National Operational Guidance

Hazard

Flashover, backdraught and fire gas ignition

NFCC National Fire Chiefs Council

Developed and maintained by the NFCC

National Operational Guidance

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Hazard - Flashover, backdraught and fire gas ignition

Hazard Knowledge

Firefighters need an adequate understanding of the development of fires in ventilated and fuel controlled states, so they can recognise any potential fire development conditions. Tactics such as venting and indirect and direct application of water can then be used more effectively and safely.

A flashover is the stage where the total thermal radiation from the fire plume, hot gases and hot compartment boundaries causes all exposed combustible surfaces to pyrolyse (release flammable gases) and ignite when there is adequate ventilation. This sudden and sustained transition of a growing fire to a fully developed fire is known as a flashover.

All firefighters should be aware of the phenomenon termed backdraught. A backdraught is sudden and fierce and may occur at any stage during enclosed firefighting operations. Tragically, this type of event has killed firefighters in the past.

A backdraught is where limited ventilation can lead to a fire in a compartment producing fire gases containing significant proportions of partial combustion products and unburnt pyrolysis products (pyrolysates). If these accumulate, the admission of air when an opening is made to the compartment can lead to a sudden deflagration. This deflagration moving through the compartment and out of the opening is a backdraught. The force of a backdraught has the potential to damage building elements resulting in an unstable structure.

Fire gas ignitions occur when gases from a compartment fire have leaked into an adjacent compartment and mixed with the air within this additional area. This mixture may then fall within the appropriate flammable limits that, if ignited, will create an increase in pressure either with or without explosive force. Where this process occurs it is not necessary for an opening to be opened for such ignition to take place. If an explosive force is experienced, this is commonly termed a 'smoke explosion'. Where an ignition occurs with much less pressure, the term 'flash fire' is more appropriate.

Fire and rescue service personnel should be aware that the above phenomena are not mutually exclusive and all could be present at the same incident.

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Control measure - Understand signs and symptoms of flashover

Control measure knowledge

The previous section provides a scientific description of events that firefighters may encounter but most importantly firefighters should be able recognise and understand the following signs.

Signs of room flashover include:

- High heat conditions or flaming combustion overhead
- The existence of ghosting tongues of flame
- A lack of water droplets falling back to the floor following a short burst fog pattern being directed at the ceiling
- A sudden lowering of the smoke layer (previously referred to as the neutral plane)
- The sound of breaking glass as windows or glazing begin to fail from exposure to heat, possibly causing a visible rise in the smoke layer (previously referred to as the neutral plane)
- A change in smoke issuing from a window (seen from the exterior), with increasing velocity, as if issuing under pressure, and a darkening of smoke colour towards black
- The sudden appearance of light-coloured smoke (pyrolysis) from low-level items being subjected to high heat flux from the hot gas layer

This video demonstrates the phenomenon of flashover.

Where it is necessary to use a combination of direct and indirect firefighting techniques and gas cooling, firefighters should take care at all times to ensure that direct firefighting jets/sprays do not impact negatively on the conditions or on firefighting teams as they move through a structure when deployed for internal firefighting operations.

Summary of key fire behaviour indicators

	Fire behaviour indicator	Hazard information
1	Slow-moving light-coloured smoke issuing from an opening	Early-stage fire development or smoke issuing some distance from the fire compartment

2	Fast-moving darkening smoke issuing from an opening	Impending flashover
3	Heavily darkened or heat-crazed windows	Under-ventilated fire conditions threatening backdraught or smoke explosion
4	Pulsing (in and out) darkened smoke movements around closed doors and windows	Fire development heading towards backdraught
5	Very hot doors or windows (feel with back of the hand)	Under-ventilated fire conditions threatening backdraught, smoke explosion or thermal runaway (flashover)
6	Sudden reversal of smoke issuing from an opening, causing smoke to head back into the compartment/building	The fire is rapidly developing and in need of more oxygen (impending flashover or backdraught), or a gusting wind-driven fire event is occurring
7	A rapid lowering of the smoke layer (previously referred to as the neutral plane)	Impending flashover
8	A rising of the smoke layer (previously referred to as the neutral plane)	A vent opening may have occurred at another location in the compartment/building
9	Turbulence or rising and falling (bouncing) in the smoke layer (previously referred to as the neutral plane)	Rapid fire development may be occurring
10	Heat radiating down from the smoke layer (previously referred to as the neutral plane)	Impending flashover
11	Detached 'ghosting' tongues of flame moving around the fire compartment	Impending flashover
12	Flaming combustion seen near the ceiling or at the smoke interface	Impending flashover

