Natural and Mechanical Smoke Control Systems

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History of Smoke Control

In August 1953, a disastrous fire completely destroyed the Livonia Plant of General Motors in Michigan. It was the largest industrial fire to have occurred at that time and caused damage totalling $55 million. The subsequent investigation (The Armour Report) brought home the importance of specifically designed smoke ventilation in large open plan factory buildings.

As a result, Vauxhall Motors, GM's UK arm, approached Colt to discuss the provision of smoke ventilators for its Luton Plant. A prototype was produced and sent to GM's UK Headquarters for approval. Subsequently, the Luton Plant was equipped with a full system of smoke ventilators and its first stage was completed in October 1956.

In February 1957, Jaguar Cars suffered a serious fire in its Coventry Plant which, in the opinion of Coventry's Fire Chief, would have had its impact greatly reduced if a system of smoke ventilators had been installed.

Colt realised the potential of automatic smoke ventilation, and enthused by the support of the Country's Fire Officers, it funded a detailed research project at the Fire Research Station.

This initiative led to the publication of Fire Research Technical Papers Nos 7 and 10, which set the scientific basis of smoke ventilation design.

Smoke ventilation went on to prove itself time after time, no more dramatically than in the case of the fire which broke out in the Trim Store at Vauxhall Motors in Luton on 14 August 1963.

After the fire Vauxhall's Chief Fire Officer commented "the Ventilators were worth their weight in gold". The smoke ventilation system had allowed Vauxhall's own firemen to tackle the seat of the blaze and prevent it spreading to the assembly line next door where the new Viva was being built.

Reasons for Smoke Control

From the early fires referred to, it can be seen that the main reasons for installing smoke ventilation systems were primarily those associated with property protection. This could be provided by giving fire-fighters relatively unhindered access to the seat of the blaze so that they could put out the fire and by venting the heat to reduce the risk of flashover and of structural collapse of the building.

The motivation to do this came not from reduced Insurance Premiums, but from the desire to maintain production and hence continue to provide a service to customers and thus remain in business. This benefit was borne out when statistics showed that many industrial companies who suffered a major fire not protected by smoke ventilation equipment, went into liquidation.

Because of the benefits that early venting of fires brought to fire fighters themselves, various local Government Acts were soon on the Statute Book prescribing a minimum level of smoke control. This normally took the form of an area of openings in the roof, equal to a proportion of the floor area.

This prescriptive approach, however, meant that some buildings were over protected and some under-protected when comparing the prescribed solution with the solution derived from scientific means given in Fire Papers 7 and 10.

At this stage, whilst Public Life Safety was undoubtedly important, it was not yet a reason in its own right for installation of smoke ventilation (save in theatres and auditoria) but came to the fore in the early Seventies with the advent of the enclosed shopping centre.

Until the emergence of the enclosed shopping centre, most buildings requiring smoke ventilation systems were single storey. The congregation of people in unfamiliar multi-storey surroundings without detailed knowledge of escape routes led to the revision of design guides for Covered Shopping Centres, backed up by research at FRS.

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In summary, the [...] reasons for use of smoke control systems are:

1. Property protection.
2. Employee life safety.
3. Fire fighter life safety.
4. Business security.
5. Public life safety.

Benefits of Smoke Control

Before detailing the undoubted benefits a correctly designed smoke control system will bring, it is important to state that smoke ventilators themselves need to form part of an integrated system to provide the best solutions.

Such an integrated system will include some or all of the following:

1. Sprinklers and suppression systems.
2. Smoke/heat detectors.
3. Smoke curtains/barriers.
4. Inlet air systems.

Correctly integrated and utilised, a smoke control system will bring the following benefits:

1. Early venting, leading to internal temperatures that are below those that cause structural damage.
2. Good means of escape/clear visibility.
3. Tenable atmosphere.
4. Limit high level temperatures/flashover.
5. Prevent unnecessary smoke damage.
6. Prevent unnecessary water damage.
7. Reduce clean up time.
8. Allow clear vision of fire.
9. Aid early extinguishment.
10. Reduce fire costs.

From the building designers viewpoint, providing a performance based smoke control system can enable waivers for both increased compartment and building sizes by allowing increased travel distances.

Types of Smoke Control System

The fires referred to earlier were in single storey structures and all were subsequently fitted with natural ventilators. Natural ventilation was chosen, because at the time:

1. Most ventilators provided summertime ventilation too.
2. Fan/motor technology did not offer reliable alternatives.
3. Installation costs were high for mechanical systems.

However, buildings requiring smoke control systems are now so varied that the need for both natural and powered (mechanical) systems is apparent and technology improvements mean that powered ventilation is no longer disadvantaged.

To make a suitable selection for a building an understanding of the principles of operators and characteristics of the two systems is required. These are described as follows.

Natural Extract Ventilation - Principles

As its name implies, natural ventilation is concerned with the movement of air by natural forces, and in particular, the movement of air through a building.

