GUIDANCE FOR THE DESIGN OF
SMOKE VENTILATION SYSTEMS FOR
SINGLE STOREY INDUSTRIAL BUILDINGS,
INCLUDING THOSE WITH MEZZANINE FLOORS,
AND HIGH RACKED STORAGE WAREHOUSES

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FOREWORD

The use of smoke and heat exhaust ventilators has been widespread and their value in assisting in the evacuation of people from buildings, reducing fire damage and financial loss by preventing smoke logging, facilitating fire fighting, reducing roof temperatures and retarding the lateral spread of fire is firmly established. Therefore, it is essential that the purpose of the scheme is identified.

The members of the Smoke Ventilation Association have had many years of interpreting and applying the various design principles included in the many publications dealing with smoke control. Based on this experience, the Guide sets out their recommendations for design considerations. Actual methods of calculation are set out in various Fire Research Station (FRS) papers, which are referred to in the text and listed in Appendix 2.

No scheme will work satisfactorily unless it is correctly installed and maintained.

1 SCOPE

This guide covers Single Storev Industrial Buildings such as Factories and Warehouses, including such buildings which contain Mezzanine Floors, and High Racked Storage Warehouses.

2 DEFINITIONS (see Appendix 1 Reference 1)

DESIGN FIRE SIZE	The base dimensions of the largest fire with which a smoke ventilation system should be expected to cope. A Design Fire is normally taken to be square or circular.
HEAT OUTPUT	The total heat generated by the fire source, including that which may appear at any point downstream (see also 2.7).
CLEAR LAYER	The vertical distance between floor level and the bottom of the smoke layer.
SMOKE COMPARTMENT	Region of ceiling or roof void isolated from other areas, by building structures and/or purpose made screens designed to to prevent the flow of smoke from the compartment.
SMOKE LAYER DEPTH	The vertical distance from the "centroid" of the extractor (whether horizontal or vertical plane) to the bottom of the smoke layer.

REPLACEMENT AIR	Cool, ambient temperature, smoke free air entering the Smoke Compartment during course of operation of Smoke Ventilation System to replace the exhausted hot smoke.
HEAT FLUX	The total heat energy carried by the gases across a specified boundary. This flux can be convective, radiative and/or conductive, or a combination thereof. There is a further form, often referred to as a "potential" heat flux. This may be defined as the flow across a specified boundary of energy yet to be converted to heat by the fire process.
HEAT LOSS	The total heat transferred away from a body (including gas) through its boundaries by convection, radiation and/or conduction, or a combination thereof, eg heat loss from a gas layer can be by radiation, convection and conduction to its surroundings.
CONVECTIVE HEAT FLUX	That portion of the total heat output retained within the flowing gases immediately outside the combustion region. This heat flux is, of course, subject to consequent heat loss.
SMOKE CURTAINS /SCREENS	(See Appendix 1 Reference 2) These are employed as part of a smoke control system to create ceiling reservoirs from which smoke and hot gases can be extracted.
AERODYNAMIC FREE AREA	The "Measured Free Area" of the natural heat and smoke exhaust ventilator multiplied by the "Coefficient of Discharge".
MEASURED FREE	The actual measured throat area of the natural heat and smoke exhaust ventilator: This is the smallest clear opening normally between the drainage channels. No reduction should be made for controls,1ouvres and/or other obstructions, providing their obstruction is allowed for in the coefficient of discharge.
COEFFICIENT OF DISCHARGE	The ratio of Actual Flow Rate to Theoretical Flow Rate through a natural heat and smoke exhaust ventilator.

CONVECTIVE HEAT OUTPUT	Heat content of smoke, calculated as convective heat flux for a design fire minus subsequent heat losses. Normally considered as the value to be used fordesign purposes.
MEZZANINE	An intermediate floor level between the ground floor level and the roof space of a single storey industrial building. this mezzanine floor level to be open to the remainder of the building so that smoke will pass freely from one area to the other and thereby hamper the safe evacuation of the occupants of the upper levels in a fire.
HEIGHT OF MEZZANINE	The vertical distance from the floor to the underside of the lowest solid mezzanine floor level.
PERMEABLE MEZZANINE FLOORS	A mezzanine floor which has at least 25% of its total plan area evenly distributed as free area for the passage of smoke.
SOLID MEZZANINE FLOOR	A mezzanine floor which is either solid or does not meet the criteria for an open mezzanine floor.
FLASHOVER	A condition when the temperature of the gases contained in the smoke layer is sufficiently high to cause spontaneous ignition (generally due to downward radiation of heat) of materials not directly involved in the fire. This condition should be avoided for obvious reasons. It is normally considered to be when the smoky gas layer temperature is in the region of 500 - 600 degrees centigrade.
CEILING JET	A horizontally flowing layer of hot gases driven in part by the kinetic energy of the initially vertically rising fire plume. It typically has a depth of approximately 1/lOth of the building height flowing radially away from the plume axis.

3 DESIGN PARAMETERS

Fire Size
Heat Output of Fire (convective) Clear Layer
Smoke Compartments
The Effect of Sprinklers
Depth of Smoke Layer
Ambient Temperature
Air Inlets/Replacement Air Wind Effects
Speculative Buildings Sizing/Siting of Equipment Controls
Mezzanine Floors

4 FIRE SIZE

4.1 Industrial Buildings
(Excluding High Racked Storage Warehouses)

4.1.1 Calculations should be based on a steady state fire condition.

4.1.2 No scheme should be designed on a fire size of less than 3m x 3m, unless there is a known or isolated fire risk whose size is known, ie Quench Tank, Spray Booth etc.

