SMOKE CONTROL IN SPECIAL STRUCTURE

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ABSTRACT

Building codes of almost all countries generally have a 'size limitation of building and compartment' which states a maximum floor area and cubical content for various uses and configuration. If the maximum compartment size is exceeded, there is usually provision for relaxation of the codes which will involve at least some of the following: a) occupancy levels, b) means of escape, c) sprinkler system fitted, d) smoke control system fitted.

This paper is concerned for the latter, recognising the need for adequate smoke control methods in structures such as large space buildings, basements, shopping complexes, atria, factories and warehouses for the protection of life and property and to reduce fire damage.

It recognizes that research over many years by reputable organizations in a number of countries (UK, Japan and USA) have produced substantial knowledge about smoke flow within complex buildings to allows the expected condition of temperature and mass of smoke to be quantified quite accurately. From this research [1-11], an Engineering approach to the control of smoke in complex structures is likely to produce a far more reliable end result in a real fire condition than a solution based on current available prescriptive basic codes which rely on designs which merely consider the volume of the space or the floor area.

The paper deals with the physics of smoke and highlights the speed at which smoke will flow through a building, cutting off escape routes and increasing temperature with related dangers.

Design methods and sample calculations are given for establishing smoke flow rates and possible smoke flow patterns in multi-storey complexes and atrium designs. The paper covers a number of misconceptions in these areas.

Finally, the choice of equipment to effect smoke removal must be suitable and must operate under fire conditions. Unsuitable equipment may act in reverse to that intended.

This paper is generally based on U.K. research and requirements and brings together salient concepts and design ideas for the general awareness of the features and benefits of adequate smoke extract measures.

1. BACKGROUND

In the total Fire Strategy of any building smoke and hot gases are recognized as the major hazard and its control should be an important concern of not only the client, but the Consulting Engineer and equally the Architect in the design and the shape of the building.

Where the building can be divided into small spaces or fire compartments then the spread of smoke, gases and fire can be restricted and in general the available prescriptive codes provide designers with guidance in designing fire safety provisions. Compliance with these codes will allow the local authority requirements to be satisfied, and may well give adequate protection but there seems to be little scientific evidence provided in substantiation.

As new futuristic constructions are being developed and building trends toward large internal volumes such as in Atria, shopping complexes, airports, exhibition halls and where large numbers of people are present on multi levels, these situations have added to the need for design of dependable protection systems to match the risk.

A small fire in a large space can fill the building with smoke and hot gases in minutes. With complex escape routes, as in large buildings, causes those within a few feet of safety, unable to reach the exits in front of them. For the Fireman, with restriction of breathing apparatus, it is difficult for him to do his job and more difficult for him and other occupants to survive.

Smoke control measures consist of compartmentation where possible, pressurisation of escape routes to maintain a safe area of refuge, limiting excessive smoke spread and gas expansion with the effective use of smoke curtains and channeling screens and the removal of smoke from the space, in sufficient quantities, to maintain clear height of visibility at the level of escape from the space. The ventilation of the building is, in most cases, likely to be the prime task in the control of smoke.

2. TO VENT OR NOT TO VENT THE BUILDING

Without ventilation smoke and gases cannot be cleared, visibility is reduced, escape difficult, internal temperatures will rise, sprinkler activation will extend beyond the fire area, fire fighters have difficulty to find people and the fire. The stories of such conditions are well documented.

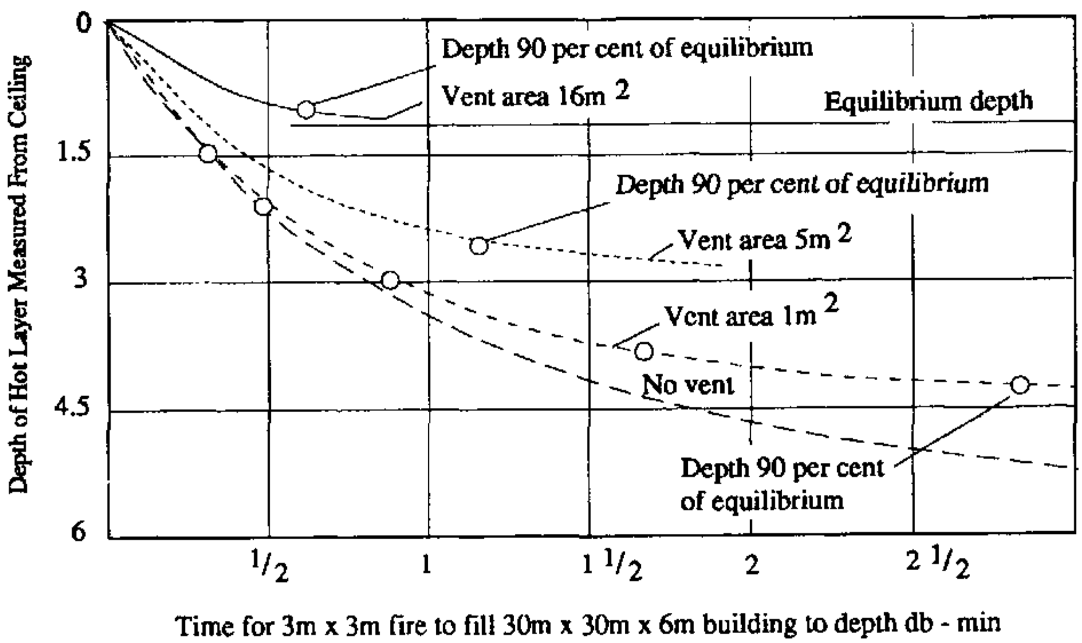
Despite research and many years practical experience of ventilating large space buildings in the event of fire there is still the misconception that to provide ventilation will increase the fire burning rate and increase the production of smoke and gases.

In domestic dwellings and small compartments closing doors will restrict smoke spread, contain heat and could well reduce the oxygen content to a level where flaming combustion will ease. There is always the chance then of flash over if at a later stage doors to the room are opened and where retained gases with incomplete combustion are fed with oxygen.

Fires in large compartments are quite different. Clearly capable of growing larger than in a domestic room the compartment would be full of hot gas long before being starved of oxygen and then more difficult to escape and difficult to enter even with breathing apparatus.

A 5 MW fire covering an area of 10 m^2 in an unventilated 1,000 m^2 building, 7 m high would take over 20 min to reduce the oxygen content to the point where flames die down [3].

