Figure 1 : Smoke movement within compartments.

The Management and Extraction of Smoke and Toxic Fumes — Why, Where and How?

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Part 2 of 4

The discovery of fire must have sparked man's fertile imagination. It certainly helped fuel his ongoing quest for safety, security and the occasional well-cooked meal. No doubt a few burnt fingers also helped to inspire effective fire control and smoke management. The ideas of Prevention, Protection and Extinction were likely born at about the same time.

Indeed, these three concepts remain at the heart of worldwide fire engineering sciences today:

- PREVENTION of fire is based on conservative risk management strategies aimed at eliminating fire.
- PROTECTION of life and property is optimised if all buildings are adequately equipped with integrated, active and passive fire protection systems.
- EXTINCTION/EXTINGUISHMENT of fire is possible only if principles of compartmentation are sustained, inhibiting spread of fire and allowing fire fighters time and access to extinguish the fire.

The behaviour and use of fire remain largely unchanged but fire science technologies fortunately enjoy continual improvement, thanks to education, increased awareness, changes in the regulatory climate, improvements in design and materials, control systems and even methods of testing and commissioning of effective fire safety products and systems.

Evolving Lifestyles Influence Smoke Management

In the past, many structures were spacious and naturally ventilated. Modern buildings tend to be compact, multilevel and relatively compact, with noticeably fewer openable windows, creating problems with natural ventilation.

Exacerbating smoke extraction, ceiling heights have changed too. These are typically between 2700mm and 3200mm in an average Southeast Asian home design, compared to much more generous ceiling height of 3500mm and 4500mm found in older structures.

About the Author

Ian R. Holt has worked in the fire protection industry for more than 20 years where he has been involved in the R & D of both materials and end-user systems for use as fire-resisting constructions. He has extensive experience of constructing and performing material and system fire tests in laboratories around the world and to most of the recognised national and international test standards. He has also been involved with a number of Asian countries in the drafting of building code standards related to fire protection.

The luxury of space has been replaced by maximising revenue-generating floor areas, particularly in congested urban areas.

Many features that have helped limit fire and disperse smoke in the past are simply no longer available in modern buildings that paradoxically demand ever greater compartment sizes and the omission of natural construction barriers.

Most modern buildings are required to be more or less airtight in order to maintain comfortable internal climate control conditions.

Conversely, making a building weatherproof — keeping wind and rain out — also means that any smoke or fumes generated by a fire are constrained within the building, further endangering the lives of occupants while also making the work of fire fighters considerably more hazardous.

The Lethal Nature of Smoke

Inhalation of smoke and fumes claims more fatalities than victims succumbing to actual heat and flames.

In very simple terms, smoke is lethal because the process of combustion depletes life-giving air of oxygen, making it increasingly difficult to breathe.

Secondly, many natural and lethal materials produce a potentially lethal cocktail of toxic gases. Plastics for example, certainly generate several kinds of extremely toxic fumes and pollutants.

Toxicity has such a drastic effect on emotional and psychological state of mind that even experienced fire fighters behave uncharacteristically, all too often producing tragic results.

The third and most common cause is that smoke contains unburned particulate matter and floating, airborne condensation. When visibility is obscured, panic can quickly follow, especially when victims find themselves lost in unexpectedly smoke-logged, unfamiliar or overcrowded places.

The Behaviour of Smoke

Smoke is a by-product of combustion. No fire = No smoke.

Smoke results even when only a small volume of heat is generated. Emissions are usually the first visible sign of fire.

Lighter than air, smoke rises and mixes with cooler surrounding air, eventually falling when it is cooled to such a degree that it is denser and heavier than the surrounding air.

In an actual fire scenario, smoke usually fills a room from the ceiling downwards, dropping quickly to floor level, before spreading horizontally to penetrate other parts of the building at a greater rate. This phenomena alone clearly demonstrates the need for sensible compartmentation.

The smoke then forms a layer at the highest level within a fire compartment, clearly illustrated in *Figure 1* on page 98. It should also be noted that smoke generates pressure which makes it difficult to contain within a single fire compartment.

As more smoke is generated the fire becomes hotter, and the layer effect continues to become thicker, completely filling the entire room or space within seconds, as outlined in the following table.

Approximate times for a 3m x 3m fire to fill a building with smoke down to a given distance from floor level.