4.1.3 It is recommended that for sprinklered buildings one of the following steady state fire sizes in Table 1 is used.

TABLE 1 - STEADY STATE FIRE SIZES

Hazard Category	**Fire Size**	**Perimeter**	**Approx Area (m^2)**	**Examples of Occupancy (see also Appendix 3)**
Group 1	3.0 x 3.0m	12m	9	Breweries
Group 2	4.5 x 4.5m	18m	20	Bakeries
Group 3	6.0 x 6.0m	24m	36	Cotton Mills
Group 4	9.0 x 9.0m	36m	81	Paint Manuf’ring
Group 5/1	3.0 x 3.0m	12m	9	Electrical W’house
Group 5/2	4.5 x 4.5m	18m	20	Pharmaceutical W’hse
Group 5/3	6.0 x 6.0m	24m	36	Paper Storage W’hse
Group 5/4	9.0 x 9.0m	36m	81	Plastic Foam W’house

In unsprinklered premises there is the possibility that, in the absence of effective suppression (eg. sprinklers), the fire may grow unchecked and eventually destroy the building. In this instance the detection of the fire is paramount, and human detection should not be relied upon. Hence a fire/smoke detection system is recommended to:

(a) raise the alarm both within the building and with the fire brigade;

(b) initiate the operation of the venting system

The fire may then develop if unchecked to a size at fire service intervention which will be dependent upon:

(i) the nature of the goods, ie. combustibility, burning.rate, radiation

output, etc;

(ii) the disposition of the burning material with respect to other combustibles;

(iii) the geometry of the building (eg. ceiling height etc);

(iv) the attendance and deployment time of the fire service

An assessment of the largest likely fire size that the fire service will encounter should be based upon the above variables. In the absence of sufficient information or other guidance being available (eg. British Standards), it is suggested that the fire size for an unsprinklered fire be taken as being twice the area of its sprinklered counterpart, eg. a fire in a Group 3 hazard should be taken as 70m² area (8.5m x 8.5m). An upper limit of around 100m² (10m x 10m) may be considered as an arbitrary maximum beyond which the venting system will produce no further tangible benefit, other than to assist fire-fighting operations.

Fire sizes outside these are not normally considered, and in no circumstances should the design fire size for an unsprinklered fire be less than that for a sprinklered fire of the same hazard rating.

4.2 High Racked Storage Warehouses

4.2.1 The potential for fire growth needs to be fully considered since it is much greater within racked goods than with materials stored only at ground level.

Thus for high racked storage systems that do not employ in-rack or ESFR sprinkler systems the assumed minimum fire size should not be less than 3m x 3m, and this minimum size should only be considered in exceptional circumstances.

4.2.2 The nature of the stored goods is vital in the consideration of the fire size.

4.2.3 The type of packaging material must be considered in the assessment of the fire size.

4.2.4 The manner of the storage will affect the potential fire size. For example, paper rolls stored upright', ie with the hole in the centre vertical, will allow the fire to grow much faster than if the paper is stored horizontally.

4.2.5 The surface area of material which can support combustion must be considered.

4.2.6 The type of sprinkler system to be installed will affect the fire size selected. See clause 9.

5 TOTAL HEAT OUTPUT OF FIRES

5.1 Figures for the heat release rate (RHR) of known fuel combinations were compiled for various storage and process risks in industrial buildings by the Fire Research Station (see Appendix 2, Reference 1), but Were categorised in a way unhelpful to smoke control designers. These data were later revised to provide the necessary basis for smoke control design (see Appendix 2, Reference 2). The National Fire Prevention Association (NFPA) of America have similarly compiled RHRs for various fuels following experiments (see Appendix 2, Reference 3). Further data for specific fuels have also been compiled by the FRS (see Appendix 2, Reference 4). Appendix 4, Tables A4.1-A4.3 list the various fuels and fuel arrays, from both UK and USA references.

5.2 For storage risks there is a wide range of values of RHR for essentially very similar storage categories, eg. goods stacked in cardboard cartons.

TO BE EDITED

It is a fundamental principle of smoke ventilation that the RHR chosen for the design fire will affect the calculated ventilation area or rate of exhaust. Storage risks may also vary from the initially chosen fuel, eg. glassware in cardboard cartons to plastic components in cardboard cartons. The nature of the occupancy (risk) will not have changed (ie. storage), but the potential RHR will, perhaps reducing the value of the smoke control system. This can, to a certain extent, be alleviated by designing the system to deal with the worst-case scenario for the risk. Table 2 provides the data in Table A4.1 (storage risks) in terms of upper and lower limits for the various storage categories. The values provided are RHR per square metre (plan area) for each metre height of storage.

TABLE 2 RATES OF HEAT RELEASE FOR VARIOUS STORAGE CATEGORIES, PER METRE HEIGHT OF FUEL

Storage	**Range of RHR ($kW/m^2/m$)**
Loose wood & wood products, Inc. wood cribs & pallets; Upright wood storage.	1800 - 2900
Stacked wood & wood products, Inc. furniture; books; Crated objects.	30 - 720
Cardboard & paper products, Inc. stacked or loose cardboard boxes or cartons which are <u>empty</u>; cardboard tubes or reels; mailbags,	120 - 240
Any storage in cardboard boxes or cartons*.	160 - 1200
Loose or stacked plastic prodcuts, inc. PP & PE films in rolls; PU & PS Insulation Boards; PE Trays.	260 - 1280

* NB Excludes the apparently anomalously high values for PS jars in cartons.

The total heat output is calculated from the product of the plan area of the fire, its height and the appropriate RHR values.

5.3 Where information on the exact nature of the fuel Is unknown, eg. speculative buildings, and the local regulatory authorities have not recommended the design fire size and RHR, then a range of RHR of 60-500kW/m²/m is recommended, with a minimum ·assumed storage height of 2m (see Appendix 2, Reference 5). Further design details for speculative buildings may be found in Section 14.

