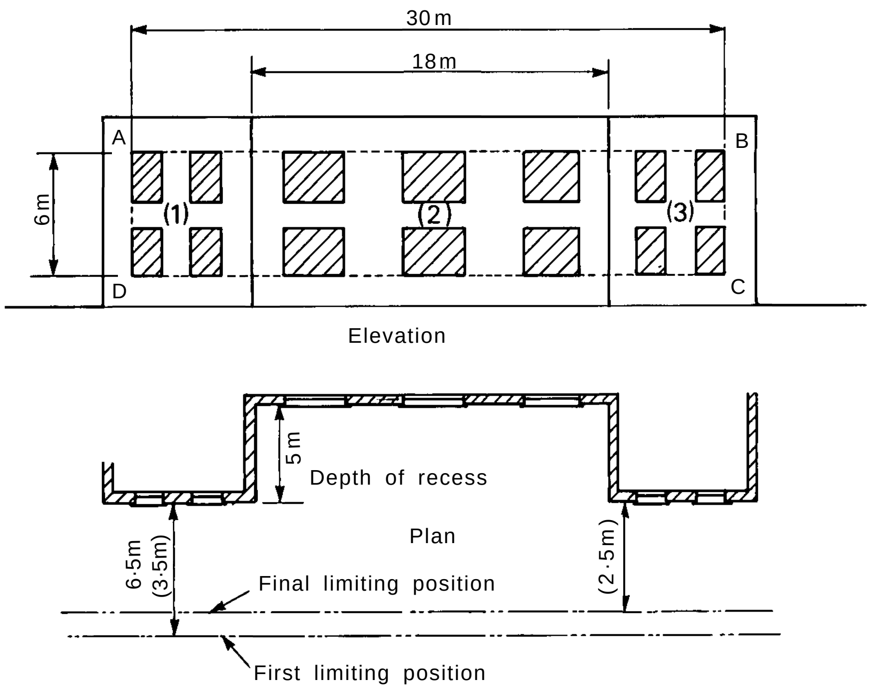


Diagram 12 Recesses with windows only in the rear wall

Aggregate Notional Areas (Protractor method)

This method consists of viewing the building from a series of points on the boundary and calculating the effective areas of the visible 'unprotected areas'. The further an unprotected area is from the boundary, the smaller its effective or notional area and this is calculated by multiplying the actual area by a factor which depends on distance. The factors are obtained by placing a 'protractor' (Diagram 13) made to the same scale as the plan and noticing in which zones, corresponding to different factors, the unprotected areas fall. The sum of the effective areas of all the unprotected areas ('aggregate notional area') must not exceed a fixed amount.

The method may be sub-divided into the following stages:

1 determine what part(s) of the side of the building (termed 'unprotected areas') must be taken into account,

2 determine the points on the 'relevant boundary' to be tested,

3 determine which unprotected areas need to be taken into account, and

4 calculate the 'aggregate notional area' of these unprotected areas.

Stage 1 Unprotected areas

If the Enclosing Rectangle method has been carried out first, this stage will have been done already.

Stage 2 Determination of points on boundary to be tested

Mark off a series of points at 3 m intervals along the length of the **relevant boundary**. Where a boundary has been calculated by the Enclosing Rectangle method it is only necessary to test those points on the relevant boundary which fall inside it. The points can be selected by starting 3 m from the point of intersection.

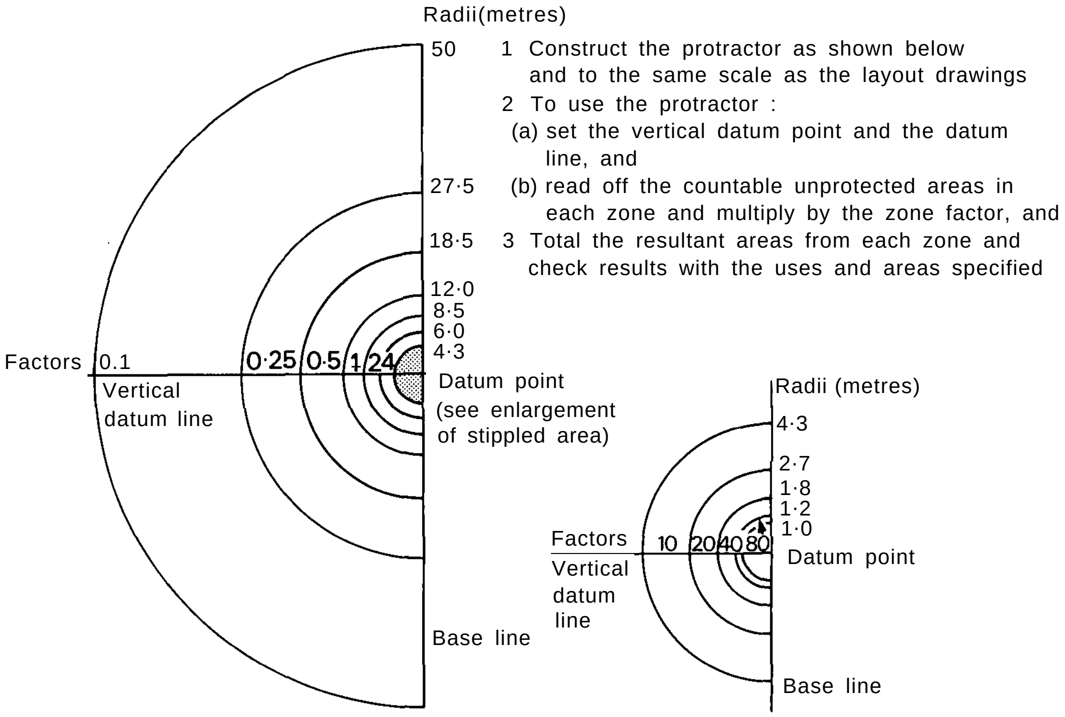


Diagram 13 Constructing a notional area protractor

Stage 3 Determination of which unprotected areas may be ignored

This stage is considered in two parts:

(a) At the first point to be tested, set a **vertical datum** of unlimited height and from this point draw a **datum line** to the nearest point on the building or compartment. (Where the boundary distance has not been set, an assumed relationship with the **relevant boundary** should be made). Then place the protractor so that its datum point and datum line respectively coincide with the vertical datum and datum line marked.

(b) Establish which **unprotected areas** cannot be 'seen' from the **vertical datum**, ie those which:

i are beyond the limit of the base line or the 50 m arc on the protractor,

ii are facing away from the vertical datum (Diagram 14(a)),

iii are screened from the vertical datum by any part of the external wall which has the required period of fire resistance (Diagram 14(b)), or

iv make an angle not exceeding 10° with a line drawn from the unprotected area to the vertical datum (Diagram 14(c)).

These areas and any areas which can be disregarded under Stage 1 can be ignored in Stage 4.

Stage 4 Calculation of aggregate notional area

The notional area of each unprotected area is found by multiplying its actual area by the factor given for the zone in which it falls. This process is carried out for each unprotected area which cannot be ignored.

For those unprotected areas which have to be considered:

(a) establish the appropriate multiplication factors. (If part falls in one zone and part in another, each part is given its appropriate factor),

(b) multiply each unprotected area (or part) by its factor, and

(c) total these to give the aggregate notional area for that vertical datum.

The **aggregate notional area** should not be more than:

i 210 m^2, if the building or compartment has a Residential, Office or Assembly and recreation use, or

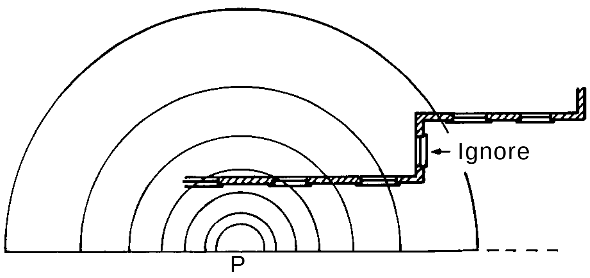
ii 90 m^2, if the building or compartment has a Shop and commercial, Industrial, Storage or Other non-residential use.

Repeat Stages 3 and 4 for each point to be tested.

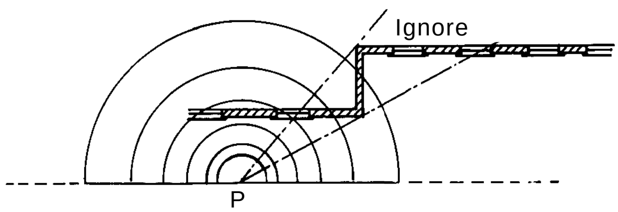
To find the maximum unprotected area for a given boundary position

If any one of the resultant series of **aggregate notional areas** is greater than the allowance (see Stage 4), the design should be modified accordingly until the proposed **unprotected areas** are suitable for the boundary distance.

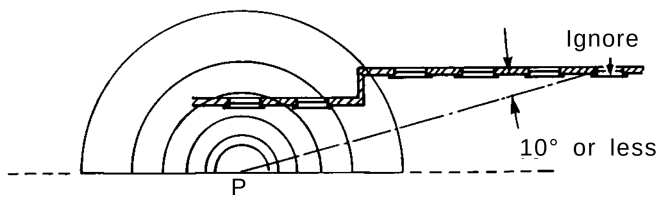
Repeat the process for all sides of the building situated not less than 1 m from any point on the **relevant boundary.**



(a) Areas which face away



(b) Areas shielded by fire–resisting wall



(c) Areas viewed obliquely

Diagram 14 Unprotected areas which cannot be seen

To find the nearest position of boundary for a given building design

If any one of the resultant series of **aggregate notional areas** is greater than the allowance (see Stage 4), adjustments should be made to the assumed relationship with the boundary.

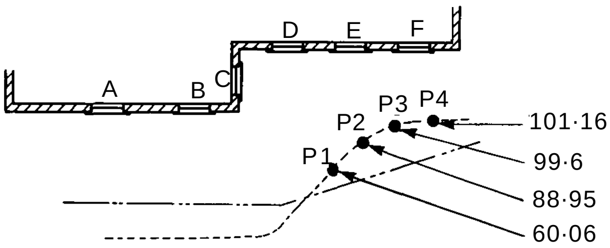
Repeat the process for all sides of the building until a zone around the building is established upon which a boundary should not encroach.

Example of use of protractor

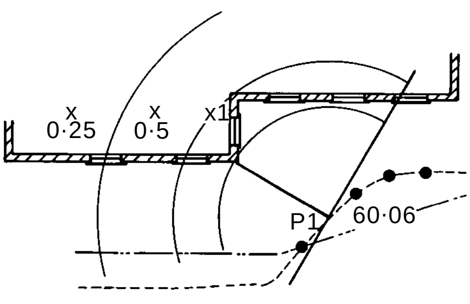
Diagram 15 shows the plan of a proposed uncompartmented building in relation to the relevant boundary. The minimum boundary distance given by the Enclosing Rectangle method is also shown. The relevant boundary falls outside this distance on the left-hand side of the plan and therefore the building is well spaced from the relevant boundary at this region. However, it falls inside near the setback and it is therefore necessary to check with the protractor whether the proposed building is too near. This is done at the 3 m intervals marked. (The position of the protractor is sketched for two of the points in Diagram 15(b) and 15(c)).

Table 2 shows the details of the calculation for one storey. Since each storey is the same, the answer is multiplied by 3 to give the **aggregate notional area**. If the building is assumed to have a Shop and commercial, Industrial, Storage or Other non-residential use, it is clear that the building would be too close to the boundary. Three courses are then open to the building designer:

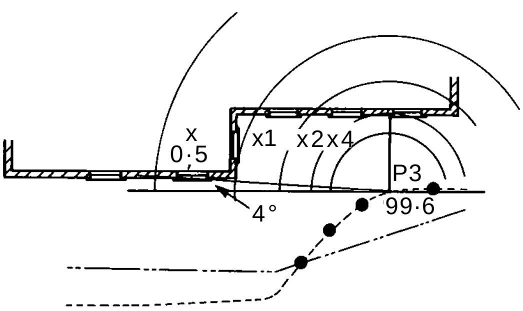
- the building can be moved back,
- the extent of unprotected areas can be reduced, or
- compartment walls and/or floors can be introduced.



(a) Figures at each point denote aggregate notional area



(b) Point P1



(c) Point P3

-··——··—··— Boundary given by enclosing rectangle method

- - - - - - - - - - Actual boundary

Diagram 15 Calculation of 'aggregate notional area'

Table 2 Calculation of aggregate notional area (Diagram 15)

Opening (Unprotected area)	Area (m²)	Opening discounted	Zone	Area in zone (m²)	Notional area (m²)	Opening discounted	Zone	Area in zone (m²)	Notional area (m²)
		Point P1				**Point P2**			
A	4.5	No	0.25 0.5	2.25 2.25	0.56 1.12	Yes*	—	—	0
B	4.5	No	0.5 1	1.12 3.38	0.56 3.38	No	0.5	4.5	2.25
C	4.0	No	1	4.0	4.0	No	1	4.0	4.0
D	5.2	No	1	5.2	5.2	No	1	5.2	5.2
E	5.2	No	1	5.2	5.2	No	2	5.2	10.4
F	5.2	Yes+	—	—	0	No	2 1	2.6 2.6	5.2 2.6
Total for 1 storey					20.02				29.65
Total for 3 storeys					60.06				88.95
		Point P3				**Point P4**			
A	4.5	Yes*	—	—	0	Yes*	—	—	0
B	4.5	Yes*	—	—	0	Yes*	—	—	0
C	4.0	No	0.5	4.0	2.0	No	0.5	4.0	2.0
D	5.2	No	1	5.2	5.2	No	1 0.5	1.04 4.16	1.04 2.08
E	5.2	No	2	5.2	10.4	No	2 1	2.6 2.6	5.2 2.6
F	5.2	No	4 2	2.6 2.6	10.4 5.2	No	4	5.2	20.8
Total for 1 storey					33.2				33.72
Total for 3 storeys					99.6				101.16

Key: * at 10° or less
+ beyond limit of base line

Appendix A

Alternative approach to Table 1 for calculating maximum permitted unprotected areas in relation to enclosing rectangles

S J Melinek, BSc, PhD

This approach gives the distance to the **relevant boundary** (or the maximum proportion of the **enclosing rectangle** which may be unprotected) as a simple function. It can be applied to any size of enclosing rectangle, with any fraction unprotected.