Building Height	Building area 100m² Distance of smoke from floor			Building area 1000m² Distance of smoke from floor			Building area 10,000m² Distance of smoke from floor		
(m)	3 mtrs	2 mtrs	1.5 mtrs	3 mtrs	2 mtrs	1.5 mtrs	3 mtrs	2 mtrs	1.5 mtrs
	(Time in Seconds)			(Time in Seconds)			(Time in Seconds)		
4 metres	4	11	17	7	18	28	69	184	280
5 metres	7	14	20	12	23	33	115	230	330
6 metres	9	16	22	15	26	36	150	265	360
8 metres	12	19	25	20	31	41	200	310	410
10 metres	14	21	27	23	35	44	230	350	440
15 metres	17	24	30	28	40	49	280	400	495

If smoke is allowed to remain and an adequate supply of air is available, the smoke will reach a temperature where spontaneous combustion can easily occur. This is known as flashover and it dangerously accelerates the rate of fire and smoke spread.

Effective Smoke Control, Management And Extraction

Effective smoke control and management follows more or less the same principles of Prevention, Protection and Extinction applicable to fire.

In smoke control, Prevention means two lines of defence, starting with reduction of the amount of combustibles on the premises.

In contrast with their Stone Age counterparts, modern buildings are conspicuous for an abundance of high risk combustible materials on site. Fire risk is substantially reduced by restricting these materials and by using others, which burn less easily, and do not produce toxic gases and smoke emission.

The next line of defence is to reduce the possibility of ignition through coordinated education and fire prevention campaigns.

An effective smoke control and management system is at the heart of every Protection strategy. This contains and collects smoke before venting it from the building. It is based on the ideas of compartmentation with additional designed-in smoke reservoirs to contain smoke. Openings and windows that naturally vent smoke are essential

If natural ventilation is deemed inadequate, mechanical services and mechanical extraction systems to remove smoke and/or pressurise the relevant compartments to confine smoke to the fire compartment only, must be considered vital.

Due to extreme competition, building cost issues and the nature of business, most developers see few incentives in the value of common fire protection systems. For many, properly designed, installed and maintained smoke control and management systems simply do not compute. Effective, proactive measures must therefore be enforced by legislation and regulatory authorities in most countries.

Where and How for Effective Smoke Extraction Systems?

A number of different measures can be integrated into the design and installation of effective smoke control and management systems.

Passive smoke control and management requirements include:

- Smoke containment — different uses and occupancies within buildings separated (vertically AND horizontally) by fire resisting compartments;
- Openings through compartments sealed with fire stopping or provided with fire dampers or fire doors etc
- Certified fire doors for protecting means of escape, i.e. staircases, protected lobbies and corridors etc;
- Drop down smoke barriers around the perimeter of floor voids to form a smoke reservoir to prevent or delay spillage of smoke into the void and other parts of the building.

It's also interesting to note local regulatory provisions, for example:

Any single compartment within a building to be not greater than specified in the National Building Code of India 2005, clause C-1.8:

"All floors shall be compartmented with area not exceeding 750m2 by a separation wall with 120 minute fire resistance, for floors with sprinklers the area may be increased be 50%. For departmental stores, shopping centres and basements, the area may be reduced to 500 m2 for compartmentation. Where this is not possible, the spacing of the sprinklers shall be suitably reduced."

Smoke Venting

It's a good rule of thumb that buildings for habitation should provide openable windows with an aggregate area not less than 6.25% of the floor area.

Similarly, each basement compartment should have smoke vents connected to open air and have an aggregate area of not less than 0.5% of the floor area.

Active Requirements

Active smoke control and management requirements can be quite varied.

These include but are not necessarily limited to pressurisation of firefighting lobbies and staircases, pressurisation of escape stairways, smoke extraction system and ventilation/air conditioning systems.

Pressurisation of Staircases

There are two main reasons to pressurise staircases.

- To maintain a tenable environment in the staircases for building occupants to safely evacuate during the early stages of a fire incident.
- To provide conditions within the staircase that assist fire and emergency personnel to conduct search and rescue operations and to locate and control the fire.

Design Considerations for Pressurised Staircases

Design pressures, with all doors closed and all over-pressure relief systems in operation, should provide a minimum positive pressure of 50Pa.

There is no maximum pressure although occupants must be able to open fire escape doors. This can vary — depending on type of building and occupant demographics — but generally should not exceed 133N.

The design air flow rate is best based on an average egress velocity of 0.75m/s across three of the largest entry doors, with only one door leaf of the largest exit door open, plus leakage allowance for all the remaining doors.