5.4 The designer should use both values of RHR from Table 2 for the particular occupancy examined, or as in 5.3 above for speculative buildings, and calculations performed to determine all of the necessary design parameters. From these two sets of results, the worst case parameters resulting from either value of total heat output should then be used in the design.

5.5 For specific non-storage occupancy or liquid fuel risks, then the RHRs in Tables A4.2 and A4.3 should be used to determine the total heat output.

6 CONVECTIVE HEAT OUTPUT

When heat is given off some of it is lost to the structure and contents by radiation from the hot gas plume. If the roof reservoir compartments exceed 2000m² in plan area then consideration should also be given to the radiative and conductive losses from the established smoke layer to the roof structure (see Appendix 2 Reference 6).

The convective heat output of the fire is determined by applying a correction factor to the total heat output (see Section 5).

Various technical papers give differing values for the heat loss correction factor. Further research is desirable but, in the meantime, a 20 percent loss should be applied. For roof areas greater than the recommended smoke compartment size, calculations of the heat lost from the smoke layer should be provided to support the increase in recommended reservoir size such as a Newtonian heat transfer coefficient method (see Appendix 2 Reference 7).

7 CLEAR LAYER

7.1 Industrial Buildings excluding High Racked Warehouses

7.1.1 The minimum clear layer should be 3.0m. This is to permit the escape of personnel and the entry of fire fighters. Note, however, that the maximum clear height which car be physically achieved is 80-90o of the building's height, due to the presence of the ceiling jet in the smoke layer (see Appendix 2 Reference 7).

7.1.2 Where the chances of spontaneous ignition and flashover present a considered risk, and the maximum clear height available permits it, the clear layer should extend at least 500mm above the stacked goods.

7.1.3 To avoid disruption of the smoke layer in any single compartment, the base of the smoke layer should be at least 1-2m above any door/opening which might either by design or chance be a source for replacement air, unless the incoming air velocity is less than 1m/s, in which instance it should be no less than 500mm above the opening.

7.1.4 Where the floor level changes within a compartment, the height of rise should be measured from the shallowest end for safety purposes and the overall height from the deepest end for the entrainment calculation.

7.1.5 Special considerations are necessary when designing for-mezzanine floors. Note the comments contained within the Design Parameters for Mezzanine Floors.

7.2 High Racked Storage Warehouses

7.2.1 In sprinklered warehouses, the system objectives must be clearly defined for a design to be produced. These objectives may be to.

(a) Protect personnel within the building, by ensuring that their escape routes remain unaffected by smoke;

(b) Protect stock and materials which may be combustible or salvageable;

(c) Facilitate fire-fighting operations.

7.2.2 For objective (a) to be achieved the design approach can be either 7.2.2.1 and 7.2.2.3 or 7.2.2.2 and 7.2.2.3.

7.2.2.1 (1) Ensure that the smoke layer is is established well above head height ie >10m above the floor or highest exposed walkway (other than those used for infrequent maintenance purposes).

(ii) Provide no reservoir compartment sub-divisions but ensure that the additional heat losses from the smoke layer due to the extended layer area are accounted for, using a calculation technique which takes into account convective and radiative heat transfer from the layer to the buildings fabric and atmosphere. The final smoke layer temperature should not be less than 20^{o}C above the average roof level ambient temperature.

The relaxation on compartmentation is based on the assumption that escaping personnel will be able to travel hrough, and out of, the building without being detrimentally affected (psychologically) by the presence of the smoke layer above their heads, by virtue of its height above the floor and the nature of their escape routine, (ie regimented and practiced escape drill).

(iii) Ensure that an adequate fail-safe low level inlet air supply is available at all times, except where reservoir sub-division are used for this purpose (see clause 12). Note. It should be remembered that low level doors/windows may be secured and low level inlets may be partially blocked by stored materials.

7.2.2.2 (i) Where it is desirable for the smoke layer to descend below lOm above the floor, then the minimum height of rise should be 3m, and screen separation of the roof space into reservoirs not exceeding 60m in the direction of escape is required. Note, if the plan area of the reservoirs is greater than 2000m^2, consideration should be given to the heat losses sustained by the layer.

(ii) In exceptional circumstances it may be impractical to install such screens. In these instances alternative smoke ontrol solutions may be considered, and etailed calculations shall be provided in support of any alternative strategy.

7.2.2.3 All life safety systems should operate on smoke detection and where possible sprinkler flow switch.

7.2.3 For objective (b) to be achieved the design approach can be.

(i) Ensure that the design smoke layer is established above the salvageable stock levels (except in the instance where this will result in a smoke layer depth less than 1/10th the building height, see 7.2.5 below).

(ii) Provide screen separation of the roof space into reservoirs not exceeding 3000m². Where for practical purposes it is desirable to exceed this area, the heat losses from the layer should be taken into account (see 7.2.2.1 (ii) above). The final design smoke layer temperature should not be less than 20°C above the average roof level temperature.

(iii) The inlet air supply may be provided from adjacent, unused reservoirs, or dedicated low-level openings.

(iv) The venting system should preferably be operated by a smoke detection system, but as a minimum should operate on sprinkler flow switch for in-rack sprinklers, smoke detectors for roof mounted sprinklers or on both.

7.2.4 For objective (c) to be achieved the design approach can be as per objective (a) (see 7.2.2 above), with the exception that smoke reservoir screens will not be required except to provide inlet air, and the system may be operated by sprinkler flow switch and manually by fire-fighters.

7.2.5 The minimum layer depth used in a design cannot be less than 10% of the building (room) height, due to the presence of the ceiling jet in the smoke layer (see Appendix 2 Reference 7).