The method described in Part 1 of this Report should be followed, but in Stage 3(a) the **enclosing rectangle** should be taken as the actual rectangle which encloses all the relevant **unprotected areas** in the side of the building or compartment projected onto the **plane of reference** (instead of using Table 1 in which the enclosing rectangles are given in 3 m increments).

The approach enables calculations to be carried out, for example, on a programmable calculator.

To find the maximum unprotected area for a given boundary position

The maximum proportion of the **enclosing rectangle** which may be unprotected (u) is given by the following equation:

$$u = \frac{(d/f)^2}{(wh)}$$

where:

d = distance from the relevant boundary,
h = height of the enclosing rectangle,
w = width of the enclosing rectangle, and
f = factor from Table 3 or Diagram 16.

If 'h' or 'w' are greater than 140 m, a value of 140 m may be used.

Where u = 1 or more, this is equivalent to 100% unprotected area.

To find the nearest position of boundary for a given building design

The minimum distance (d) from the **relevant boundary** is given by the following equation:

$$d = g\sqrt{(uwh)}$$

where:

h = height of the enclosing rectangle,
u = proportion of the enclosing rectangle which is unprotected,
w = width of the enclosing rectangle, and
g = factor found from Table 4 or Diagram 17.

If 'h' or 'w' are greater than 140 m, a value of 140 m may be used.

Where u = 1, this is equivalent to 100% unprotected area.

Table 3 Factor 'f' (where boundary distance has been set)

h/d if 'h' is greater than 'w'; or w/d if 'h' is not greater than 'w'	Factor 'f' (a)	Factor 'f' (b)
1*	—	1.00
1.5*	0.67	0.98
2	0.66	0.95
3	0.62	0.89
4	0.57	0.82
6	0.50	0.71
8	0.44	0.63
10ϕ	0.40	0.57

(a) Residential, Office, and Assembly and recreation uses.

(b) Shop and commercial, Industrial, and Other non-residential uses.

Note: 'f' may be estimated by interpolation for intermediate values of $\frac{h}{d}$ and $\frac{w}{d}$

* In the case of values less than:

- 1.00, for Shop and commercial, Industrial, and Other non-residential uses, and
- 1.5, for Residential, Office, and Assembly and recreation uses —

the maximum proportion of the enclosing rectangle which may be unprotected (u) can be taken as 1.0.

ϕ For values greater than 10, the maximum proportion of the enclosing rectangle which may be unprotected (u) can be taken as:

- $0.6\left(\frac{d}{w}\right)$ or $0.6\left(\frac{d}{h}\right)$

  (whichever is greater), for Residential, Office, and Assembly and recreation uses, and

- $0.3\left(\frac{d}{w}\right)$ or $0.3\left(\frac{d}{h}\right)$

  (whichever is greater), for Shop and commercial, Industrial, and Other non-residential uses.

Examples

1 Find the maximum permitted unprotected area for an uncompartmented Office building 27 m high and 20 m wide, 6 m from the relevant boundary. Therefore using Table 3:

$$\frac{h}{d} = \frac{27}{6} = 4.5$$

Hence, f = 0.55

$$\text{Therefore 'u'} = \frac{(d/f)^2}{wh} = \frac{(6/0.55)^2}{20 \times 27} = \frac{119}{540} = 0.22$$

Hence, the maximum permitted unprotected area is 22% of the enclosing rectangle, which is 0.22 × 27 × 20 = 120 m^2.

2 Find the maximum permitted unprotected area for an uncompartmented Industrial building 6 m high and 20 m wide, 5 m from the relevant boundary. Therefore using Table 3:

$$\frac{w}{d} = \frac{20}{5} = 4$$

Hence, f = 0.82

$$\text{Therefore 'u'} = \frac{(d/f)^2}{wh} = \frac{(5/0.82)^2}{20 \times 6} = \frac{37.18}{120} = 0.31$$

Hence, the maximum permitted unprotected area is 31% of the enclosing rectangle, which is 0.31 × 6 × 20 = 37 m^2.

3 Find the maximum permitted distance from the relevant boundary for an uncompartmented Office building with enclosing rectangle 12 m high and 18 m wide, of which the proportion unprotected is 0.50. Therefore using Table 4:

$$\frac{w}{uh} = \frac{18}{0.50 \times 12} = 3.00$$

Hence, g = 0.63

Therefore

$$\text{'d'} = g\sqrt{(uwh)} = 0.63\sqrt{(0.50 \times 18 \times 12)} = 6.5\text{m}$$

4 Find the minimum permitted distance from the relevant boundary for a compartmented Office building, the enclosing rectangle of each compartment being 6 m high and 12 m wide, of which the proportion unprotected is 0.35. Therefore using Table 4:

$$\frac{w}{uh} = \frac{12}{0.35 \times 6} = 5.71$$

Hence, g = 0.57

Therefore

$$\text{'d'} = g\sqrt{(uwh)} = 0.57\sqrt{(0.35 \times 12 \times 6)} = 2.9\text{m}$$

Table 4 Factor 'g' (where minimum boundary distance is being determined)

w/(uh) if 'w' is greater than 'h'; or h/(uw) if 'w' is not greater than 'h'	Factor 'g' (a)	Factor 'g' (b)
1	0.67	1.00
2	0.66	0.98
3	0.63	0.96
4	0.61	0.94
6	0.56	0.91
8	0.52	0.87
10	0.49	0.84
12	0.45	0.80
14	0.43	0.77
16	0.40	0.74
18	0.38	0.71
20	0.36	0.69
25	0.33	0.63
30*	0.30	0.60

(a) Residential, Office, and Assembly and recreation uses.

(b) Shop and commercial, Industrial, and Other non-residential uses.

Note: 'g' may be estimated by interpolation for intermediate values of $\frac{w}{uh}$ and $\frac{h}{uw}$

* For values greater than 30, the minimum distance (d) from the relevant boundary can be taken as:

- 1.67 uw or 1.67 uh (whichever is less), for Residential, Office, and Assembly and recreation uses, and
- 3.33 uw or 3.33 uh (whichever is less), for Shop and commercial, Industrial, and Other non-residential uses.

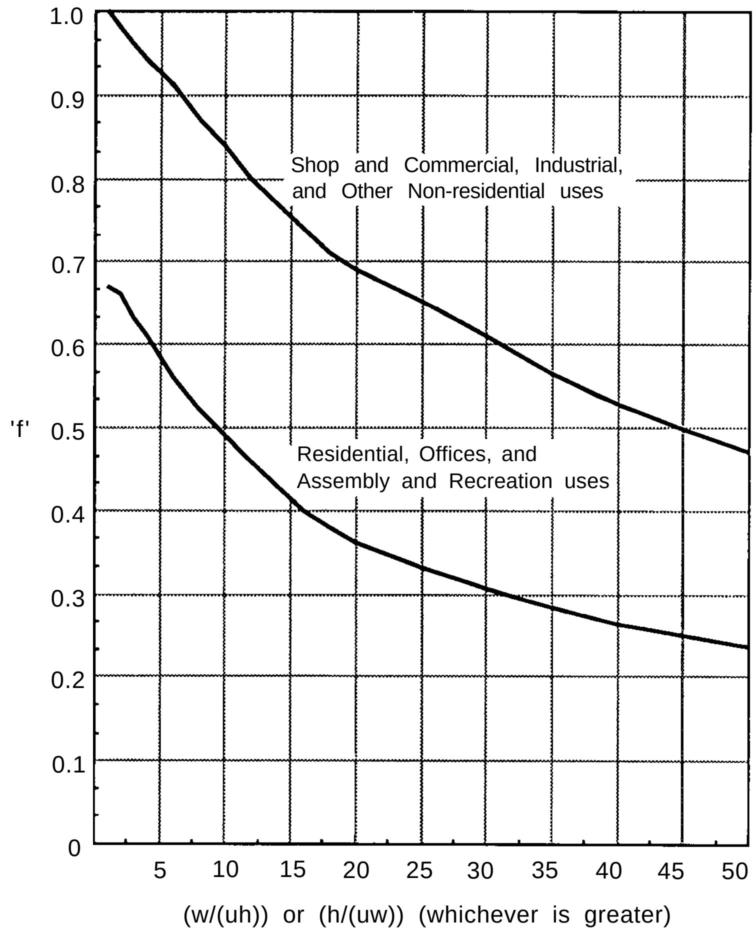


Diagram 16 Factor 'f' (where boundary distance has been set)

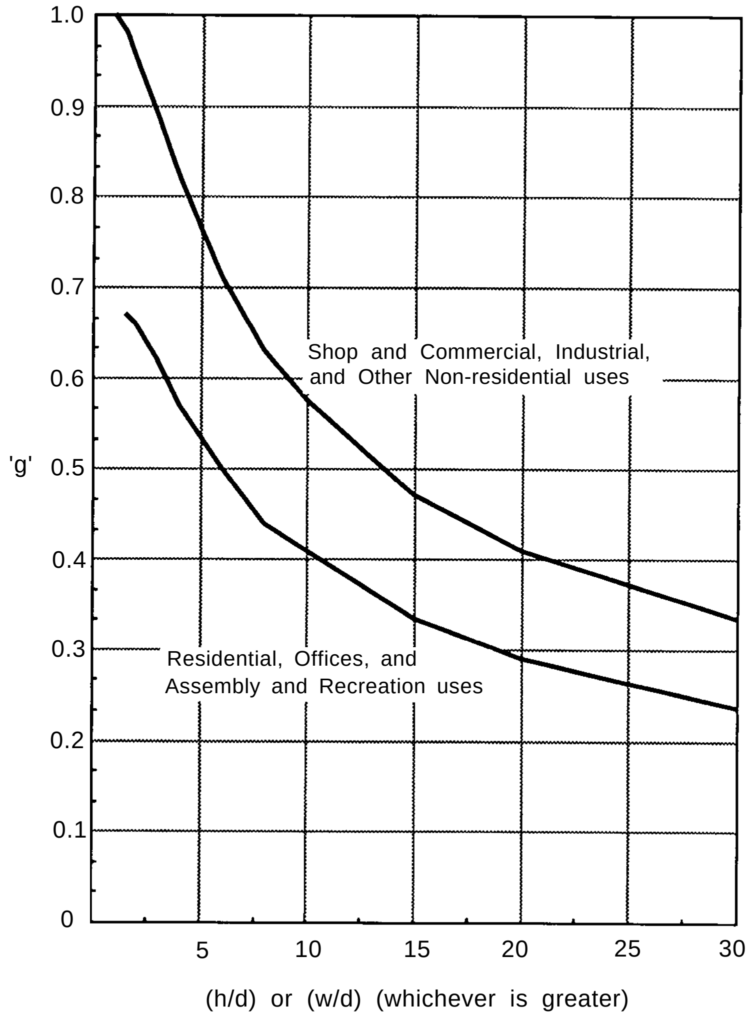


Diagram 17 Factor 'g' (where minimum boundary distance is being determined)

Part 2: Heat radiation from fires and building separation

Margaret Law, BSc

Preface

The risk of spreading fire is one of the factors which must be taken into account in deciding the spacing between buildings. By studying the conditions under which materials ignite and the amount of radiation at various distances from buildings, it is possible to arrive at adequate separating distances.

The information in the report was used to assist the Building Regulations Inter-Departmental Committee in drafting building regulations for Scotland and it is hoped that the discussion of the principles will be of value in deciding adequate standards of fire protection.

It would be economically impracticable to provide for building separation such that spread of fire from one building to another could never occur. This paper provides a method for calculating separation so that the risk may be minimised, and where ignition of a neighbouring building may occur, to ensure that it will be sufficiently delayed to enable action by the Fire Brigade to be taken.

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January 1963

Summary

This report discusses the spread of fire by radiation from a burning building to neighbouring property. The levels of radiation likely to be encountered and their effect on combustible materials are considered. Flying brands are a hazard but it is considered that fires started by them would develop slowly and could be dealt with by the Fire Brigade. From these considerations, simple rules are developed for arriving at the separation between buildings to avoid fire spread.

Introduction

This report discusses the risk of fire spreading from a burning building to surrounding property due to heat radiation. It describes ways of determining the separation between buildings so as to reduce the hazard to an acceptable level, and considers methods of specifying requirements for building separation.

It has long been recognised that buildings must be adequately separated to reduce the risk of fire spreading from one to another. Buildings are not normally close enough for fire to be transferred by actual flame contact, nor are most building materials ignited by flying brands when these alight on a cold surface. However when brands alight on a surface heated by radiation from a fire, ignition is much more likely to occur and there is a very real possibility of secondary fires being started. Increasing the separation between buildings reduces the radiation hazard but, for a given separation distance, the intensity of radiation received by the exposed building depends on the area of the burning facade and the flames. Clearly a fire in a building with large windows or other large openings emitting radiation is more hazardous than one in a building with a small amount of openings and, with the trend in modern architecture towards larger windows, combustible cladding and curtain walling of low fire-resistance, the reliable assessment of exposure hazard is becoming increasingly important.

It is necessary, therefore, when planning the separation of buildings, to have a knowledge of two major factors:

i The levels of radiation which will ignite materials both on the outside of an exposed building and within the rooms due to radiation entering through the window.

ii The level of radiation from a fire in a building.