Hot smoke would initially spread as a layer beneath the ceiling reaching walls in about 20s. The smoke layer would then deepen and at the end of 1 min would have reached a depth of about 2.5 m. Thus far, it would not be a hindrance and might not even be perceived as a threat to the occupants since they would be a 4.5 m deep layer of clear air flowing slowly towards the fire. After 2 min, the layer would more than half fill the building and at 3 min would be to head height. By then smoke would have mixed into the air flowing back to the fire enveloping anyone still there and increasing the smoke density. From that point escape is increasingly difficult. Fig. 1 [3] indicates how quickly smoke filling will occur in a simple space 6 m high without ventilation and the equilibrium smoke depth achieved with various natural openings for ventilation to remove smoke.



(Extract from U.K. FRS Technical Paper No. 10 – Model Test Simulation – Ref 3)

Fig. 1

A building with a lower ceiling height or smaller floor area the effect from the same fire size can happen more quickly. In that case 'higher' rates of exhaust or smoke release will be necessary to reach a smoke level equilibrium and maintain clear height of visibility.

However using prescriptive codes where the requirement for the exhaust rate selection is based, for example, on a given air change rate, or opening area as a % of the floor, the actual provision for exhaust of smoke in a small area is less than before.

3. THE BENEFITS OF 'ADEQUATE' SMOKE CONTROL

Adequate smoke control, which includes automatic smoke release or extraction from large areas combined with the necessary screening and smoke barriers will give considerable benefits for life safety and building protection if Engineering calculations are followed:

1. Provide improved visibility for people to reach the means of escape,
2. Gain more time to safely evacuate the building,
3. Assist in lowering temperature so people can breath more easily, building materials and contents can be kept below their flash point and structural collapse can be avoided,
4. Assist the fire fighters to do a better job,
5. Reduce water, fire and smoke damage and the risk of explosion and flash over.

4. FACTORS OF DESIGN

The design of an adequate smoke control system depends on a large number of factors such as: Building dimensions and structure, Contents and layout, Special hazards, Fire /smoke detectors, Building occupancy, Call out time of fire brigade, Escape routes, Sprinkler, Likely fire development size, Adjacent structures.

For large volume areas such as shopping complexes, atria, underground structures, warehouses, depots and the like, in practice more than say 1000 m^2 undivided [4], the same basic approach should be followed for the design of a control system for protecting those escape routes running through and open to the large undivided volume. The intention is to keep the smoke in the upper reaches of the building, leaving clear air near the floor to allow people to move freely. Means of escape, which are likely to be within to smoke layer or obscured from view when needed, can hardly be classified as 'means of escape'. The stratification or layering of the smoke is made possible by the buoyancy of the hot smoky gases produced by the fire and it follows that to be most successful the high level layer must remain warm and above the internal ambient temperature.

5. PRINCIPLES

Fig. 2 indicates the general approach where the fire source is at the floor level [4].

Smoke and gases will rise from the fire and in doing so entrain air over the height of rise on one or all sides to increase the mass flow. The mixed gases form a layer beneath the ceiling, which can spread over a wide area or, contained within a smoke reservoir. The boundaries of this reservoir can be screens, walls or other features. Gases need to be removed from the reservoir at least as rapidly as they enter from below, either mechanically (using fans) or naturally (using buoyancy of the gases to drive them through openings in the roof). Sufficient air must enter the space below the smoke layer to replace the extracted gases or the system will not work efficiently. These principles apply to all types of building in this class.

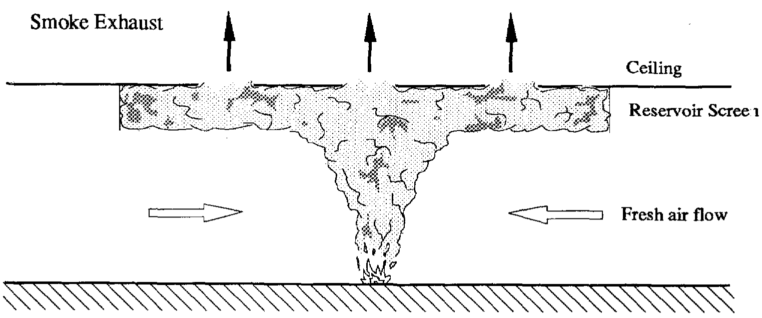


Fig. 2: Principle of system needed to contain smoke in a well-defined layer
Section across building

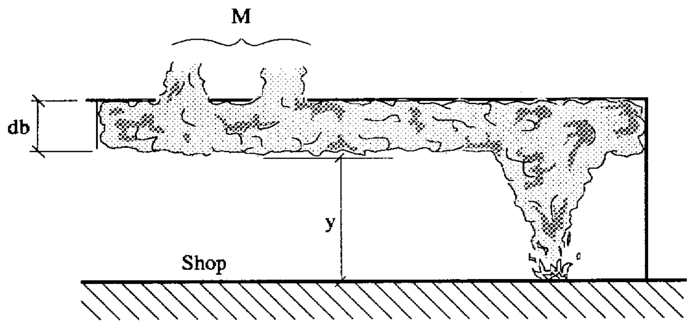


Fig. 3: Hot smoky gases entering (and being removed from) a ceiling layer

Fig. 3 indicates the arrangement for the basic calculation of mass flow from a fire source.

Fire Research Technical Papers [2-5] provide formula for more specific calculations of mass flow of gases from a fire under given conditions.

$$MF = 0.19\ P \times (Y)^{3/2} = \text{Kg/sec} \qquad (1)$$

Where MF is the mass flow in the rising plume entering the smoke layer = kg/s.

P is the perimeter of the fire (m).

Y is the height from the base of the fire to the smoke layer (m).

It can be seen that from equation (1) that the mass flow of gases to be exhausted considerably increases as the height of clear layer increases. This is because of the entrainment of cooler air as the gases rise.

Providing the rate of smoke emission from the fire into high level reservoir can be matched with an equivalent rate of smoke removal out of the reservoir to outside, then a fixed level of clear visibility can be maintained above the heads of the people in the escape routes giving them more time to exit the building.

The success of the system is therefore based on calculating the quantity of smoke and then providing adequate ventilation, the value of which would be related to the design fire size, the risk, other fire suppression systems and a thorough knowledge of how smoke flows through the building to form a clear area of visibility.