7.2.6 Where the floor level changes within a compartment, the height of rise should be measured from the shallowest end for safety purposes and the overall height from the deepest end for the calculation.

7.2.7 In unsprinklered warehouses, the current fire experience has been the total involvement, and subsequent loss, of the building. The speed of fire growth in all but the least combustible of materials (eg. steel) is such that venting is ineffective for practical considerations of stock protection and fire-fighting operations. See 9.2 below.

8 SMOKE COMPARTMENT

8.1 Buildings without Mezzanine Floors

8.1.2 Where required smoke compartments should have a maximum area of 2000m² for life safety purposes to 3000m² for other purposes with the latter used only in exceptional circumstances (see Appendix 2 Reference 8).

8.1.2 When used for personnel protection the maximum length of any side of a smoke compartment in the direction of escape should be 60.0m (see Appendix 2 Reference 6).

8.1.3 Smoke curtains should terminate 500mm below the design smoke layer base.

8.2 Buildings with Mezzanine Floors

8.2.1 Where reservoir limitations are required below the mezzanine as part of the design, the parameters given in 8.1 above should be applied. When the design philosophy applied is to allow the smoke to spill into an adjoining area, care must be taken not to exceed the total reservoir size of 2000 to 3000m² maximum.

The size of the reservoir is the combined total of the under mezzanine floor smoke control zone plus the area of the smoke control zone into which the smoke is designed to flow.

9 SPRINKLERS

9.1 Industrial Buildings Excluding High Racked Storage Warehouses

Whilst it is generally agreed that the operation of sprinklers will reduce the fire size and the amount of heat released, current research shows that where sprinklers and smoke vents are installed, the operation of the ventilators in any one compartment does not delay significantly the activation of sprinklers (see Appendix 2 References 7 and 9).

The effect of the sprinklers on the temperature and buoyancy of the smoke must be allowed for in the design of the smoke extraction system, as the smoke may have to pass through several rings of sprinklers before being exhausted (see Appendix 2 Reference 10).

The designer should specify the allowances made for sprinklers in the calculations.

9.2 High Racked Storage Warehouses

Unsprinklered high racked storage buildings have been commonplace, but due to the fire experience in such environments are now becoming less frequent. However, if a design is required for such a building the fire risk will be substantial, and experience has shown that smoke ventilation has provided very limited additional escape time, sufficient to save lives, but cannot be depended upon to aid the fire brigade in fighting the fire. Flashover in these circumstances is almost certain to occur. The smoke ventilation system designer should strenuously recommend the installation of a sprinkler system.

The effect of sprinklers in a high bay warehouse has to be considered in more detail than in other situations.

The type of sprinkler heads must be considered, eg.

Early suppression fast response ceiling mounted (ESFR)
Ordinary response ceiling mounted
Ordinary response in-rack
Fast response in-rack

The operating temperature of such heads must be considered. Typical temperatures are.

68 degrees centigrade
93 degrees centigrade
141 degrees centigrade

The spacing of the sprinkler heads, eg.

Every storage level
Alternative storage levels
Roof level only
A combination of any of the above

All of the above are alternatives and will affect the design fire size. The designer should state within his calculations what assumptions have been made.

9.2.1 Ceiling Level Sprinklers

Ordinary Response

With ordinary response ceiling mounted sprinklers only, the water sprays will find it difficult to penetrate into the middle of the racks. Extinguishment will depend on water trickling into the main seats of fire, with the consequence that higher water flow rates will be needed.

Fire can be expected to "burrow" through shielded areas of fuel until it reaches parts where sprinklers are not yet wetting,the racks. At this point the fire will flare up and set off more sprinklers.

This behaviour was observed in some of LPC's High-Piled palletted fires for the CEA. The design fire size will be as hazard category 5 of Table 1 (see Section 4).

9.2.2 ESFR Sprinklers

Research carried out by others has indicated that ESFR sprinklers appear to provide the best means of control for a ceiling mounted system, for buildings up to 12m in height. At or below this height the design of the smoke control system can be treated as for an in-rack sprinkler system. There appears to be no research on the efficiency of these systems above this height.

It therefore seems reasonable to treat the sprinklers as being more effective than ordinary-response ceiling mounted systems, but less effective than in-rack systems. In which instance the design fire size adopted may be taken as a mean value between the two.

The heat flux generated by the fire becomes less important, as the effect of the sprinklers will be to reduce the smoke layer temperature, and in turn the smoky gas buoyancy. This must be considered when natural ventilators are to be installed, and the smoke layer temperature rise above ambient should be limited to the minimum sprinkler operating temperature minus ambient air temperature. When mechanical ventilators are to be used, it is recommended that a maximum of 50o of this cooling should be considered. (This is the average of the maximum calculated temperature plus the sprinkler operating temperature).

The designer must state the degree of cooling caused by the sprinklers which has been allowed for in the calculations. Where there are extended reservoir sizes (or no reservoir at all) calculations of the additional heat lost from the layer beyond the zone of sprinkler activity must be stated.

9.2.3 In-Rack Sprinklers

Where there are sprinklers mounted in-rack, the flame front rising up the rack may pass some sprinkler heads before they operate. This effect is particularly marked for face ignition. This could lead to a fire which may be controlled, but not extinguished, by the sprinklers when they do operate, and the fire is likely to continue burning.

In high racked fires the rising gases become "channelled" by the flues formed by the racks. The fire plume effectively has vertical sides corresponding to the flues. The pattern of smoke movement may be complicated by some smoke spreading horizontally beneath shelves, but the plume will rarely spread beyond a 2 bay width. It does not spread at an angle of 15 degrees from the vertical as is assumed for most axisymmetric plumes in single storey buildings.

