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Firefighting in under-ventilated compartments: Literature review

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The findings and recommendations in this report are those of the consultant authors and do not necessarily represent the views or proposed policies of the Office of the Deputy Prime Minister.

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Management Summary

Firefighting, search and rescue in under-ventilated compartments involves additional risks due to the possibility of rapid fire development as firefighters enter the compartment. This rapid fire development may come in the form of a backdraught, flashover or related phenomena. The aim of the project was to review the relationship between operational firefighting practices and procedures and fire safety provisions within under-ventilated compartments, in order that guidance can be provided on these issues.

The project included a literature review of previous research, guidance and building regulations, an analysis of FDR1 statistics and a review of reported fire incidents involving backdraught. Initially it was intended to include computer modelling and experimental work on backdraught but these plans were abandoned when it was realised that a project in this area called 'FIRENET' [Ref. 18] was already underway, led by Kingston University.

This project was part of the work programme of the Building Disaster Assessment Group (BDAG). The group was established to consider the issues, for fire authorities and their fire brigades in the UK, that have been highlighted by the World Trade Centre incident of 11th September 2001.

The review found that although a number of research projects had been carried out on backdraught in recent years but there was still some way to go before we have a sufficient understanding of backdraught and the factors that affect its likelihood of occurrence and severity.

The fires at Blaina and Bristol in 1996 resulting in firefighter fatalities brought the issue of backdraught to the fore in the UK. Following these events, revised guidance was issued to brigades in Fire Service Manual Volume 2 [Ref. 1] with specific reference to backdraught and flashover. Also, firefighter training has been extended in recent years to cover rapid fire development, backdraught and flashover and the use of real fire simulators.

The design of buildings for fire safety, including features such as compartment sizes, smoke ventilation, smoke detection systems and sprinkler systems, will affect the likelihood of occurrence and severity of a backdraught. Venting of basements is a problem due to the lack of natural openings and a particular concern is the guidance on this in the UK Building Regulations [Ref. 24] that allows some spaces in basements to be vented indirectly by firefighters opening connecting doors.

Modern building practices such as the installation of well-sealed windows and doors and highly insulated walls may increase the likelihood and severity of a backdraught occurring in the event of a fire. However, it has not yet been determined what effect these factors have on a fire and on the likelihood and severity of a backdraught.

Recommendations

Guidance in the Building Regulations [Ref. 24] on venting of basements should be reviewed as it allows some spaces in basements to be vented indirectly by firefighters opening connecting doors. This action is likely to be a particularly serious hazard to firefighters, leaving them vulnerable to a backdraught should one occur, with no easy exit.

Building Regulations Approved Document B Section 19.8 [Ref. 24] specifies a vent area for natural smoke outlets of 'not less than 1/40th of the floor area' for basements, for use by firefighters on arrival. However, the use of natural vents at ground level creates uncertainty in operational fire-fighting as to what should be opened to avoid adverse wind-pressure effects.

Further research, by experiment, modelling or otherwise, may be worthwhile to investigate the effectiveness of natural vents further. Alternatively, it could be decided that only powered exhaust should be allowed at ground level.

It would be worthwhile investigating by experiment and modelling whether the amount of background ventilation and insulation in modern buildings has a significant effect on the development of conditions which may cause a backdraught.

The review of smoke ventilation of basements carried out by Morgan [Ref. 44] recommends for the safety of occupants and firefighters that basements be protected by smoke and heat exhaust ventilation systems, smoke shafts, pressurisation or depressurisation systems and by sprinkler systems, the system selected depending on the basement geometry.

Further research to obtain a better understanding of the physical processes involved in backdraught would be worthwhile. The FIRENET project described in Section 5.4 is an example of work already underway in this area. Once a better understanding of backdraught has been obtained, it will be possible to evaluate alternative firefighting tactics for use at incidents where a potential for backdraught is diagnosed.

Before implementing any changes to building designs or firefighting practices to reduce the risks of backdraught, the effect on other possible means of rapid fire development such as flashover or gas explosions would need to be considered.

1 Introduction

Firefighting, search and rescue in under-ventilated compartments involves additional risks due to the possibility of rapid fire development as firefighters enter the compartment. This rapid fire development may come in the form of a backdraught, flashover or related phenomena. This project seeks to review the relationship between operational firefighting practices and procedures and fire safety provisions within under-ventilated compartments, in order that guidance can be provided on these issues.

The initial idea was to carry out the following work:

(i) a literature review of previous research, guidance and building regulations,

(ii) an analysis of FDR1 statistics,

(iii) a review of reported fire incidents involving backdraught and

(iv) computer modelling and experimental work to provide more information on which guidance could be based.

However, after starting the project it was discovered that a project called 'FIRENET' was already underway, led by Kingston University, to carry out experimental and modelling work in this area. It was decided therefore to limit the ODPM project to items (i), (ii) and (iii).

This project is part of the work programme of the Building Disaster Assessment Group (BDAG). The group was established to consider the issues, for fire authorities and their fire brigades in the UK, that have been highlighted by the World Trade Centre incident of 11th September 2001. The terms of reference of BDAG were:

'To consider the potential implications, for the UK fire service, of terrorist activities within the built environment, taking into account fire authorities responsibilities for ensuring the provision of appropriate fire precautions for buildings in use and safe operating procedures that reflect building design.'

The project brief was initially expressed as:

> *'A review of the relationship between operational firefighting practices/ procedures and fire safety provisions within unfenestrated compartments.'*

The initial project rationale and brief stated that:

> 'This study was felt to be appropriate since the present fire safety arrangements within unfenestrated compartments may present a significant hazard to firefighters resulting from backdraught. This may arise due to an absence, or failure of ventilation arrangements, or in

> the case of firefighting facilities within basements, the absence or subsequent loss of appropriate replacement air provision …'

Later, the brief was extended to include firefighting in *under-ventilated* compartments, as it is a lack of ventilation that is the key factor in causing conditions which may lead to a backdraught.

2 The Problem

The possibility of backdraught presents a hazard to firefighters when entering buildings or compartments within buildings. A backdraught is defined in the Fire Service Manual Volume 2 [Ref. 1] as follows:

> 'Limited ventilation can lead to a fire in a compartment producing fire gases containing significant proportions of partial combustion products and unburnt pyrolysis products. If these accumulate then 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.'

Backdraught can occur when the ventilation to an under-ventilated compartment is increased, for instance by opening a door or window, which may occur when or after firefighters enter the building. Basements may be a particular problem due to lack of windows and natural ventilation. Compartments above ground may be a problem where there is a lack of windows for security or where all windows are closed and remain in place during a fire.

Other forms of rapid fire development that may occur on firefighter entry are flashover and fire gas explosions. These may be an equally serious risk and will also be considered in this report. A flashover is defined in the Fire Service Manual Volume 2 [Ref. 1] as follows:

> 'In a compartment fire there can come a stage where the total thermal radiation from the fire plume, hot gases and hot compartment boundaries causes the generation of flammable products of pyrolisis from all exposed combustible surfaces within the compartment. Given a source of ignition, this will result in the sudden and sustained transition of a growing fire to a fully developed fire. This is called flashover.'

A description of a fire gas explosion, where different from a backdraught, is given by Karlsson and Bengtsson in Section 5.2 of this report.

A better understanding of under-ventilated fires and backdraughts and the circumstances under which they occur is needed to allow:

- better guidance and training to be given to the fire service

- development of more effective firefighting tactics to detect and deal with potential backdraught conditions

- consideration to be given to revision of the building codes for new buildings to reduce the chance of backdraughts occurring and the severity of backdraughts if they do occur. Such revision may include for instance the requirement for the provision of fire suppression or appropriate emergency ventilation in the event of a fire.

3 Rapid Fire Development

Firefighter casualties sometimes occur because a fire spreads more rapidly than expected. This is particularly the case when the rapid fire development comes in the form of a backdraught, flashover or fire gas explosion. Measures such as guidance, training and tactics for firefighters, supported by guidance for building designers and enforcing authorities can help to reduce the hazards from all types of rapid fire development. Specific measures include:

- Reducing the fire load of the building contents
- Installation of smoke detectors and sprinklers
- Improving firefighter training and awareness of the different hazards

Actions to control ventilation of the fire, either by firefighters or by occupants, can have positive and negative effects:

- Reducing the ventilation to the fire will reduce the chance of fire spreading but increase the chance of backdraught. Reduction in ventilation may be achieved for example by:
    - automatic shutdown of air-conditioning systems in response to a fire,
    - house occupants closing doors on leaving,
    - firefighters closing doors as a firefighting tactic to contain the fire
- Conversely, increasing the ventilation, e.g. when firefighters open doors and create vents to clear smoke, may increase the chance of fire spread and flashover but reduce the chance of backdraught.

4 Previous research on backdraught and related issues

4.1 Basement Fires

A topic of concern of relevance to the backdraught issue is the ventilation of basement fires. Basements are a particular concern to firefighters, as they typically have no natural ventilation and may require firefighters to descend through the hot gas layer from above to reach the fire. Knock-out pavement lights are a common feature of the design of basements and are intended to allow the fire service to ventilate the basement in the event of a fire. However, there is no specific requirement mentioned in the design guidance (that supports the Building Regulations in England & Wales or the technical Standards in Scotland) for the need for dedicated inlets for fresh air to replace the smoke being removed. Doubts had been expressed about the effectiveness of this type of smoke ventilation, which might depend for instance on the nature and size of the fire, the location and layout of the affected compartments, the external wind direction and the external wind pressures. In addition, critical factors to ensure the safety of the personnel involved will be the ability to ascertain the temperatures within the fire compartment before committing personnel to breaking the pavement light and exposing themselves to the hot gases; and the ability to locate the appropriate pavement light and determine its relationship to crews that may be committed within the building.