13	Smoke seen issuing from closed windows, doors or roof eaves, as if under pressure	Under-ventilated fire and impending backdraught

Strategic actions

Fire and rescue services should:

- Provide information, instruction and training to ensure all personnel are aware of the indications, safety measures and actions to take for potential flashover events
- Develop tactical guidance and support arrangements to ensure the safety of personnel when dealing with potential flashover events
- Maintain systems and processes to acquire and act on operational information on the occurrence of flashover events at operational incidents
- Share operational information and organisational learning on flashover events with relevant stakeholders

Tactical actions

Incident commanders should:

- Where flashover conditions are suspected, consider direct firefighting techniques
- Consider employing a combination of direct firefighting and gas cooling to control conditions
- Brief crews to carry out self-protection, door entry and compartment firefighting techniques

Control measure - Understand signs and symptoms of backdraught

Control measure knowledge

All firefighters need an adequate understanding of the development of fires in ventilation-controlled and under-ventilated states, so they can recognise potential backdraught conditions. Tactics such as venting and/or the indirect and direct application of water can then be used more effectively and safely.

Signs of backdraught include:

- Fires in tightly closed compartments, especially in energy efficient buildings
- Dark oily deposits and condensation running down the inside of windows
- Windows, doors and door handles that are hot to touch (back of the hand)
- Rattling sounds or smoke pulsating around openings
- Smoke being drawn back into openings and large air movements (draughts) seen heading into openings as the fire searches for more oxygen
- Ghosting tongues of flame seen in the compartment
- Turbulence in the smoke layer (previously referred to as the neutral plane), sometimes seen to 'bounce' up and down
- Whistling and roaring sounds, sometimes denoting high-velocity air flowing in or gases burning off in the compartment, preceding a backdraught event
- A change in fire conditions, with fast-moving smoke seen from the exterior to exit at high velocity, as if under pressure, and a steady darkening of smoke colour

This video demonstrates the phenomenon of backdraught

Strategic actions

Fire and rescue services should:

- Ensure all personnel receive information, instruction and training in the indications, safety measures and actions to take for potential backdraught events
- Develop tactical guidance and support arrangements to ensure the safety of personnel when dealing with potential backdraught events
- Maintain systems and processes to acquire and act on operational information on the occurrence of backdraught events at operational incidents
- Share operational information and organisational learning on backdraught events with relevant stakeholders

Tactical actions

Incident commanders should:

- Where backdraught conditions are suspected, apply media and ventilate before interior deployment

Control measure - Gas cooling

Control measure knowledge

Gas cooling is the approach of directing variable bursts or 'sweeps' of water-fog into the hot gas layer

Essentially, this involves the distribution of finely divided water droplets into the hot gas layer using a short 'burst and pause' (or pulsing) action at the branch nozzle as a means of reducing the temperature in the fire gases to a point where the threat of an impending flashover is limited or avoided. This technique can also be used where the hot gas layer is igniting and threatening to develop into a full compartmental flashover.

In either situation, an adequate flow rate (litres per minute) and an optimum spray pattern must be available at the branch.

It is extremely important to understand that gas cooling is predominantly a means of reducing the likelihood of flashover and should not be considered as a technique for dealing with either a fast developing or post-flashover fire. In such cases a solid stream (jet) directed at the fuel base becomes the dominant technique for fire suppression.

To fully understand the effects of gas cooling, it is essential to understand what the intervention is trying to control. Once it is understood that combustion can take place within the fire gases and how and why it occurs, firefighters are more prepared to intervene effectively.

Combustion is a chemical reaction that results in heat and light being produced. The fact that it is a chemical reaction means that new chemical substances are generated. Many chemical reactions generate heat but critically a combustion reaction will also produce light. The elements essential to the initiation of a combustion reaction are sometimes described in terms of the fire triangle; an ignition source or sufficient heat together with fuel and a supporter of combustion all have to be present.

Supporter of combustion

In its simplest form, combustion is a sequence of exothermic oxidation reactions, which means that energy (heat and light) is generated as the fuel source is broken down and an oxidant is added. This oxidant is the supporter of combustion. Under normal circumstances, the oxidant is most likely to be the oxygen in air.

A number of different factors can have a significant impact on the danger and intensity of a reaction within the fire gases:

- Stoichiometric mixture (ideal mixture)
- Flammable limits
- Flash point
- Fire point
- Auto-ignition temperature
- Ventilation

Intervention

When water evaporates it expands to water vapour (steam); this can be anywhere within the ratio range of 1,700:1 and 3,400:1 depending on the temperature. When restricted to a compartment, this can have significant benefits but it also carries some risks, for example; the expansion can lead to a significant increase in pressure in the compartment.