These factors have been investigated in a series of experiments by the Joint Fire Research Organization and by other workers, and the first part of this report is concerned with a discussion of their effect on building separation.

Once the basic requirements for building separation have been decided, it is possible to calculate the minimum separation necessary between two buildings. The report shows how this may be calculated for any size and type of building.

Since it is hoped that the information in this report could be used as a basis for legal requirements, and since the calculations may be somewhat complex, simplified methods of determining separation distance have also been devised. These simple methods give distances which are sufficiently accurate for most purposes. They have been designed so that any inaccuracy tends to over-estimation of the distances, but where this is considered undesirable then the more accurate calculation may be undertaken.

In practice the position of a building is planned in relation to its site boundary rather than to neighbouring buildings. The implications of this are discussed later.

Effect of radiation on combustible materials

When a building is exposed to radiation there is not only a hazard to any combustible material on the outside of the building, but also to the combustible contents of a room from radiation entering the windows.

The most commonly found combustible material on the exterior of buildings is wood and its behaviour when exposed to radiation is representative of a large variety of building materials. If it is exposed to a sufficiently high intensity it will ignite spontaneously; at a lower intensity it will only ignite if a subsidiary source of ignition is sufficiently near to the surface to ignite the flammable gases released by the heated surface (pilot ignition)[1]. For a vertical surface this is generally within about 1/2 in.

Spontaneous ignition of wood will only occur for incident intensities above 0.8 cal $cm^{-2}s^{-1}$ (177 Btu $ft^{-2}min^{-1}$) and, except for certain types of behaviour (Appendix I) which will be disregarded, pilot ignition only occurs with intensities above 0.3 cal $cm^{-2}s^{-1}$. Spontaneous ignition in the open takes place fairly quickly after exposure to radiation and either occurs within about 2 min or not at all[2] but the ignition time for pilot ignition in the open can be much longer, and near the threshold level of radiation, heating times of the order of 10 min are needed before ignition can take place. Since with building fires a spark or flying brand can act as a subsidiary source of ignition, it is clear that pilot ignition is possible. It is not practicable at present to assess the effect of wind on dispersing sparks, flying brands etc, but it would seem desirable that the incident intensity should not exceed the minimum for pilot ignition, though at distances sufficiently large for the intensity to be near this minimum value, many sparks will have burnt out before they reach the exposed surface or indeed may not reach it at all. Even if the intensity should slightly exceed this minimum, there would still be a margin of safety since ignition would only occur some 10 min after the primary fire had become fully developed and it may be assumed that the Fire Brigade would be available to afford protection to the exposed building. The report of the Joint Committee on Standards for Fire Cover[3] recommends that for areas of concentrated building in industrial and commercial cities, the time of attendance of the first appliance should be 5 min after the call. Statistics for some large fires show that four out of five Fire Brigades in County Boroughs in the United Kingdom attend within 4 min[4]. It would appear reasonable therefore to adopt as the criterion, a distance such that the intensity of radiation on the exposed building will not exceed the minimum for pilot ignition ie it should not exceed 0.3 cal $cm^{-2}s^{-1}$ (66 Btu $ft^{-2}min^{-1}$). Though minimizing risk, the possibility of an ember starting a fire is not completely eliminated but if such a fire were started it would develop slowly and would be dealt with by the Fire Brigade.

The minimum intensities given above are for ignition of oven-dried wood unprotected by paint. In practice the wood will always contain some moisture which may have the effect of raising the minimum intensity at which ignition will occur[2]. The amount of moisture in the exposed wood may vary but there is no condition which will be more hazardous than the oven-dried one. Most paints also raise the minimum intensity but, since weathering and cracking may expose bare wood, the protective value of any paint has not been taken into account. It will thus be seen that the figure taken of 0.3 cal $cm^{-2}s^{-1}$ errs on the side of safety.

Experiments[5] have shown that a material in an enclosure will ignite at a lower intensity of radiation than in the open, so that although the intensity of radiation falling on an exposed building may be below the minimum for pilot ignition in the open, there may still be a hazard to the contents of a room because of radiation coming through the window. Although the plate glass in a window can absorb some 40 to 60% of the radiation from a building fire, it cannot be relied on to afford protection to the contents of the room since large areas are liable to crack and fall out. No figure of a maximum 'safe' intensity for glass can be given with confidence since such variable factors as restraint at the edges and stresses in the glass itself affect its behaviour. The worst case of immediate cracking and falling out must therefore be assumed. Experiments[6] with one-tenth scale model rooms with an opening either 33 or 100% of the area of the exposed wall showed there was a greater hazard with the larger opening. The rooms were furnished and lined either with plasterboard or fibre insulating board. A small gas flame was introduced to represent a subsidiary source of ignition such as a fire in the grate or other heating appliance. The experiments showed that with the larger opening and either type of lining, spontaneous ignition of one of the articles of furniture near the window would occur after 20-min exposure to an intensity at the opening of 0.3 cal $cm^{-2}s^{-1}$. With the 33% opening, pilot ignition of the lining would occur within half an hour for an intensity of 0.8 cal $cm^{-2}s^{-1}$ with the plasterboard lining and 0.56 cal $cm^{-2}s^{-1}$ with the fibre insulating board lining. There is reason to believe that on full scale rather higher intensities of radiation would be needed to produce the above effects[5]. The worst situation that can be envisaged is a room with one whole side occupied by a window, the glazing destroyed, and exposed to the peak radiation from a building fire for at least 20 min. When in addition the time taken for a fire to develop to its peak is considered, then the Fire Brigade, even at night, should be able to arrive sufficiently soon to protect the exposed building. It therefore appears reasonable to specify that the separation of buildings must be such that the incident intensity of radiation will not exceed 0.3 cal $cm^{-2}s^{-1}$.

Intensity of radiation from compartment fires

In general, the intensity of radiation, I, emitted from a hot body is related to its absolute temperature, T, according to the well-known law:

$$I = e s T^4 \qquad (1)$$

where e is emissivity, less than or equal to unity

and s is the Stefan-Boltzmann constant $= 1.36 \times 10^{-12}$ cal $cm^{-2}s^{-1}$ $°C^{-4}$.

The emissivity of a surface has a maximum value of unity and a small opening in a uniformly heated enclosure will radiate with an emissivity approaching unity. 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. The temperature and hence the radiation from a fire in a compartment varies with time, as the walls become hotter, and differs between compartments. Differences in the distribution and amount of fuel, in the geometry of the window and the compartment can affect the rate of burning and this will affect the temperatures attained. To make useful regulations, considerable simplifications have to be introduced and in this report only a typical value of the intensity emitted by fires for a wide class of buildings and occupancies is sought. The temperature of a burning compartment will obviously have an important effect on the heat radiated since this depends on a fourth-power relation (equation (1)) and it is necessary now to consider the temperature attained in fires in compartments.

The temperature of the fire depends on the rate of burning and fires may be considered as divided into two types:

i Those in which the ventilation is restricted and the rate of burning depends on the size of the window, and

ii Those in which the window area is comparable with the floor area where the rate of burning depends on the fire load*, its surface area and arrangement, and not on the window area. Such fires may be said to be fully ventilated.

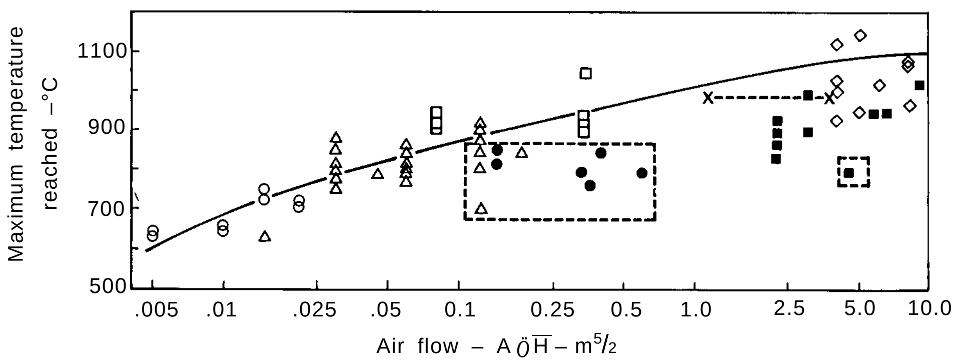
These two types of fire will now be considered in more detail. It will be shown that for practical purposes the effect of ventilation on the rate of burning may be disregarded, and that for both types, the radiating intensity tends to an upper limit of 4 cal $cm^{-2}s^{-1}$ and the intensity is reduced if the fire load is small.

Type 1. Fires with restricted ventilation

With this type of fire there are many more experimental values available for temperature than for radiation, and in using these data, temperatures measured near the ceiling are assumed to be typical of the maximum in the compartment. Some results are shown in Figure 1 plotted as a function of *A ÖH* where *A* is the area of the single window opening and *H* is the height of the window. *A ÖH* is the most important parameter affecting the rate of burning irrespective of compartment size.

The temperatures attained increase with ventilation, the results tending to a limiting value of less than 1100°C which corresponds to a theoretical maximum radiating level of 4 cal $cm^{-2}s^{-1}$. The results indicate that there is no evidence of any marked increase of intensity as *A ÖH* increases above 8 $m^{5/2}$, so that 4 cal $cm^{-2}s^{-1}$ can be taken as the maximum intensity for this type of fire.

It is clear from Figure 1 that it is only when *AÖH* is less than 5 $m^{5/2}$ that ventilation has a significant effect on the temperature of the enclosure. Since one window measuring 1.5 m × 3 m (5 ft × 10 ft) gives a value of 5.5 $m^{5/2}$ for *A ÖH*, it is apparent that for the majority of buildings a fire may always be considered capable of reaching temperatures of 1100°C.
There are however two conditions where the temperatures are significantly less than 1100°C.



Points within the broken lines are those where the fire load is less than 25 kg/m^2 ($5lb/ft^2$)

	Scale I floor area $0.09m^2$	Scale II floor area $0.49m^2$	Scale III floor area $1m^2$	Large-scale floor area $9m^2$
J.F.R.O.(7) (8) (10)	○	△	□	◇
Swedish test (9)				x--------x
Kawagoe (11) (12)			●	■

Figure 1 Maximum temperature and air flow

* 'Fire load' denotes the total amount of combustible material in the enclosure.

Compartments with AÖH less than 5 $m^{5/2}$

It is assumed that the data for small values of *AÖH* in Figure 1 can be used for full-scale compartments with small windows. It is clear that, for small values of *AÖH*, separation would always be small simply on account of the small size of the window. Thus a reduced intensity, due to restricted ventilation, would introduce only a small absolute change in separation and the effect can therefore be disregarded.

Compartments with a small fire load

Where the fire load/unit floor area is 25 kg/m^2 (5 lb/ft^2) or less, the fire does not last long enough for the compartment itself to become sufficiently hot and the radiating intensity is significantly less than 4 cal $cm^{-2}s^{-1}$. The data for such fires are shown enclosed by dotted lines in Figure 1. It is therefore justifiable to take a lower intensity of radiation for fires of low fire load. The value of the reduced intensity is discussed below.

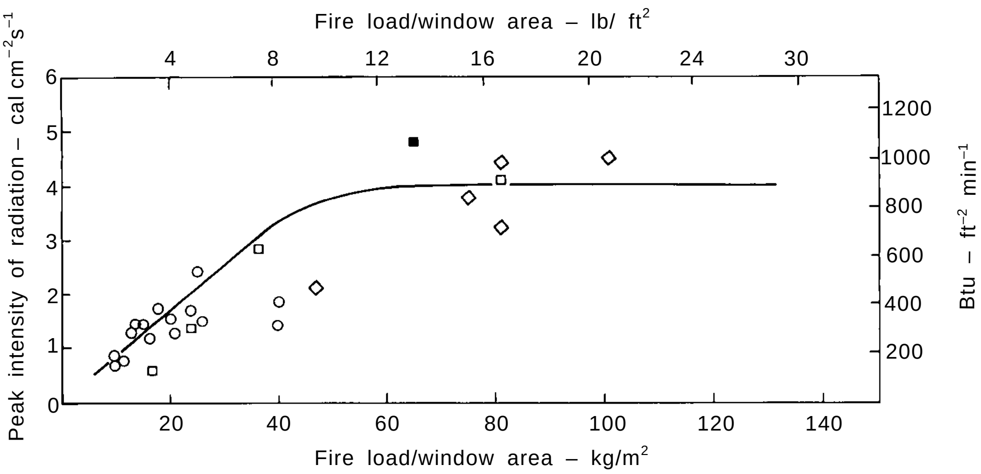
Type 2. Fully-ventilated fires

When the window is comparable with or larger than the floor area, the fires burn at a rate which is largely independent of *AÖH* and the intensity emitted for a given size of compartment is found experimentally to be related to the rate of burning. The intensity of radiation gives a better correlation with the rate of burning per unit *window* area than the rate of burning per unit *floor* area and since the rate of burning in fully-ventilated fires is approximately proportional to the total amount of fuel, the intensity of radiation is shown in Figure 2 in terms of the fire load per unit window area. However, for a fire of this type the window area must be comparable with the floor area, so that the horizontal scale of Figure 2 may be taken, for the purposes of these arguments, as being nominally the same as the fire load per unit floor area, this being a familiar concept in the context of building regulations. In Figure 2 there is a certain amount of scatter in the results and the line has been drawn to err on the side of safety. For comparison, peak intensities for some full-scale fires[(8)(11)], with openings exceeding half the floor area, have been estimated from their peak temperatures using equation (1), assuming an emissivity of unity. These are also plotted in Figure 2.