It can be seen therefore that the mass flow of gases to be exhausted to maintain the clear conditions has little relationship with the building volume or indeed the total floor area of the building. Hence the previous design methods, based on air changes per hour, or % opening to that of the floor area, is unlikely in practice to provide effective smoke control as factors fundamental to the production of mass flow of gases are not taken into account.

6. HEAT OUTPUT AND GAS TEMPERATURE

If the likely heat output from the fire (Design fire size) can be assessed, then the temperature of the gas layer can be established and this is vital information in the selection of the smoke control method and the selection and sizing of the equipment.

$$\Delta t = \frac{Q}{MF} \qquad (2)$$

where

Δt = temperature rise, ^{o}C
Q = heat flux of fire less any radiation loss to the structure, kw
MF = mass flow of gases, kg/s

Having calculated the mass flow from the rising plume and the expected gas/smoke temperature, calculations can then be made to establish the exhaust rate to maintain the design conditions.

7. NATURAL SMOKE RELEASE – STATIC SYSTEM

Where a natural (static) system is considered suitable, the aerodynamic area of opening for smoke release can be calculated from the following formula, (FRS / BRE Papers) [4,7]:

$$\text{AvCv} = \frac{\text{M}}{\text{Po}}\left[\frac{\text{Tc}^2 + (\text{AvCv/AiCi})^2\,\text{ToTc}}{2\text{gdb}\theta\text{cTo}}\right]^{1/2} \qquad (3)$$

where

Av, Cv = aerodynamic free area of natural ventilation, m^2

Av = measured throat area of ventilators for the reservoir being considered, m^2
Ai = total measured area of all inlets, m^2
Cv = coefficient of Discharge (Usually between 0.5 and 0.7)
Ci = entry coefficients for inlets (typically about 0.6)
MF = mass flow rate of smoke to be extracted, kg/s
Po = ambient air density, kg/ m^2
g = acceleration due to gravity, m/s
db = depth of smoke beneath ventilator, m
Oc = temperature rise of smoke layer above ambient, ^oC
Tc = absolute temperature of smoke layer, K
To = absolute temperature of ambient air, K

The resulting opening area is then related to the design and efficiency of the vents to be used.

8. POWERED SMOKE RELEASE

Where a fan powered exhaust system is considered suitable, the capacity of the system can be calculated from:

$$V\,(m^3/s) = \frac{MF}{1.2} \times \frac{Tc}{To} \tag{4}$$

where

MF = Mass flow of smoke (kg/s)
Tc = exhaust absolute temperature
To = ambient absolute temperature

9. THE DESIGN FIRE

As a general rule, the larger the fire the greater the quantity of smoke and the larger the required capacity of the smoke ventilation extract. It is clearly impossible to design a system to cope with the largest possible fire since there is no limit to the size of fire. In general however, larger fires are rare and the design can be for a “largest likely” fire defined in some appropriate manner. This would be known as the Design Fire size.

In single storey buildings consideration would be given as to the risk, building location and call out time of the fire brigade, as well as the existence of fire alarms and detectors. For example, a fire in a building fitted with smoke detectors is likely to be smaller in size by the time the fire brigade arrives than one without. Much can be gained from experience, case histories and hard logic, to determine the likely fire size when tackled.

Except in special cases, the design fire size would vary, for example from 3 m x 3 m for lower risk to a 10 m x 10 m for a high risk area [12].

For shopping malls, Fire Research Station has used the UK Fire Statistics computerized database to deduce a ‘largest likely’ fire for retail premises. This fire is of 5 MW output and is 3 m by 3 m in size when sprinklers are present and is used as the basis for calculation when designing smoke control systems in malls. There has been a tendency to use the 5 MW design fire for smoke control in all types of building. This is potentially misleading, since it strictly applies only for fires in sprinklered retail premises.

For fires in office and hotel bedroom locations BR 258 [11] indicates recommended design fire sizes for specific risks.

10. HEIGHT OF SMOKE BASE

If the internal geometry of the building is known, it is simple to select the height above the highest occupied floor of the case of the buoyant smoke layer hugging the ceiling. This should be sufficiently high so that people can move freely beneath it without encountering smoke. Where the primary concern is the protection of easily damaged goods or other contents, the smoke base needs to be above these goods.

It should be recognized that the base of a buoyant layer is never sharply defined, being ‘fuzzier’ for cool smoke than for hot. This fuzziness must be allowed for in choosing the height of the smoke base and explains why a single storey shopping mall can have a smoke base at least 2.5 m above the floor, while a two-storey mall with a cooler buoyant layer should have at least 3 m above its upper floor. The calculations shown above will generally hold good for fires in both single storey structures, basement and the larger space of a shopping complex or atria where it is expected there will be a conventional rising plume into the smoke layer, although smoke movement in these latter areas may change due to other factors.

11. LARGE SPACE SHOPPING OR OFFICE COMPLEX

Where a number of individual larger shop or office units extend over more than say 1300 m^2 each, separate smoke control systems should be considered for each area and the mass flow calculated as equation (1) above [4]. With a larger number of smaller shops, offices as in a complex, it would be impractical to individually vent each unit and hence it can be expected that exhaust from the common mall or central void would occur, provided the smoke depth at ceiling level is above the heads of those escaping.

Experiments have shown that smoke passing from a shop unit into a mall will approximately double in quantity before turbulence damps out sufficiently to prevent further entrainment of air [4]. Hence, in such a situation as Fig. 4 the mass of hot smoky gases that must be removed from the mall ceiling reservoir each second is double the value given by equation (1) where 'Y' is now the height from the floor to the base of the smoke layer in the mall area. Multi-storey malls having several shopping levels with one or more voids and openings vertically connecting the different levels, are far more difficult to successfully ventilate, since the hot smoky gases rising from the lower levels to a higher, will mix with large quantities of air and can spread to balconies of the upper levers.

In such cases, the volume of entrained air can be reduced by the use of adequate channeling screens and smoke barriers. One suggestion is shown in Figs. 5A and 5B. Screens and smoke barriers are an integral part of the system design to limit spread and reduce air mixing. This equipment should not be confused with roller shutters which play a different role entirely.