One study was carried out for the Department of the Environment (DOE) by the Fire Research Station and reported by Ghosh [Ref. 2]. Scale model fire tests were carried out. It was concluded that for a vitiated fire, breaking a pavement light may not produce a significant improvement. Also, as the fire is vitiated, the possibility of a backdraught cannot be ruled out. Better results were obtained with rapidly burning fires or where powered ventilation was used at the broken pavement light. As identified above, the direction and strength of the external wind and the 'over pressures' created can have a significant impact on the results achieved, and whilst in theory only a downwind pavement light should be opened, this may be difficult if not impossible to identify on the fire ground.

Another study on basement fires was carried out by the Fire Experimental Unit and reported by Rimen [Ref. 3] in which full-scale fire tests were carried out. It was concluded that the removal of the pavement light could have a significant beneficial effect in improving the firefighting environment, particularly when forced ventilation is being used.

As a result of these two studies the Home Office recommended in 1996 that 'the existing provisions for basement ventilation should remain within the revised Approved Documents as an interim measure' and that 'detailed consideration of the needs of the fire service, in respect of basement ventilation, should form part of the review of "Assumed Fire Service Intervention" contained in the Approved Documents, associated British Standards and other guides' [Ref. 4]. This review by ODPM is planned to take place in 2004.

4.2 Chitty: A Survey of Backdraught

In 1994, Chitty of the Fire Research Station [Ref. 5] carried out a survey of backdraught for the Home Office. This study was the result of a request by the Joint Committee on Fire Brigade Operations to look at the ways in which fire losses could be reduced in large fires. The study found that:

- There was a need to clarify the terminology. The terms backdraught and flashover referred to different events and should be used consistently.
- Only one group was identified which was active in research on backdraught. This was Fleischmann et al at the University of California (Berkeley) [Ref. 6]. This study included experimental work with a half-scale domestic room, salt water modelling and numerical modelling. The work identified the phenomena involved in backdraught such as the gravity current providing fresh air to the compartment. Results indicated that unburned fuel mass fractions greater than 15% are necessary for a backdraught to occur and that the backdraught severity strongly depends on the delay time to ignition and gas species concentrations.
- There is a known set of conditions that may lead to backdraught, which firefighters should be able to identify.
- There was no practical training given to firefighters regarding backdraught in the UK, although training was provided for Swedish firefighters.
- There was a clear need within the Fire Service for a sound education on all aspects of fire science, development of fire in well and under-ventilated conditions and the phenomena of backdraught and flashover.

A lack of communication was identified between fire scientists and firefighters. To bridge the gap, Volume 2 of the Fire Service Manual [Ref. 1] was published which attempts to address what firefighters need to know about fires and ventilation. This was followed by production of a series of video training films produced by the Fire Experimental Unit, part of the Fire Research and Development Group (FRDG) of the Home Office.

4.3 Fire Experimental Unit (FEU): Backdraught Simulator

A backdraught simulator was developed at the FEU. The purpose of this was to provide material for the training videos and to enable further research on the phenomenon, described by Foster and Roberts [Ref. 7]. The main lesson for the fire service, which has been demonstrated from the investigations, is the severity and unpredictability of a backdraught. The test conditions in the compartment were closely controlled and have shown the varying severity that can be achieved with different delays, compartment temperatures and venting conditions.

4.4 ODPM Fire Statistics and Research Division: Positive Pressure Ventilation (PPV) and Backdraught

A note was produced by FRD [Ref. 8] to summarise the research carried out by or on behalf of FRD on PPV and backdraught. It was noted that current guidance to the fire service covers backdraughts and ventilation including PPV and has taken account of the research completed. It was thought unlikely that PPV could be used to prevent a backdraught coming out of an opened door due to the high over-pressure associated with backdraught. One possible tactic to prevent backdraught thought worth investigating was to clear the flammable gases by letting air in through a closed door in a controlled manner. This could be done by creating small vents at high level and low level for outlet and inlet.

4.5 Mowrer: Enclosure Smoke Filling Calculations

This paper by Mowrer [Ref. 9] contains information of interest to those attempting to model fires in under-ventilated compartments and the conditions leading up to a possible backdraught. The paper revisits the smoke filling calculations developed by Zukowski which have been used for 20 years and are included in the zone model ASET [Ref. 10]. The equations are expanded to address the issues of global temperature rise in the compartment and oxygen depletion in closed-room fires. For oxygen depletion, equations are given to relate both the total heat release of the fire at extinction and the global temperature increase at extinction to the limiting oxygen concentration for extinction. The paper quotes that flame extinction occurs at a limiting oxygen concentration of approximately 13% by weight.

An example is given where the predicted temperature rise is below ‘the temperature rise of approximately 580K commonly associated with flashover conditions’. This suggests ‘the difficulty of attaining flashover conditions in a poorly ventilated, fully enclosed compartment’. On the other hand, ‘this calculated global temperature rise might be sufficient to cause fracture and collapse of ordinary plate glass windows if present, providing new pathways for the introduction of oxygen to the enclosure and escalation of the fire intensity’.

5 Recent and Current Research

5.1 Gottuk, Peatross, Farley and Williams: The development and mitigation of backdraft: a real-scale shipboard study

Gottuk et al. [Ref 11] describe the results of a real-scale experimental test series to study the development and mitigation of backdraughts. Experiments were carried out on an ex-US Navy ship. The study showed that the key parameter for backdraught development is the fuel mass fraction in the vitiated compartment prior to venting. Using diesel fuel for the fire, it was found that a fuel mass fraction of at least 0.16 was required for a backdraught to occur.

The backdraught occurred in a room adjacent to the fire room. They looked at the effect of varying the size and ventilation conditions in the adjacent room. The room size was more significant, with the smaller room sizes being associated with more intense backdraughts. Shutting off the ventilation in the adjacent room did not mitigate the backdraught and so it was thought more beneficial to maintain ventilation through the space to reduce temperatures and improve tenability.

The injection of water spray into the fire compartment was shown to be an effective mitigating tactic that was able to completely suppress backdraughts mainly by diluting the atmosphere and reducing the fuel mass fraction rather than by cooling.

5.2 Karlsson and Bengtsson: Fire Service Perspective

This paper [Ref. 12] reports on a project commissioned by the National Swedish Rescue Services Board to look into the subject of flashover and related phenomena. Karlsson (Lund University, Sweden) and Bengtsson, (Helsingborg Fire Department, Sweden) describe the processes involved in flashover and related phenomena, experimental and modelling work carried out, how modelling can be used to enhance understanding of the processes involved and the new terminology used in training programs for firefighters in Sweden. Karlsson is also involved in the FIRENET project (see Section 5.3) as a sub-contractor to Iceland Fire Authority.

Three terms were thought sufficient to describe a sudden change in development of a building fire: flashover, backdraught and smoke gas explosion. The use of other terms might be confusing or misleading. Where the smoke gases are transported to compartments adjacent to the fire compartment and mix with fresh air, they may form a flammable mixture. If a source of ignition is available, such as when the fire burns through from the first compartment, a smoke gas explosion will occur. This occurrence is described in the Fire Service Manual Volume 2 [Ref. 13] but no name is given to it.

Both 1/3 scale experiments using heptane and methane fuels and full-scale experiments in an apartment building were carried out. In the apartment experiments, the initial fire, lining materials and ventilation openings were varied. Pressure differences and temperatures were measured and a water-cooled video camera was placed in the fire compartment. Doors and windows were opened and closed to produce flashover, vitiation and backdraught.

The CFD model SOFIE [Ref. 14] was used to simulate some of the experiments. It was found that calculated temperatures and species concentrations compared well with the experimental data. However, the paper states that in order to fully simulate the flashover process, the combustion models in SOFIE must be developed further.

The paper recommends that further work, both experimental and modelling, is carried out in order to enhance the understanding of under-ventilated fires.

5.3 Loffler: Simulation of Ventilation Controlled Room Fires

This paper [15] describes the use of a field model called KOBRA-3D to model ventilation controlled room fires. A combustion factor is used to modify the free burn heat release rate depending on the oxygen concentration present. Comparisons made with experimental data of room fire tests were encouraging. However, it was found that the results were very sensitive to the critical oxygen mass fraction, i.e. the minimum fraction of oxygen necessary for combustion to continue, which must be provided as input data.

5.4 Gojkovic and Bengtsson: Firefighting tactics in a backdraught situation

This paper [Ref. 16] describes a study where CFD calculations are used to gain an understanding of the effectiveness of different firefighting tactics in backdraught situations in an apartment.

The CFD model used was SOFIE. Since pre-mixed burning could not be modelled, the simulations focussed on the gravity current of fresh air entering the compartment and the mixing of cold fresh air and hot smoky gases. A flammable region could then be predicted near the interface between the hot and cold gases where the gas mixture is within the flammability limits. The CFD calculations were used to predict the potential for occurrence of a backdraught when different tactics are used.

In the modelled scenarios, it is assumed that burning has been underway for a long time. Therefore the temperature in the three-room apartment has increased to 600K (327°C), the flaming fire has died out and the hot gases have pyrolysed the hot combustible material so that the combustible gas concentration has reached 30%.

The scenarios modelled were:

- *BA team enter the apartment to carry out a rescue*. The model predicted only a few seconds are needed for a gravity current to produce a flammable region large enough to create a hazard. Within this time, the BA team would have to cool the hot gases with water spray to reduce the risk of ignition. Closing the door after entry to reduce the volume of air entering did not appear to help.

- *Natural ventilation*. It was assumed that no people were left inside. As well as the door, a second vent was created by opening a window in another room of the apartment with the purpose of clearing the air and allowing the origin of the fire to be found. This outlet vent would be protected with water to prevent backdraught here. The model showed that the apartment was more quickly vented with the two openings but rapid flame spread may still occur.

- *Positive Pressure Ventilation (PPV)*. The model simulated the effect of a fan positioned in the open doorway, again with a window open in another room to take the outflow. Using the PPV seemed to increase the mixing and also the possibility of backdraught. However, the increased mixing did not last long and the apartment soon emptied of smoky gases.

- *Incorrect usage of PPV*. In this case a blockage of the flow through the apartment is assumed to occur e.g. due to a door closing in the apartment. In this case the risk of a backdraught was highly increased.

