Fire Safety in Buildings
Questions and Answers

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CMIOSH

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Preface

Fire Safety in Buildings: Questions and Answers has been written as a practical guide to the wide-ranging subject of fire safety.

This book follows the very successful format of practical questions and answers found in *CDM 2015 Questions and Answers: A practical approach to design, safety and wellbeing* (2021), *Health and Safety: Questions and Answers: A Practical Approach* (2016) and *Risk Assessments: Questions and Answers: A Practical Approach* (2017).

The book is aimed at a wide readership from clients, employers, developers, architects, construction professionals, property managers, students and anyone who has responsibility for buildings where people are employed, live or visit. It is a quick 'pocket book' guide to the key provisions of fire safety law and is intended to give an overview of fire safety and to direct the reader to more detailed information where appropriate.

It is a practical guide to the subject of fire safety. It is not a detailed technical handbook of fire safety engineering, fire safety law nor fire safety science.

Fire safety has always been an important topic. Sadly, changes to the law and regulatory standards only occur when major incidents happen. There have been some catastrophic incidents in recent years and the law of fire safety has changed.

Prior to the Regulatory Reform (Fire Safety) Order 2005 (RRO), fire safety law was spread over 80 acts of parliament and regulations. The RRO consolidated the laws and is still the basis of substantial fire safety law today.

The Grenfell Tower fire in 2017 heralded new fire safety and building laws governing high-rise residential buildings. In addition, amendments have been made to the RRO and new regulations have been introduced to strengthen fire safety.

This book covers those new requirements for high-rise buildings and explores the new duties placed on responsible persons and others involved in the design, construction and management of buildings.

Each chapter of this book is designed to stand alone and to be used as a reference guide to provide the reader with quick access to pragmatic information on how to comply with fire safety law and to understand the key principles of fire safety and prevention. Given the interconnections between the subject areas, some topics are mentioned in more than one chapter.

Fire safety is about prevention – preventing fire from starting, fires from spreading and fire preventing escaping from buildings and other structures.

Often, fires become catastrophic because of a failure in the first line of defence. There is then a knock-on effect as other precautionary standards fail. Risk is interconnected. An error, oversight or event in one area may trigger an event in another area. Grenfell Tower took the lives of over 70 people because, amongst other reasons, a fire started, it was not contained, it spread to flammable materials, it breached compartmentation, it took advantage of poor construction methods, escape routes were inadequate and residents failed to know what to do to protect their own and others' safety.

Failures by building owners, building managers, designers, contractors, residents and the fire service.

Knowledge is important. It is hoped that the contents of this book will add to the reader's knowledge of fire safety and provide them with a thirst to seek additional knowledge on the subject of fire safety.

Pat Perry CMIOSH
May 2023

About the author

Pat Perry CMIOSH qualified as an environmental health officer in 1978 and spent the early years of her career in local government in the UK enforcing environmental health regulations, particularly health and safety law, which became her passion.

Pat left local government and established a very successful Environmental Health Consultancy which was subsequently integrated into a large regulatory compliance group.

She has extensive knowledge of the retail, commercial and hospitality sectors and has served on various working parties on both health and safety and food safety issues. Pat regularly contributes to professional journals and appears as a speaker at related conferences and seminars. Her previous publications include *CDM 2015 Questions and Answers*, *Health and Safety: Questions and Answers*, *Risk Assessments: Questions and Answers* and *Fire Safety: A Practical Approach: Questions and Answers*.

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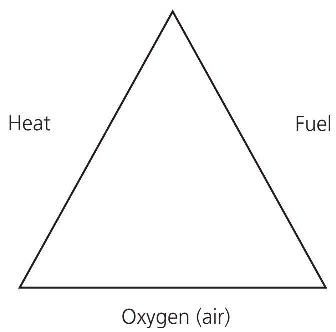
Chapter 1
Introduction to the principles of fire

What is fire?
A standard definition of fire is

> a process of combustion characterised by the emission of heat accompanied by smoke or flame.

Mostly, when the term fire is referred to, we usually mean the uncontrolled development of fire not a controlled fire such as happens in furnaces and so on. Fire is often unwanted, unexpected, disastrous and costly, both in terms of human life and business costs.

What causes a fire?
There is an inter-relationship between heat, fuel and oxygen. This is known as the 'Fire Triangle'.



Fire is the result of a chemical reaction between a fuel and oxygen. Fire cannot occur if one of the key components is missing – that is, eliminate either the heat, the fuel or oxygen.