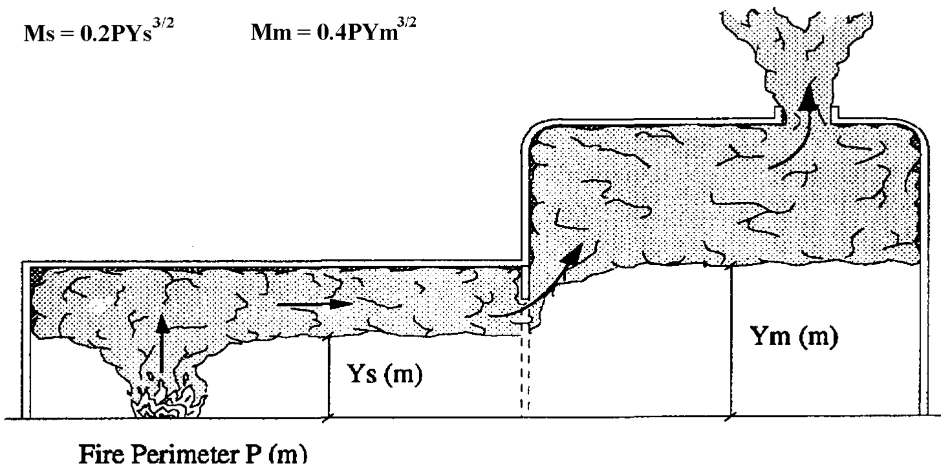


Fig. 4: Entrainment into plume

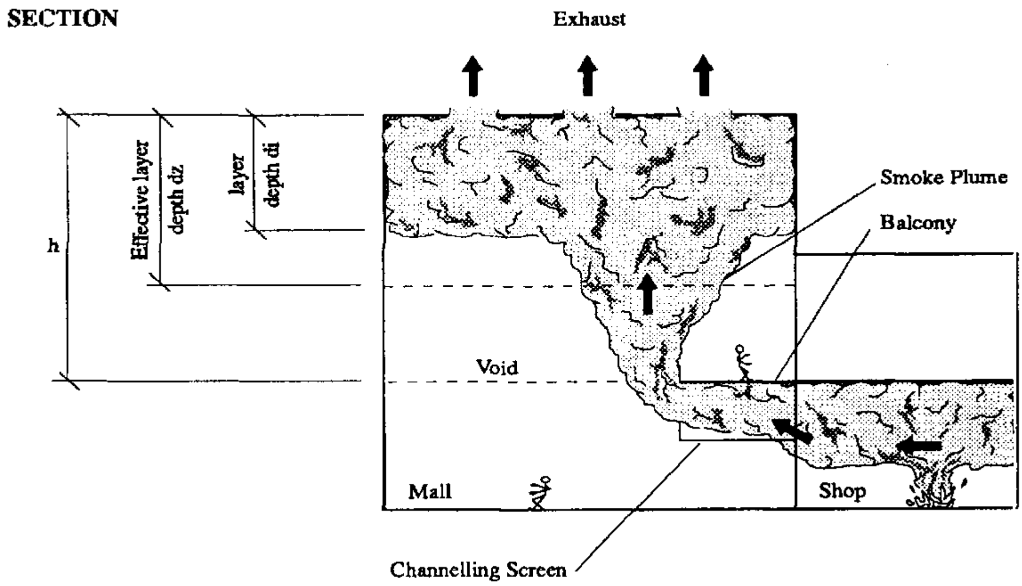


Fig. 5A

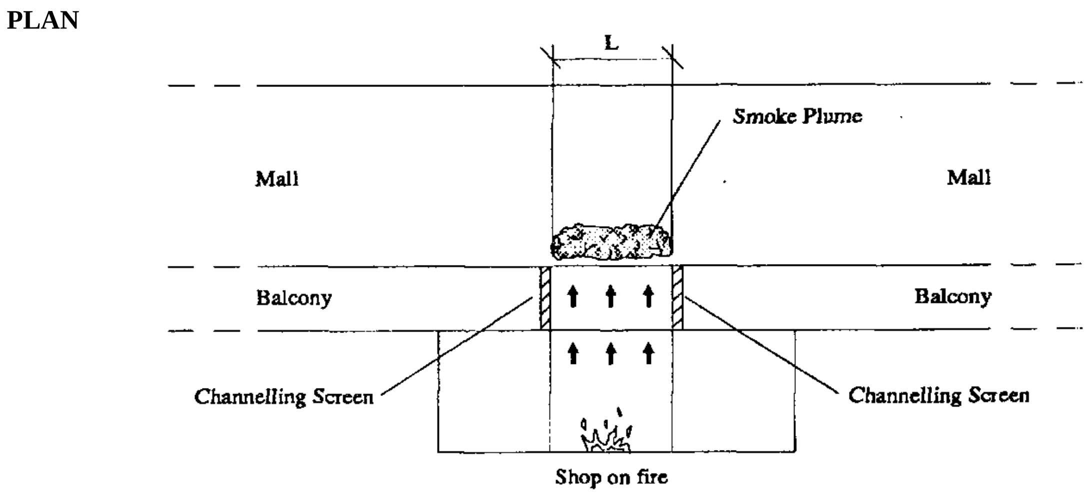


Fig. 5B: The use of smoke channelling screens to produce a compact rising plume

Alternatively, individual exhaust from each floor could be considered. Figs. 6A and 6B illustrate in schematic form a mall, whose upper floor is penetrated by voids that will leave a considerable area for pedestrians. If suitably void edge screens are provided, to the correct depth, the area below can be turned into a ceiling reservoir similar to that of a single storey mall albeit of a more complicated geometry. This reservoir can then be provided with its own smoke extraction system. Other screens can be positioned across the mall to limit the size of the reservoir, as for a single storey mall.