Heat may be generated through a significant height of the rack, even when the fire is being controlled by the sprinklers. This suggests a useful analogy with the "Thomas" large-fire plume, since its original derivation was for those parts of a flame plume where combustion was taking place in the gas phase, ie heat was being generated throughout the height of plume. This has the advantage that the large fire entrainment model for a single storey building may be used.

The height of rise used should be taken as the height from the lowest possible seat of fire (ie usually the floor) to the base of the smoke layer, and the perimeter of the fire must be that part of the fire open to the air being entrained. In practice this means that where the fire is in the middle of a long rack, the only contribution to the perimeter will come from the front 'face of the rack (or if the fire is able to burn through to both faces, from both front and back faces of the rack). The lateral extent of fire spread is less easy to assess, but should be assumed to be the lateral separation between sprinkler heads or two bay widths, whichever is less - in most instances around 3m.

The fire 'size should therefore be taken as either.

(a) One side of rack affected only

(b) Both sides of rack affected

The perimeter described by (b) should be used in all cases. The only exceptions are when there is a physical separation between the two faces of a rack or when fast-response in-rack sprinklers are installed to the precise specification and within the limitations (experimental) laid down by the FRS (Appendix 2 References 11-14) in these cases perimeter (a) can be used.

During in-rack sprinkler tests at Cardington, casual observation by FRS staff of the amount of shimmer at a metre or two above the top of the 12m test rack suggested a gas temperature of 200°C ± 50°C when sprinklers were operating in-rack. This estimate was unfortunately not supported by any instrumentation at the time, since it lay outside the design objectives of the particular experiments. It is hoped that further research will yield better data.

There is no indication that fire will progress further up the racks, hence this value can be taken as a limiting parameter, with the heat flux being generated over a 12-14m height. Using the previously described values of fire perimeter, and the mass flow equation, the convective heat flux generated can be approximated.

Where ceiling sprinklers are installed, either complementary to, or in replacement of the topmost in-rack sprinkler level, the final gas layer temperature must be limited as described in 9.2.1 above, prior to further calculation of any losses due to extended reservoir sizes.

10 DEPTH OF SMOKE LAYER

10.1 Industrial Buildings Excluding High Racked Storage Warehouses

In order to avoid the risk of "flashover", sufficient ventilation should be provided to ensure the smoke layer temperature does not exceed 600°C for the design conditions (see Appendix 2 Reference 2). However, the smoke layer depth cannot be less than 10% of the building (room) height. Where this occurs consideration should be given to other (additional) forms of protection, eg sprinklers.

10.2 High Racked Storage Warehouses

10.2.1 Since it is extremely unlikely for an unsprinklered high racked storage area to survive a fire, the following applies to areas which are sprinklered, where flashover is not likely to occur. However, flashover should alvaays be considered, as this guide recommends.

As the smoke layer base will be in many instances, by design, at a high level within the building, it is likely that cool smoke temperatures will result, especially if extended reservoirs are employed.

Smoke temperatures less than approximately 20 degrees centigrade above the average roof level ambient temperature have resulted in the smoke layer de-stratifying and mixing downward with the ambient air beneath. This is mainly due to weak cross-draughts and convection currents, and will occur despite the provision of a smoke extraction system. This scenario must be considered by the designer.

10.2.3 The cooling effect of the operation of the sprinklers must be considered, refer to 9.2 above.

The designer must state the degree'of cooling caused by the sprinklers and extended layer travel which has been allowed for in the calculations.

11 AMBIENT TEMPERATURE

For smoke venting calculations a figure of $288^{O}K$ should be used (see Appendix 2 Reference 8).

12 AIR INLETS/REPLACEMENT AIR

12.1 For any scheme to be effective, sufficient replacement air must be provided in order that extract ventilators operate properly (see Appendix 2 Reference 6).

12.2 Doors and windows, as well as ventilators, can be used for replacement air. However, if intended for use in this way the'y should be fitted with automatic controls compatible with the system. The designer should state the ratio of extract to inlet area used in his calculations.

12.3 To avoid disruption of the smoke layer in any single compartment, the base of the smoke layer should be at least 1-2m above any door/opening which might either by design or chance be a source for replacement air, unless the incoming air velocity is less than lm/s, in which instance it should be no less than 500mm above the opening.

12.4 The design inlet velocity shall not exceed 5.0m/s.

12.5 Ideally, replacement air should be introduced at low level from all directions. However, natural ventilators in the non-fire compartments can be used if smoke curtains/screens are fitted to prevent short circuiting.

12.6 Powered ventilators can be used for replacement air. Care should be taken as they may cause turbulence which can increase smoke/fire spread.

12.7 Where security bars, "insect" mesh or bird screens are fitted, the effect of these should be considered when determining the ventilator discharge coefficient.

13 WIND EFFECTS

The designer should consider the effect of wind pressures on smoke extraction systems.

Information published by the Building Research Establishment and BSI *(CP3,* chapter V pt 2) shows for a building considered in isolation, natural ventilators will be subject to negative pressure of roof slopes of 30^{o}, or less, from the horizontal.

Installations of natural ventilators on roofs over 30° from the horizontal should not be considered without some form of baffling unless supporting data from wind tunnel tests and/or computer simulation is available. This baffling can be external to the unit or part of the ventilator design.

When changing wind directions may cause positive or negative pressure fluctuation in the building structure, natural extract ventilators should be installed in sufficient numbers and positions and controlled via wind sensor/pressure monitors to ensure that an appropriate number open at any one time.

If in doubt about pressure distribution on the building structure, a powered system should be used.

Snow loadings should also be considered when designing/ siting of both powered and natural supply/extract systems.

Any effects caused by the wind which may affect the smoke ventilation system proposed, must be clearly stated by the designer.