The intensity emitted by fires of Type 2, as for Type 1, tends to an upper limit of about 4 cal $cm^{-2}s^{-1}$, and for fires of low fire load of Type 2 the intensity is proportional to the fire load. It is also justifiable therefore to allow a reduced intensity for fires of low fire load of Type 2 and in this context low fire load can be described in terms of fire load per unit floor area.

It is seen from Figure 2 that for cubical compartments with large windows, the intensity of radiation is 2 cal $cm^{-2}s^{-1}$ for a fire load per unit floor area of about 25 kg/m^2 (5 lb/ft^2) and this has been taken as a secondary standard lower than the primary one of 4 cal $cm^{-2}s^{-1}$. Fires with less than 25 kg/m^2 (5 lb/ft^2) fire load per unit floor area would give temperatures less than about the value 800°C which corresponds to an intensity of radiation of 2 cal $cm^{-2}s^{-1}$.

Hence, for the purpose of devising regulations on space separation, 4 cal $cm^{-2}s^{-1}$ is taken as the normal standard and 2 cal $cm^{-2}s^{-1}$ for fire loads per unit floor area less than 25 kg/m^2 (5 lb/ft^2), for both Type 1 and 2 fires.



	Measured Intensity		Intensity estimated from temperature
	Small scale	3m scale	3m scale
J.F.R.O (8)(13)(14) (15)(16)	○	□	◇
Kawagoe (11)			■

Figure 2 Peak intensity of radiation at opening for fires where window and floor areas are comparable

Radiation from facades of burning buildings

The number of openings in a building which radiate will depend on how far the fire spreads inside the building. A fire in a building will tend to grow until it completely involves the room in which it started. It will spread to other rooms within the building until stopped by a fire division wall or ceiling. In theory the fire will involve the whole building if there are no such fire division walls but if there are it can be assumed that only the space bounded by them is involved. This space enclosed by fire division walls is called a fire compartment. Only one compartment would in theory radiate at a time and the required separation distance would be based on the compartment with the largest area of openings.

An opening can be considered here as any part of an external wall which has less fire-resistance than that specified for the building under consideration and hence could allow the transmission of radiation. A sub-standard part of a wall would be regarded as an opening. A wall clad with timber would be considered as an opening since the burning timber would act as a source of radiation and the area of any timber on part of the wall should be added to the area of openings. This procedure tends to over-estimate the hazard. On the other hand the contribution of flames outside a window to the radiation has been neglected. This is reasonable for a first approximation although there have been cases where large flames have been observed outside a window contributing radiation[(5)]. The size of these flames and the factors affecting them, both in still air and in the presence of a wind, are now being investigated and may lead to some modification, in certain cases, of the separation distances recommended in this report. One way of modifying the distances without changing the basis of these recommendations would be to ascribe an effective window area greater than the actual window area by some factor which could be determined separately. For unprotected buildings of more than one storey there will be a tendency for air to enter the lower openings and flames to emerge only from the upper ones, Figure 3. The exposed building would be placed in position on the assumption (p 29) that the point opposite the centre of the burning building would receive maximum radiation but the upper portion, exposed to the flames, would necessarily be, at least, at the same distance. The largest error in separation, due to the emergence of the flames, is likely to be for a single-storey building or a building with fire division floors.

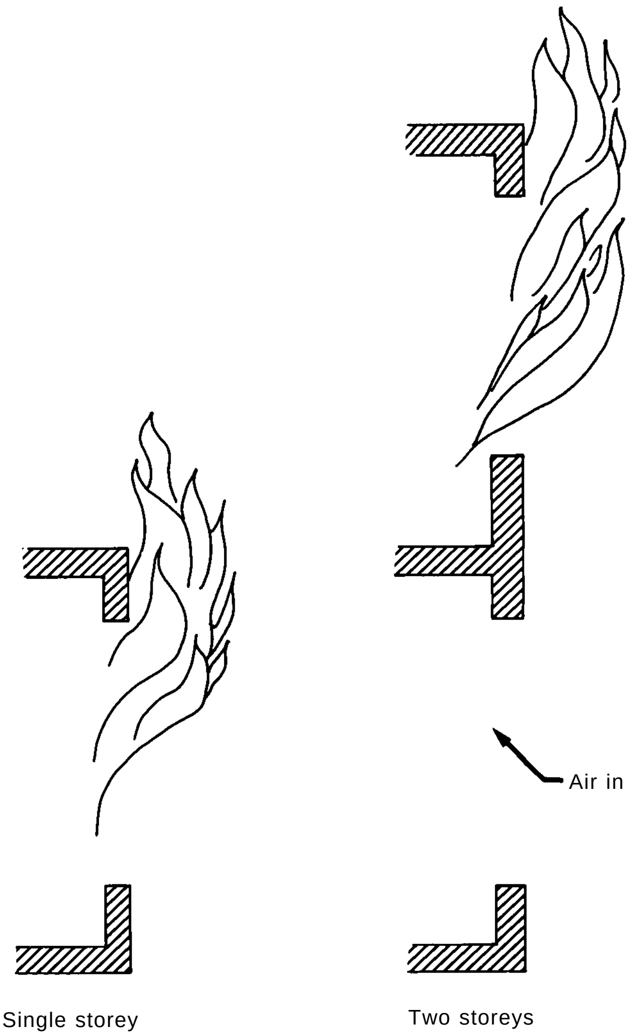


Figure 3 Flames from burning buildings

Calculation of intensity of radiation at any point

Having dealt with the radiation emitted from a burning building, it is now necessary to discuss how much of the radiation will fall on a neighbouring building. If a point source is emitting radiation, then the intensity of radiation at any other point is inversely proportional to the square of the distance between them, ie the well-known inverse square law. If, however, the source of energy is not a point but an extended area (or volume) then this simple law does not hold and the intensity received at any point depends on the shape and orientation of the radiator with respect to the receiver.

Consider a small elemental area *dA*, at *P′* on a radiating surface of temperature *T*, at a distance *R* from a point *P* on a receiving surface (Figure 4).

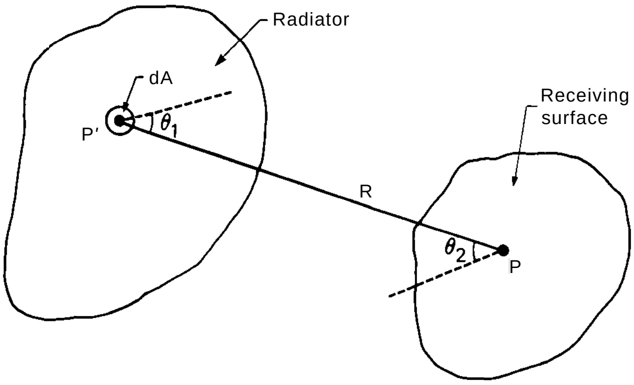


Figure 4 Radiator and receiving surface

The normals to these surfaces make angles q_1 and q_2 with the direction *P′ P*. It is assumed that the radiating surface emits radiation according to Lambert's cosine law; ie the amount of radiation per unit area in the direction *P′ P* is proportional to cos q_1 so that in the direction of the normal it is a maximum, and parallel to the surface, when q_1 is a right angle, it is zero. The law does not hold for all surfaces but may be assumed to hold for the purposes of this report with little loss of accuracy. The projection of the receiving surface at point *P* is similarly proportional to cos q_2 and the intensity at *P* is:

$$dI \;\; a \;\; dA \cos q_1 \cos q_2 e s T^4$$

Since *dA* is small compared with R^2 the inverse square law holds and

$$dI \;\; a \;\; \frac{dA \cos q_1 \cos q_2 e s T^4}{R^2}$$

The values of *dI* are then summed for all the elemental areas *dA* over the area *A* for all the values of *R* giving:

$$I = f e s T^4$$

The expression for *dI* only involves distance as a ratio $\frac{dA}{R^2}$ so that the integrated sum *I* at a point *P* is of the form $I \; a \; e s T^4$ and the constant of proportionality does not depend on distance or scale but only on relative shapes and relative distances. It is called *f* the shape factor or configuration factor[17] and since the maximum intensity close to the radiation source is $e s T^4$, *f* is always less than unity and measures the reduction in intensity at a distance. For large separations:

$$f \;\; a \;\; \frac{A}{R^2}$$

where *A* is the radiating area
and *R* is the separation.

Values of *f* for different radiators have been calculated by various authorities[17][18] for certain simple geometries so that given *f* and *A* it is possible to find *R*.

A useful property of configuration factors is that they can be added or subtracted. Thus the value of *f* for a number of radiators, is the sum of the values for each separate radiator. For example, the value of *f* for area AEFGCD in Figure 5 is that for ABCD minus that for EBGF

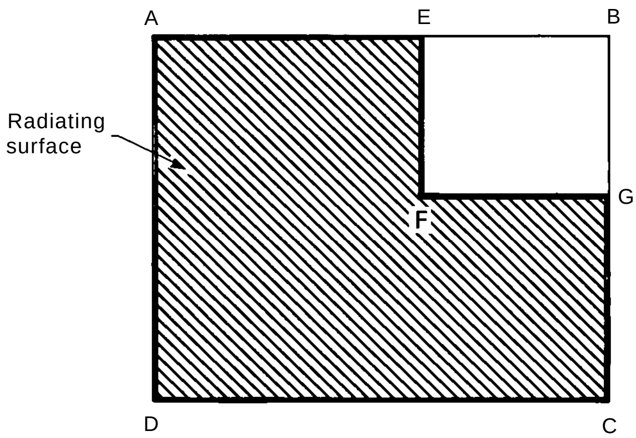


Figure 5 Radiator with corner removed

Given the intensity of radiation emitted by a fire, assumed to be the same for all openings, and the dimensions and distribution of the windows and other openings of the building, it is therefore possible to calculate the maximum distance at which the intensity at a point on a vertical facade facing this building, if on fire, would not exceed 0.3 cal $cm^{-2}s^{-1}$, the minimum intensity for ignition.

If a burning enclosure is emitting I_o cal $cm^{-2}s^{-1}$, where I_o is 4 or 2 according to the fire load per unit floor area, then the intensity at the point is given by:

$$I = f I_o$$

For a number of windows, *n*, similarly radiating:

$$I = (f_1 + f_2 + f_3 + \ldots + f_n) I_o$$

So that if $I = 0.3$ cal $cm^{-2}s^{-1}$:

$$S f_n = \frac{0.3}{I_o}$$

For I_o equivalent to 2 cal $cm^{-2}s^{-1}$, this defines separation as the distance where the maximum value of f_n is less than 0.15 and for I_o equivalent to 4 cal $cm^{-2}s^{-1}$, less than 0.075. f relates dimensions and shape of the radiating source to the separation distance so that, given the dimensions and dispositions of the windows, it is possible to find the distance to give the required value of Sf_n.

The calculation of separation distance can thus be expressed as a purely geometrical problem which is the approach discussed by Bevan and Webster[19]. Since windows are almost invariably rectangular in shape, only configuration factors for rectangular radiators will be considered, and the exposed point will be assumed to be on a vertical plane parallel to the plane of the radiator, since opposite the centre of the radiator a parallel plane receives the maximum level of radiation. For other shapes and other orientations, reference can be made to the authorities already quoted. Values of f [17],[18] are given in Figure 6 for a point P on a perpendicular axis through the corner of the rectangular radiator, as shown in Figure 7(a). By using the additive property of configuration factors, the value of f at any point can be found. Thus in Figure 7(b) the value of f at P is the sum of f for the rectangles AEP′H, EBFP′, P′FCG and HP′GD, and in Figure 7(c) the sum for rectangles AEP′G, GP′FD minus the sum for BEP′H and HP′FC. Figure 6 shows that for a point opposite the corner of a rectangular radiator f cannot exceed 0.25, and it is clear that for f to approach unity the point must be opposite the centre of the rectangle, since the point will then receive radiation from four rectangles. In general, for a rectangular radiator, the maximum intensity at any distance lies on the perpendicular axis through the centre of the rectangle and for more general application it is convenient to employ the additive property and Figure 6. For more than one radiator, the position at which there is maximum intensity in any plane depends on the relative positions and sizes of the radiators.