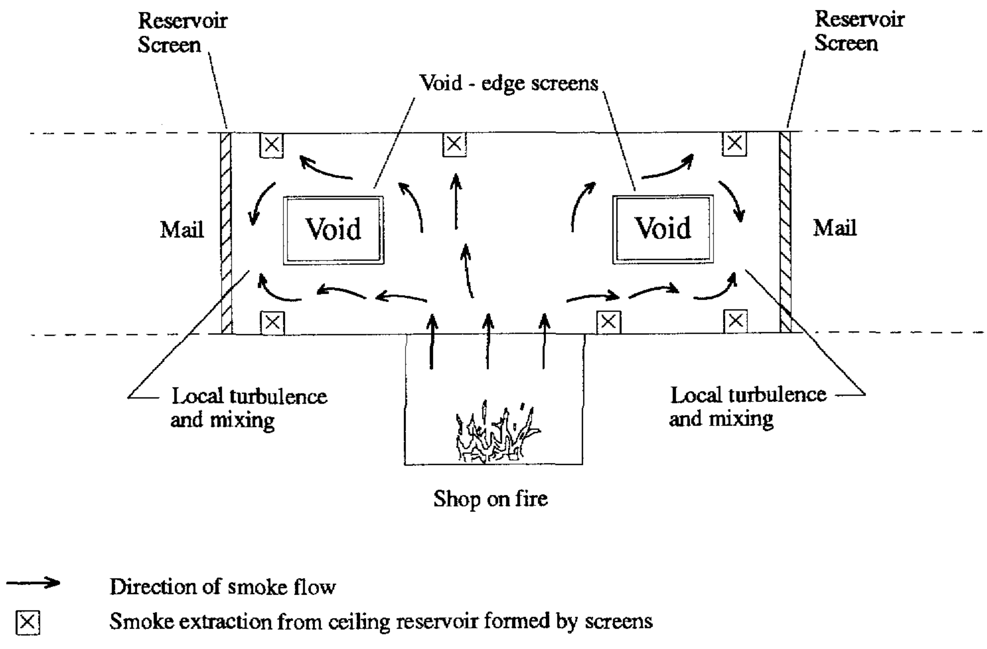


Fig. 6A: Schematic plan of multi-storey mall with a smoke reservoir on each level

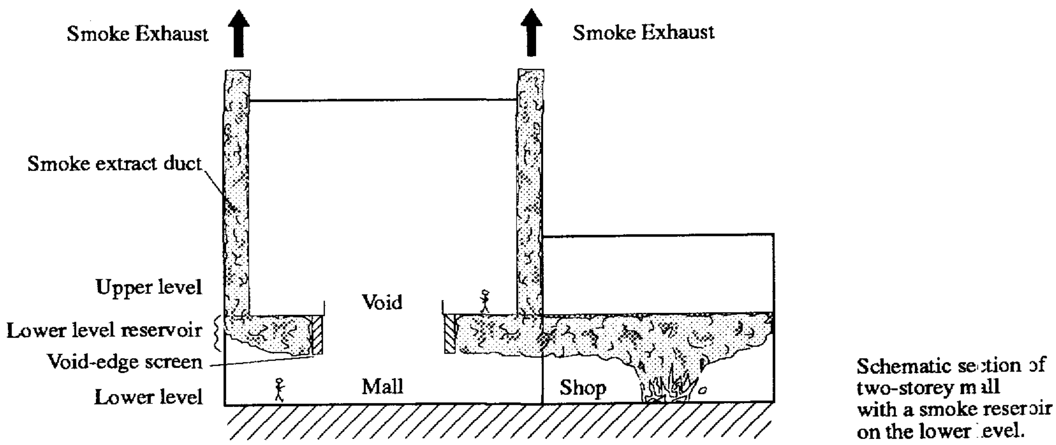


Fig. 6B: Schematic section of two-storey mall with a smoke reservoir on the lower level

Where smoke flows through the small void as in Figs. 7A and 7B, care must be taken if the upper levels are used as escape routes. The quantity of smoke entering the ceiling reservoir can be found by using graph such as Fig. 5C which relates the mass flow rate of gases to the height of rise above the floor immediately above the level on fire. Note the rapid increase in gases with increase in height.

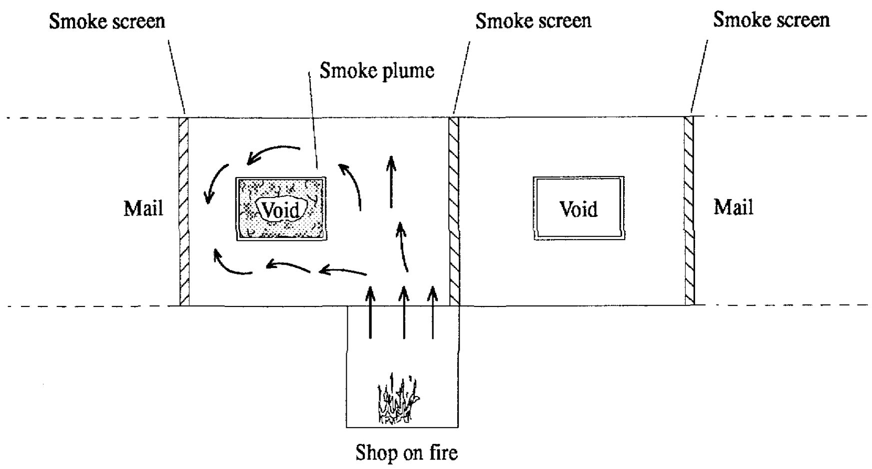


Fig. 7A: Plan view of smoke circulation pattern below upper deck with smoke-restraining screens

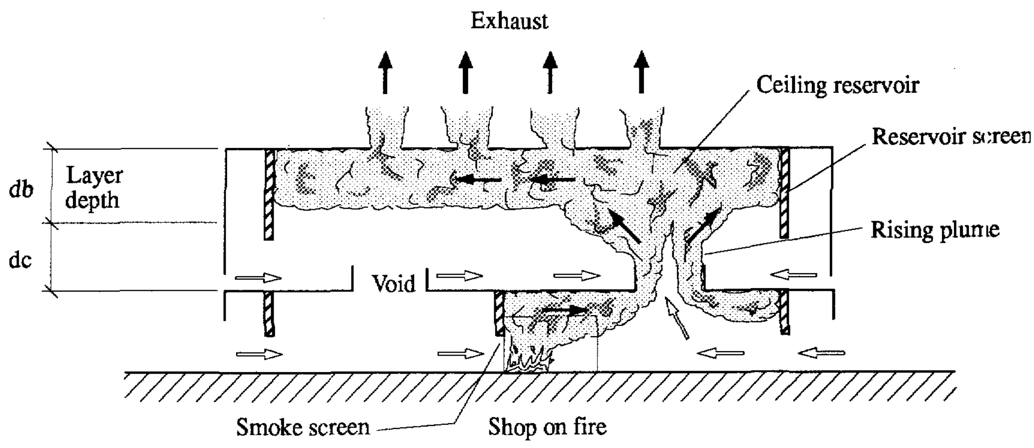


Fig. 7B: Smoke and air movements in two-storey mall with small connecting voids

If gases have to rise through one upper level plus a further higher level and still allow clear visibility for people on that level to move freely, it can be seen from Fig. 5C [4] that the extraction from the ceiling reservoir must be considerably greater than 200 kg/s - a very large extraction rate. It is large enough to suggest that a smoke control system for more than 3 to 4 open levels is not practical proposition unless the highest level or levels can be allowed to become smoke logged without affecting means of escape. The effective use of void edge screens to these upper levels will again assist in containing the flow of smoke.