This is the principle under which fires are fought

- drench with water thereby removing the heat
- smother with inert material – for example, sand to deprive the fire of oxygen
- remove the fuel – for example, separate burning material from other materials.

What are the four stages of fire?

It is generally accepted that the four stages of fire are

- ignition/incipient
- growth
- fully developed
- decay.

Ignition/incipient

This first stage begins when heat, oxygen and a fuel source combine and have a chemical reaction resulting in fire. This is usually represented by a very small fire, which often goes out on its own before the following stages are reached. Recognising a fire in this stage provides your best chance at suppression or escape.

Growth

The growth stage is where the structure's fire load and oxygen are used as fuel for the fire. There are numerous factors affecting the growth stage, including where the fire started, what combustibles are near it, ceiling height and the potential for 'thermal layering'. It is during this shortest of the four stages when a deadly 'flashover' can occur, potentially trapping, injuring or killing building users, residents and firefighters.

Fully developed

When the growth stage has reached its maximum and all combustible materials have been ignited, a fire is considered fully developed. This is the hottest phase of a fire and the most dangerous for anybody trapped within the building.

Decay

Usually the longest stage of a fire, the decay stage is characterised with a significant decrease in oxygen or fuel putting an end to the fire. Two common dangers exist during this stage

- existence of non-flaming combustibles can potentially start a new fire if not fully extinguished
- danger of a backdraught when oxygen is reintroduced to a volatile, confined space.

Is it the actual material that burns?

In many cases it is the body of the material that burns, for example, furnishings, wood, clothing and construction materials, but in many instances it is also the gaseous vapours that are given off during the burning process re-igniting and causing the fire to develop.

How does fire spread?

Fire generally spreads in six ways.

Direct contact

Materials adjacent to each other ignite through a domino-type effect.

Radiation

When a fire is strong enough, it can emit sufficient radiated heat to ignite combustible materials that are not in direct contact with it. This process is similar to sunlight directed through a lens onto dry paper or straw – the paper or straw will eventually ignite.

Conduction

Heat is transferred through materials that ignite adjacent materials that are in contact. A wall may get so hot that it ignites the surface coverings on the other side. Handles on fire doors often get so hot that they cannot be touched, thereby confirming a fire inside the room with very high temperatures.

Convection

Currents of air rise above a fire and may concentrate at an upper limit – for example, beneath a ceiling. When substantial hot gas and smoke has accumulated, the temperature at the upper level rises to such an extent that it can set materials on fire, thereby causing a secondary fire and possibly a flashover (see below).

Flashover

The hot air and gases accumulated by convection may eventually start to descend to a lower level through radiation and, at sufficiently high temperatures (around 500°C), may make combustible materials start emitting gases that spontaneously ignite.

Backdraught

Fire in a room with little oxygen will start to decay but, if a door opens or glass in a window shatters, the sudden inflow of air/oxygen can reignite the fire with explosive effect.

How quickly does fire spread?

Fire development is often described as exponential. In simple terms, fire tends to double its size at regular intervals (sometimes as quickly as every 30 s) causing everything in a room to burn in as little as three minutes.

Fires in buildings develop differently to fires outdoors – for example, bonfires and the speed at which they spread takes most people by surprise.

The rate of fire spread within a building will depend on

- the degree of fire separation (fire compartmentation) that exists
- the combustibility of the materials present (some materials such as soft furnishings may burn at faster rates than others)
- the presence of air/oxygen (draughts and convection currents can fuel fires to burn more rapidly)
- the presence of active firefighting systems to detect and suppress fires.

It is said that the average domestic sitting room with usual equipment of TV/video and furnishings will be totally alight in about 4 min.

Often, members of the public fail to comprehend the speed at which fires develop and do not believe that they must evacuate or do anything in relation to their safety.

The major fires in Woolworths, Manchester in 1979, the Dublin Disco in 1981 and the Bradford fire in 1985 are all examples of a rapidly spreading fire and people delaying in evacuating the building.

What is a wind-driven fire?

A wind-driven fire may be described as one where external wind or ventilation-forced pressure causes strong air movements, affecting the severity of fire spread. It is often used to describe fires that may also be referred to as forced-draft, wind-assisted, force-vented or blowtorched.

Wind-driven fires can occur at ground floor level. High-rise buildings, by their very nature, create abnormal, unpredictable air flows and wind speed generally increases with height.

Fires can be affected by wind pressure and high-velocity air movements. The impact can be experienced in open fires or wildfires, while in buildings the greatest impact is usually experienced with fires in tall buildings. If windows are open, or have failed through exposure to heat, external wind can affect the speed and direction of fire development.