However, when properly applied, the contraction of the fire gases can be greater than the amount of water vapour formed. The result should be a noticeable rise in the smoke layer (previously referred to as the neutral plane) in the fire compartment. This benefits effective application as the overpressure area will rise with the smoke layer (previously referred to as the neutral plane); firefighters should not be subjected to a wave of hot fire gases and visibility will improve.

Incident commanders should be aware of:

- The most appropriate firefighting media, for example, water and foam
- The most appropriate weight of intervention (litres per minute), for example, firefighting jets and hose reels
- The most appropriate method of firefighting, for example, smothering, starvation and cooling (indirect or direct cooling)
- Contingency plans that are formulated, implemented and communicated to ensure the safety of committed personnel in the risk area, for example, committing a supporting firefighting team

Strategic actions

Fire and rescue services should:

- Provide appropriate equipment and media to enable effective gas cooling tactics to be implemented
- Develop tactical guidance and support arrangements for the hazards that may be encountered and the actions to be taken when considering gas cooling tactics for fires in buildings

Tactical actions

Incident commanders should:

- Use appropriate gas cooling techniques and equipment for the internal conditions identified

Control measure - Tactical ventilation

Control measure knowledge

Ventilation is one factor that will need to be considered as part of the overall incident plan. When planned and performed correctly, ventilation can save lives, improve firefighting conditions, and reduce damage to property.

Ventilation can be defined as:

'The removal of heated air, smoke or other airborne contaminants from a structure or other location and their replacement with a supply of cooler, cleaner air'

Ventilation is something that will occur naturally as part of the fire development and decay process. It will have an impact on the development of a fire before and after the-arrival of the fire and rescue service. However, ventilation is also a tool that should be considered as part of any overall firefighting strategy.

Ventilation can be performed after the fire has been extinguished or controlled, to clear residual smoke and heat from buildings or structures.

The benefits of controlled and co-ordinated tactical ventilation should be balanced against the hazards associated with accelerated fire growth and the introduction of oxygen into under-ventilated fires in buildings.

If applied and managed correctly, tactical ventilation can provide beneficial effects to any firefighting strategy by:

- Replenishing oxygen and reducing carbon monoxide levels
- Controlling temperature and humidity
- Removing moisture, dust, and other airborne contaminants
- Improving visibility and aiding navigation

Tactical ventilation is a planned intervention that requires co-ordination and control, to open up buildings and structures to release the products of combustion and can be defined as:

'The planned and systematic removal of heat and smoke from the structure on fire and their replacement with a supply of fresher air to allow other firefighting priorities.'

As part of an overall firefighting strategy, incident commanders should always have a clear and informed objective before commencing any form of ventilation activity. This will ensure that the full range of benefits of ventilating can be realised including:

- Improving conditions for the survivability of people in the building
- Improving conditions for personnel to enter and search for or rescue people
- Reducing the potential for rapid fire development, including flashover, backdraught, or fire gas ignition
- Restricting fire and smoke damage to property

In broad terms ventilation can be separated into two types:

Natural ventilation – This is the process of supplying and removing air through a structure or space without using mechanical systems. In firefighting terms, this refers to managing the flow of air (flow path) into and out of a structure or location, using the prevailing atmospheric conditions, such as wind strength, speed, and direction, via structural openings, such as windows, doors, and vents, to clear any smoke or hot fire gases.

Forced ventilation – This is the process of using fans, blowers or other mechanical means or devices to assist in creating, redirecting, and managing the air flow (flow path) into and out of a structure or location, so that heat, smoke and fire gases are forced out.

In both instances, additional factors related to climatic and atmospheric conditions, such as temperature and pressure, will have an impact on the relative success of any ventilation activity.

Type of forced ventilation	Considerations

Positive pressure ventilation (PPV)	This is achieved by forcing air into a building using a fan. Using the fan will increase the pressure inside the building relative to atmospheric pressure. The most appropriate tactic for PPV will depend on whether the inlet vent is also being used for access and egress. If the fan has to be placed further back because of operations at the entrance to a building, the fan may be less effective. The effectiveness of PPV will depend on a range of factors, including the: • Wind direction and strength • Size, type, and number of fans • Proportion of the fan's air that enters the building (fan performance) • Relative sizes of inlet and outlet vents • Size of the room to be cleared • Temperature of the fire gases or smoke in the building Personnel should always be aware of the potential risk of increasing the level of carbon monoxide (CO) in other areas of a building when ventilating, either when directing or forcing fire gases through a building or, in particular, if using petrol-driven PPV fans. Personnel should ensure that fans are positioned to prevent any build-up of CO. Consideration should be given to monitoring the levels of carbon monoxide.
Negative pressure ventilation (NPV)	NPV refers to extracting the hot air and gases from the outlet vent. This will reduce the pressure inside the building relative to atmospheric pressure. This can be achieved by using fans or water sprays.
Heating, ventilation and air conditioning (HVAC) and fire-engineered systems	HVAC systems are often engineered into buildings so that, in the event of a fire, they can be operated to ventilate public areas and support safe evacuation, as well as improve conditions for personnel. These systems are normally automatic but can also be operated by a manual override.