The use of a 'cutting extinguisher' as another tactic against backdraught was discussed although this was not modelled. During the cutting phase, an abrasive is added to the water flow making it possible to cut through construction materials. The cutting extinguisher can be used to cut through an apartment door and cool the gases inside without creating an opening for fresh air to enter. Due to the small droplet size, approximately 0.1 mm, the cooling is mainly to the gas rather than to the fuel surfaces. Care needs to be taken to prevent the spray being directed towards people left inside the apartment, usually located near floor level. Alternative nozzles are under development to modify the spray angle. This equipment has been recently developed in Sweden, although only a few fire and rescue services in Sweden possess it at present.

Gojkovic and Bengtsson concluded that the cutting extinguisher has a great potential for use in backdraught situations although further development is necessary. The choice of tactics used will depend on whether there are people left in the building, the risks firefighters are willing to take and what resources in terms of personnel and equipment are available.

This work is based on one specific set of circumstances as a starting point: a three room apartment where the gases have reached a set temperature. It would be interesting to see how much the results vary when parameters such as room geometry and temperature are varied.

A project to 'Evaluate High Pressure Fog' is due to be carried out by the Fire Statistics and Research Division, ODPM, later in 2004.

5.5 Knutsen and Chapman: Development of a Re-Entry Evaluation Detector

Knutsen and Chapman of Qinetiq Ltd [Ref. 17], describe the development of a 're-entry evaluation detector' for use on ships to evaluate whether a compartment is safe to enter. In the event of a fire on a ship the affected compartment may be sealed, leading to eventual extinguishment by oxygen starvation. The detector is then used to determine when it is safe to re-enter the compartment without danger of re-ignition. The detector is portable, contained in a brief-case sized box and includes five chemical sensors and a sampling probe fitted with a thermocouple which can sample the fire atmosphere remotely. The probe is inserted through specially drilled holes, ½ inch in diameter, in the compartment walls. An algorithm is used to determine whether the compartment is safe to enter based a combination of the sampled conditions and an LED indicator lights up accordingly.

This device or something similar might be of use to the fire service attending a fire where there are signs of an oxygen-starved fire and a potential backdraught to help them decide whether to open a compartment. However, the practicability for fire service use would need to be considered. Also, consideration would need to be given to whether a reliable judgement could be made about the conditions in the compartment from a small number of sampling points or whether the variation in conditions in the compartment would be too great.

5.6 FIRENET: Under-ventilated compartment fires

This project began in June 2002 and runs for 4 years and is funded by the Human Potential Programme of EC Framework 5. The main goal is 'to advance our understanding and predictive capability of under-ventilated fires' [Ref. 18]. Both experimental and numerical methods are to be used. Research will address backdraught, ghosting flames and flashover. The project is undertaken by a consortium of eight partner organisations plus one sub-contractor and is co-ordinated by Kingston University.

The planned research includes:

- Provide detailed experimental measurements on local flame characteristics
- Provide detailed analysis of new and existing experimental data
- Develop solid combustion models for realistic fuels in under-ventilated conditions
- Develop Large Eddy Simulation (LES) and Computational Fluid Dynamics (CFD) techniques for prediction of under-ventilated fires
- Further our understanding of the behaviour of glazing when subject to under-ventilated fires

- Provide recommendations on the mitigation of hazards due to under-ventilated fires and underpin development of performance-based European regulations.

5.7 Building Research Establishment: The Potential for including Fire Chemistry and Toxicity in Fire Safety Engineering

Most fire tests of materials have until now been carried out under ‘free burn’ conditions, i.e. with sufficient ventilation. In this project, sponsored by the Building Regulations Division, ODPM [Ref 19], a small-scale test method is being developed in which materials can be exposed to a range of fire conditions including different fuel/air ratios. The aim of the project is to provide the ability to calculate toxic product smoke yields. Although backdraught is not specifically being addressed, the method will allow information to be obtained on burning behaviour in under-ventilated conditions. This information will help in other efforts to model vitiated fires which are the precursor of a backdraught.

5.8 Weng and Fan: Reduced-scale experimental study

Weng and Fan [Ref. 20] describe recent experimental work carried out at the University of Science and Technology of China. They used a compartment representing a $\frac{1}{4}$-scale residential room (1.2 m × 0.6 m × 0.6 m) and found that ‘the key parameter determining the occurrence of backdraft is the mass fraction of unburned fuel’. They estimated that the critical value of the mass fraction of unburned fuel for backdraught to take place was 9.8%. This compares to a value of 15% reported by Fleischmann.

6 Guidance for firefighters

This section describes the various guidance issued for the fire service about backdraught and related issues.

6.1 HSE Improvement Notice to South Wales Fire Authority, July 1996

Following a fire at Blaina in February 1996 (see Section 9.1.3) at which two firefighters lost their lives, the Health and Safety Executive issued an improvement notice dated 29 July 1996 to the South Wales Fire Authority, stating that the authority was contravening the Health and Safety at Work Act, because ‘employees are not provided with adequate health and safety training to equip them for the risks to which they are exposed’. The improvement measures required included: identifying any deficiencies in the training program in comparison with national guidance, revising the training program accordingly and developing a system of monitoring and review of the training.

6.2 Fire Service Manual Volume 2: ‘Fire Service operations – compartment fires and tactical ventilation’

This document [Ref. 1] supersedes the earlier document ‘Manual of Firemanship, A Supplement: The Behaviour of Fires – Compartment Fires’ [Ref. 21].

The document gives a definition of backdraught (quoted in Section 2 of this review), how it occurs and describes possible scenarios and indicators. The recommended actions for firefighters are listed as:

- check for signs and symptoms of backdraught before opening door
- cover the door with a charged branch if they decide to open it
- spray the gases building up outside the door before opening
- consider option to ventilate compartment thoroughly before entering.

6.3 FEU training videos

Three videos were produced by the Fire Experimental Unit (FEU) to coincide with publication of the Fire Service Manual Volume 2 [Ref 1], entitled:

- Fire Growth and Flashover (DCOL 9/1997 refers)

- Backdraught (DCOL 9/1997 refers)
- Tactical Ventilation of Fires (DCOL 9/1997 refers)

A fourth video was produced to support DCOL 14/1999 section B on tactical use of PPV entitled:

- Positive Pressure Ventilation (DCOL 14/1999 refers)

6.4 Home Office – Dear Chief Officer Letter (DCOL) 11/1999 Practical Training for Compartment Fires

This DCOL gives guidance for brigades that may be considering the use of compartment fire training facilities using real fire to provide practical fire behaviour and firefighting training.

A set of training aims are stated which include the following on the subject of backdraught:

- Describe the characteristics and effects of flashover and backdraught conditions
- Recognise the signs and symptoms indicating the potential for a flashover or backdraught to occur
- Implement measures to minimise the occurrence of a flashover or backdraught
- Take the actions necessary to prevent a backdraught from occurring by adopting appropriate methods of ventilation and fire suppression.

The DCOL emphasises the need for caution when using training facilities that involve the production of real or simulated backdraughts.

6.5 Home Office – Dear Chief Officer Letter (DCOL) 14/1999 Positive Pressure Ventilation – an implementation strategy

This document provides an overview of the subject of Positive Pressure Ventilation (PPV) and its potential contribution to future firefighting within the UK. The document states that the Generic Risk Assessment GRA 3.6 on fighting fires using PPV is to be revised to take into account this work.

On the basis of discussions with a broad selection of UK firefighters, one of the concerns noted about the use of tactical ventilation was that it would increase the potential for backdraught and flashover.

6.6 Report of Her Majesty's Chief Inspector of Fire Services for England and Wales 1998/99

This report [Ref. 22] refers to training issues related to backdraught (see Section 7.1).

6.7 Fire Service manual. Volume 4. Fire Service Training: guidance and compliance; framework for compartment fire behaviour training

This document includes the following references to backdraught:

'2.1.3 Developments in the construction industry and in the materials used for internal fixtures and fittings have increased the possibility of flashover and backdraught in fires within compartments. Recent experience of these phenomena emphasises the importance of operational personnel being able to perform their role safely and effectively. In particular, it is essential that personnel receive training to ensure that they are competent to:

- Understand the burning characteristics, development and behaviour of compartment fires.
- Recognise and assess the risks involved when dealing with compartment fires.
- Prevent flashover and backdraught or mitigate their effects where possible.
- Implement control measures to protect themselves from the effects of fire.
- Recognise the operating limitations of firefighters' Personal Protective Equipment (PPE) and fire fighting and ancillary equipment.'

6.8 Health and Safety Fire Service Guide. Volume 3: A Guide to Operational Risk Assessment, The Stationery Office (TSO), Crown copyright 1998

This document contains a set of 32 generic risk assessments. Those relevant to backdraught and under-ventilated fires are described below.

6.9 GRA 3.1 Fighting Fires in Buildings

This document examines the hazards, risks and controls that are common to firefighting in all buildings. A brief mention is made of flashover and backdraught.

6.10 GRA 3.6 Fighting Fires – Using Positive Pressure Ventilation

This document examines the hazards, risks and controls that relate to the use of Positive Pressure Ventilation (PPV) during operational incidents. The document states that the benefits of using PPV far outweigh the disadvantages but that there are a number of hazards and risks associated with its use, including uncontrolled spread of fire.

In the section 'Command and Control', it is stated that 'the Incident commander should recognise those situations when PPV should not be used, for example where there is a potential for backdraught'. 'A fire that has produced potential backdraught conditions should discourage the use of PPV'.

6.11 GRA 5.8 Flashover and Backdraught

This document examines the hazards, risks and controls that relate to flashovers and backdraughts.

Specific measures to take on opening up a compartment containing an oxygen-starved fire for the purpose of extinguishment are listed as:

- If a compartment must be entered personnel must be properly protected, breathing apparatus and charged hose will be used.
- Personnel opening up must stay low and to the side of the door.
- Escape routes must be secured and protected.
- Cool the outer compartment with a spray jet and ventilate the outer compartment.
- An escape route for the gases must be planned before opening up.
- The door must only be opened slightly and a spray jet operated through the gap and aimed upwards.
- As much of the compartment as possible must be cooled.
- Personnel must only enter the compartment if it is absolutely necessary.
- If it is not necessary to enter the compartment immediately, ventilate from outside.
- Tactical ventilation prior to opening up.