14 SPECULATIVE BUILDINGS

This is not, relevant to Mezzanine Floors or High Racked Storage Areas since it is extremely unlikely that such a building would be built speculatively.

Where designers are called upon to design systems for buildings where details of the occupancy, use, sprinklers etc. are unavailable, the following minimum criteria should be used for design.

14.1 4.5m x 4.5m sprinklered fire (see Sections 5.3 and 5.4 for heat output).

14.2 Clear layer to eaves level or 500mm above the top of the highest opening.

14.3 Replacement air not available from doors and windows.

14.4 Smoke compartments to be limited to 2000m² max.

15 SIZING / SITING OF EQUIPMENT

All smoke control products should comply with the requirements of the "SVA Guide to good practice on application of smoke control equipment and systems" (see Appendix 2, Reference 15). Extract equipment should not exhaust at a rate likely to puncture the smoke layer and should be sited in such a way as to not disturb the smoke layer base. Particular consideration should be given to High Racked Storage Areas since the smoke layer depth is freguently very shallow in these buildings. (In this context) mass flow rate and velocity should be considered (see Appendix 2 References 16 and 17).

Rules used in the Industry are:

15.1 The size of natural and powered extract units should be limited to prevent puncture of the smoke layer.

Reference 16, Appendix 2 shows methods of calculation and limiting factors.

15.2 Natural extract ventilators should not be spaced morethan 20m apart.

15.3 For natural systems, the preferred aerodynamic area Of inlet should be at least equal to the aerodynamic areaof extract. The designer should state the actual ratio taken into account in calculations.

15.4 For mechanical systems, inlet resistance should be considered when sizing equipment extraction and the value should be stated by the designer.

15.5 Fan motors should be rated at temperatures compatible with the system design, but should be sized to operate at ambient conditions (288°K).

15.6 Compressed air receivers should be capable of three operations of the system after power failure.

15.7 Exhaust equipment should meet the specifications of the relevant British Standard (see Appendix l, References 3 and 4).

16 CONTROLS

Controls form an integral part of the system design.

16.1 A smoke extract system is operated by an automatic control system, which may be activated by any of the following:

Smoke detection; heat detection; sprinkler flow switch; manual alarm.

The preferred system is activation by zoned smoke detection.

16.2 Ventilators operated only by a fusible link/thermal device do not constitute a smoke extract "system".

16.3Power system controls and their connections should maintain their integrity under design conditions in a fire and should be designed to "fail" in the "on" position.

16.4 Zone Control - The time taken for all ventilators within a fire compartment to be fully operational must not exceed 60 seconds from system activation/smoke detection.

16.5 For natural ventilators used for life safety purposes, in the event of power/system failure, the equipment must failsafe in the "open" position.

17 MEZZANINE FLOORS

The effect of a mezzanine floor on smoke flow is not only to induce more air entrainment but also to result in larger quantities of cooler smoke. Therefore, there are additional requirements when considering the smoke free clear layer to ensure that the upper levels of the building remain free of smoke for escaping people.

17.1 Clear Layer

The minimum clear layer, wherever possible, to the underside of the smoke layer shall be.

3.0 metres above the floor level where the smoke is contained to the floor or origin.

OR

3.0 metres above the uppermost occupied level of mezzanine floor level where the smoke is allowed to spill out from under the mezzanine floor:

1.0 Life safety, ie escape travel distances.

2.0 Smoke layer temperature, ie will "flashover" occur.

3.0 Stock protection, ie maintaining a clear layer above stored products.

Smoke which has travelled laterally beneath a solid mezzanine floor with entrain additional air as it rotates around the balcony edge. Further entrainment will occur as the smoky gases rise to the smoke reservoir. The amount of entrainment is dependant upon the width of the plume of smoky gases at the edge of the mezzanine floor and the height of smoke must rise from the mezzanine floor to the underside of the smoke layer.

Thus, it is clear that the type of mezzanine floor may affect the quantity and temperature of any smoke to be extracted. For smoke control design purposes there.are only two mezzanine types to be considered, Open Mezzanine Floors and Solid Mezzanine Floors.

17.2 Permeable Mezzanine Floors

A mezzanine floor level within a single storey industrial building is deemed to be a <u>permeable mezzanine floor</u> if there is at least 25% free area of the total floor plan area (<u>not</u> around the edge) evenly distributed as openings over the whole floor area (see Appendix 2 Reference 16). The calculation to determine the free area should be the total floor plan area less all obstructions to smoke flow through the mezzanine, for example offices, storage areas, flooring material etc.

If, by calculation, it can be proved that the mezzanine floor has, and will continue to have, at least 25% free area, then for smoke control purposes it does not exist, since it has been proved that false ceilings with this amount of free area do not appreciably interfere with the flow of hot smoky gases.

The design philosophy and methodology given in the main body of this document shall apply, with the proviso that the clear layer shall be, wherever possible, at least 3.0 metres above the upper occupied mezzanine floor level.

The smoke control designer shall ascertain whether the 25% criteria can be met initially, and advise his client of the relevance and importance of the figure.

The smoke control system commissioning and maintenance documents should also refer to the critical nature of the 25% criteria, in an attempt to ensure that this figure will not be reduced in the future.

17.3 Solid (Non Permeable) Mezzanine Floors

Where mezzanine floors are solid or do not meet the requirements of a permeable mezzanine floor, the following design methods shall be applied.

There are two alternative design approaches which can be considered for this type of mezzanine; containment of the smoke to the floor of origin or to allow the smoke to spill around the mezzanine floor edge and rise to the roof smoke reservoir. The design considerations for these alternative methods are completely different and therefore these have been shown separately.