Powered smoke and heat exhaust systems	These systems are generally operated automatically and are likely to be operating before the arrival of the fire and rescue service. They can also be operated manually but this will need careful consideration by incident commanders as part of the firefighting and ventilation tactical strategy.

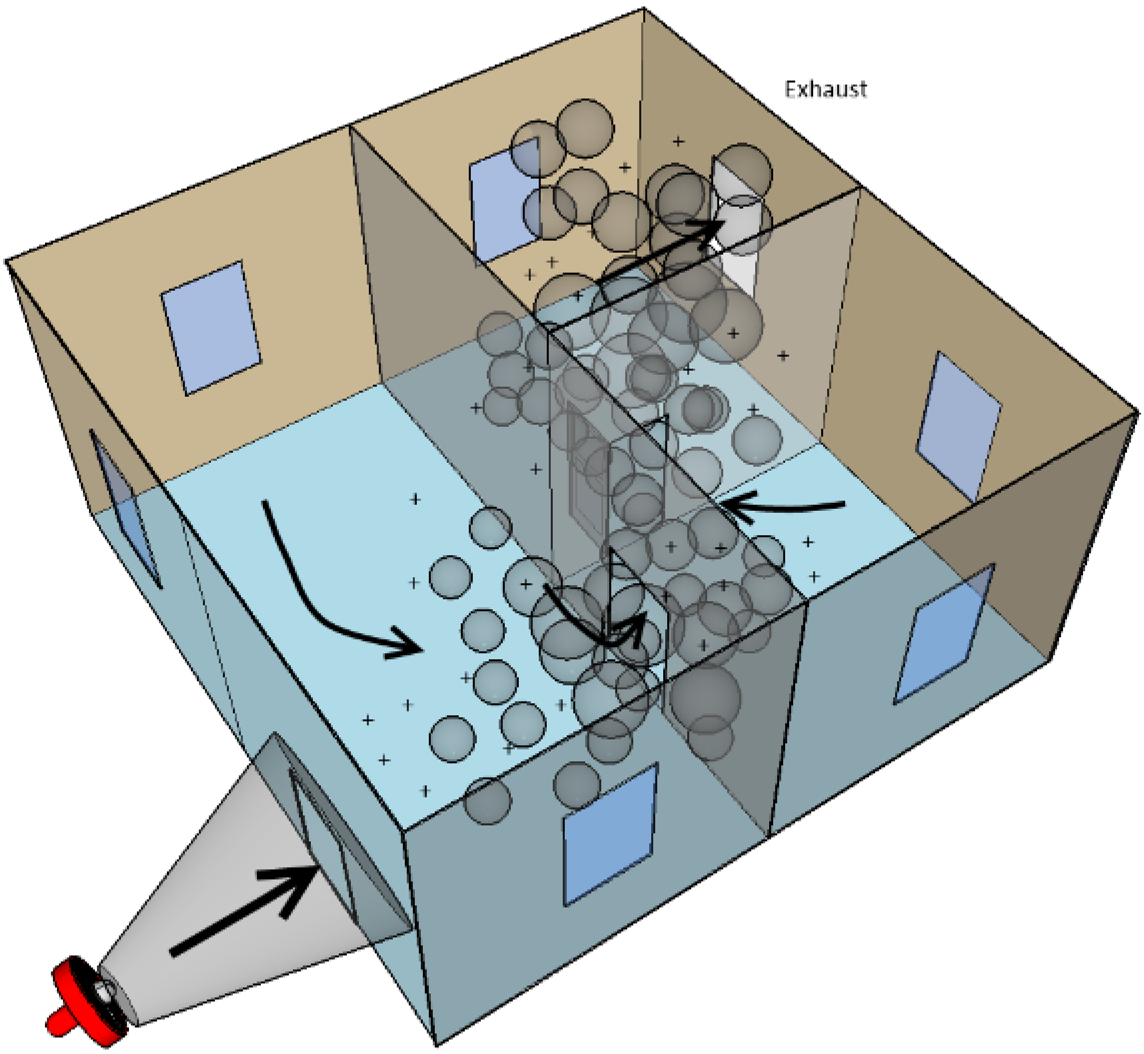

Figure 7: Positive pressure ventilation

Source: Building Research Establishment

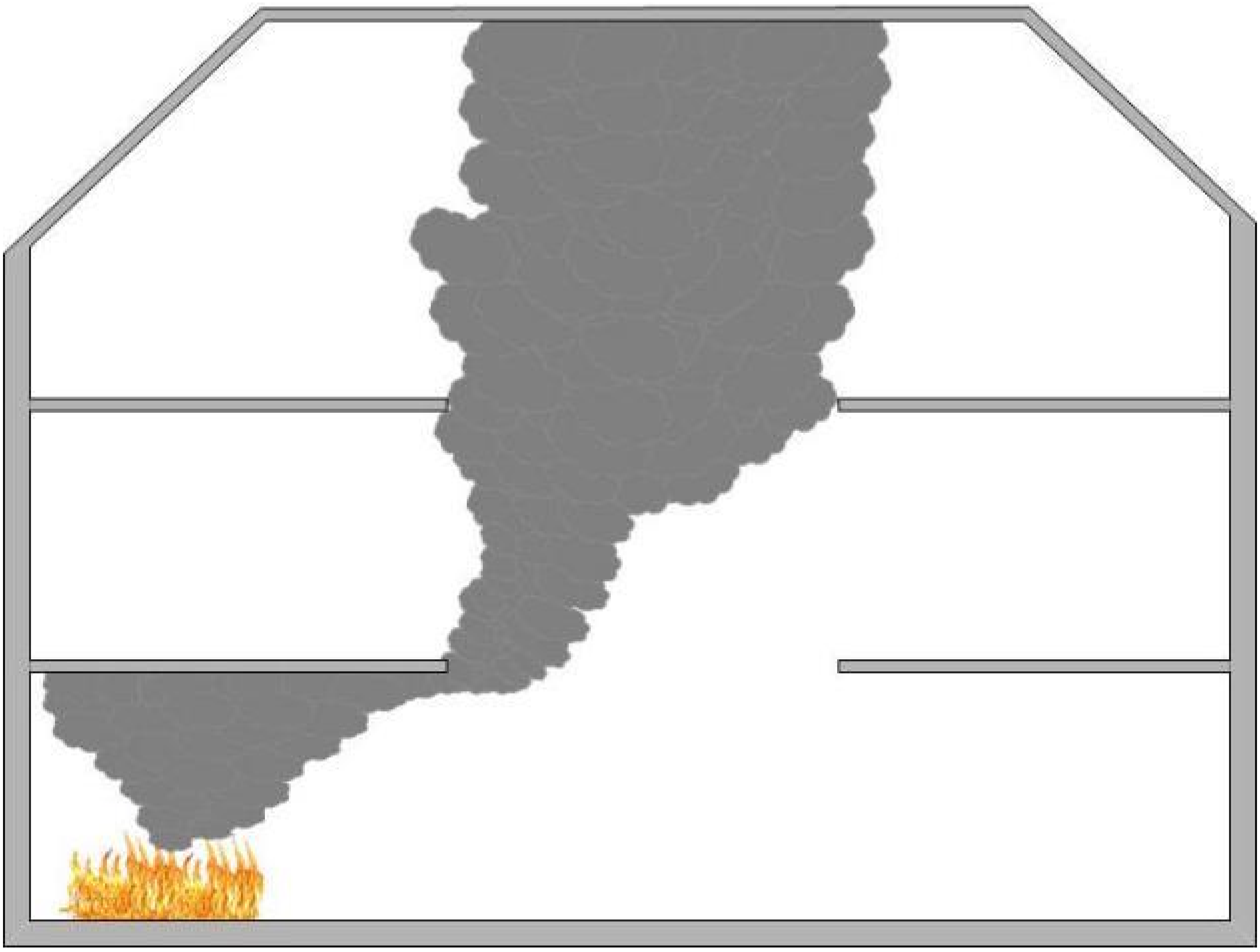

Figure 8: Heating, ventilation and air conditioning system in an atrium