This fact is more recently confirmed in research work in Atrium buildings BR258 [11] where it is concluded that 'through flow' smoke ventilation will rarely allow escape routes to be open to the atrium above the fourth or fifth floor.

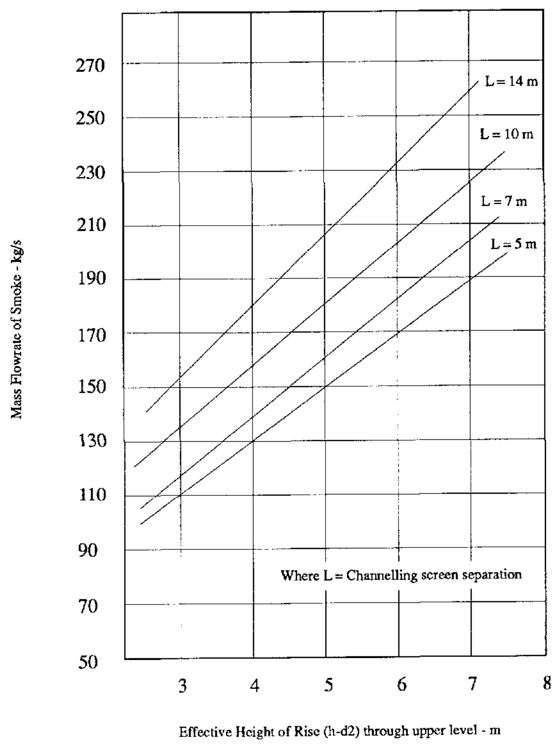


Fig. 5C

12. AIR INLETS

If smoke venting is to be effective, it is necessary for cool air to flow into a building to replace the hot air being extracted or flowing out through the vents. Therefore adequate inlets for cold air are a necessary design consideration.

In a shopping center or mall, it may be necessary for low level doors or louvres to open automatically on a signal from the smoke detector system. In a single storey building normally existing doors or windows can be relied upon although the available area should be checked at the design stage. In large buildings with a number of roof compartments, vents & other openings in the roof some distance from the fire zone may be opened to act as inlets. This method of providing replacement air is a particular advantage of natural smoke release.

The area of inlet opening for smoke exhaust ventilators to operate efficiently must approach that of the exhaust or the efficiency of the exhaust system will reduce dramatically. Equation (3) allows for the ratio of area of exhaust to area inlet to be considered and included.

Where mechanical smoke exhaust is incorporated, replacement inlet air can be provided by either natural openings or louvres where an inlet area velocity should not exceed 3m/s or, with mechanical inlet, where it is recommended that not less than 80% of the exhaust should be available. The location of forced inlet system grilles is important to ensure that the replacement entering air does not disturb the contained smoke gas layer.

The equal air replacement design is suitable where 'through flow' smoke control concept is considered. Where 'depressurization ventilation', concept is used the inlet replacement air is purposefully restricted, as in the case of Theatre Stage smoke control. This concept is described later.

13. CONTROL

Whenever a smoke ventilation system is designed to protect life, it should operate automatically on the first detection of smoke.

Natural smoke ventilators, many of which will normally be closed, should NOT operate solely on fusible links since they take far too long to operate in large areas. Pneumatic systems that provide opening when air pressure is released are commonly used due to their reliability and reduced maintenance. These are activated by smoke and/or heat detectors. If sprinklers are present, the system should be linked to flow switches and to the fire alarm system. Manual override must be included for testing or inspection purposes.

Mechanical smoke systems require electrical control that must be independently dedicated to the operation of the ventilators in the event of a main electrical supply. In this case, a stand-by emergency generator will usually be required.

14. SCREENS AND SMOKE BARRIERS

Smoke reservoirs can be formed by downstand fascia of shops or with fixed or automatic screens. Screens and barriers help to contain smoke spread and restrict entrainment. However the size of the reservoir should depend on calculation and the depth of the screen should not be less than the 'flowing layer' [4]. To prevent excessive heat loss the size of individual smoke reservoirs is usually limited to 1000 m^2 for shop areas. For larger spaces especially industrial premises areas of 2000 m^2 / 3000 m^2 have long been the practice [4].

Current prescriptive codes with reservoir areas restricted to 500 m^2 may well be suitable for multi storey buildings with low height floors, but for current complex building designs this size would prove unworkable, impracticable & unnecessary with an engineering solution.

15. ATRIUM STRUCTURES

Atria today are designed to create very large undivided volumes within a structure, creating visually and spatially the ideal external environment indoors.

Modern atrium buildings are designed with the atrium creating a feature that can be appreciated from within the adjacent rooms. Thus the room/atrium boundary is usually either glazed or completely open. When compared to 'conventional buildings', this architectural / aesthetic requirement imposes additional problems of life safety during a fire as smoke, hot gases and even flames may travel from one (or more) rooms into the atrium and hence affect areas that would not be affected in the absence of an atrium.

Experience of fires in atrium buildings in the United States has shown the problem of flame travel internally through the atrium to be minor in comparison to the hot and toxic gases accumulating at the ceiling and building down in the atrium [1,10]. There has been a need for a properly designed smoke control system in atrium buildings and the most recent research by UK Fire Research Station has produced design considerations in the publication BR 258 [11].

The smoke control systems in most cases required exhaust ventilation, the type depending on the building arrangement.

1. For the **sterile tube** atrium, where the atrium space is separated from the remainder of the building by fire or heat resistant glass and where the space has no general function, the control method employed could be:

a) Ventilation of the compartment direct

b) Depressurization ventilation of the atrium space.

The only time depressurization ventilation will be deemed necessary, is if it can be assumed that the fire rated glass onto the compartment will shatter, thus allowing smoke and hot gases to flow into the atrium or if a fire could occur on the atrium floor.