In all instances where there is an oversupply of oxygen then

- the fuel will burn at a higher temperature
- the fuel will burn more quickly
- the fuel liberates energy at a higher rate.

By definition, a higher energy fire will be harder to put out, usually requiring more water and some form of direct attack.

The Grenfell Tower fire was fatal for so many people because of external spread of flame. What does this mean?

External fire spread may develop if the fire breaches the external envelope of the building. This may be a result of external window glazing or wall panels failing, or by way of open windows. External fire spread may compromise compartments above or below the fire floor, irrespective of the materials used in construction.

A fire can spread from combustible material to combustible material or be spread by combustible gases. Flames may take hold in external cladding, as in Grenfell Tower, and travel rapidly across the material. Cavities may exist as part of a cladding system or facade assembly. Cavities may also be created by damage, delamination or movement. Fire may spread within cavities, with flames becoming elongated due to the restricted space. The flame length may increase regardless of the materials used in construction, resulting in rapid, hidden fire spread if appropriate fire barriers are not present.

Fire travels up the building in between the external cladding, travelling along the cavities and transferring to new combustible material.

Why is smoke such a hazard?

Smoke is defined as

> the product of combustion, consisting of fine particles of carbon and other substances carried by hot gases and air.

Smoke spreads easily around a building, and scientifically it is proved that smoke moves faster than people can walk.

Smoke contains particulate matter, and this makes the 'flame' opaque – so you can't see through it. Therefore, it is a hazard because it cuts down visibility.

Smoke also contains the 'products of combustion', depending on what materials are burning, and contains poisonous gases and toxic fumes. Common gases produced during combustion include carbon monoxide and hydrogen cyanide.

Carbon monoxide, an odourless colourless gas, is lethal and kills within minutes at high concentrations. Most people caught in a fire die from breathing in carbon monoxide gas.

Before inhalation of the smoke becomes lethal it can cause severe respiratory irritation and breathing becomes difficult.

Carbon monoxide, in non-lethal concentrations, will affect a person's ability to concentrate. Combine a lack of concentration with visual difficulty, and quickly people become disorientated in a smoke-filled environment. This is one of the reasons why fire exit and emergency signage must be clear and properly lit.

People are reluctant to walk through smoke even though it would lead them to safety. People therefore become trapped, perhaps by their own making, and as a result suffer injury or death.

What does the term 'flashover' mean?

Flashover is defined as

> a sudden transition to a state of total surface involvement in a fire of combustible materials within a compartment.

After the first item in an enclosure is ignited, hot gases rise vertically in a narrow plume into which air is pulled from the natural ventilation in the room, so increasing the volume of the smoke and gases.

As smoke reaches the ceiling it spreads out in all directions and begins to form a thickening layer below the ceiling.

As the fire grows, the flames reach the ceiling and are deflected horizontally across the surface of the ceiling. Radiation is so strong that flame will spread over all combustible surfaces and items over a relatively large area, reaching temperatures at which they spontaneously burst into flames.

At flashover, virtually all items in the room are alight because the room temperature exceeds 1000°C and survival of occupants in the room is impossible.

What does the term 'backdraught' mean?

Backdraught is defined as

> a phenomenon in which a fire that has consumed all available oxygen suddenly explodes when more oxygen is made available, typically because a door or window has been opened.

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. Pyrolysis is the chemical decomposition of organic (carbon-based) materials through the application of heat. If these products accumulate, the admission of air when an opening is made to the compartment can lead to a sudden deflagration (to burn rapidly with intense heat and sparks being given off). 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.

Case study: King's Cross fire (1988): Flashover

The fire brigade was called at 19:36 to a fire on an escalator at King's Cross Underground station. The fire seemed controllable and in one location. Passengers were evacuated up escalators by way of the ticketing hall. Tubes were still stopping and passengers were still embarking and disembarking.

At 19:45 the fire suddenly erupted up into the ticket hall. It was described as 'flashing, with searing heat and thick smoke through the ticket hall'. And 'within seconds, the area was in total darkness and the conditions had become unbearable'. Escalators carried passengers up into the ticket hall and certain death.

The cause of the fire was established to be discarded smoking material that fell through a wooden escalator onto grease and debris that was very combustible.

As a result of the King's Cross fire, 31 people died and many more suffered catastrophic burns and other injuries.