Source: Building Research Establishment

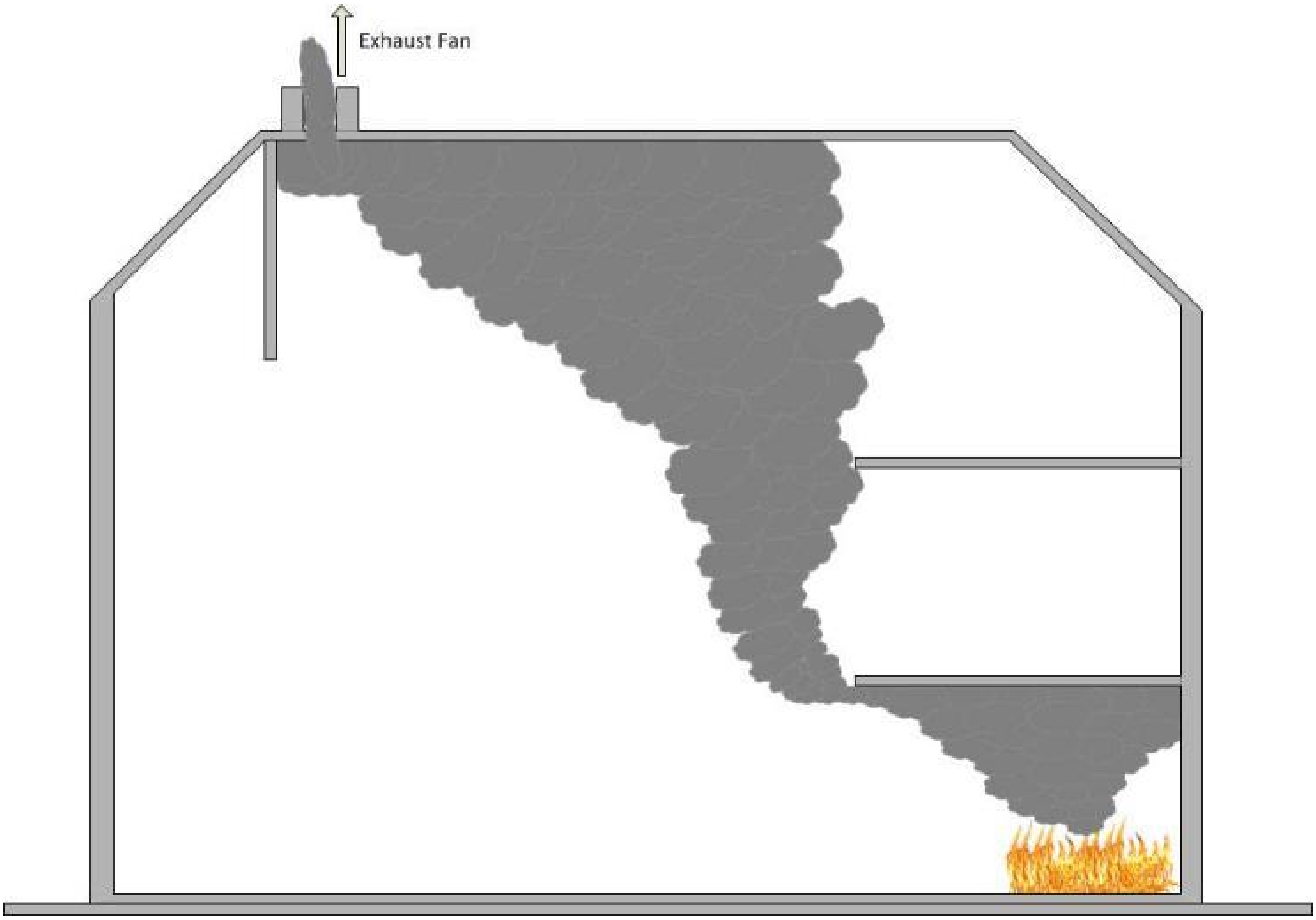

Figure 9: Heating, ventilation and air conditioning system

Source: Building Research Establishment

The success of any ventilation plan or strategy will to a greater degree depend on the techniques employed to effectively plan and manage:

- Where air will enter a building, structure, or location (inlet vent)
- Where hot gases and smoke will leave a building, structure, or location (outlet vent)
- The route that they will take (flow path)

Personnel should be aware that creating a vent in a previously under-ventilated area can increase the risk of creating a backdraught.

In broad terms, two techniques may be considered, which present both barriers and enablers to the ventilation process:

- Vertical (or top) ventilation: Making an opening at high level to take advantage of the natural characteristics of hot gases and smoke, for example, buoyancy, allowing them to escape
- Horizontal (or cross) ventilation: Making openings in external walls, using doors and windows

to aid the removal of hot fire gases and smoke

Both techniques can be employed using natural or forced methods of ventilation.