- Once a compartment containing an oxygen starved fire has been opened up and fresh air has been allowed in, there is little which can be done to prevent a backdraught happening.

- All personnel receive information, instruction and training in hazards associated with backdraughts and flashover.

Training measures are listed as:

- The training of firefighters in Brigades should include realistic training in a live fire environment where the effects of heat and smoke can be experienced, ventilation practised and backdraughts and flashovers witnessed under controlled conditions.

- Firefighters must be aware of the effects of heat stress which can occur during prolonged firefighting activities due to the insulation effects of PPE.

- Reducing the oxygen supply to a fire.

- Possible backdraught scenarios.

- Signs and symptoms of a backdraught.

- The actions to be taken by firefighters.

- All personnel wear full protective clothing, including gloves and firehoods – (Home Office specification A.28) to ensure that no unprotected skin is exposed to the fire environment.

- All personnel are under full supervision.

6.12 Grimwood: Discussion of Guidance in Fire Service Manual Volume 2

Grimwood [Ref. 23] discusses the current guidance in the Fire Service Manual Volume 2 and lists some additional signs and symptoms of backdraught not mentioned in the manual, such as ‘rolling’ black smoke, ‘rattling’ windows and blue flames.

7 Training for Firefighters

7.1 HM Chief Inspector's Report

The Report of Her Majesty's Chief Inspector of Fire Services for England and Wales 1998/99 [Ref. 22] describes the training facilities available in brigades for flashover and backdraught:

> 'There is an important point I would like to make in relation to the TRAINING OF FIREFIGHTERS. Developments in the construction industry and in the material used for internal fixtures and fittings have increased the possibility of flashover or backdraught in fires within compartments. The sometimes tragic consequences for firefighters exposed to these phenomena have been brought home to us only too dramatically during recent years and have prompted vigorous interest in finding better ways to prepare firefighters for the hazards they face. Much of this work has involved the introduction by brigades of compartment fire training facilities that can replicate the conditions firefighters might encounter. The training facilities, generally using either wood or liquid petroleum gas as a fuel, can be used to teach firefighters to recognise the signs and symptoms of a pending backdraught or flashover and learn how to protect themselves and control fire safely.'
>
> 'It is generally accepted that this kind of training is vital to the education and training of today's firefighters. But, it is essential that the preparations brigades make to provide the training and the manner in which it is delivered, are carefully planned and not a knee-jerk reaction that perpetuates an ill-conceived macho image of the service. Benefit must balance risk with due regard for the identification and understanding of the operational requirement, relevant guidance, professional expertise and the determination and fulfilment of sensible and meaningful training objectives.'

7.2 Training at the Fire Service College

Fire behaviour training at the Fire Service College is now carried out on following courses:

- Fire Behaviour Training Instructor Course (2 week Specialist Instructor Course)
- Tactical Ventilation Instructor Course (1 week Specialist Instructor Course)
- Crew Manager Managing Incidents and
- Retained Junior Officer BA Course.

Fire behaviour training includes the phenomena of backdraught and flashover and the signs and symptoms that they may be about to occur. A fire crew arriving at an incident should therefore be aware of the dangers of backdraught and flashover.

In addition to the courses provided by the Fire Service College, some brigades in the UK provide their own fire behaviour training.

8 Building Codes: how the building codes affect the problem

Building work is subject to the building regulations in place at the time. The following section refers to the latest editions of the approved documents to the Building Regulations.

8.1 Building Regulations for England and Wales – Approved Document B (Fire Safety)

Approved Document B of the Building Regulations [Ref. 24] provides guidance to meet the requirements on fire safety. The guidance covers design features such as compartment sizes, smoke ventilation, smoke detection systems and sprinkler systems to achieve compliance with the requirements of the regulations. All of these design features will affect the fire safety of the building and the likelihood and severity of any backdraught that may occur.

8.2 Building Regulations for England and Wales – B1 Means of Warning and Escape

Section B1 of Approved Document B covers the requirement for means of warning and escape. The provision of an escape route, such as a protected stairway, will also provide access for firefighters. In the case of a fire in a basement, if the smoke layer has not yet descended to the floor, a protected stairway may allow the firefighters to gain access to the basement floor without having to descend through the smoke layer.

As mentioned in Section 2 of this review, basements may be particularly prone to backdraughts as a lack of windows and natural ventilation may produce an under-ventilated fire. The following extracts from Section B1 therefore concentrate on the provision of a protected stairway from basements in various building types.

For dwelling houses, guidance on providing an adequate escape route from basements is given in Section 2.10:

> '**2.10** Because of the risk that a single stairway may be blocked by smoke from a fire in the basement or ground storey, if the basement storey contains any habitable room, either provide:
>
> a. an external door or window suitable for egress from the basement (see paragraph 2.11); or
>
> b. a protected stairway leading from the basement to a final exit.'

For flats and maisonettes, basements are covered by Section 3.8, which states that the guidance in Section 2.10 also applies.

For other building types, Section 5 on vertical escape applies. Section 5.5 states that single escape stairs are acceptable from a basement, if it requires only a single escape route for horizontal evacuation, defined by Section 4.5 b:

> 'A storey (except used for in-patient care in a hospital) with an occupant capacity of not more than 60 people, where the limits on travel in one direction only are satisfied (see Table 3).'

Table 3 of the approved document permits a single escape stair where the horizontal travel distance is up to 9 m, 18 m or 25 m depending on the use of the premises.

Section 5.22 onwards gives guidance on protection of escape stairs:

> '**Protection of escape stairs**
>
> **General**
>
> **5.22** Escape stairs need to have a satisfactory standard of fire protection if they are to fulfil their role as areas of relative safety during a fire evacuation. The guidance in paragraphs 5.23 to paragraph 5.31 should be followed to achieve this.
>
> **Enclosure of escape stairs**
>
> **5.23** Every internal escape stair should be a protected stairway (ie it should be within a fire-resisting enclosure).
>
> However an unprotected stair (eg an accommodation stair) may form part of an internal route to a storey exit or final exit, provided that the distance of travel and the number of people involved are very limited. For example, small premises described in clause 10 of BS 5588: Part 11: 1997 *Fire precautions in the design, construction and use of buildings, Code of practice for shops, offices, industrial, storage and other similar buildings* and raised storage areas.
>
> There may be additional measures if the protected stairway is also a protected shaft (where it penetrates one or more compartment floors, see Section 9) or if it is a firefighting shaft (see Section 18).'

Thus, every internal escape stair should be protected within a fire-resisting enclosure unless the distance of travel and the number of people involved are very limited as for example in small premises described in BS 5588: Part 11.

8.3 Building Regulations for England and Wales – B3 Internal Fire Spread (Structure)

Requirement B3 (3) deals with compartmentation of a building to inhibit fire spread:

> '(3) To inhibit the spread of fire within the building, it shall be sub-divided with fire-resisting construction to an extent appropriate to the size and intended use of the building.'

Guidance on maximum dimensions of compartments for different building purpose groups is given in Table 12 of Approved Document B. For office buildings there are no limits to compartment dimensions. For multi-storey shops, the maximum floor area is 2,000 m^2 (or 4,000 m^2 with sprinklers). Although basements are not specified in the table, the same limits can be applied as for any other floor of a multi-storey building.

Additionally, paragraphs 9.20 (c) and (d) of Approved Document B specifies compartment floors (i.e. fire separating) for the floor of the ground storey if the building has one or more basements and compartment floors for every basement storey if the building has a basement of more than 10 metres below ground level.

8.4 Building Regulations for England and Wales – B5 Access and facilities for the fire service

This subject is also covered by BS 9999 as described in Section 9 of this review.

Access and facilities for the fire service are dealt with in Requirement B5 which states:

> **'B5.**-(1) The building shall be designed and constructed so as to provide reasonable facilities to assist fire fighters in the protection of life.
>
> (2) Reasonable provision shall be made within the site of the building to enable fire appliances to gain access to the building.'

One of the requirements of B5 is:

> '(d) the building is provided with adequate means for venting heat and smoke from a fire in a basement.'

And by way of explanation:

> **B5.**ii: '(e) Products of combustion from basement fires tend to escape via stairways, making access difficult for fire service personnel. The problem can be reduced by providing vents. Venting can improve visibility and reduce temperatures, making search, rescue and fire-fighting less difficult.'

Section 19 'Venting of heat and smoke from basements' of Approved Document B then deals with how this requirement can be met by the provision of smoke outlets such as pavement lights. Research on the effectiveness of pavement lights in the event of basement fires is described in Section 4.1 of this review where one project concluded that removal of pavement lights could have a significant beneficial effect in improving the firefighting environment.

Approved Document B goes on to say under 19.3 of B5 that:

> 'It is therefore acceptable to vent [basement] spaces on the perimeter and allow other spaces to be vented indirectly by firefighters opening connecting doors.'

However, a building employing this indirect venting may present a significant hazard to firefighters and expose them to a possible backdraught while they are inside the basement as they open internal doors in search of the fire or occupants. This is particularly true as the firefighters will not have a precise knowledge of such issues as the wind direction and the resulting 'over pressures' on all the faces of the building, the location of the fire, and the potential interaction between these factors.

Furthermore, as the operation of pavement lights is uncontrolled their operation also potentially places firefighters operating the vents in the path of unpredictable fire development.

This does not apply to separate compartments in a basement as Section 19.3 goes on to state:

> 'However if a basement is compartmented [i.e. with fire resistant barriers], each compartment should have direct access to venting, without having to open doors etc into another compartment.'

Section 19.4 specifies exceptions where no smoke outlet is required:

> '**19.4** Smoke outlets, connected directly to the open air, should be provided from every basement storey, except for:
>
> a) a basement in a single family dwellinghouse of Purpose Group 1(b) or 1(c); or
>
> b) any basement storey that has:
>
> i. a floor area of not more than 200 m^2, and
>
> ii. a floor not more than 3 m below the adjacent ground level.'