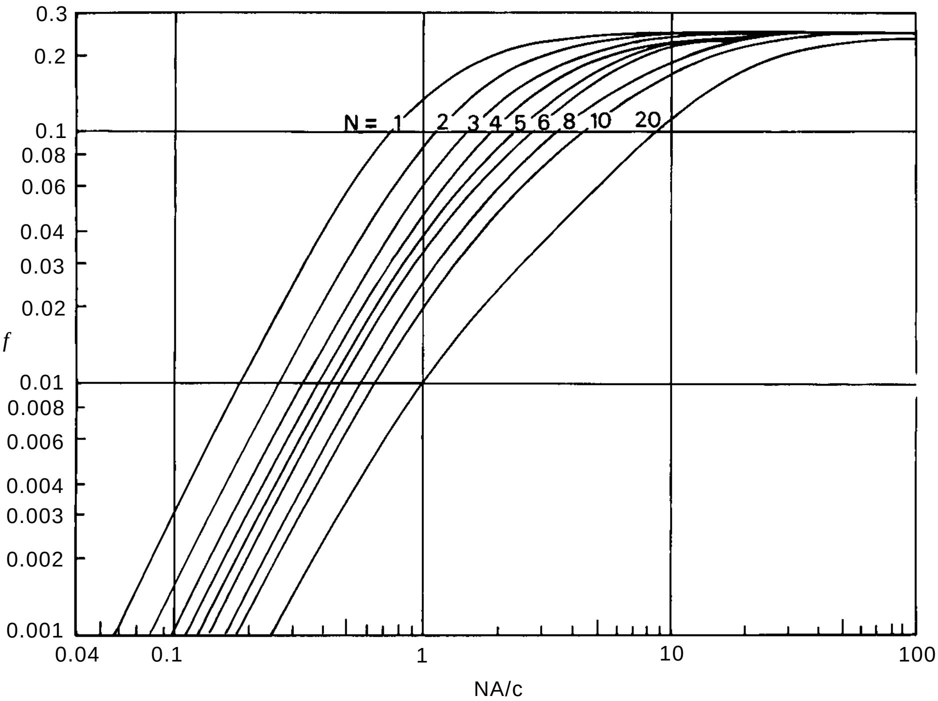


Figure 6 Configuration factor f for differently shaped radiators

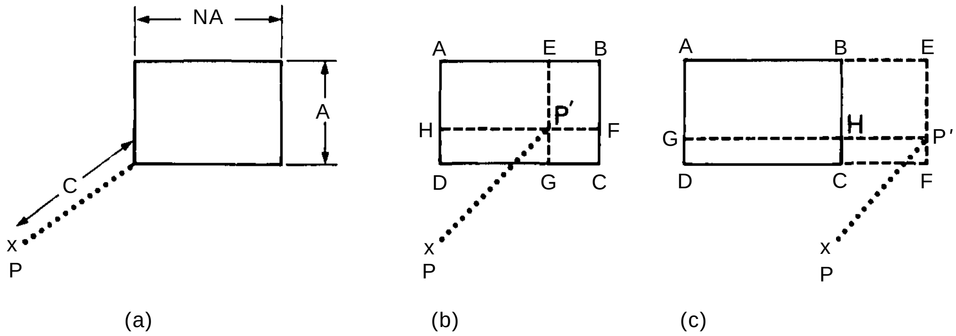


Figure 7 Additive property of configuration factors

The minimum separation distance is the maximum distance at which an intensity of 0.3 cal $cm^{-2}s^{-1}$ can be received. This, as has been shown above, introduces a safety factor which tends to counteract the neglect of flame radiation.

The above outline of the principle of evaluating the necessary separation distance from the required value of f and the size of radiator, usually rectangular, leads to tedious calculations and any application of the general method will not be discussed here. The remainder of the report is concerned with practical application in the light of simplifications to the above arguments.

Specification of boundary distance

In practice, when a building is being planned, the position of the potentially exposed neighbouring building is not known and it is necessary to place the former building in relation to its site boundary. For this, and legal reasons it is the boundary distance which is specified in regulations. One obvious way of specifying this boundary distance, is to make it half the separation distance, so that if two similar buildings, one the mirror image of the other, are then placed on opposite sides of the boundary, the distance between them is the correct separation distance. For two dissimilar buildings, however, the building with smaller openings and hence with the smaller boundary distance, may receive a higher intensity of radiation than 0.3 cal $cm^{-2}s^{-1}$, if the other is on fire. To allow for such inequalities as these, a larger fraction than half the separation distance might be specified. However, to ensure that in every situation no less than the correct separation would be attained, there would be land wasted since, in the limiting and absolutely safe condition, the separation would have to be such that the intensity at the boundary did not exceed 0.3 cal $cm^{-2}s^{-1}$. If the principle of placing buildings in relation to the site boundary must be accepted, then some form of compromise is inevitable.

It may be noted that, in general, the maximum intensity of radiation will be received opposite the centre of the facade of a burning building and a small building exposed to fire may be well below this level. Thus a smaller building may not be at so much of a disadvantage as appears at first sight.

It has been suggested that for the 'mirror image' criterion it would be simpler to specify an intensity at the boundary, rather than half the distance for an intensity of 0.3 cal $cm^{-2}s^{-1}$. However, for the correct separation distance, the intensity at the boundary depends on the shape of the buildings and amount of openings, since the variation of intensity with distance from a rectangular radiator does not follow a simple law. For example, consider two pairs of buildings with 100% openings, one pair very wide and the other square. The intensity halfway between the wide buildings is 0.6 cal $cm^{-2}s^{-1}$ and halfway between the square ones is 0.95 cal $cm^{-2}s^{-1}$. By choosing an intensity at the boundary to cover all types of building, it can be shown that the boundary distance might be as much as 40% greater than half the separation distance. However, such a specification would remove some of the discrepancies outlined in the preceding paragraph and the possibility of specifying boundary distances in this way, as another form of compromise, could be borne in mind.

The remainder of this report is devoted to illustrating simplified methods of obtaining the separation distance c. If the boundary distance b is taken as half this value, then b can be found by substituting in each case:

$$b = \frac{c}{2} \ .$$

Calculation of separation distance

Elevation with a number of openings

For most elevations with a number of windows, the problem can be reduced to that of a single radiator. This single radiator is the rectangle which totally encloses all the openings in the elevation (termed the overall enclosing rectangle) considered as radiating 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 50% of the enclosing rectangle and the building contained a normal fire load, then the intensity 4 cal $cm^{-2}s^{-1}$ would be reduced by a factor 50/100 and the effective radiating intensity of the rectangle would be taken as 2 cal $cm^{-2}s^{-1}$. The appropriate configuration factor would then be calculated to find the required separation distance.

Consider the elevation in Figure 8(a). The rectangle ABCD encloses all the openings and their area is 50% of the area of ABCD. The equivalent radiator is shown in Figure 8(b) with I_o = 2.0 cal $cm^{-2}s^{-1}$.

Therefore:

$$f_n = \frac{0.3}{2.0} = 0.15$$

At any distance, f_n is a maximum on the line normal to the centre of the rectangle so that the point on this normal, when f_n = 0.15, gives the minimum separation distance.

f_n for the point P is the sum of f for each of the separate rectangles, as in Figure 7(b), and since these rectangles are identical:

$$f_n = 4 \times f \text{ for EBFP}'$$

Therefore:

$$f \text{ for EBFP}' = \frac{0.15}{4} = 0.0375$$

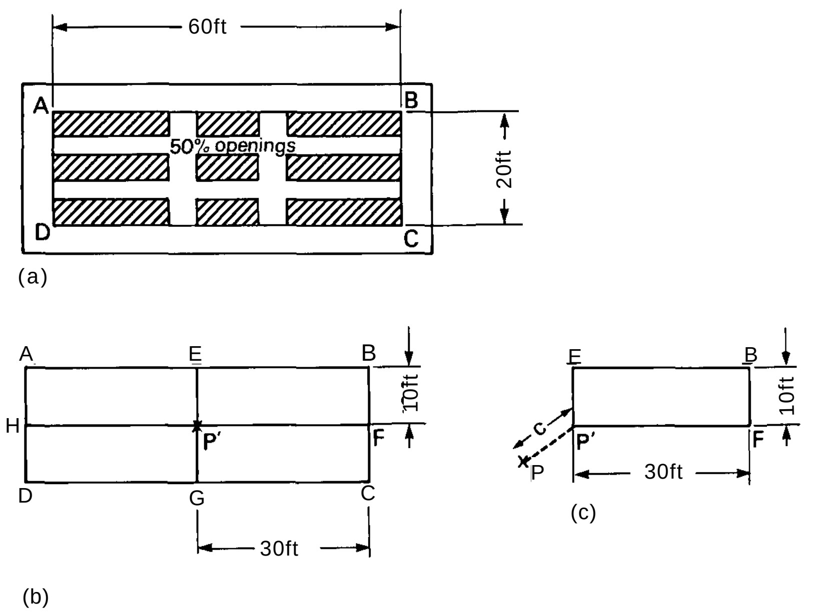
Referring to Figure 6:

$$A = 10 \text{ ft}$$
$$N = 3$$

and for $f = 0.0375, \ \frac{NA}{C} = 0.69$

Therefore: $c = 44$ ft

Separation distances have been calculated for different percentages of opening and different length to width ratios and are shown in Figures 9 and 10 for fire loadings per unit floor area respectively greater and less than 5 lb/ft^2. It is clear from these figures that for large values of N, c/A is constant and that once a radiator is a certain length, any increase in length (ie any increase in N) makes no difference to the separation distance as measured by c/A. This may be visualised by imagining that an observer is standing in front of a wall sufficiently long for the ends to appear to vanish into the distance, so that if a piece were added to the end, the addition would not be perceived. Similarly, a receiver in front of a sufficiently long radiator cannot 'see' extra radiation from the end. For a given incident intensity, the value of N at which c/A becomes constant depends on the radiating intensity and here for small percentages of openings, c/A rapidly reaches its steady value. It is sufficient for practical purposes that, for percentages of openings with values between those shown in Figures 9 and 10, the curve with the next higher value should be used.



Equivalent radiator with I_o = 2 cal cm^{-2}s^{-1}

Figure 8 Elevation with a number of openings

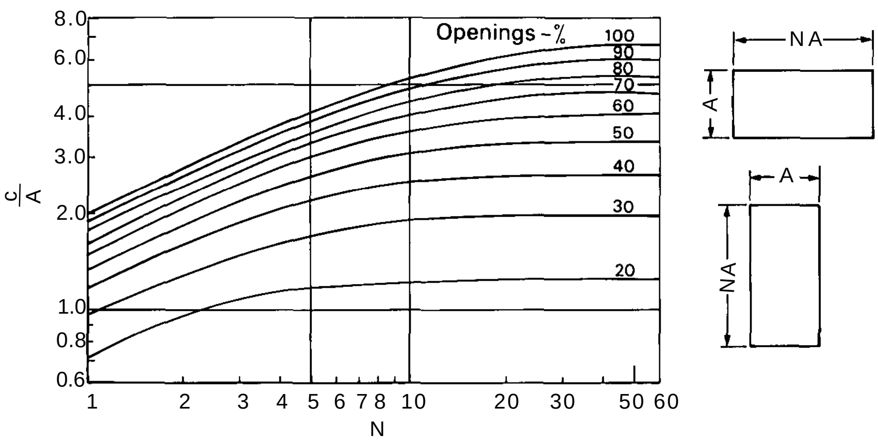


Figure 9 Separation distance c for normal intensity fire (Fire load per unit floor area greater than 5lb/ft^2)

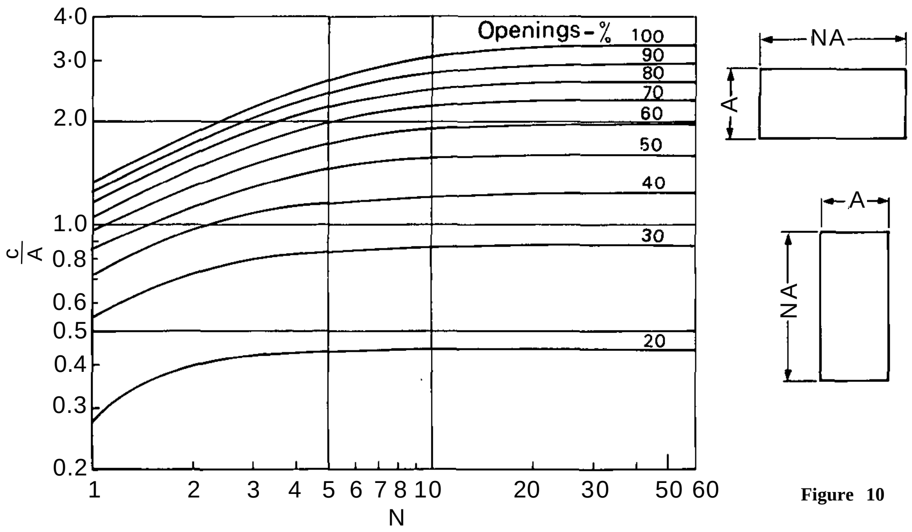


Figure 10 Separation distance c for low intensity fire (Fire load per unit floor area less than $5 lb/ft^2$)

Experimental determination of configuration factor

The configuration factor for an elevation with any number of openings could alternatively be found with an optical analogue, which exploits the similarity between the transmission of light and thermal radiation. A piece of diffusing glass is evenly illuminated and used as the radiator. This glass is then masked except for portions representing the radiating openings and the light intensity at any point is measured by a photo-electric cell [20]. The intensity close to an open portion ie the maximum intensity, is also measured by the cell. The ratio of the intensity at any distance to this maximum value is the value of f at the point chosen, all distances being scaled in proportion.

With this device it is possible to find the values of f for facades which are of too complicated a shape for simple calculations to be practicable.

Variation in separation distance

The distance normal to a rectangular radiator at which the intensity is a given fraction of the intensity at the window, is a maximum opposite the centre and is less opposite the edges. The locus of a given configuration factor, defining the necessary separation distance, is shown diagrammatically in Figure 11 for vertical and horizontal sections normal to the radiating surface and through its centre point. The vertical section shows that the separation distance of some of the storeys of the exposed building must inevitably be greater than required. This gives a factor of safety.

The locus on the horizontal section, projected on plan, gives the locus of the separation distance and it can be seen that exposed buildings opposite the sides of the radiator could be nearer than those opposite the centre. In most cases, however, little is lost by requiring that the maximum separation distance, opposite the centre, should extend for the full width of the radiator but where, for example, there is an opening next to a portion of blank wall, part of the exposed building could be nearer the blank portion and a simple rule devised to allow for this will now be described.