The flow of air through a building depends on the following factors:

1. The temperature difference between the air and hot gases inside and outside the building.
2. The difference in height between the air inlet and the exhaust vents.
3. Wind speed and direction.

And in case of fire:

4. Convention current rising from the fire.
5. Smoke layer depth.

There are several advantages in using natural ventilation; for day to day ventilation, as well as for smoke ventilation:

1. Silent ventilation.
2. Almost maintenance free.
3. Low running costs (pneumatic or electric).
4. Dual purpose capability - day to day as well as fire.
5. Strong psychological appeal of clear view of sky.
6. Large open area allows heat loss by radiation.
7. Easy installation - lightweight.
   - replace sheets of glass.
   - span the purlins.
   - sit on curbs in flat roof.
8. Aesthetically can blend into the structure.
9. Self regulating-airflow rate increases with heat load.

And in case of fire:

10. Fail safe operation.
11. Extract vents outside the fire zone can provide inlet air.

There are also some disadvantages:

1. Flow conditions can be affected by wind pressure and direction, and local topography is thus important.
2. Natural ventilation can be less effective in the early stages of a fire.

How Natural Extract Ventilation Works

Buoyancy Driven

When air is heated its density is reduced by expansion. It becomes buoyant in relation to the surrounding cooler air (ie. it rises).

In the vicinity of large heat sources such as fires, the rising column will accelerate as it rises, much as a heavy body accelerates when it falls.

The velocity at which an air current rises will depend upon:-

a) The height above the source of heat.

b) The difference in temperature between the hot air and the surrounding air.

As a hot thermal current rises it entrains and mixes with the air through which it is rising. It is being diluted and therefore the difference between its temperature and that of the surrounding air becomes less as it rises higher.

The dilution works against the tendency for the rising air to accelerate and, if carried far enough, would eventually cause the 'hot' column to stop rising and spread horizontally, floating like a raft on top of air slightly cooler than itself.

Therefore, we can use the natural buoyancy of warmed air as the driving force of a natural ventilation system by providing openings in the building at both high and low level. The buoyant warm air will exhaust through the high level openings and will be replaced by cooler ambient air entering through the low level openings.

Combined Buoyancy and Wind Driven

Wind will also create air movement through a building, at a rate varying with the wind speed and direction.

When both mechanisms are operating, they both create pressure differences across the building. Depending upon actual conditions, the pressures created across any aperture may be additive or opposite. The flow rate and direction through any aperture will depend upon the sum of pressure differences across the aperture.

Calculation of the combined effects is complex, even for a simple building, but a reasonable approximation of the total ventilation rate may be made by calculating the flow rates for each mechanism separately and taking the larger of the two figures. Therefore, in our scheme design we normally take the 'worse case' of a still day and design the ventilation system on buoyancy only.

Powered Extract Ventilation - Principles

As the name implies, powered ventilation is concerned with the movement of air by mechanical means, normally an electric motor driven fan.

The use of a mechanical system to move the air results in a number of advantages over natural ventilation.

1. Operation is independent of building height, thermal currents, and wind pressure.
2. Ventilators are normally weather proof in operation.
3. Performance is predictable and repeatable.
4. Ventilators can operate against an external resistance to flow, ie, wind, duct systems.

There are also a number of disadvantages:

1. Airflow through each fan is fixed and cannot be adjusted for conditions except by changing fan speed as the mass flow does not increase when the internal temperature rises.
2. Each fan has a constant electricity demand and for safety reasons needs a maintained supply and fire resistant wiring for the power supply to be maintained throughout the fire. Fans cannot be failsafe.
3. All fans create noise. Attenuation of this noise to an acceptable level can be expensive if the fans are to be used for dual purpose.
4. Powered inlet is not recommended for replacement ventilation, due to early entrainment of air-premature cooling of smoke.
5. Does not permit zone to zone inlet.

How Powered Extract Ventilation Works

When a fan blade rotates it does work on the air around it, creating both a static pressure increase across the fan and air movement, mainly axially along the outlet duct, but with other components, such as swirl, depending upon the fan type. In defining the performance of the fan, we only consider the axial air movement. The other components are by convention ignored as they cannot readily be converted into useful work.

Although air is a compressible fluid, when designing powered ventilation systems, we treat it by convention as an incompressible fluid. This is justifiable as both pressure and temperature changes within most systems are negligible compared to absolute pressure and temperature. The exception to this of course, are Smoke Ventilation Systems where temperature changes are very significant and must be corrected for in design.

Ventilation Equipment Standards

The importance of using correctly designed and tested equipment whether natural or powered is paramount and reference to the following British Standards is recommended:-

1. Natural Smoke and Heat Exhaust Ventilators BS 7346 Pt. 1
2. Powered Smoke and Heat Exhaust Ventilators BS 7346 Pt. 2
3. Smoke Curtains BS 7346 Pt. 3.