For the natural smoke outlets, the Building Regulations Approved Document B requirements include:

> '**19.7** Smoke outlets should be sited at high level, either in the ceiling or in the wall of the space they serve. They should be evenly distributed around the perimeter to discharge in the open air outside the building.
>
> **19.8** The combined clear cross-sectional area of all smoke outlets should not be less than 1/40th of the floor area of the storey they serve.'

If the firefighters decide to open the smoke outlets to clear the basement, the requirement for siting at high level will allow hot buoyant smoke and gas to be ejected but fresh air may still be drawn in at the same opening, causing a backdraught.

No evidence can be found to support the criterion that the vent area should be 'not less than 1/40th of the floor area'. However, the same figure is used in BS 5588 (see Section 9.1) Research may be worthwhile to determine (i) whether this area allows for effective clearance of smoke and (ii) whether there is a range of vent areas which allow for effective clearance of smoke and at the same time minimise the likelihood and severity of backdraught caused by opening the vent.

Section 19.13 states that 'a system of mechanical extraction may be provided as an alternative to natural venting to remove smoke and heat from basements, provided that the basement storey(s) are fitted with a sprinkler system.' Under Section 19.14 '[the air extraction system] should come into operation automatically on operation of the sprinkler system; alternatively activation may be by an automatic fire detection system'.

There is therefore no requirement for a mechanical smoke extraction system for the basement of any building, however big the floor area. If smoke extraction and sprinkler systems are fitted in basements this would clearly reduce the likelihood and severity of any backdraught and would therefore reduce the hazards for attending firefighters.

In conclusion, consideration should be given to revising Section 19 of Approved Document B and this should be considered in the review of the 'Assumed Fire Service Intervention' planned for 2004.

For comparison, the equivalent regulations for Scotland are quoted in Section 8.8 of this review.

8.5 Building Regulations for England and Wales – Basement car parks

Guidance on basement car parks is given in Section 12 of Approved Document B which relates to requirement B3 'Internal Fire Spread (structure)'. Either openings or smoke vents totalling 1/40th of the floor area should be provided (Section 12.6) or a mechanical ventilation system should be provided, designed to operate at 10 air changes per hour (Section 12.7).

8.6 Building Regulations for England and Wales – Approved Document F (Ventilation)

The amount of ventilation provided in a building to control the daily environment will affect the conditions in the event of a fire and the possible development of backdraught conditions. Approved Document F of the Building Regulations [Ref. 25] provides guidance to meet the requirements on means of ventilation and condensation in roofs. For ventilation the requirement is:

> 'F1. There shall be adequate means of ventilation provided for people in the building.'

Means of ventilation are divided into rapid ventilation (e.g. opening windows), background ventilation (e.g. trickle ventilators or air bricks) and extract ventilation (e.g. mechanical). For instance, for a habitable room in a domestic building the guidance specifies rapid ventilation of 1/20th of the floor area and background ventilation of 8,000 mm^2. In the event of a fire in such a room, if doors and windows to the fire room are closed, no rapid ventilation is provided. The only ventilation to the fire is then background ventilation and also any ventilation provided by leakage at door and window cracks. Furthermore, the specification of a fixed area vent of 4,000 mm^2 for background ventilation was introduced in 1990 and increased to 8,000 mm^2 in 1995. Before 1990 no fixed area was specified but only the installation of trickle ventilation in doors opening to the external air.

Older properties tended to have sufficient ventilation from leakage at windows and doors, chimney stacks and air-bricks. However, newer properties built before 1990 may not be designed with background ventilation but may be well-sealed due to installation of double-glazing, and consequently have very little ventilation. In office buildings, un-openable glazing is often installed and this tends to provide a good seal and therefore little leakage. Consequently, these well-sealed buildings, often provided with high levels of insulation and air-tightness for energy efficiency (see Section 8.7), are likely to increase the backdraught hazard. It would be worthwhile investigating by modelling or experiment whether the amount background ventilation and insulation in modern buildings has a significant effect on the development of conditions which may cause a backdraught.

8.7 Building Regulations for England and Wales – Approved Document L (Energy Efficiency)

To meet the Building Regulations requirements for energy efficiency, modern buildings tend to be provided with high levels of insulation and air-tightness. Both of these features can affect the behaviour of a fire, causing higher fire temperatures and under-ventilated fires respectively. In turn, these will affect the likelihood and severity of a backdraught.

The air-tightness regulations were introduced in 2002 while the insulation standards for energy efficiency were introduced in the mid-70s in response to the oil crisis. Both regulations only apply to buildings constructed after those dates.

The Building Regulations Schedule 1 Part L1 states the requirements for conservation of fuel and power in dwellings. More specifically, Part L1 (a) states the requirement for limiting heat loss:

> '**L1.** Reasonable provision shall be made for the conservation of fuel and power in dwellings by -
>
> (a) limiting the heat loss:
>
> (i) through the fabric of the building;
>
> (ii) from hot water pipes and hot air ducts used for space heating;
>
> (iii) from hot water vessels;'

Approved Document L1 of the Building Regulations [Ref. 26] gives guidance on ways of meeting the requirement. Section 0.1 of this document states that:

> 'requirement L1 (a) will be met by the provision of energy efficiency measures which:
>
> a) limit the heat loss through the roof, wall, floor, windows and doors etc by suitable means of insulation, and where appropriate permit the benefits of solar heat gains and more efficient heating systems to be taken into account; and
>
> b) limit unnecessary ventilation heat loss by providing building fabric which is reasonably airtight; and …'

The guidance specifies thermal performance levels of different building elements (walls, floors, roofs and windows) defined by U-values. The U-value or thermal transmittance is a measure of how much heat will pass through one square metre of a structure when the air temperatures on either side differ by one degree centigrade. Under 'Limiting air leakage' (paragraphs 1.33 – 1.35) the guidance states: 'reasonable provision should be made to reduce unwanted air leakage' and refers to a separate document on this [Ref 27], the main principle being 'to provide a continuous barrier to air movement around the habitable space …'. Fireplaces will provide some ventilation but may not be provided in modern buildings depending on the current fashion and are generally not provided in purpose-built blocks of flats.

To meet the requirement, modern buildings are therefore likely to have (i) well-insulated walls, floor and roofs which would hold in the heat in the event of a fire, and (ii) airtight building fabrics which will reduce any natural ventilation in the event of a fire to very low levels unless provided for by background ventilation (see Section 8.6).

8.8 Building Standards (Scotland) Regulations 1990

The Technical Standards for compliance with the Building Standards (Scotland) Regulations 1990 [Ref. 28] include specifications for smoke ventilation in basements in E10 which are similar to the UK (England and Wales) regulations:

> '**E10 Facilities for fire-fighting**
>
> **SMOKE VENTILATION OF BASEMENT STOREYS**
>
> **E10.15*** Suitable smoke outlets, communicating directly with the external air, must be provided from every *basement storey*, and where the *basement storey* is divided into *compartments* from every *compartment* of the *basement storey*,
>
> **except -**
>
> a. in a *building* of *purpose sub-groups* 1B, 1C or 7C; or
>
> b. where the floor area of the *basement storey* is not more than 200 m^2; or
>
> c. where the *basement storey* is at a depth of not more than 4.5 m; or
>
> d. where a window or windows opening direct to the external air have a total area not less than 1% of the floor area; or
>
> e. where the *basement storey* or part of the *basement storey* is used as a strong room; or
>
> f. where the *basement storey* has an appropriate fire control system and is ventilated by a suitable mechanical smoke and heat extraction system.'

8.9 Hong Kong Building Regulations

The Hong Kong Fire Services use the 'Code of Practice for Minimum Fire Service Installations and Equipment' [Ref. 29] as the standard for the provision of fire service installations for buildings in Hong Kong.

For basements not exceeding 230 m^2 of 'usable floor area', there are requirements for emergency lighting, exit signs, fire alarm and fire detection systems. For basements exceeding 230m^2 of 'usable floor area', additional requirements include sprinkler systems and static or dynamic smoke extraction systems. For basements of three or more levels, additional requirements include firefighting and rescue stairways and pressurised staircases.

These requirements, particularly the requirement for sprinklers, lessen the likelihood of a backdraught occurring and lessen the likely hazard to firefighters.

8.10 Building Code of Australia

The Building Code of Australia, Part E2 – Smoke Hazard Management [Ref. 30] specifies in the 'Deemed-to-Satisfy Provisions' for basements (other than car parks):

> '(b) where the basement has a total *floor area* of more than 2,000 m^2, be provided with:-
>
> (i) if not more than 2 below ground storeys:-
>
> (A) a zone smoke control system in accordance with AS/NZS 1668,1, if the basement has more than one *fire compartment*, or
>
> (B) an *automatic* smoke detection and alarm system complying with Specification E2.2a, or
>
> (C) a sprinkler system complying with Specification E1.5, or
>
> (ii) If more than 2 below ground *storeys*, a sprinkler system complying with Specification E1.5.'

There is some similarity here with Approved Document B [Ref. 24], which in certain instances specifies sprinklers for floor areas of more than 2,000 m^2.

In Part D1, 'Provision for Escape', for basements the specification is:

> 'in addition to any *horizontal exit*, not less than 2 *exits* must be provided from any *storey* if egress from that *storey* involves a vertical rise within the building of more than 1.5 m, unless:
>
> (i) the *floor area* of the *storey* is not more than 50 m^2 and
>
> (ii) the distance of travel from any point on the floor to a single *exit* is not more than 20 m.'

This compares with the UK regulations where Approved Document B (section 4, table 3) permits a single escape stair from a basement where the horizontal travel distance is up to 9 m, 18 m or 25 m depending on the use of the premises.

9 British Standards on Fire Safety in Buildings

9.1 BS 5588: Fire precautions in the design, construction and use of buildings, Part 6: Code of practice for places of assembly.