2. For the **closed atrium,** where the atrium that is separated from the remainder of the building by ordinary (non-fire resisting) glass, the atrium space may well be functional (cafeterias, restaurants, recreational, etc.), the methods of smoke control may be:

a) Direct ventilation of the compartments.

b) Throughflow ventilation of the atrium space.

c) Hybrid ventilation of the atrium space.

3. For the **partially open atrium,** where the atrium has some lower levels open to the atrium and the remaining levels closed off by glazing. The methods of smoke control that may be employed are:

a) Direct ventilation of compartments,

b) Throughflow ventilation of the atrium space,

c) Hybrid ventilation of the atrium space,

4. For the **fully open atrium,** where the atrium has some upper or all of its levels open to the atrium space the methods of smoke control that may be employed are dependant upon the vertical information of levels within the atrium.

a) Compartment boundaries vertically in line with each other or stepping back from the atrium as it rises: Direct ventilation of the compartments, or throughflow ventilation.

b) Compartment boundaries stepping into the atrium as it rises: Direct ventilation of the compartment only.

16. DIRECT COMPARTMENT VENTILATION

This is done in order to prevent hot smoke and gases entering the atrium. It may be achieved by either a dedicated smoke exhaust system or by adapting and boosting an air conditioning or ventilation system. If the compartment is open to the atrium, then the compartment must have either a 'suitably sized' downstand barrier to the void edge to create a reservoir within the compartment, or a high powered exhaust slot at the boundary edge to achieve a similar effect. If the compartment is glazed, or roller shutters are employed then some provision will need to be made for an inlet air supply. In general inlet air may be supplied from the atrium via roof ventilators.

17. THROUGHFLOW VENTILATION

This is the steady state vent system familiar to most. It is used when the fire is in the same space as the people, contents, or escape routes being protected, without it filling that space. The intention is to keep the smoke in the upper reaches of the building, leaving the clean air near the floor to allow people to move freely. This stratification or layering of the smoke is made possible by the buoyancy of the hot smoky gases produced by the fire, and it follows that to be most successful, the high-level smoke layer must remain warm. Smoke ventilation is therefore only suitable for atria where fires can cause smoke to enter the atrium space, rise and remain buoyant. Calculation can determine this.

18. DEPRESSURIZATION VENTILATION

This is a special case of pressurization, where gases are removed from the smoke affected space in a way that maintains the desired pressure differences and/or air speeds across leakage openings between that space and adjacent spaces. Note that depressurization does not protect the smoke affected space in any way. Instead it protects the adjacent spaces. In the circumstances of an atrium it is sometimes possible to use the buoyancy of the smoke and gases themselves to create the desired depressurization effects. Depressurization will generally apply only in closed atria and in special situations.

19. HYBRID VENTILATION

This technique employs a combination of throughflow ventilation to create a distinct layer for some purpose and the depressurization concept of raising the building neutral pressure plane to a higher level to protect sensitive areas above. This form of smoke control is that most frequently employed in designs for example over theatre stages to protect auditoriums.

20. PRACTICAL DESIGN CONSIDERATIONS

It is not practical to detail, in this paper, the calculations of the mixing of air into the rising plume. Fig. 8 shows examples of the output curves that can be produced. As seen from the examples, the mass flow rates generated by the entrainment into the rising plume is very large hence the plume cools quickly with height. This large increase in mass flow with increase in height tends to suggest that there may be some cut-off point in the rise of the plume above which it might become economically impracticable in terms of a smoke control system.

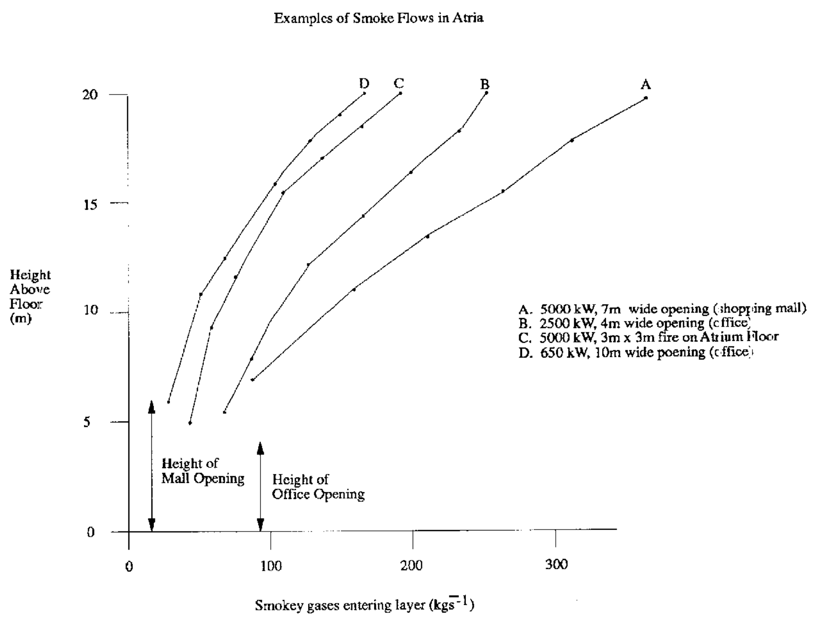


Fig. 8

Experience suggests that it is often is true for flows larger than 150 to 200 kg/s [11].

Another effective limit may also occur if the temperature of the gas layer forming in the roof void is too low, perhaps below 10 or 20 ^{o}C above ambient, as the stability of the layer may be affected by internal day to day heat gains in the atrium or adverse air currents (draughts) due to ventilation, air conditioning, or weather conditions. There is little information available on the destabilization of cool buoyant layers, so a precise limiting temperature cannot be given. Further research is desirable in this area.

Which limit is reached first will depend on the situation being considered, i.e. on the type of fire, construction of the compartment, construction of the atrium, the mode of ventilation.

Experience suggests that one or other limit is usually reached when the height of rise above the fire room opening exceeds 18 to 20 m. It follows, that it does not usually appear to be practicable to design a continuous (steady state) smoke ventilation system requiring more than 4 to 5 storeys (sometimes less) **to be kept free of smoke** regardless of whether it is powered or natural smoke ventilation. However calculation can determine this [11].

21. CHOOSING THE SMOKE VENTILATOR

Smoke can be ventilated from the building mechanically or naturally. The choice will depend on the nature of the fire and in the structure in which it occurs. There are many factors common to the types of equipment.

First, operation of the ventilation must be automatic, triggered by smoke detectors or some other alarm device so that smoke removal occurs as early as possible.