Locating the fire

Locating a fire is critical in formulating a robust, safe, and effective ventilation strategy. The following factors should be considered:

- The location of the fire may be evident on arrival, but it is possible that the fire has developed in hidden areas or not be visible at all. It is vital to identify any routes of potential fire development and any flow paths that may be created, considering the impact on firefighting operations and their potential to create or intensify undetected fire development.
- In the majority of incidents, ventilation should only be used when a fire has been located and the likely impact of ventilation has been assessed. If the seat of fire is difficult to locate, tactical ventilation can be used to clear adjacent rooms, corridors, or staircases to:
  - Help identify the seat of fire
  - Maintain safe access and egress routes to and from a hazard area
  - Reduce the potential of phenomena, such as fire gas ignition
- Monitoring systems, such as automatic fire detection systems or closed-circuit television (CCTV), can be used to identify the seat of fire
- Thermal scanning and thermal imaging equipment may help to identify the seat of the fire

Ventilation strategy

The ventilation strategy implemented at any fire will be affected by a range of factors but in broad terms, the strategy should initially be based around either one or a combination of the following:

- Offensive ventilation: Close to the fire to have a direct effect on the fire itself, to limit firespread and to make conditions safer for personnel
- Defensive ventilation: Away from the fire, or after the fire, to remove heat and smoke, particularly to improve access and escape routes and to control flow paths to areas of the building unaffected by the fire
- Control flow paths and anti-ventilation: Planned and co-ordinated confinement of fire gases and reduction of air flows into the fire, to prevent the fire and smoke from spreading, protecting access and egress, and limiting oxygen to reduce fire development

When planning and developing any ventilation strategy, it is vital that due consideration be given to the impact that any unplanned or poorly considered ventilation can have. The safety of personnel and people in the building is vital when forming a ventilation strategy. The impact and effects of ventilation and fire conditions should be constantly monitored and reassessed and, if appropriate, tactics should be adjusted.

The benefits and effects of any planned ventilation should be considered together with the:

- Location of the fire
- Location of people and protection of escape routes
- Access and egress of personnel
- Internal and external layout and design; including any fire-engineered solutions
- Likely fire dynamics and development
- Presence of natural ventilation, including local topography that may affect wind effects and pressure differentials
- Effect of heating, ventilation, and air conditioning (HVAC) systems incorporating smoke control, sprinklers, and design features, such as atriums and smoke curtains
- Impact of natural fire phenomena on fire development, for example Coandă, stack, trench or piston effects or wind-driven fire
- Potential for a dust explosion

Ventilation strategies should be reassessed continuously to ensure that safety is maintained and that any planned ventilation activities are supporting the overall incident plan, considering relevant factors including:

- Wind direction and strength
- Whether ventilation is appropriate and the correct ventilation tactics
- Whether personnel should be withdrawn while ventilation takes place
- Location of outlet vents, which should ideally be downwind and at a high level
- Whether external covering jets are in place
- Whether an inlet vent is created and kept clear, ideally as soon as possible following creation of the outlet vent
- The requirement to constantly monitor the effects of ventilation

Post-fire considerations

Consider:

- Using ventilation post-fire to assist in clearing any smoke and other airborne particles as part of the salvage activities
- Ensuring that bullseyes (hot spots) are identified and fully extinguished before the fire scene is handed over; turning over and damping down will assist in identifying such areas
- Advising the fire investigation officer or other agencies of any ventilation activities undertaken during firefighting operations, as this may have some relevance to the subsequent fire investigation in respect of fire development and post-fire indications; for more information refer to Operations – Preserve evidence for investigations

Strategic actions

Fire and rescue services should:

- Consider providing means of controlling ventilation at incidents
- Consider arrangements for providing forced ventilation at incidents
- Ensure any equipment provided for forced ventilation is maintained and used according to the instructions of the manufacturer

Tactical actions

Incident commanders should:

- Ensure covering jets are in place before creating exhaust vents
- Consider the effect of firefighting tactics and the flow path of smoke on access and egress
- Consider limiting ventilation to control fire development
- Develop, implement, and maintain a ventilation strategy
- Monitor the effects of the ventilation strategy and adjust if necessary
- Consider using tactical ventilation to improve conditions and maintain access and egress routes
- Ensure any fire and rescue service equipment deployed for forced ventilation is used appropriately
- Consider gas monitoring, including the levels of carbon monoxide, when using positive pressure ventilation

Control measure - Personal protective equipment (PPE): Fires and firefighting

Control measure knowledge

Personal protective equipment (PPE) for firefighting purposes is a key requirement for fire and rescue services. Services should provide PPE for firefighting that conforms to BS EN 469:2005 Protective clothing for firefighters — Performance requirements for protective clothing for firefighting.

Fire service personnel should be aware that in the event of flashover, structural firefighting PPE on its own is unlikely to provide adequate protection to the wearer.