BS 5588 Part 6 [Ref. 31] covers 'Smoke control for firefighting' in clause 31:

> '31.1 Commentary
>
> Smoke control is necessary to enable the fire service to sustain an attack on a fully developed fire. Well distributed natural ventilation openings need to be provided where a smoke control system designed using fire engineering principles is not provided.
>
> This form of ventilation for firefighting is normally provided by openable windows, but in auditoria, halls and arenas the enclosing walls are not normally penetrated. In these areas suitable openable vents need to be provided with controls sited for operation by the fire service.'

Although basements are not mentioned, they would also need to be provided with 'suitable openable vents'.

Clause 31.3, recommends 'well distributed openable vents with a free area of not less than 2.5% of the floor area'. This equates to 1/40th floor area specified in Approved Document B clause 19.8.

Clause 31.3 also recommends that 'in the case of basements the vents should be situated at high level in well distributed positions along street frontages or adjacent to external walls easily accessible to the fire brigade.'

9.2 BS 9999: Code of practice for fire safety in the design, construction and use of buildings

BS 9999 [Ref. 32] is currently in preparation and is due to be published as a draft for development. This standard will eventually replace the relevant parts of BS 5588. In BS 9999, clause 8 'Fire service access and facilities', clause 8.10.6 deals with 'Venting of smoke and heat from basements'. This section closely follows Approved Document B of the Building Regulations [Ref. 24]. However, where natural smoke venting is used, no minimum vent area is specified, whereas the building regulations specify a minimum of 1/40th of the floor area (see Section 8.4 of this review).

10 Analysis of UK Fire Statistics from FDR1 Forms

An analysis of FDR1 returns is given in Appendix A. This analysis includes all records where a backdraught is indicated on the FDR1 form at '5.7 Abnormal Rapid Fire Development'. This question has 'Yes' and 'No' tick-boxes. Beside the 'yes' box is a blank space to allow a description of the type of abnormal development to be entered. The contents of the blank box are coded by ODPM as one of:

- Accelerant,
- Backdraught,
- Flashover,
- other specified or
- no details specified.

As flashover is a term that has been used more generally in the past, it may be that some incidents marked as flashover are more correctly backdraughts. Also, some incidents encountered by firefighters, such as an explosion caused by a gas leak or by the heating of a sealed propane container, may be indistinguishable from backdraughts and may be wrongly recorded as backdraughts.

Table A1 shows an analysis of FDR1 data for the 3 years: 1999, 2000 and 2001 and the response to question 'Abnormal rapid fire development?'. As the table shows, reported backdraughts are a fairly rare occurrence, with an estimated frequency of little over 50 per year for the UK as a whole. About 50% of these reports are for fires in dwellings.

From Table A1 it can also be seen that backdraughts are reported more frequently in dwelling fires (453 reports of backdraught per million fires) than in fires in other buildings (341 backdraughts per million fires).

The remaining tables in Appendix A refer to an analysis of FDR1 data over the period 1994–2001 inclusive, collected by Fire Statistics and Social Research Section of ODPM. During the data entry process carried out by Fire Statistics and Research Section, the data is sampled. Typically data from 1 in 5 FDR1 forms are sampled and entered in the database, but the sampling rate depends on the circumstances of the fire. For instance, all fires involving casualties are included. Each data record includes a weighting factor that indicates its sampling rate. Estimated totals of any parameter, such as the number of fires, can be determined by multiplying the value for each data record by that record's weighting factor before summing for all records. The tables in Appendix A refer to numbers of records sampled rather than the total number of fires unless 'weighted total' is specified.

Table A2 shows the number of fires where a backdraught was reported, by type of property. This table shows that backdraughts have been reported in a range of property types, some of the more common being dwellings, offices, sports facilities, private garages and single shops. Significant numbers of backdraughts have also been reported for car fires.

Table A3 shows the number of fires and casualties where a backdraught was reported, over the period 1994–2001 inclusive. For fires, both the number of sampled records and the estimated total is given. For casualties, all data is included in the database so only the total figures are given. The total number of fires has averaged around 50 per year over the period, with somewhat higher numbers in recent years. The number of casualties has averaged 5.5 fatal and 28 non-fatal per year. The number of casualties per thousand fires where backdraught was reported can be estimated at 104 fatal and 524 non-fatal.

One might expect a greater frequency of casualties from fires where backdraught is reported than from other fires in buildings. To determine whether this is the case, the FDR1 data from the year 2000 was analysed (see Table A4). After removing records where information on backdraughts and casualties was not available, an estimated total of 219,473 FDR1 records for that year were analysed. The table analyses the numbers of fires depending on whether a backdraught was reported or not and on whether any casualties were reported or not. The table also shows the results of a Chi-squared test to determine any correlation and its significance. This test shows that there is a strong likelihood that there is a relationship between the two variables, or in other words, in fires where a backdraught is reported, there is more likelihood that casualties are reported. However, it cannot be assumed from this that one is necessarily the cause of the other.

Table A5 shows the numbers of casualties of brigade personnel in fires where backdraught was reported. There were no fatal casualties reported for these fires, but there were a total of 34 non-fatal casualties in 24 fires. Although the casualties are classified by the nature of the injury, it is not possible to determine the severity from these figures. The two firefighter fatalities which occurred at Blaina in 1996 are not included as this incident was classified on the FDR1 form as a flashover. Similarly, the firefighter fatality in a supermarket in Bristol in 1996 is not included for the same reason.

11 Fire incidents where a backdraught or similar event has been reported

11.1 UK

11.1.1 Private Cinema Club, London, February, 1994.

Grimwood [Ref. 33] reports a backdraught occurring at the fire on 26 February at a Private Cinema Club in London where there were several fatalities:

> 'The classic "roaring" sounds experienced by firefighters attempting to reach the upper floors by the interior stair-shaft demonstrated a backdraft situation where fire gases were burning off in the shaft as air rushed in from the access doorway.'

11.1.2 Blaina, February 1996.

A fire involving a backdraught or similar event occurred in Blaina, Gwent on 1 February 1996. From the FDR1 form returned by the brigade [Ref. 34], the fire is thought to have started in the ground floor kitchen of the two-storey house. Three pumps and four main jets were used. An abnormal fire development was recorded by the brigade and it was estimated that 100% of the building was damaged. Two firefighters were killed in their efforts to rescue those inside and a five year old child died upstairs, trapped by smoke.

Grimwood [Ref. 23] writes:

> 'The subsequent HSE investigation led to the issue of improvement notices suggesting deficiencies in training and a lack of awareness of fire growth and development amongst the firefighters on scene contributed to such a tragic outcome'.

The HSE notice is described in Section 6.1 of this review. The sequence of events reported by Grimwood includes:

05:48	Occupier discovered fire in ground floor kitchen at the rear of the premises.
06:00	Entire building smoke-logged despite containment in kitchen.
06:05	Kitchen window failed.
06:11	1st crew of two firefighters wearing BA enter property at front with hosereel.
06:13	1st BA crew out of property with one child found.

06:15 Fire breaks through kitchen ceiling to first floor.

06:15 Backdraught occurs engulfing entire house in flames on both ground and first floors.

Grimwood describes two possible explanations for the incident:

(i) the fire in the kitchen was contained behind a closed door until it burnt through the ceiling and ignited the combustible gases that had built up on the upper floor and

(ii) the fire started in the kitchen but the kitchen door was open and when the front door was opened, a gravity current entered, and a backdraught occurred with flames travelling from the kitchen up the stairs, possibly igniting further fire gases upstairs.

The first explanation is a smoke gas explosion as defined by Karlsson and Bengtsson (Section 5.1) rather than a backdraught, as ignition has been delayed by the lack of an ignition source rather than lack of oxygen. The second explanation is a true backdraught.

11.1.3 Bristol, 1996.

Grimwood [Ref. 33], describes the fire in February, 1996:

> 'Just three days later [than the fire at Blaina] another firefighter (female) was killed by an ensuing backdraught that occurred in a large super-market in Bristol.'

He writes that a heavy black smoke layer was seen which was continually rising and falling. He describes how the ignited gases moved across the store both under and within the suspended fibre-board ceiling and the accompanying pressure wave which knocked one firefighter off his feet. If this is a case of a genuine backdraught, this shows that backdraughts can occur in large compartments as well as small ones. The estimated area damaged by direct burning was indicated on the FDR1 form as 3,350 m^2.

11.1.4 Building Research Establishment (BRE), Review of FRS Fire Investigation Summaries, 1988 – 2003.

Under their contract with the ODPM titled 'Investigations of Real Fires', the Building Research Establishment investigate unusual fires, including where the fire spread has been unusual. For this review of backdraught, BRE were asked to review their fire investigation reports for evidence of firefighters being injured by backdraught-like incidents. A total of 572 fire reports were reviewed over the period 1988–2003. It should be emphasised that this review does not include all occurrences of backdraughts but only those that occurred in fires selected for investigation.

Of the 572 fire reports reviewed, only five were found where possible or probable backdraughts were reported. No unusual aspect of building design could be identified that would produce an unexpected backdraught scenario.

11.2 Abroad

11.2.1 NFPA Statistics on Firefighter Fatalities, 2001

The NFPA collects information on firefighter casualties in the USA. Fahy [Ref. 35] reports a total of 99 on-duty firefighter fatalities in 2001 at incidents other than the World Trade Centre. Of these, the cause was reported as ‘caught by rapid fire progress or explosions’ for 16 firefighters, of which 11 were at structure fires and 5 were on ‘wildland fires’. However, the report does not identify whether any of these incidents involve backdraught.

11.2.2 Lenox Avenue, Manhattan, June 1990

Dunn [Ref. 36] reports an incidence of a backdraught on the sixth floor of a seven storey tenement in Manhattan. The fire originated on the fifth floor, involving an entire apartment. The fire had burned undetected for several hours and during this time smoke seeped through the burned floor boards into the apartment directly above. When firefighters entered the sixth floor apartment, bringing in fresh air, the apartment exploded. Dunn reports that ‘one firefighter was burned around the mask face-piece, and the other shaken firefighter was rescued from a window.’ Dunn mentions the new double-glazing creating a tightly-sealed apartment where the fire originated as a possible factor as it kept the heat, fire and smoke in the apartment. Dunn warns that occupancies above and on each side of the fire must be considered potential backdraught hazards to firefighters.