17.3.1 Containment

This approach can be applied to the control of smoke under solid mezzanine floors. Smoke from a fire under the mezzanine is prevented from spilling out of the area into the single storey part of the building by means of smoke curtains/screens, and is extracted from this level.

In this instance, the recommendations contained in the main body of this document shall apply. However, due consideration shall be given to both the smoke layer temperature, (which may be high enough for flashover to occur due to the limited height of rise from the fire base to the underside of the smoke layer), and the necessary depth of the smoke curtains/screens required to prevent the spillage of smoke from the area of containment (which may, due to their depth, hamper escape). Furthermore, the extract equipment shall not exhaust at a rate likely to puncture the smoke layer, as detailed within Sizing/ Siting of Equipment section of this document.

17.3.2 Smoke Flowing beyond a Mezzanine Floor Edge

As has been stated above, entrainment of air into the smoke plume will occur as the smoke spills about the edge of the mezzanine floor. The amount of entrainment, and hence the mass and temperature of the smoke to be extracted, is dependant upon the following factors.

1 The height to the underside of the mezzanine floor above the fire base.

2 The depth of beam at the open edge of mezzanine floor.

3 The width of the plume of hot smoky gases at the edge of the mezzanine.

4 The height of rise of the smoke from the underside of the mezzanine floor to the bottom of the smoke layer.

5 The geometry of the rising plume of smoky gases.

17.3.2.1 The Height to the Underside of the Mezzanine Floor above the Fire Base

Consideration, must be given to the factors listed within Section 7 of this document. It should be noted however that since the smoke is not being contained under the mezzanine but allowed to spill out of the area, it is the determination of the flowing smoke layer (its depth and its temperature) that are critical. Relaxation of the minimum clear layer may need to be sought in some circumstances.

The worst case of smoke generation must be considered.

Research and evidence from real fires has shown the largest quantity of smoke is produced when the distance between the fire base and the underside of the smoke layer is greatest. Thus, a fire should always be considered as occurring on the lowest floor level.

The amount of entrainment of air into the rising plume of smoke beneath the mezzanine is dependant upon its height of rise, ie from the fire base to the underside of the flowing smoke Iayer.

The designer must state within the calculations what criteria has been allowed.

17.3.2.2 The Depth of Beam at the Open Edge of Mezzanine Floor

Research carried out, particularly in the areas of smoke flowing under balconies in shopping centres and atria buildings, has shown the importance of the balcony or edge beam in the amount of entrainment which occurs into the flowing smoke layer.

It must be determined whether or not the edge beam is "deep", relative to the flowing smoke layer (see Appendix 2 References 2 and 16).

The designer must state within the calculations what criteria has been allowed.

17.3.2.3 The Width of the Plume of Hot Smoky Gases at the Edge of the Mezzanine

The amount of additional entrainment into the rising plume of gases is related to the width of the plume of smoke as it rotates about the mezzanine floor edge.

The use of void edge smoke curtains or screens to limit this width is recommended in most instances. The depth of these smoke curtains/screens should, wherever practical, be 500mm below the depth of the flowing smoke layer beneath the lowest transverse obstruction to the smoke flow.

The designer must state within the calculations what criteria has been allowed.

17.3.2.3 The Height of Rise of the Smoke from the Underside of the Mezzanine Floor to the Bottom of the Smoke Layer

Further entrainment into the smoky gases will occur as the plume rises from the point at which it has spilt out from under the mezzanine floor up to the reservoir of smoke at roof level.

The amount of additional air which is drawn into the rising plume is dependant upon its height of rise and its geometric shape as detailed below.

Wherever possible the minimum height of rise of the smoke plume shall be 3.0 metres above the uppermost occupied level of mezzanine floor.

The designer must state within the calculations what criteria has been allowed.

17.3.2.4 The Geometry of the Rising Plume of Smoky Gases

Air can only be drawn into the rising plume of gases on those faces of the gas stream which are in open space. The smoke plumes are normally considered to have four sides, a front, back and two ends.

It will be noted therefore that there are a number of configurations of smoke plumes to be considered, all of which will introduce different quantities of air into the rising smoky gases.

The designer must state within the calculations that criteria has been allowed.

Single Sided Plume

This is rarely found since it can only entrain air into one of its four sides, normally its front. For this to occur, the plume must be as wide as the smoke curtains/screens which limit its width (and be prevented from increasing by the building structure), and the rear of the plume must rise adjacent to the face of the building structure.

Single Sided Plume with One End

This type of plume is also unusual, since the smoke plume will rise with one end and either the front or rear face adjacent to the building structure.

Single Sided Plume with Both Ends

This is one of the most common types of rising smoke plumes from under mezzanine floors.

Smoke spilling out from under a mezzanine floor and rising in free air except for the rear of the plum which is adjacent to the structure of the building.

Two Sided Plume with Both Ends

The most common of smoke in this type of building, and also the one which results in the largest mass of coolest smoke to be extracted.

The stream of smoky gases from under the mezzanine rises without restriction in free air.