The difference between the distances opposite the centre and opposite the side becomes less marked as the height of the radiator increases relative to its width. For a very wide radiator of height H, the separation distance opposite the centre, c_1, is given by[17]:

$$c_1 = \frac{H}{2f}\sqrt{1-f^2} \approx \frac{H}{2f}$$

to an accuracy of greater than 5% if f is less than $^1/_3$. and opposite the edge, the distance, c_2, is given by:

$$c_2 = \frac{H}{4f}\sqrt{1-4f^2} \approx \frac{H}{4f}$$

to an accuracy of greater than 5% if f is less than $^1/_6$.

ie: $$\frac{c_1}{c_2} \approx 2$$

For a very tall radiator of width W, the separation distance opposite the centre, c_1', is given by:

$$c_1' = \frac{W}{2f}\sqrt{1-f^2}$$

and opposite the edge the distance, c_2', is given by:

$$c_2' = \frac{W}{2f}\sqrt{1-4f^2}$$

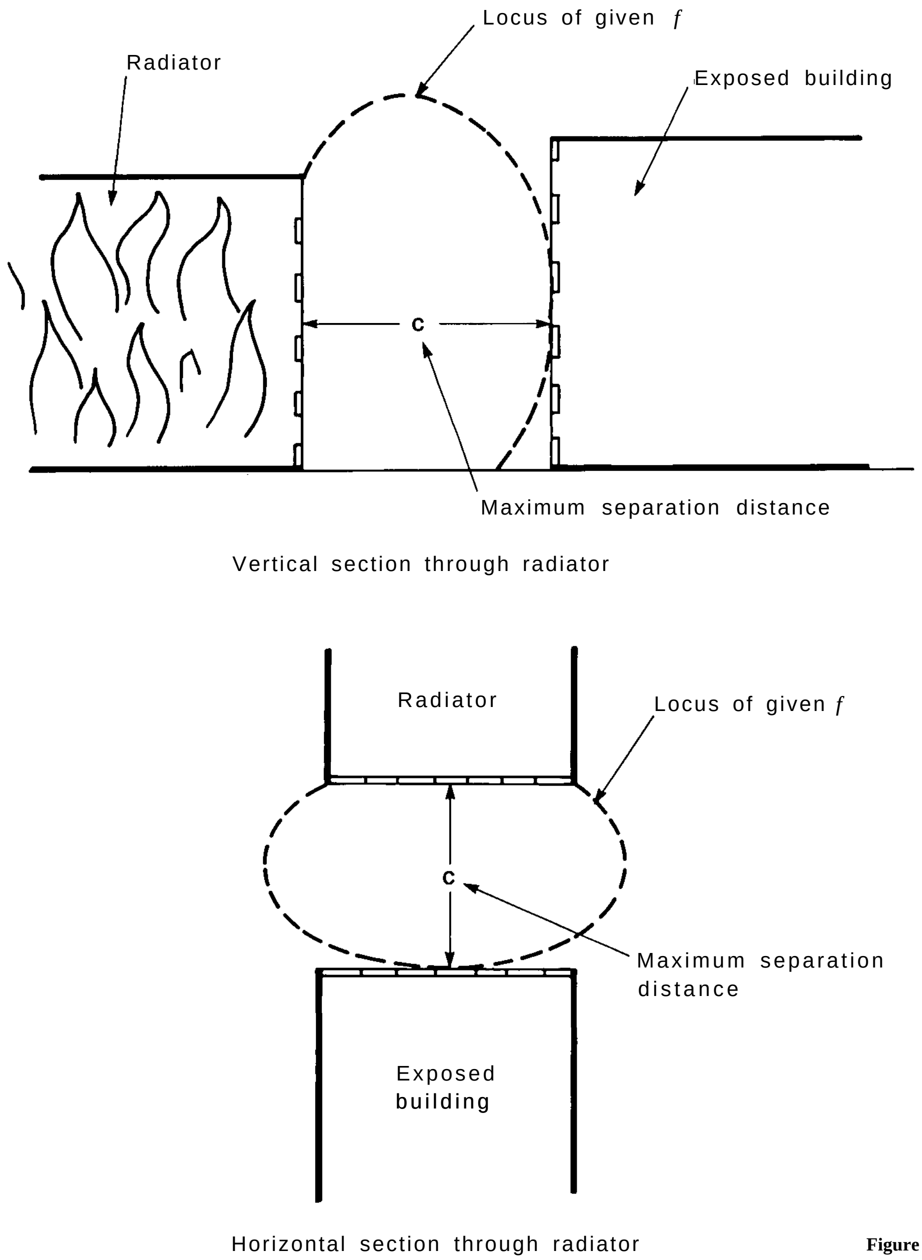


Figure 11 Locus of a given configuration factor

and here it can be seen for small values of f that $\frac{c_1'}{c_2'}$ is approximately unity. For a very wide radiator, the distance opposite the side is approximately half that opposite the centre. For a very tall radiator the distances opposite the side and opposite the centre are approximately the same.

If the separation distance for an infinitely tall radiating strip is determined, then all situations found in practice will be covered. The plane receiving the maximum radiation opposite the centre of this radiator is parallel to the radiator but at any other point, the plane receiving the maximum radiation is at an angle to the radiator. The locus of this plane is shown in Figure 12, where at any point along the curve a tangential plane has the maximum value of f at that point and along the curve this maximum is constant. In Appendix II this locus is shown to be, on plan, the arc of a circle, the

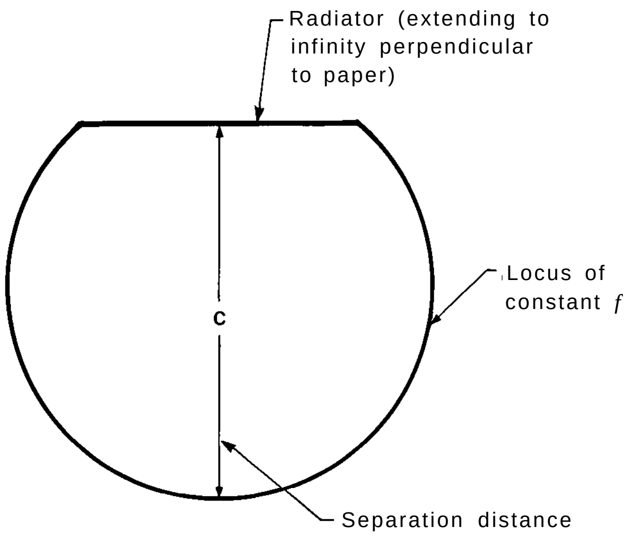


Figure 12 Locus, on plan, of a given f for an infinitely high radiator

width of the radiator forming a chord and the third point on the circle being on the perpendicular bisector of the chord at the separation distance *c*. The value of *c* depends on the percentage of openings ie the effective radiating intensity. Some values for an infinitely tall radiator of width *W* and normal intensity are given in Table 1.

A simple approximate method of drawing separation distance for any radiator is to extend the distance to the full width of the radiator and continue it as an arc of a circle as shown in Figure 13. The two methods are compared in Figure 14 which shows that the approximate method errs on the side of safety. Its application is illustrated in Figure 15, where the elevation is similar to the one in Figure 8 but with a long portion of blank wall. The separation distance, already calculated as 44 ft, is drawn as shown in Figure 15.

Table 1 Separation distance *c* for infinitely tall radiator of width *W*

Openings percentage	*c*/*W*
100	6.65
70	4.65
50	3.30
40	2.63
30	1.94
20	1.24

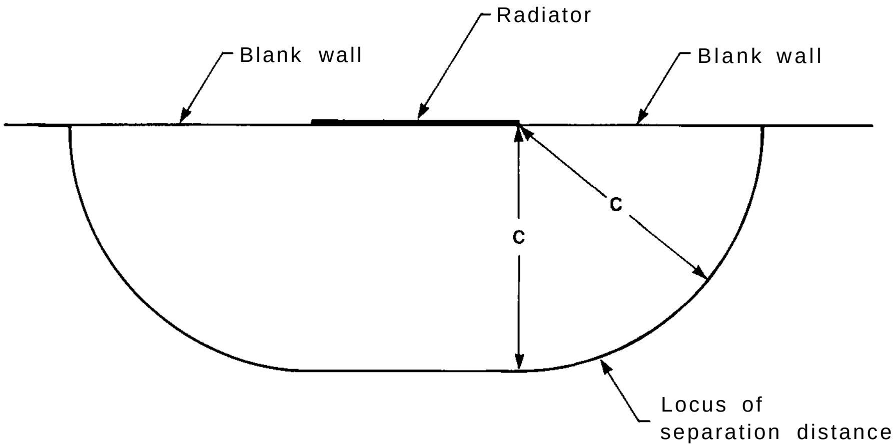


Figure 13 Simple method of continuing separation distance beyond edges of radiator

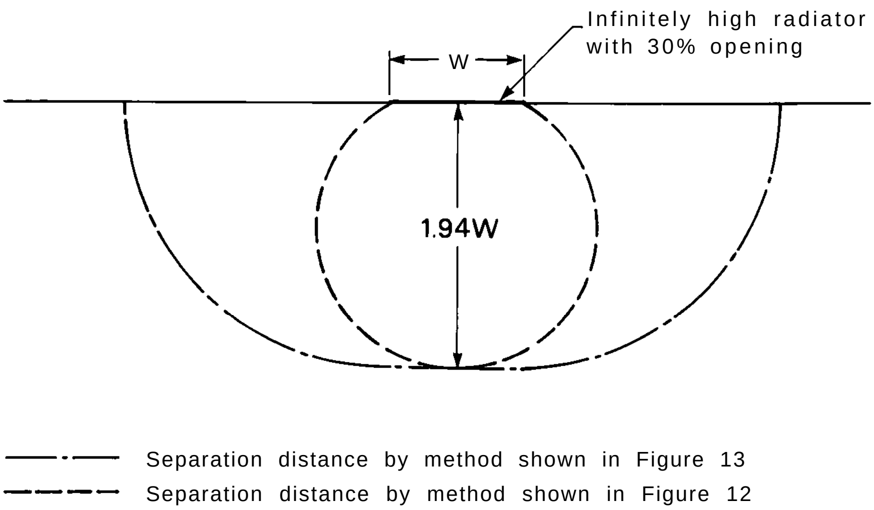


Figure 14 Comparison of approximate and accurate separation distances for an infinitely high radiator

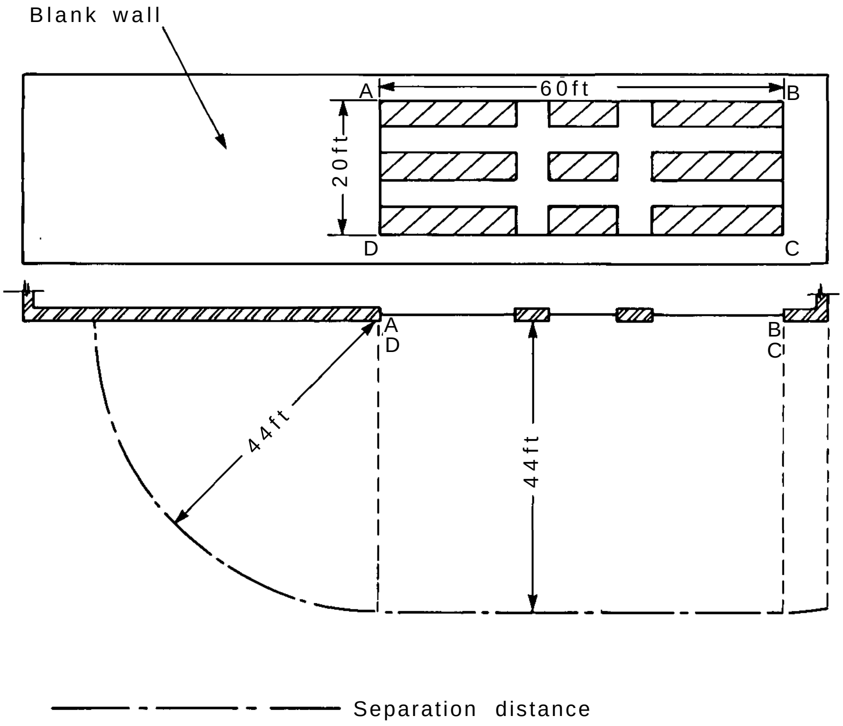


Figure 15 Separation distance at edge of enclosing rectangle

Irregular elevations

The calculation of separation distance in terms of a single radiator has been outlined for simple elevations with evenly distributed openings. It is also possible to calculate separation distances for irregular elevations in terms of single radiators and this is shown below.

Elevation with uneven distribution of openings

While, for a majority of elevations with a number of openings, the separation distance can be found from the dimensions of the enclosing rectangle and the percentage of openings, there may be one or more openings sufficiently large to require a local increase in the separation distance. Consider the elevation and plan in Figure 16. For the enclosing rectangle ABCD, there is a 30% area of opening, $N = 5$, $A = 20$ ft and from Figure 9 the separation distance is:

$c = 35$ ft

For EBCF there is a 90% area of opening, $N = 1$, $A = 20$, and from Figure 9 for a 90% opening:

$c = 38$ ft

It is necessary, therefore, to increase the separation distance in the region of EBCF. The separation position calculated for the whole rectangle ABCD is drawn first. A second separation position is then drawn for the rectangle EBCF and continued as an arc of radius 38 ft until it meets the first position (p 34).

The procedure therefore in all cases is to find first the separation distance for the overall enclosing rectangle and then to increase this locally where necessary. No simple rule has been devised to guide a designer as to when a local increase is necessary and it can only be found by trial and error. However, it will be found in practice that in most cases no local increase in separation distance will be needed.

Elevation with widely spaced openings

If openings are spaced very widely apart then a point opposite one may receive negligible amounts of radiation from the next and, for the purposes of calculating separation distance, the openings may be considered separately. The separation distance may be calculated first for the rectangle enclosing all the openings and it is shown in Appendix III that, if the distance between the openings is greater than twice this separation distance, they may be treated as separate radiators.

Considering the elevation in Figure 17, the enclosing rectangle ABCD has a 20% opening, $N = 5$, $A = 20$ ft and from Figure 9:

$c = 24$ ft

The distance between the two rectangles AEHD and FBCG is 60 ft, which is greater than $2 \times c$, so that these rectangles may be considered separately. For AEHD with a 50% opening, $N = 1.5$, $A = 20$ ft and $c = 32$ ft. For FBCG with a 50% opening, $N = 2$, $A = 10$ ft and $c = 19$ ft.