Strategic actions

Fire and rescue services should:

- Ensure that the types of personal protective equipment (PPE) used comply with relevant standards and meet the requirements of their risk assessment for fires and firefighting

Tactical actions

Incident commanders should:

- Ensure that Firefighting PPE is worn in accordance with service risk assessment, procedures and training
- Consider the need for additional PPE where compatible with firefighting PPE (e.g. high visibility, eye protection)

Control measure - Respiratory protective equipment

Control measure knowledge

Respiratory protective equipment (RPE) is a type of personal protective equipment designed to protect the wearer from breathing in harmful substances, or from oxygen-deficient atmospheres, when other controls are either not possible or are insufficient on their own.

The use of RPE allows efficient, effective and safe working practices to be adopted at incidents of all sizes and type where an irrespirable atmosphere presents a hazard to personnel. There are two main types of RPE; respirators and breathing apparatus (BA).

Further information about the use of RPE can be found in the British Standards Institution (BSI) publication, ISO/TS 16975-1:2016 Respiratory protective devices – Selection, use and maintenance: Establishing and implementing a respiratory protective device programme.

Respirators

Respirators are filtering devices that remove contaminants from the air being breathed in; non-powered respirators rely on the wearer breathing to draw air through the filter. Respirators are not suitable for use in oxygen-deficient atmospheres.

Breathing apparatus

Breathing apparatus (BA) requires a supply of breathing-quality air from an independent source such as an air cylinder. Breathing apparatus (BA) enables firefighters to breathe safely in otherwise irrespirable atmospheres. The use of BA as a control measures is likely to be applied as part of the incident plan for any incident involving:

- Smoke and fire gases
- Working in confined spaces
- Hazardous materials including:
  - Asphyxiants
  - Dusts
  - Toxic, flammable or explosive substances

Airlines

Airline equipment supplies air to the wearer from a cylinder that is located remotely from them. The technical procedures for the specific airline equipment in use should be followed. Airline equipment should only be used by trained and competent personnel. It be appropriately used and maintained, to avoid the air supply to BA wearers being compromised.

Following an appropriate risk assessment, it may be decided to use airline equipment to provide breathing apparatus capability. Its use may be appropriate:

- If an extended air supply to self-contained BA wearers is required
- If use of self-contained BA is unsuitable
- At incidents in the open, where airlines are used to provide a breathable atmosphere without the weight of a self-contained BA set
- For specialist operations that involve restricted access

Although the use of airline equipment reduces the overall weight carried by a BA wearer and can provide a limitless supply of air, the physiological limitations of the BA wearer should be considered when airline equipment is used.

Face mask fit testing

If RPE is used, it must be able to provide adequate protection for individual wearers; RPE cannot protect the wearer if it leaks.

Face mask fit testing is a method of checking that a tight-fitting face piece matches the wearer's facial features and seals adequately to their face. A face mask fit test should be carried out as part of the initial selection of the RPE and it is good practice to ensure testing is repeated on a regular basis. Further detail on face mask fit testing is provided in the Breathing apparatus foundation material.

Further information is contained in the Health and Safety Executive's publications:

- Respiratory protective equipment at work: A practical guide (HSG53)
- Guidance on respiratory protective equipment (RPE) fit testing (INDG479)

Maintenance

Maintenance is a requirement for all RPE, except for disposable (single use) RPE, and should be carried out by properly trained personnel. Thorough maintenance, examination and tests should be carried out at regular intervals in accordance with the manufacturer's instructions.

Breathing apparatus foundation material

The breathing apparatus foundation material provides the procedures underpinning the planning, use, and command and control of BA. It should also assist fire and rescue services with:

- Developing safe systems of work when deploying BA
- Managing BA operations
- Testing and maintenance of BA equipment
- Defining roles and responsibilities for BA
- Developing BA training
- Readiness of BA wearers
- Pre-planning for intraoperability and interoperability

For more information refer to The Foundation for breathing apparatus.

Strategic actions

Fire and rescue services must:

- Provide personnel with suitable and appropriate RPE that fits and protects the wearer
- Ensure that personal RPE worn simultaneously is compatible and does not negatively impact other safety measures

Fire and rescue services should:

- Specify the type of RPE required for hazards identified through risk assessments and communicate this information to personnel
- Have suitable arrangements for the provision, testing and maintenance of respiratory protective equipment
- Ensure personnel regularly undertake face mask fit testing of RPE

Tactical actions

Incident commanders should:

- Carry out a risk assessment before deploying personnel wearing RPE
- Ensure personnel wear the appropriate type of RPE
- Consider the use of airline equipment