FRDG Publication Number 6/94

HOME OFFICE

A Survey of Fire Ventilation

A Hay
Warrington Fire Research Consultants

FIRE RESEARCH & DEVELOPMENT GROUP

Pub No 6/94 A Survey of Fire Ventilation

FRDG

FRDG

Home Office
Fire Research and Development Group

A SURVEY OF FIRE VENTILATION

BY

A HAY

WARRINGTON FIRE RESEARCH CONSULTANTS

FRDG Publication Number 6/94
ISBN 1-85893-193-2

Home Office
Fire Research and Development Group
Horseferry House
Dean Ryle Street
LONDON
SW1P 2AW

ABSTRACT

Starting in September 1993, Warrington Fire Research Consultants (WFRC) undertook a survey of the tactical venting of large-scale fires for the Fire Experimental Unit (FEU) of the Home Office Fire Research and Development Group (FRDG).

The survey revealed that natural vertical and horizontal ventilation techniques are used throughout the USA in the early stages of fire attack. However, the use of Positive Pressure Ventilation (PPV) is not universal and operational research is still ongoing. It was difficult to obtain a clear picture of how frequently ventilation is employed during fire attack in the UK. Most brigades state that they do not promote the tactic but that it is used by some experienced officers when they are confident of the outcome of their actions.

Ventilation tactics are ingrained in the US system and it appears that a need has never been felt to prove or demonstrate the merits through theoretical or practical research. Although further research will be required in the UK to quantify and demonstrate the operational benefits, and develop safe working practices, it is believed that there is scope for more extensive application of ventilation tactics in the UK.

Tactical ventilation is not a solution for all problems but simply another tool for use on the fireground.

MANAGEMENT SUMMARY

INTRODUCTION

Starting in September 1993, Warrington Fire Research Consultants (WFRC) undertook a survey of the tactical venting of large-scale fires for the Fire Experimental Unit (FEU) of the Home Office Fire Research and Development Group (FRDG).

The 3 month survey formed the first stage of a research programme to assess the merits of tactical ventilation as a means of reducing large fire losses. Subsequent stages will involve a quantification of the benefits of ventilation by practical and theoretical means. If it is established that tactical ventilation is useful then further work will be required to develop safe working practices prior to its implementation by the UK Fire Service.

BACKGROUND

Definitions

During the course of the survey it was established that no clear distinction could be made between the terms *ventilation* and *venting*. Both terms were instead considered to synonymously describe:

> "the planned and systematic removal of heated air, smoke, or other airborne contaminants from a structure and their replacement with a supply of fresher air."

For firefighting this will entail the removal of the products of combustion, which may include hot, flammable gases and smoke.

Two further definitions were adopted:

1. automatic ventilation - which involves the use of pre-installed roof vents activated automatically, usually at an early stage of the fire, by the fire detection system or fusible link devices;

2. tactical ventilation - which requires intervention by the fire service to "open up" the building and release the products of combustion. This usually takes place at a later stage than automatic ventilation but can involve the use of pre-installed vents.

For the purposes of this study, consideration was focused on the application of tactical ventilation prior to control and extinction of the fire.

SURVEY PROCEDURE

A comprehensive information-gathering exercise was undertaken to survey the state of the art of venting worldwide. The key elements of this exercise were:

(1) computer database searches
(2) library visits
(3) questionnaires to UK and overseas fire services
(4) UK contacts
(5) USA visit and meetings
(6) other overseas contacts.

CONCLUSIONS

Fire Ventilation in the USA

The three most commonly applied techniques of tactical ventilation are:

top or vertical ventilation, achieved by making holes in the roof such that the buoyancy of the combustion products enables them to vent vertically;

cross or horizontal ventilation, achieved by making openings in the external walls (e.g. via windows and doors) such that external wind forces and fire gas buoyancy assist in the removal of combustible products;

Positive Pressure Ventilation (PPV), achieved by using high-volume-flowrate fans to direct the flow of combustible products.