Extract from the Public Inquiry Report into the King's Cross Underground fire (published in November 1988)

20. From 19:43 there was a rapid worsening of the conditions in the tube lines ticket hall. At about 19:45 there was a sudden eruption of black smoke and flames into the ticket hall. The flashover had taken place. The time of 19:45 shown on the stopped digital clock was confirmed by P.C. Dixon who, having escaped via the exit to the south side of Euston Road, and after leading P.C. Hanson to the street, immediately radioed his headquarters for assistance and also informed them of a 'major incident' at King's Cross Underground station. This message was recorded at 19:46:03 (i.e. 19:45:58 after being corrected] which, allowing time for P.C. Hanson to escape, suggests the time of flashover at about 19:45. So in a period of about two minutes or less, the fire observed by the firemen on their first arrival had deteriorated from what they perceived as a modest fire into a raging inferno.

21. Very few people who were in the tube lines ticket hall and who witnessed the flashover survived, and most of those who did survive were seriously injured. Others coming up the Victoria Line escalators had a limited view of the flashover looking up the escalator shaft. Temporary Sub-officer Bell who was at the bottom on the Piccadilly Line escalator shaft probably saw the fire a minute before the flashover and at some time shortly after the flashover.

22. Shortly before the flashover P.C. Hanson was a short distance down escalator 9 on the Victoria Line urging people up the escalator and staircase. He became aware of dense smoke in the ticket hall so he went to investigate. When he got about five feet into the ticket hall he saw '. . . what I can only describe as a large wall of flame or fire. It was definitely above head high, and immediately following this was like a whoosh . . . and a large ball of flame, which was about head height, hit the ceiling in the ticket hall itself. This was followed almost instantaneously by dense black smoke . . .'

P.C. Hanson later amplified this:

'To be more accurate I would say it was a jet of flame that shot up and then collected into a kind of ball' and then 'I saw it shoot up across the top of number four and collect along the roofing . . .'

What is flame spread?

Flame spread is continuous ignition. Flames spread over a solid surface as the surface in advance of the flame becomes heated by radiation, conduction or convected heat transfer, causing gaseous fuel to be released and so extending the burning zone.

The speed of advance of flames can be increased by air movement – for example, a flame driven sideways by the wind extends the area of heating, thus causing more heat, gases and fumes.

Flame spread is much quicker when the surfaces' temperatures have been pre-heated and rapid flame spread can lead to flashover.

What is spontaneous combustion?

Encyclopaedia Britannica defines spontaneous combustion

> as the outbreak of fire without application of heat from an external source.

This combustion can occur when flammable matter like oily rags, damp hay, leaves or coal is stored in bulk. Spontaneous combustion (sometimes called spontaneous ignition) begins when a combustible object is heated to its ignition temperature by a slow oxidation process. Oxidation is a chemical reaction involving the oxygen in the air around us gradually raising the inside temperature of something – for example, a pile of oily rags – to a point at which a fire starts.

The way combustible materials are stored has a lot to do with whether they will spontaneously combust or not. Aerosols and other flammable liquids or gases often have instructions about being stored away from a heat source. This prevents temperatures rising to the point of ignition.

Substances with low ignition temperatures pose a greater risk than others.

Flames, heat and smoke are major hazards in a fire. What else causes a potential risk?

When materials burn, they create 'products of combustion'. These will include various gases that could prove fatal if inhaled.

Carbon monoxide gas can be produced during a fire. Carbon monoxide is hard to detect because it has no smell, taste or colour. This also means that it is easy to inhale without realising.

Carbon monoxide is produced when fuels such as gas, oil, coal and wood do not burn fully.

When a fire burns in an enclosed room, the oxygen in the room is gradually used up and replaced with carbon dioxide. Following a build-up of carbon dioxide in the air, the fuel is prevented from burning fully and it starts to release carbon monoxide.

Hydrogen cyanide (HCN) is produced when materials that contain nitrogen in their structure – for example, orlon, nylon, wool, polyurethane, urea-formaldehyde and ABS (acrylonitrile-butadiene-styrene) – are involved in the fire. HCN and other cyanogen compounds arrest the activity of all forms of living matter. They exert an inhibiting action on the use of oxygen by the living cells of the body tissues.

Hydrogen chloride (HCl) is produced when polyvinyl chloride is decomposed by fire. If inhaled, HCl will damage the upper respiratory tract and lead to asphyxiation or death.

There are three common oxides of nitrogen: nitrous oxide, nitric oxide and nitrogen dioxide, of which there are two forms. Nitrogen dioxide, which is very toxic, can be produced from the combustion of cellulose nitrate. Nitric oxide does not exist in atmospheric air because it is converted into dioxide in the presence of oxygen. These compounds are strong irritants,