11.2.3 Watts Street, New York, 28 March, 1994

Bukowski [Ref. 37] reports on a backdraught incident at a three-storey apartment building in Manhattan resulting in the deaths of three firefighters:

> ‘When the door to the first floor apartment was forced open, a large flame issued from the apartment and up the stairway, engulfing the three firefighters at the second floor landing. The flame persisted for at least 6½ minutes, resulting in their deaths’.

The Fire Department of New York asked the National Institute of Standards and Technology (NIST) to investigate the incident in the hope of finding out why a backdraught of such a duration occurred. NIST modelled the incident using the zone model CFAST with which they were able to reproduce the observed conditions. They showed how a backdraught of such a long duration could have been caused by the accumulation of unburned fuel from a vitiated fire in the apartment which had been insulated and sealed for energy efficiency. However, some effects relating to pyrolysis and combustion cannot be modelled with CFAST, and Bukowski states that ‘the quantity of unburned fuel could be overpredicted’ and that ‘such overprediction would tend to increase the duration of the door flame'. In the simulation, the front door was opened about 20 minutes after the fire had become vitiated, resulting in a backdraught with temperatures in the stairway of over 1200°C.

Another possibility is that only an initial part of the $6^1/_2$ minute period was a backdraught and that the rest of the period of the flame was due to burning of the room contents in a flashover.

11.2.4 Basement Fire in ranch-style home, 5 February 1998.

Baldwin [Ref. 38] describes a fire in a basement of a 'ranch-style home' in February 1998, which 'claimed the lives of two firefighters, and nearly killed three more'. The location of the property is unspecified. The fire was discovered in a suspended ceiling in the basement and when a firefighter lifted a ceiling tile, a backdraught occurred. The situation was made worse by the fact that a hoseline had earlier become caught in the legs of a metal folding chair which had collapsed, pinching off the water supply. Baldwin gives reasons why basement fires can present a greater hazard to firefighters: fires of greater intensity, lack of natural ventilation, presence of stored inflammable materials which may pose an explosion or toxic inhalation hazard, presence of electrical circuit breaker or fuse box and limited access to firefighters.

A further account of this fire is given by the National Institute for Occupational Safety and Health [Ref. 39] which also lists recommendations to prevent future similar incidents. These include: first arriving 'engine company' acting as a 'command company' and conducting an initial scene survey, implementation of an incident command system with written standard operating procedures and provision of a back-up hose crew.

11.2.5 Tyre Service Centre, 11 February 1998

This fire occurred in a commercial tyre service centre and claimed the lives of two firefighters [Ref. 40]. Eight to ten firefighters entered the showroom adjoining the service area, observing only a light haze. When they entered the service area, black smoke was encountered covering the top third of the ceiling space but with no visible fire. Other firefighters went to the front and rear of the building and cut ventilating holes in the roof. They noticed that the windows were dark and smoky (one of the indicators of a potential backdraught). The report by the National Institute for Occupational Safety and Health states:

> 'Within minutes [of entering] all fire fighters in the interior of the building were caught in a hazardous backdraft that claimed the lives of two fire fighters, and nearly claimed all those who were inside. NIOSH investigators concluded that in order to prevent similar incidents, incident command must anticipate all possible circumstances which may be present in anticipation of rare and unexpected developements.'

In describing the backdraught event, the report states:

> '… without warning, the hot gases that had accumulated along the 20-foot high ceiling ignited, causing a backdraft situation. This created a pressure wave, knocking the fire fighters off balance and to the floor.'

The report suggests that:

> 'before the time of ignition, the overhead garage door into the service area was self-activated and raised, allowing additional air to fuel the fire … … the drive chain assembly had definitely opened electrically as a result of the fire shorting out the low voltage side of the switch wires.'

The report makes recommendations on ventilation tactics and warns against firefighters entering buildings during ventilation where there is a potential for backdraught or flashover as evidenced by smoke-stained windows and puffing smoke at vents.

11.2.6 Cherry Road, Washington D.C., May 1999

This fire is described in a report by NIST [Ref. 41] who carried out a simulation of the fire using the CFD model 'FDS', developed by NIST. In this fire, two firefighters were killed by a rapid fire development. The fire began in the basement of a townhouse and was largely confined behind sliding glass doors although the first (ground) floor contained heavy smoke. The occupants were alerted by their smoke alarm shortly after midnight and left the building, leaving the front door and upstairs windows open. When the firefighters arrived they descended to the basement and broke open the sliding glass doors. About two minutes later 'an intense blast of heat' was reported by firefighters on the first floor. Two firefighters working on the first floor died from injuries caused by the fire and a third firefighter survived but sustained substantial burn injuries. Post-fire investigation showed that the fire started near an electrical fixture in the ceiling of the basement.

The NIST report does not refer to this event as a backdraught but says: 'The FDS calculation indicates that the opening of the basement sliding glass doors provided outside air (oxygen) to a pre-heated, under-ventilated fire compartment, which then developed into a post-flashover fire within 60 s.' They also calculated that the upper hot gas layers in the basement and on the first floor contained less than 6% oxygen by volume.

A detailed account of this fire is given by NIOSH [Ref. 42].

11.2.7 Paris, France, 14 September 2002

Five firefighters were killed tackling a blaze in a building in Paris. The following is reported on the 'Firetactics' web-site [Ref. 43]:

> 'Two "explosions" that occurred ten minutes apart in an apartment block in Neuilly-sur-Seine, Paris on the evening of 14 September 2002, took the lives of five firefighters. Investigators are now suggesting that two backdrafts most likely resulted as firefighters

attempted to gain entry to a "routine" one room smouldering fire. It is the biggest single loss in the Paris fire department's history, the Associated Press reported. There are distinct similarities with a fire that took the lives of three NYC firefighters in 1994. The first explosion injured two firefighters and three more were hurt in a second blast as they tried to reach their colleagues. All five were taken to a nearby hospital where they died from their injuries. Local gas authorities are stating that the room involved was not fed with gas and all other supplies in the building remained unaffected.'

11.2.8 Sycamore, Illinois, USA, 9 February 2004

A backdraught, reported on the 'Firetactics' web-site [Ref. 43], 'blew apart' a church in Illinois and has been named the largest backdraught ever documented in the US. The backdraught knocked flat eight firefighters on the scene who thought they were responding to a simple rekindle from a fire the day before. Two firefighters were injured including one who nearly lost his leg due to a severed artery when he fell from a ladder. The sanctuary where the backdraught occurred was located below the main church area and measured 80 by 150 feet.

11.2.9 Pittsburgh, USA, February 2004

A second backdraught in the same week occurred at a church in Pittsburgh, USA. As reported on the 'Firetactics' web-site [Ref.43]: 'Five firefighters suffered burns and broken bones early in the fire when they broke through an interior wall, sparking a *backdraft* that blew the firefighters out the front door'. Two firefighters were later killed by a collapse of the structure when they entered the building several hours later.

12 Review of Smoke Ventilation of Basements

In May 2004, the Building Disaster Assessment Group who initiated this review, requested Howard Morgan of International Fire Consultants Ltd to carry out a review of smoke ventilation in basements [Ref. 44]. The review describes the different methods available for ventilating basements in the event of a fire including smoke and heat exhaust ventilation systems, pressurisation and depressurisation systems, natural cross-ventilation and smoke shafts using wind suction at roof level. The review makes a number of recommendations on the appropriateness of different systems for different basement geometries. The conclusions and recommendations from the review by Morgan are as follows:

- Basements have a variety of geometries, requiring a variety of smoke control solutions.
- Large undivided volume basements are best protected by Smoke and Heat Exhaust Ventilation Systems (SHEVS) where the ceiling is high enough.
- SHEVS can be designed to keep a smoke layer above access doors where the ceiling height permits.
- SHEVS can be designed with layer bases below the top of doors (as in Section 20 buildings at present) but only where there is always a closed door between the smoke and the stairwell used for access and/or escape. This may not always be feasible.
- SHEVS solutions will usually require sprinklers to limit fire growth.
- BRE (Building Research Establishment) 'open-bottomed' smoke shafts can be used, with dampers opening from common ducts to reduce the areas needed rising through the building, to produce a pressure difference at selected doors. These may be stairwell doors, lobby doors, corridor doors, or the fire-room door itself, or even a combination of these.
- Depressurisation as described in BS 5588-4 is the most effective option for protecting stairwells accessing basements, even more so than pressurisation described in the same standard. It is recommended that the present requirement for pressurising fire-fighting shafts deeper than 10 m (see BS 5588-5) be amended to allow and to encourage the depressurisation option being adopted.
- Any smoke control system preventing backdraft risks allowing flashover. Any smoke control system preventing flashover risks allowing backdraft.
- Sprinklers as part of the smoke control package should prevent both flashover and backdraft.

- Sprinklers should be fitted in deeper basements. Perhaps the same 10 m criterion could be used as for pressurising fire-fighting shafts?
- The use of natural vents at ground level creates uncertainty in operational fire-fighting as to what should be opened to avoid adverse wind-pressure effects.
- It is suggested that only powered exhaust should be allowed at ground level.
- All natural exhaust should be taken to the top of the building.

13 Conclusions

Previous and current research. A number of research projects have been carried out on backdraught in recent years and further research is underway. However, there is still some way to go before we have a thorough understanding of backdraught and the factors that effect its likelihood of occurrence and severity.

Firefighter guidance and training. The fires at Blaina and Bristol in 1996 resulting in firefighter fatalities brought the issue of backdraught to the fore in the UK. Following these events, revised guidance was issued to brigades in Fire Service Manual Volume 2 [Ref. 1] with specific reference to backdraught and flashover. Also, firefighter training has been extended in recent years to cover rapid fire development, backdraught and flashover and the use of real fire simulators.