Natural vertical and horizontal ventilation techniques are used extensively throughout the USA in the early stages of fire attack but the use of PPV is not universal and operational research is ongoing. The tactics are ingrained in the US system and it appears that a need has never been felt to prove or demonstrate the merits through theoretical or practical research.

There is a strong belief amongst US fire departments that vertical ventilation is the most appropriate method of venting large single-storey industrial buildings.

The scope for horizontal ventilation is normally limited by the availability of openings and the danger of spreading fire through the building.

Opinion differs over the use of PPV. Some feel that the large volumes of these buildings and the lack of convenient openings limit its practical application.

In multi-storey industrial buildings vertical ventilation is used only if the fire involves the upper floor. Cross ventilation is employed to deal with fires on the lower floors. Some departments use PPV to supplement cross ventilation or to pressurize other floors and limit smoke ingress.

The general advice offered in the US is to vent early and often, provided that it can be achieved safely and that charged hoselines are available to counter any consequential increase in fire severity.

Training literature on ventilation tactics exists in the USA and particular emphasis is also placed on practical and classroom training to instill in firefighters an understanding of fire behaviour and the methods of building construction.

Fire Ventilation in the UK

In the UK it is difficult to obtain a clear picture of how frequently ventilation is employed during fire attack. Most brigades state that they do not promote the tactic but that it is used by some experienced officers when they are confident of the outcome of their actions. However, many UK firefighters have experienced the benefits of ventilation whilst attending fires which have self vented and a strong interest is developing in the use of such tactics, especially PPV.

Cross ventilation (e.g. using openable windows on stairways) is commonly practised but vertical ventilation is not widely used. The practice of vertical ventilation from aerial appliances is being developed by some brigades.

A small number of brigades are conducting trials in the use of PPV, although reports of its use during firefighting operations are limited.

Scope for Further Implementation in the UK

Tactical ventilation, and in particular PPV, is not a panacea for all problems but simply another tool at the disposal of the Officer in Charge. Subject to further research, aimed at quantifying the potential operational benefits and developing safe working practices, it is felt that there is scope for more extensive application of ventilation tactics in the UK.

In large industrial buildings it may not be safe to commit firefighters to offensive roof top operations and consideration may need to be given to the use of aerial appliances, pre-installed vents or defensive operations instead. (Defensive operations are considered to be safer than offensive ones because they are carried out away from the seat of the fire.)

Defensive trench or strip cutting could also be more extensively used in commercial units and terraced properties where there is a risk of concealed horizontal flame extension at roof level.

In high-rise buildings there may be scope for the use of PPV fans to pressurize stairways and corridors and afford protection against the ingress of smoke. US experience suggests that there is little scope for natural ventilation in many instances because of the difficulties created by wind and stack effects.

In low-rise residential buildings consideration should be given to the benefits of channelling smoke into stairways, even though this may be alien to UK firefighters. PPV appears to be a method of tactical ventilation that would be well suited to this type of compartmented building and especially two storey residential premises.

US fire departments place great emphasis on training specifically aimed at ventilation techniques and before a more widespread introduction of tactical venting in the UK, detailed procedures and training schemes would need to be developed.

Basic Theory and Modelling

The majority of scientific, theoretical and experimental research has been directed toward developing a better understanding of ventilation for the purposes of designing automatic systems. Consequently, the theory of venting hot gases from a stratified smoke layer is generally well established but the theory of cross ventilation and forced ventilation, where considerable mixing of fresh air and smoke is likely to occur, is not well understood. Theory to describe the interaction between venting and water attack, and the potential implications in backdraught and flashover situations, is also not well established.

It may be possible to make use of computer modelling to develop a better understanding of the effects of tactical ventilation. However, at present, there are no theoretical models to describe the effect of ventilation on lateral fire spread at roof or floor level. Large scale experimental data may exist but detailed analysis has not been undertaken.