Elevation with recessed portion

If one part of an elevation is recessed, then there may be a corresponding change in the separation distance, the effect of the recess depending on the amount of

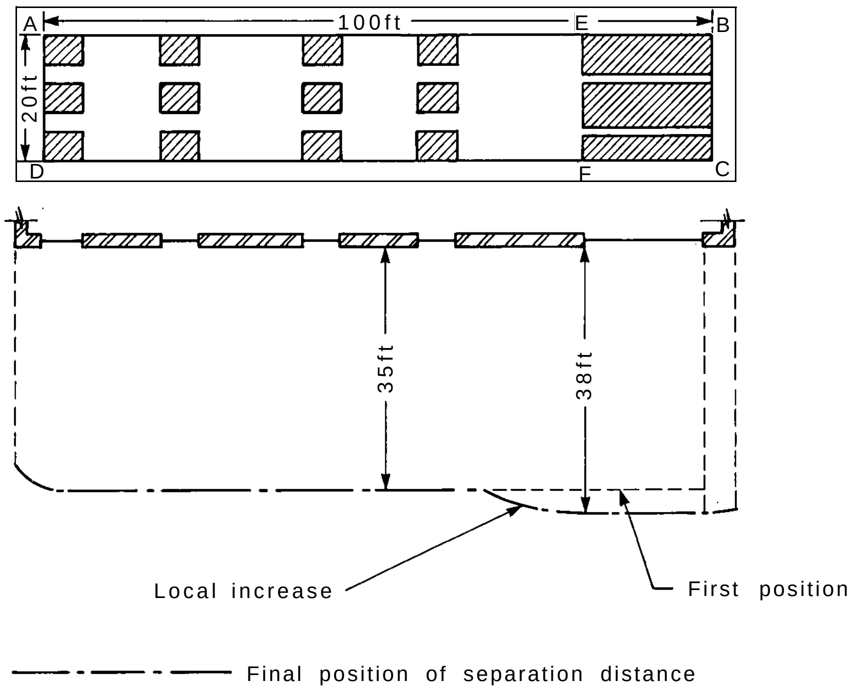


Figure 16 Local increase of separation distance

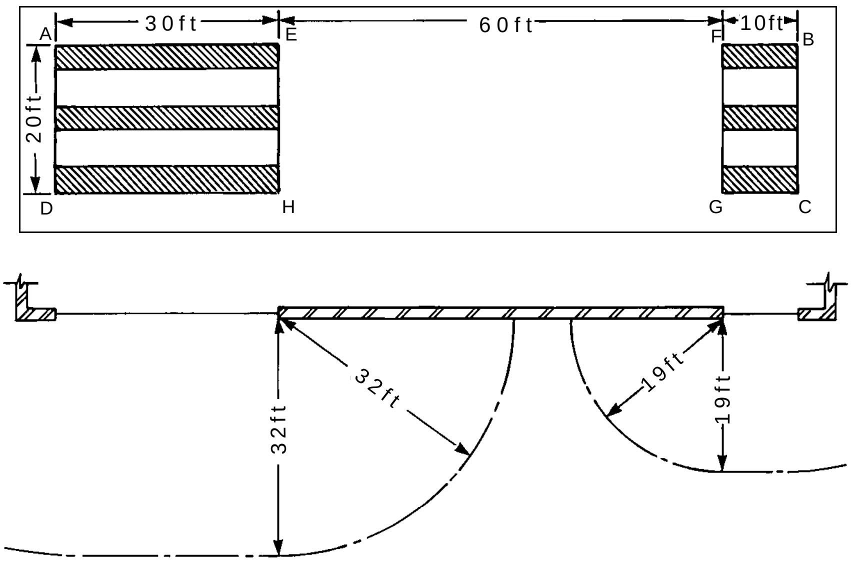


Figure 17 Elevation with widely spaced openings

openings. If the recess contains openings on all three walls, then it will appear as a radiating enclosure and if, for example, there were 100% openings on all the walls, it would have the same effect as a 100% opening at the front of the aperture, ie the worst case. In general, the total area of the openings in the recess should be added together, expressed as a percentage of the area of the aperture, the aperture then being considered as a radiator and the distance for the whole elevation found accordingly. Where the total area of the openings is equal to or greater than the area of the aperture, the aperture should be considered as a radiator with 100% openings. These procedures err on the side of safety.

In Figure 18 the rectangle EFGH is set back 15 ft. The total area of openings in this recess is 60% of the area of the rectangle EFGH. Assuming this area to be at the aperture and with a 40% opening in the other two rectangles, the area of opening for the enclosing rectangle ABCD is 45%.

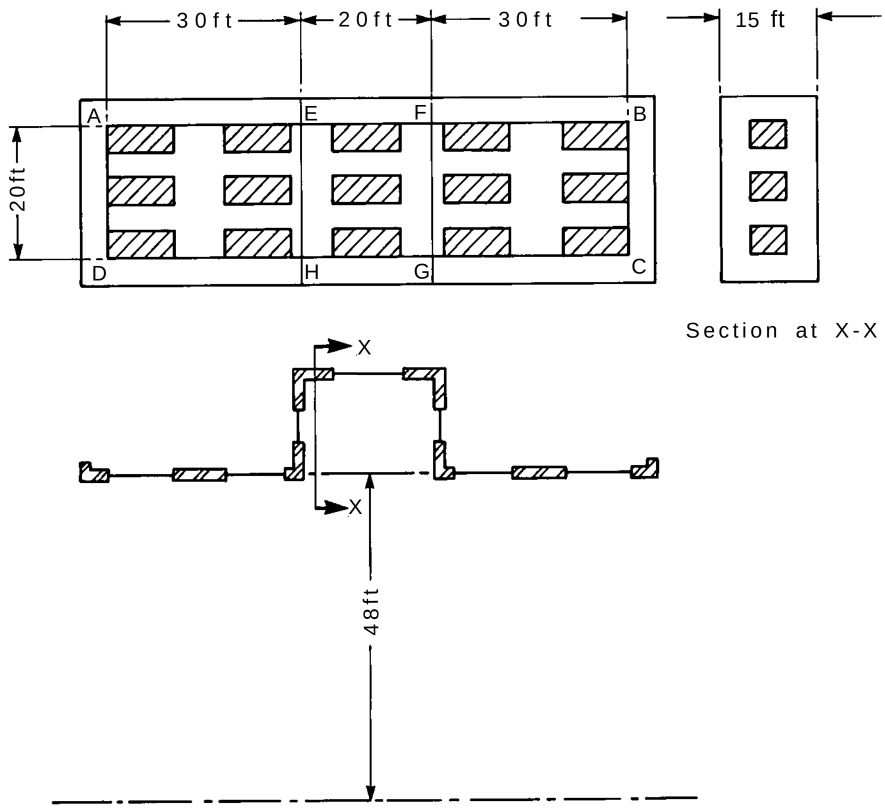


Figure 18 Recessed elevation: openings in all sides

In Figure 9 for a 50% opening, $N = 4$, $A = 20$ ft and

$c = 48$ ft

Where there are openings on the rear wall only of the recess, then a reduction in the separation distance may be effected as follows. A first value of the distance c_1, may be made assuming as before all the openings to be radiating at the aperture. The area of openings in the recess can then be reduced by the factor,

$$\left(\frac{c_1}{c_1 + r}\right)^2$$

where r is the depth of the recess. The adoption of the reduction factor,

$$\left(\frac{c_1}{c_1 + r}\right)^2$$

is due to simple geometrical considerations of the apparent size of the openings in the recess as compared with the other openings, when viewed from a point at the separation distance. This is illustrated in Figure 19 which shows the equivalent radiator used. This reduction enables a second distance, c_2 to be found. It would be possible to repeat the process to reduce c_2 and continue until there was no further change in successive values but such refinement is hardly necessary and for practical purposes c_2 may be taken as the final estimate of separation distance.

In Figure 19 the rectangle EFGH is set back 16 ft and there are no openings on the sides of the recess. Each of the three rectangles contains a 40% area of openings. For the enclosing rectangle ABCD, $N = 5$, $A = 20$ ft and from Figure 9 for a 40% opening:

$c_1 = 44$ ft

The openings in the recess can be reduced by the factor:

$$\left(\frac{c_1}{c_1 + r}\right)^2 = \left(\frac{44}{60}\right)^2$$

so that EFGH can be considered to have a 22% opening. For the enclosing rectangle ABCD, this gives a 30% opening and for $N = 5$, $A = 20$ ft, from Figure 9:

$c_2 = 35$ ft

Alternatively, Table 2 can be used. This indicates when the recess effectively reduces the overall radiating area by a given percentage. A theoretical basis for the table is given in Appendix IV.

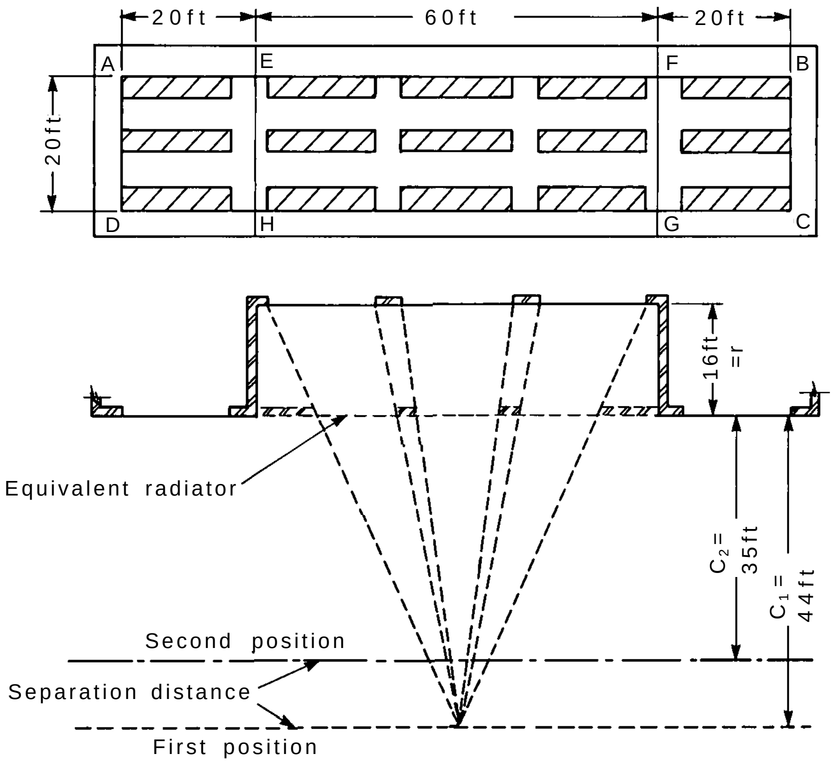


Figure 19 Recessed elevation: openings in rear wall only

Table 2 Depth of recess and effective percentage of openings

Depth of recess exceeding ft	Openings in recess as percentage of overall enclosing rectangle not exceeding									
	15	20	30	40	50	60	70	80	90	100
	Limiting value of c_1 for reduction of 10% in effective opening									
5	7	12	22	32	42	52	62	72	83	92
10	13	24	44	64	85	105	125	145	166	185
15	20	36	66	97	127	157	188	217	249	278
20	27	48	89	129	170	210	250	290	332	—
25	34	60	111	161	212	262	312	—	—	—
50	68	120	222	323	—	—	—	—	—	—
100	136	241	—	—	—	—	—	—	—	—
	Limiting value of c_1 for reduction of 20% in effective opening									
5	—	—	7	12	17	22	27	32	37	42
10	—	—	13	24	34	44	54	64	74	85
15	—	—	20	36	51	66	82	97	112	127
20	—	—	27	48	68	89	109	129	149	170
25	—	—	34	60	86	111	137	161	186	212
50	—	—	68	121	172	222	273	323	—	—
100	—	—	136	242	344	—	—	—	—	—

The use of this table can be illustrated with the previous example.

The openings in the recess are 24% of the overall enclosing rectangle. The percentage opening, assuming no recess, is 40% and this can be reduced by 10% if c_1 is less than the value in Table 2. For a recess of 15 ft the value in Table 2 is 66 ft. Therefore the effective radiating area can be considered as 30% and c_2 = 35 ft.

The separation distance for a building with some upper floors recessed can be calculated in a similar way. Where some floors are recessed a distance r_1, and others a distance r_2, then the reduction factors

$$\left(\frac{c_1}{c_1 + r_1}\right)^2, \left(\frac{c_1}{c_1 + r_2}\right)^2$$

should be applied to the area of openings in the relevant portions.

Elevation with set back

When part of a building is set back there can be a corresponding set back in the separation distance and its final position is found by considering the building from two aspects. The position of the line denoting separation is first found assuming the elevation is in one plane and then part is altered to allow for the set back. This allowance is made by viewing from the side and constructing an equivalent radiator which encloses all the openings, these openings being expressed as a percentage of the equivalent radiator and the appropriate separation position found. For the final separation position, the first one is taken until it meets the second.

In Figure 20 the rectangle FBCG is set back 30 ft behind AEHD. Assuming no set back then for the enclosing rectangle ABCD, N = 5, A = 20 ft, and for a 40% opening, from Figure 9:

$$c = c_1 = 44 \text{ ft}$$

Now consider the equivalent radiator, A'B' on the plan. A'B' = 103 ft and the height of this radiator is 20 ft. The openings in AEHD, EFGH, FBCG are 50% of the area of the equivalent radiator. For this radiator $N = 5.15$, $A = 20$ ft, and from Figure 9 for a 50% opening:

$$c = c_2 = 53 \text{ ft}$$

The positions of the two separation distances are shown in Figure 20, the portions of each which are nearer to the elevation being taken as the final position.