Secondly the equipment must capable of being regularly tested.

Thirdly the equipment should be specifically designed for the purpose, capable of operation after years of installation and suitable to handle hot smoke and gases at various temperatures.

Where there is an accessible roof and where the mass flow is high at a suitable temperature, a **natural smoke release system** would be the most suitable and is likely to have advantage and reliability over a mechanical system. A natural system will operate even when the electric supply is lost or cut off and does not need fire rated controls or stand by generators.

Natural (static) smoke release units tend to adapt to fire size and to the quantities of heat and smoke produced by automatically adjusting their capacity. This is, however, directly related to the unit coefficient of exhaust, which should be determined by wind tunnel tests.

Current natural smoke vents available are able to suit the architectural aesthetics of modern buildings but consideration must be given to location and the effects of wind pressure.

Mechanical equipment is preferred where wind can produce positive pressure across a building, where multi storey buildings require exhaust from the compartments and usually where basements and underground structures are involved.

The fan is, however, a device with a constant output, so any increase in heat from a fire will increase the smoke volume and the fan system should be designed with reserve capacity to cope with this. Care should be taken to calculate the gas temperature to be sure the fan operating conditions will not be exceeded. The fan system will require a maintained supply.

22. STANDARDS FOR SMOKE VENT EQUIPMENT

Standards for specialist smoke control equipment are set down in various Countries where the requirements for smoke control in buildings are advanced. In UK Standards are now set down by the British Standards Institution for the design and construction of various equipment, to ensure the equipment is designed and operates correctly in fire conditions.

BS 7346 1990 for “COMPONENTS FOR SMOKE AND HEAT CONTROL SYSTEM”:

Part 1 - Specification for Natural Smoke and Heat Exhaust Ventilators

Part 2 - Specification for Powered Smoke and Heat Exhaust Ventilators

Part 3 - Specification for Smoke Curtains

Users of this British Standard are advised to consider the desirability of assessment and registration of a suppliers quality against the appropriate part of ISO 9001 or BS 5750 by a third party certification body.

23. MISCONCEPTIONS

There are many misconceptions on the way that smoke and gases flow through a building and the use of either mechanical or natural methods for smoke removal. Smoke and gas flow does not necessarily adopt the same rules as a conventional HVAC system and trained HVAC engineer should be aware of this. Generally the choice of system should depend on the results of calculation of mass flow and temperature. Previously engineers have believed that 'to be safe – use mechanical methods and add a safety factor.' In practice quite the reverse could be true. A natural system may have advantage in many large space structures, whilst to 'over do' the mechanical exhaust capacity could easily cause the smoke layers to descend lower than expected to effect escape routes. This is why prescriptive codes may not be suitable in current building designs.

A further misconception is that mechanical exhaust will 'draw' smoke up an atrium to higher levels. Smoke will only rise providing the gases are sufficiently warm to maintain buoyancy.

24. SMOKE CONTROL BY PRESSURIZATION

Pressurization is the term commonly applied to mechanical smoke control systems in which a supply of fresh air to a space within a building is used to maintain that space at a slightly higher pressure than the rest of the building.

The normal applications for pressurization are corridors, lobbies or staircases that form part of an escape route. The enclosing construction of this part of the escape route will be fire resisting and the doors leading to it from the fire area will also be fire resisting, although there will be cracks around their edges large enough to allow the ingress of smoke. In a fire, one would also expect the door to be opened temporarily permit escape of personnel.

The smoke control system should be capable of producing a significantly higher pressure in an escape route than in adjoining spaces in the event of a fire. Since a fire can itself produce a pressure differential of 8N/rn2 across a door, pressurization must exceed this amount to maintain an outward flow of air.

The subject of pressurization is complex and not the specific subject of this paper other than the total concept of smoke control should take account of the various strategies of containing and removing smoke and maintaining safe areas of refuge for escape.

25. INTERACTION WITH OTHER SUPPRESSION SYSTEMS

Other fire protection systems such as sprinklers, smoke/heat detectors and alarms all have a vital and distinct part to play and in combination they provide the most effective means of protecting life and safety of the buildings occupants and the integrity of the building itself.

The sprinkler puts water on the fire to provide cooling and reduce fire spread, as well as give in an alarm. The smoke detector provides early warning and is able to actuate other fire control devices. The ventilation system removes smoke to increase visibility. If the sprinkler does or does not control the fire, it is quite likely that manual fire fighting will be required, hence visibility must be clear and smoke removed for fire fighters to find and see the fire.

There has been much conjecture in the past about the interaction of smoke ventilation and sprinklers and the benefits of each. Much of the concern has been that one system would counteract the effects of the other. With a full understanding of the part played by each and further research [9,13], it is concluded that when designed together correctly the actions are completely complementary. It should also be understood that in some high spaces and in structures where the fire load is small the activation of sprinklers could be very much delayed or not operate at all due to low temperature. In which case the effects of smoke venting may be vital to keep these escape routes clear.

26. CONCLUSION

The need and the benefits of adequate smoke control should not be in any doubt in large space commercial and industrial buildings and in special structures. It should also be clear that smoke control systems should not just be restricted to maintaining smoke free staircase and lobbies. With the modern and futuristic building designs, smoke control will be vital to play the required role in the total fire protection concept.

Current research on the subject allows specific conditions and strategies to be designed providing factors of fire size, heat output, entrainment patterns, smoke reservoirs, height of rise and a knowledge of smoke flow patterns can be incorporated. Without this approach the success of the smoke control design will not be certain and may well be limited. Despite testing at the commissioning stage, the real test and end result may only be realised in a real fire emergency. This may then be too late to rectify if the system lacks capacity.

Hence the current prescriptive codes, which, in many cases, fail to incorporate the design methods indicated in the research information, could well result in the building safety being jeopardised. The engineering approach to smoke control design would give a greater degree of success and there would be benefit in codes being revised to include certain design papers.

It is noted that previously in Singapore the requirements on smoke control were based on the limited local knowledge and expertise in the area, but in the new Code the SCDF has adopted the requirements recommended in the British Research Establishment guidelines as detailed in BR 186 [4] and BR 258 [11]. Engineers now have a comprehensive set of precise guidelines for their smoke control design, with less designs 'left to chance'.

Finally it is recognised that despite current research relating to smoke flow within buildings, this research can never catch up with the modern building shapes and structures now being designed. Hence to need for on going research on the subject.

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