Entrance doors to staircases also act fire doors. They must be close-fitting to the frame and to the floor. Large gaps are not acceptable. Not surprisingly, all doors must be fully compliant with the relevant criteria of BS 476: Part 22: 1987.

Due to the strategic importance of stairways, any electrical wiring or equipment linked to the building's primary and secondary sources of supply should be fire protected for continuous operation for at least 60 minutes. This ensures continuous functionality of pressurisation systems exposed to fire.

Design standards are available, setting out relevant statistical data and providing calculations for leakage rates. Unfortunately space limitations here preclude in-depth exploration.

Smoke Extraction Systems

Smoke extraction is usually a mechanical ventilation system capable of removing smoke and products of combustion from a designated fire compartment. It also supplies fresh air that maintains a specified smoke free zone below the smoke layer.

Although most are active systems, natural smoke ventilations systems are also available. These do not rely on mechanical assistance but rather on natural buoyancy effects to remove

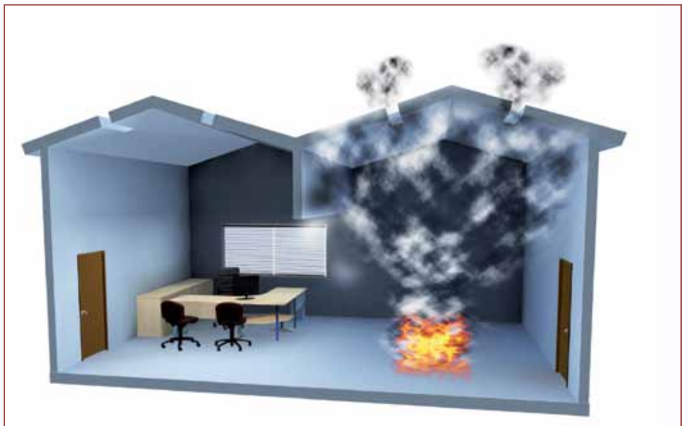

Figure 2 above and Figure 3 alongside show the effects of employing smoke curtains to act as a smoke reservoir.

smoke from the smoke logged area.

To extract smoke effectively, it is necessary to provide an adequate supply of make up air at low level to avoid disturbing the smoke layer and interfering with the smoke free zone. This also has the beneficial effect of supplying air to anyone temporarily overcome by smoke and perhaps lying on the floor.

In the initial stage of a fire, smoke is produced in fairly large volumes. If a fire is starved of air, incomplete combustion will occur and produce a thicker layer of black smoke which in turn reduces the ability of occupants to move to safety. By supplying air, the combustion process is improved, reducing the volume of thick black smoke.

Automatic smoke extraction systems will, if properly maintained, operate immediately on detection of smoke. They also provide a suitable safe haven environment for occupants. Once fire fighters arrive, they can decide whether it is more beneficial to keep the smoke extraction system in operation or shut it down.

There are a range of design guides and international accepted standards that allow the designer, with sufficient knowledge and experience of fire behaviour, to calculate smoke emission rates, direction and range of spread, and smoke volumes produced. From this it is possible to design a suitable system capable of extracting smoke to the desired comfort level.

Ventilation/Air Conditioning systems

The objective is to shut down the ventilation/air conditioning system in the event of a fire, reducing air movement within the affected compartment and preventing the circulation of smoke to other compartments. Smoke allowed to rise and form a layer at ceiling level will not be disturbed by the introduction of air into that smoke layer.

However, not all ventilation/air conditioning systems need to be shut down, such as the following:

- Any mechanical ventilating system forming part of the fire service installation, i.e. pressurisation of staircase and smoke extraction system;
- Individual, self contained or split-type, direct expansion room cooling units not connected to ductwork systems, e.g. window units;
- Minor ventilating systems, e.g. fan coil unit, with all air distribution ductwork contained within the same compartment and the air flow handled by each air distribution ductwork system, not exceeding 1,000 litres/second;
- Exhaust system discharging to open air with extraction point at a high level.

Shut down of the extraction system should ideally be automatic and actuated by smoke detection systems. The smoke detector can be part of the automatic smoke detection and fire alarm system within the compartment but it can also be an individual duct-mounted type which has the capability of shutting down only parts of the systems affected by smoke.

It is essential that the fire performance of all ventilating and smoke extraction ductwork systems is proven by published test reports and shown capable of withstanding the high temperatures of hot gases and smoke from fires. This is particularly critical where ducts or services pass through more than a single compartment. ❖