The basis for this procedure is similar to that for the recess with openings in all three walls, described on p 36, the set back being viewed from the corner as a radiating enclosure.

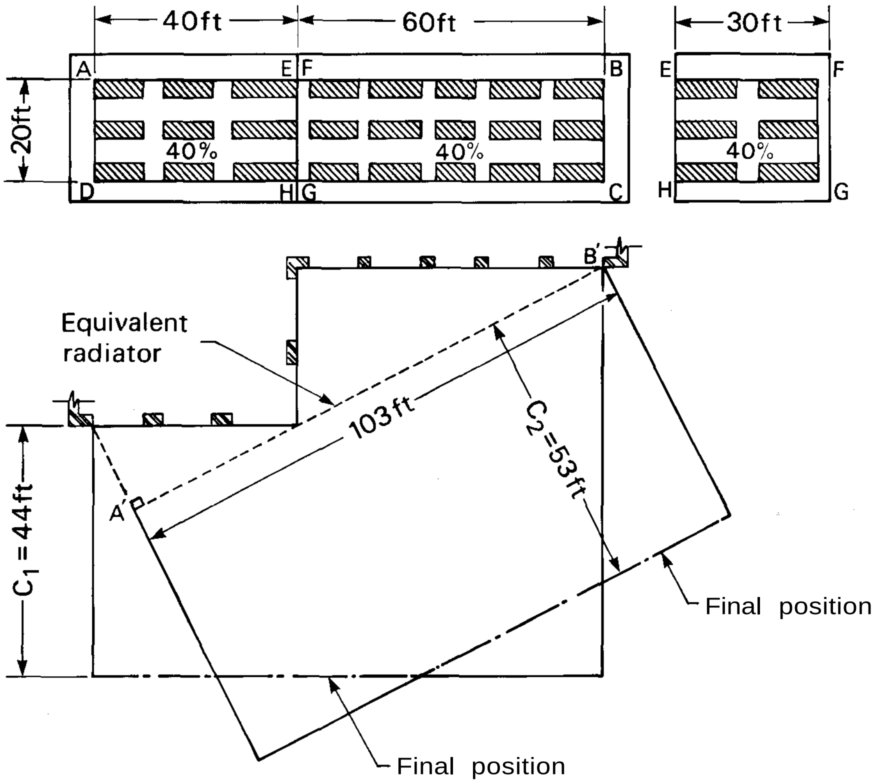


Figure 20 Elevation with set back

Acknowledgement

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Appendix I

Pilot ignition with the flame on the surface

It is possible for ignition of wood to occur, for an incident intensity of radiation of less than 0.3 cal $cm^{-2}s^{-1}$, if an igniting flame is in direct contact with the surface of the wood (surface ignition)[21] and it is not clear whether this is a limiting case of pilot ignition or a function of the size and heating effect of the flame itself. When ignition occurs in this way a thin flame appears, its rate of spread being slow, depending on the intensity of the supporting radiation. If a combustible surface is at a great distance from a building fire, then many sparks will have burnt out before they reach the surface and it will probably be only the larger burning particles that may cause ignition. If burning particles reach a surface and the intensity of radiation is too low for pilot ignition, surface ignition is possible only if the particles lodge on the surface. Even then the development of flame is likely to be slow. If it is assumed that the Fire Brigade will be available within a short time of a fire's starting, for the protection of exposed property, it would appear unreasonable therefore to try to guard against the possibility of surface ignition.

Appendix II

Separation distance from infinitely high radiator

Consider a vertical plane radiator of infinite height (Figure 21(a)). The configuration factor f, at a point P on a vertical plane not necessarily parallel to the plane of the radiator, is given by[17]:

$$f = ½ (\cos \alpha + \cos \beta) \qquad (2)$$

The position of P defines only the angle $g = 180 - (a + b)$.

The value of b which will give the maximum value of f at any point is required.

Writing $a = 180 - (b + g)$

then $$\frac{df}{db} = ½[\sin(b + g) - \sin b]$$

For f to be a maximum: $g = 180 - 2b$

and $a = b$

Therefore: $f_{max} = \cos b = \sin g/2$

For a given value of f_{max} and $a = b =$ constant then g is constant and the locus of P is therefore the circumference of a circle subtended by the radiator as a chord.

If the width of the radiator is W, the maximum value of the separation distance c from the centre of the radiator is obtained from:

$$f_c = f_{max} = \frac{W}{\sqrt{W_2 + 4c^2}} \qquad (3)$$

where f_c is the required value of f_{max}.
The separation distance is then given by:

$$c = \frac{W}{2}\sqrt{\frac{1}{f_c^2} - 1} \qquad (4)$$

By requiring the separation distance to be not less than c at all points, the separation will always err on the side of safety (Figure 21(b)).

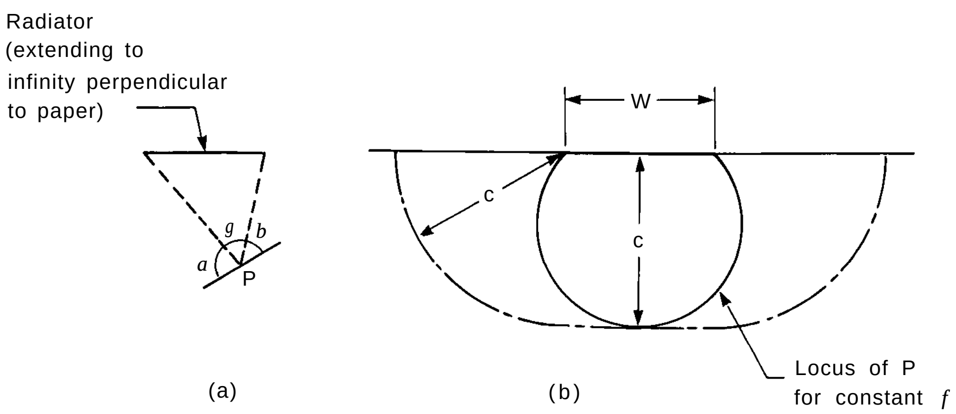

Figure 21 Variation in separation distance

Appendix III

Widely spaced openings

Consider two radiators 1 and 2, in the same plane, of widths W_1 and W_2, separated by a blank wall of length l (Figure 22).

Let $W_1 = n W_2$ where $n \geq 1$ (5)

It is necessary to find the value of l such that for a point P, at a distance c_2, opposite the smaller radiator 2, the radiation received from radiator 1 is negligible, c_2 being the separation distance for radiator 2. Since an infinitely high radiator would have the maximum configuration factor at P, it is assumed that the radiators are of infinite height. For simplification, P has been taken opposite the side of radiator 2, rather than opposite the centre. This means that the configuration factor, f_1, for radiator 1 at P is slightly less than the value opposite the centre. From equation (2), Appendix II:

$$f_1 = \tfrac{1}{2}\left[\frac{l + W_1}{\sqrt{c_2^2 + (l + W_1)^2}} - \frac{l}{\sqrt{c_2^2 + l^2}}\right] \qquad (6)$$

From equation (4) Appendix II, the separation distance c_2 for the radiator 2, is given by:

$$c_2 = \frac{W_2}{2}\sqrt{\frac{1}{f_2^2} - 1}$$

For $I_o = 4.0$ cal $cm^{-2}s^{-1}$,

$$f_2 = \frac{0.3}{4.0} = 0.075$$

and

$$c_2 = 6.65 \; W_2 \qquad (7)$$

If the effect of radiator 1 is considered negligible when its contribution to the radiation from radiator 2 is not greater than 5% then:

$$f_1 \leq 0.05 \times 0.075 \qquad (8)$$

Combining equations (5), (6), (7) and (8) gives:

$$\frac{l + nW_2}{\sqrt{6.65^2 \; W_2^2 + (l + nW_2)^2}} - \frac{l}{\sqrt{6.65^2 \; W_2^2 + l^2}} \leq 0.0075 \qquad (9)$$

Equation (9) gives l in terms of W_2 for any value of n. However, it is more convenient to express l in terms of the separation distance for the combined radiators, which is the quantity first calculated on the assumption that the openings are considered together.

For the whole elevation the percentage of openings is:

$$\frac{W_1 + W_2}{W_1 + W_2 + l} \times 100 = \frac{(n + 1) W_2}{(n + 1) W_2 + l} \times 100$$

and

$$I_o = 4.0 \times \frac{(n + 1) W_2}{(n + 1) W_2 + l}$$

Therefore:

$$f_c = \frac{0.3}{4} \times \frac{(n + 1) W_2 + l}{(n + 1) W_2} \qquad (10)$$

From equation (3) Appendix II:

$$f_c = \frac{(n + 1) W_2 + l}{\sqrt{\left[(n + 1) W_2 + l\right]^2 + 4c^2}} \qquad (11)$$

where c is the separation distance for the whole elevation.
Combining equations (10) and (11):

$$c = \tfrac{1}{2}\sqrt{\frac{(n + 1)^2 \; W_2^2}{0.075^2} - [(n + 1) W_2 + l]^2} \qquad (12)$$

From equations (9) and (12) it is possible to obtain values of the ratio l/c for different values of n. It can be shown that the maximum value of l/c is obtained when $n = 1$, ie when the two radiators are the same width.

When $W_1 = W_2$, it follows that for the limiting case of

$$c = 9.17 \; W_2$$

then $l = 17.4 \; W_2$

ie $l \approx 2c$

Therefore for $l > 2c$, one radiator has a negligible effect at a point opposite another. Since the interaction of the two radiators is greatest when they are equal in width, this rule holds for all other cases.

Similar equations can be derived for finite radiators but the calculation is complex. Calculations for some finite radiators show that the rule applies generally.

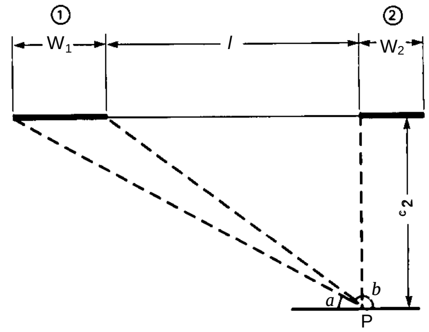

Figure 22 Widely spaced openings

Appendix IV

Recess with openings in rear wall only

Let the overall enclosing rectangle have area A, the front portions areas of openings A_1 and A_2, and the recess area of openings A_R, (Figure 23). The first value of separation distance, c_1, is based on

$$100\left(\frac{A_1 + A_2 + A_R}{A}\right)\% \text{ openings.}$$

This gives an overestimate of the effect of the openings.

The effective radiating area of the openings in the recess is less than A_R and to a first approximation is given by:

$$A'_R = \left(\frac{c_1}{r + c_1}\right)^2 \times A_R \qquad (13)$$

where r is the depth of the recess.
Since c_1 exceeds the true separation distance, A'_R itself is slightly overestimated by this equation. Thus the error is on the side of safety.

The difference between this and the former value, A_R, expressed as a percentage of the overall enclosing rectangle, is:

$$100\left(\frac{A_R - A'_R}{A}\right) = 100\frac{A_R}{A}\left[1 - \left(\frac{c_1}{r + c_1}\right)^2\right]\%$$

$100\frac{A_R}{A}$ is the area of openings in the recess, expressed as a percentage of the overall enclosing rectangle.

The limiting values of c for

$$100\left(\frac{A_R - A'_R}{A}\right) \geq 10\ \%$$

or

$$\geq 20\ \%$$

have been calculated for various values of 100 A_R/A and r and are given in Table 2. In theory this method can be used to give successively more accurate approximations by repeated application of equation (13) with successively smaller values of c. However, in practice one such application will usually be sufficient and any error will be less than the increments used in Table 2.

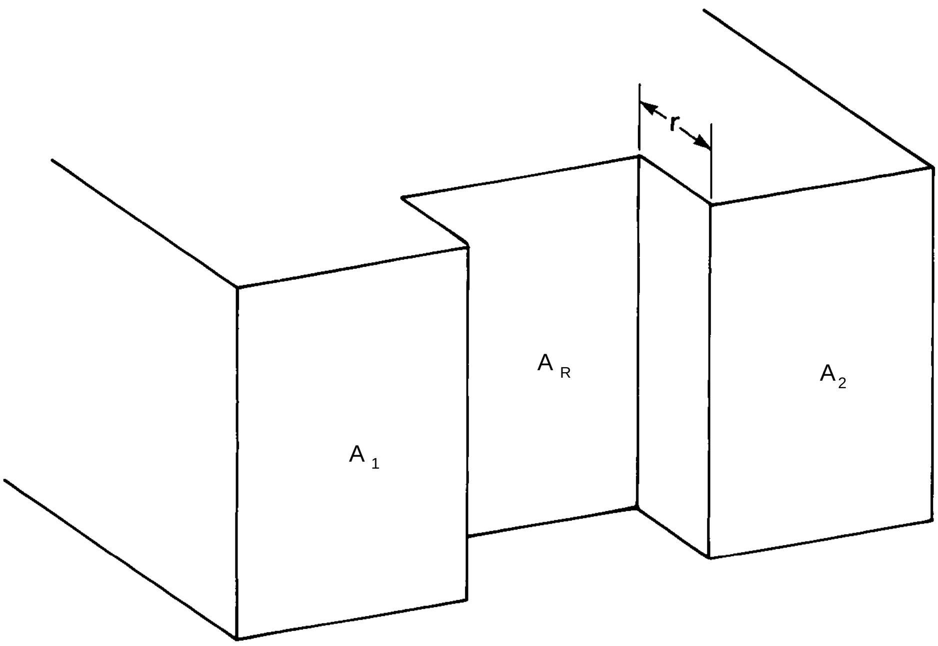

Figure 23 Recess with openings in rear wall only

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