Basements. The design of buildings for fire safety, including features such as compartment sizes, smoke ventilation, smoke detection systems and sprinkler systems, will affect the likelihood of occurrence and severity of a backdraught. Venting of basements is a problem due to the lack of natural openings and a particular concern is the guidance on this in the UK Building Regulations [Ref. 24] that allows some spaces in basements to be vented indirectly by firefighters opening connecting doors. Installation of smoke control and sprinkler systems would improve safety for both firefighter and occupant [Ref. 44].

Compartments above ground. Compartments above ground may also present a problem where there is a lack of windows for security purposes or where all windows are closed and remain in place during a fire. Information on the response of glazing systems exposed to under-ventilated compartment fire conditions would help to show the extent of this problem and work on this issue is planned in the FIRENET project [Ref. 18].

Well-sealed buildings. Modern building practices such as the installation of well-sealed windows and doors and highly insulated walls may increase the likelihood and severity of a backdraught occurring in the event of a fire. Since 1990 the regulations on ventilation [Ref. 25] have specified a level of background ventilation to control humidity and toxins, and this may also have an effect in the event of a fire. However, it has not yet been determined what effect these factors have on a fire and on the likelihood and severity of a backdraught. Also, the picture is complicated by the fact that the regulations do not apply retrospectively and that different regulations will have applied for buildings of different ages. For instance, buildings put up before 1990 may not be designed with background ventilation but may be fitted with well-sealed windows and doors.

Existing buildings. Review of the guidance to the Building Regulations would only affect the design of new buildings and alterations to existing buildings. Improvement in the safety of firefighters in existing buildings might be achieved by a better understanding of backdraught, allowing development of alternative firefighting tactics.

Fire incidents. This review has described a number of fire incidents involving backdraught over recent years. These incidents have occurred in a variety of buildings: several in domestic premises but also in a supermarket, a tyre service centre and a cinema club, where the compartment sizes may be larger. Although the phenomenon is more widely known and understood in the last few years than previously, backdraughts have continued to take the lives of firefighters, most recently in the Paris incident in 2002 and further firefighter injuries occurred in Illinois, USA, in February 2004.

14 Recommendations

14.1 Recommendations from literature review

- Guidance in the Building Regulations [Ref. 24] on venting of basements should be reviewed as it allows some spaces in basements to be vented indirectly by firefighters opening connecting doors. This action is likely to be a particularly serious hazard to firefighters, leaving them vulnerable to a backdraught, with no easy exit.

- Building Regulations Approved Document B Section 19.8 [Ref. 24] specifies a vent area for natural smoke outlets of 'not less than 1/40th of the floor area' for basements, for use by firefighters on arrival. This figure does not appear to be based on any documented evidence of its effectiveness. Research, by experiment, modelling or otherwise, may be worthwhile therefore to determine:

  - whether this area allows for effective clearance of smoke and

  - whether there is a range of vent areas which allow for effective clearance of smoke and at the same time minimise the likelihood and severity of backdraught caused by opening the vent.

  Also, see final three recommendations in Section 14.2.

- It would be worthwhile investigating by experiment and modelling whether the amount of background ventilation and insulation in modern buildings has a significant effect on the development of conditions which may cause a backdraught. This investigation could form part of a larger piece of work on modern well-sealed buildings, looking at:

  - the hazard from exposure to high levels of toxic gases produced by vitiated fires, and

  - the possible health hazards in the daily environment in the building due to lack of ventilation, for instance due to humidity or the build up of toxic gases.

- Further research to obtain a better understanding of the physical processes involved in backdraught would be worthwhile. The FIRENET project described in Section 5.4 is an example of work already underway in this area. Once a better understanding of backdraught has been obtained, it will be possible to evaluate alternative firefighting tactics for use at incidents where a potential for backdraught is diagnosed. Such tactics include the cutting extinguisher under development in Sweden (see Section 5.2) and controlled venting suggested by FSRD (Section 4.4).

- Before implementing any changes to building designs or firefighting practices to reduce the risks of backdraught, the effect on other possible means of rapid fire development such as flashover or gas explosions should be considered.

14.2 Recommendations from 'Smoke Ventilation of Basements' review

The following are key recommendations made by Morgan [Ref. 44] in his review 'Smoke Ventilation of Basements':

- Large undivided volume basements are best protected by Smoke and Heat Exhaust Ventilation Systems (SHEVS) where the ceiling is high enough, but SHEVS solutions will usually require sprinklers to limit fire growth.

- Depressurisation as described in BS 5588-4 is the most effective option for protecting stairwells accessing basements, even more so than pressurisation described in the same standard. It is recommended that the present requirement for pressurising fire-fighting shafts deeper than 10 m (see BS 5588-5) be amended to allow and to encourage the depressurisation option being adopted.

- Sprinklers should be fitted in deeper basements. Perhaps the same 10 m criterion could be used as for pressurising fire-fighting shafts?

- It is suggested that only powered exhaust should be allowed at ground level.

- All natural exhaust should be taken to the top of the building.

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Appendix – Analysis of FDR1 data

Based on the sampled FDR1 records provided by Statistics Group, the following analyses were made. In all cases the data refers to numbers of records available after sampling rather than the total numbers for all completed FDR1s unless 'weighted total' is specified.

Table A1. Primary fires by location and abnormal development, UK, 1999–2001

Response to question 'Abnormal rapid fire development?' (*)						
	Abnormal rapid fire development?'	Total	Dwellings	Other Buildings	Road Vehicles	Other
1999	Total fires	218,404	72,228	43,685	90,111	12,380
	No	213,166	71,226	42,640	87,180	12,119
	Yes – Accelerant	4,275	682	669	2,740	184
	Yes – Backdraught	59	32	15	12	0
	Yes – Flashover	187	79	82	10	17
	Yes – other specified	421	131	170	77	43
	Yes – no details specified	296	78	108	93	17
2000	Total	219,535	70,897	41,747	94,827	12,064
	No	213,937	69,921	40,978	91,273	11,764
	Yes – Accelerant	4,567	649	483	3,266	168
	Yes – Backdraught	87	34	15	37	1
	Yes – Flashover	176	79	53	19	25
	Yes – other specified	435	140	158	96	42
	Yes – no details specified	270	70	49	130	21
	Unspecified	62	4	11	6	42
2001	Total	228,136	68,976	43,547	102,057	13,556
	No	222,044	68,117	42,780	97,958	13,189
	Yes – Accelerant	5,108	562	457	3,880	209
	Yes – Backdraught	55	30	14	6	5
	Yes – Flashover	101	53	19	13	17
	Yes – other specified	436	116	152	105	63
	Yes – no details specified	298	78	105	90	25
	Unspecified	94	21	21	4	48
1999- 2001	Backdraughts per million fires	302	453	341	192	158

* The figures above are taken from FDR1 data, weighted to account for sampling used by Fire Statistics and Research Group, e.g. 1 in 5 FDR1 forms are sampled for some cases. The sampled number is then multiplied by a weighting to estimate the total figure.

Table A2. Number of fires where backdraught was reported by type of property (1994–2001)		
Category	**Type of Property**	**Total (weighted)**
Dwellings	Caravan	1.0
	Dwelling, not fully specified	44.4
	Flat, conversion	8.5
	Flat, purpose built, sheltered	7.2
	Flat, purpose-built	39.5
	House, detached	14.0
	House, semi-detached	64.6
	House, semi-detached (sheltered)	2.0
	House, terraced/end of terrace	85.2
	Mobile home	5.0
Dwellings Total		**271.5**
Other	Building not specified	7.2
	Small craft (water)	1.0
Other Total		**8.2**
Other Buildings	Agricultural buildings	4.3
	Block accommodation	1.0
	Building of worship	3.0
	Casino	1.0
	Derelict building	2.0
	Hotel, boarding house, guest house	3.0
	Industrial premises	7.0
	Offices	10.7
	Other building	10.7
	Other private non-residential building	1.0
	Other sports facilities	11.8
	Outdoor storage (paper/cardboard)	1.0
	Private garage	17.4
	Private shed or greenhouse	1.0
	Public houses	1.0
	Public lavatories	1.0
	Railway station building (above surface)	1.0
	Restaurant	3.0
	Schools etc	2.0
	Shopping mall/centre/indoor market	5.0
	Single shop	16.7
	Social clubs	1.0
	Sports clubs etc	9.8
	Supermarket	5.0
	Warehouse	7.3
Other Buildings Total		**127.7**
Road	Car	16.0
	Lorry	1.0
Road Total		**17.0**
Grand Total		**424.4**

Table A3. Numbers of fires and casualties where backdraught was reported (1994–2001)

	Fires		Casualties (*)	
Year	Number of records where backdraught was reported	Estimated Total (weighted)	Fatal	Non-fatal
1994	26	44	5	20
1995	33	41	4	35
1996	25	40	5	33
1997	28	68	6	30
1998	22	30	6	28
1999	33	59	8	24
2000	35	87	1	35
2001	24	55	9	17
Total	226	424	44	222

* For casualties, all data is included in the database so the total figures are given.

Table A4. Numbers of Fires where there are Casualties (Year 2000 only)

		Any casualties?		Total
		No	Yes	
Backdraught reported?	No	207,041	12,345	219,386
	Yes	72	15	87
Total		207,113	12,360	219,473[1]
		Value	**Sig.[2]**	
Pearson Chi-square		22.073	0.000	

[1] This total excludes an estimated 62 cases where the categorisation is not known.
[2] The significance gives the estimated probability of obtaining a difference at least as large as the one observed if there was no relationship between the two variables.

Table A5. Casualties of brigade staff in fires where backdraught was reported (1994–2001)

There were 24 fires in all where there were both casualties of brigade staff and where backdraught was reported. In these fires, the following casualties were reported.

Category	No. of casualties
A – Overcome by gas, smoke or toxic fumes, asphyxiation	2
B – Burns or scalds	18
C – Physical injuries including cuts, abrasions, bruises, dislocation, sprains and fractures	8
P – Precautionary check-up	6
Total	**34**