APPENDIX 1 - ASSOCIATED BRITISH STANDARDS

1 BS 4422. Part 5. 1988
ISO 8421 - S. 1988
Terms associated with fire, part 5, smoke control

2 BS 7346. Part 3. 1990
Components for smoke and heat control systems
Specification for smoke curtains

3 BS 7346. Part 1. 1990
Components for smoke and heat control systems
Specification for natural smoke and heat exhaust ventilators

4 BS 7346. Part 2. 1990
Components for smoke and heat control systems
Specification for powered smoke and heat exhaust ventilators

APPENDIX 2 - REFERENCES

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APPENDIX 3

GROUP 1

CLASSIFICATION OF SPRINKLER CATEGORIES FOR INDUSTRIAL BUILDINGS

Breweries (excluding bottling sections) Restaurants and cafes
Power Stations
Butchers' slaughter houses
Creameries and wholesale dairies Abrasive wheel and power manufacturers Cement works
Jewellery factories

GROUP 2

Bakeries and biscuit manufacturers
Chemical works with little fire hazard
(otherwise Group 3 or 4)
Motor car repair shops and large motor garages Motor vehicle and accessories manufacturers Food - and preserved food manufacturers
Machine factories including light metal manufacturers

GROUP 3
Cotton spinning mills
Bleacheries, dye-works
Brandy distilleries
Brush manufacturers
Printing offices
Tanneries,1eather good manufacturers
Cereal mills, grinding and peeling mills
Rubber and rubber articles manufacturers(excluding foam rubber)
Flax, jute, hemp mills
Aircraft manufacturers (excluding hangars)
Plastic and plastic products manufacturers (excluding foam)
Cardboard, paper and paper products manufacturers
Radio and television manufacturers (and appurtenances)
Sawing mills and wood using manufacturers
(including furniture factories)
Soap and wax products manufacturers
Textiles and carpets manufacturers
Sound, radio, film and television studios just as
Broadcasting rooms
Wool and worsted mills
Sugar works and refineries

GROUP 4

Manufacturing and/or working up.

Celluloid
Paint, sealing wax, resin, turpentine, soot, tar Fire works, lighting goods
Floor covering, linoleum etc
Aircraft hangars
Wood-wool Oil mills
Foam rubber, foam goods

GROUP 5

Warehouses with racking for combustible and non-combustible materials in combustible packing. Not high bay warehouses or palletised stock etc, as these are covered by other procedures.

SUB-DIVISION OF GROUP 5

GROUP 5/l

(Combustible and non-combustible materials in combustible packing)

Electrical apparatus
Presswood boards
Glass and ceramic goods
Textiles
FoodMetal goods
Carpets

GROUP 5/2

Bottles with alcohol (packed in cardboard)
or alcohol in barrels
Pharmaceutical goods and cosmetics
Paper, cardboard
Roofing felt (tarred board) (stacked horizontally)
Veneering boards or timber
Furniture
Cork
Plastic products (excluding foams)
Varnish in tins (packed in cardboard)
Paper rolls (stored horizontally)
Floor covering

GROUP 5/3

Roofing felt in rolls (stored vertically)
Rubber goods
Wood goods
Oil and wax paper
Cardboard and paper rolls (stored vertically)
Foams and plastics (packed and unpacked) and all products packed in foam material
Cellulose
Wooden pallets, wooden battens and well aerated stacks of wood
Celluloid

GROUP 5/4

Scraps of plastic or foam rubber, stored foam rolls and latex foam rubber

APPENDIX 4 - RATES OF HEAT RELEASE FOR VARIOUS FUELS OF A KNOWN HEIGHT

TABLE A4.1 STORAGE RISKS

Stored Products	RHR (kW/m2)		Fuel Height (m)
	UK Data	USA Data	
Wood crib	290	-	
Wood crib	544	-	
Wood crib	990	-	
Wood crib	1582	-	
Wood pallets, stacked	-	1250	
Wood pallets, stacked	-	3500	
Wood pallets, stacked	-	6000	
Wood pallets, stacked	-	9000	
Crated furniture	28		
Stacked sawn timber	82		
Stacked chipboard	134		
Cellulosics generally	160		
	-	350	
Mail bags	524	-	
Stacked cardboard	840	-	
Cardboard reels	1030	-	
Cardboard cartons	-	1500	
Cartons, compartmented, stacked	284	-	
Cartons, electrical, goods	1130	-	
Packaged goods	-	870	
Fibreglass components in cartons			
PE fibreglass shower stalls in cartons, stacked	-	1250	
Plastic bottles in cartons, stacked	-	4320	
PVC bottles packed in cartons, compartmented, stacked	-	3000	
PE bottles in cartons,	-	5500	
compartmented stacked		1750	
PE bottles in cartons, stacked	-	7500	
PE letter trays, filled, stacked			
PE trash barrels in cartons,	-	1750	
stacked	-	4200	
Plastic films in rolls	-	5500	
PP & PE films in rolls, stacked			
PP tubs packed in cartons compartmented, stacked	-	3900	

APPENDIX 4 - RATES OF HEAT RELEASE FOR VARIOUS FUELS OF A KNOWN HEIGHT

TABLE A4.1 Continued

Stored Products	RHR (kW/m2)		Fuel Height (m)
	UK Data	USA Data	
PU Insulation packed, stacked	-	1210	4.6
PU Insulation boards, rigit foam in cartons, compartmented, stacked	-	1700	4.6
PS Insulation boar, rigid foam, stacked	-	2900	4.3
PS jars in cartons*	-	12400	4.6
PS jars packed in cartons compartmented, stacked*	-	12500	4.6
PS tubs in cartons	-	3450	4.3
PS tubs nested in cartons, Stacked	-	4750	4.3
PS toy parts in cartons	-	1400	4.6
PS toy parts in cartons, stacked	-	1800	4.6
Books, furniture	2160	-	3.0

- NB These figures appear to be anomalously high compared With those following in the next four rows, which are essentially the same product.

TABLE A4.2 SPECIFIC RISKS

Stored Products	RHR (kW/m2)		Fuel Height (m)
	UK Data	USA Data	
Furnished Offices	230	-	-
Workshops for vehicles, petrol, Paint	260	-	-
Garages for trucks	1860		

TABLE A4.3 LIQUID FUEL RISKS

Liquid Fuels	RHR (kW/m2)		Fuel Height (m)
	UK Data	USA Data	
Industrial methylated spirit	740	650	-
Gasoline, petrol	1590	-	-
Light fuel oil	1470	-	-