RECOMMENDATIONS

On the basis of this study it is considered that further work is required to:

(a) demonstrate the effectiveness of tactical ventilation procedures by modelling and large scale tests;

(b) develop procedures appropriate to UK conditions;

(c) provide firefighter training and ensure safe implementation.

TABLE OF CONTENTS

		PAGE
1	**INTRODUCTION**	1
2	**BACKGROUND**	3
	2.1 Definition of Ventilation	3
	2.2 Advantages of Ventilation	4
	2.3 Automatic Ventilation	5
	2.4 Tactical Ventilation Techniques	6
3	**SURVEY OF VENTING**	7
	3.1 General	7
	3.2 Computer Database Searches	7
	3.3 Library Visits	7
	3.4 Questionnaires	7
	3.5 UK Contacts	8
	3.6 US Contacts	8
	3.7 Other Overseas Contacts	9
	3.8 Additional Information	9
4	**TACTICAL VENTILATION TECHNIQUES**	10
	4.1 General	10
	4.2 Ventilation Considerations	10
	4.2.1 Introduction	10
	4.2.2 Assessing rescue/life hazards	10
	4.2.3 Determining the location and extent of the fire	11
	4.2.4 Identifying building construction features	11
	4.2.5 Is there a need for ventilation?	12
	4.2.6 Where is ventilation needed?	12
	4.2.7 How should ventilation be accomplished?	12
	4.3 Ventilation Tactics	13
	4.3.1 Cross or Horizontal Ventilation	13
	4.3.2 Top or Vertical Ventilation	14
	4.3.3 Forced Ventilation	15
	4.4 Ventilation Requirements	18
	4.4.1 Organization and Personnel	18
	4.4.2 Equipment	19

5 **TACTICAL VENTILATION FOR COMMON BUILDING TYPES** 21

5.1 General 21
5.2 Single-storey Warehouse/Industrial Building 21

5.2.1 Considerations 21
5.2.2 Tactics 22
5.2.3 Discussion 24

5.3 Two-storey Warehouse/Industrial Building 25

5.3.1 Considerations 25
5.3.2 Tactics 26
5.3.3 Discussion 26

5.4 Small Commercial Units 26

5.4.1 Considerations 26
5.4.2 Tactics 27
5.4.3 Discussion 28

5.5 High-rise Buildings (Seven storeys or more) 28

5.5.1 Considerations 28
5.5.2 Tactics 29
5.5.3 Discussion 30

5.6 Low-rise Apartments (Less than seven storeys) 30

5.6.1 Considerations 30
5.6.2 Tactics 31
5.6.3 Discussion 31

5.7 Two-storey Residential House 32

5.7.1 Considerations 32
5.7.2 Tactics 32
5.7.3 Discussion 33

5.8 Summary 33

6 **FIRE VENTILATION IN THE UK** 36

6.1 Summary of Questionnaire Response 36
6.2 Meetings with the UK Brigades 36
6.3 Other Contacts 37

7 **FIRE VENTILATION IN THE USA AND OVERSEAS** 39

7.1 Summary of Questionnaire Response 39

7.1.1 US Response 39
7.1.2 Overseas Response 40

7.2 Meetings with US Fire Departments 40
7.3 Other Contacts 41

8 BASIC THEORY OF VENTILATION 42

8.1 Ventilation Research 42

8.1.1 Introduction 42
8.1.2 Early Research 42
8.1.3 Recent Research 43
8.1.4 Sprinklers and Ventilation 44
8.1.5 PPV Research 46

8.2 Ventilation Theory 46

9 MODELLING OF FIRE VENTILATION 48

9.1 General 48
9.2 Theoretical Modelling 48

9.2.1 Field models
9.2.2 Zone models 48
9.2.3 Network models 49

9.3 Physical Modelling 49

9.3.1 Scale modelling 49
9.3.2 Simulation modelling 50

10 CONCLUSIONS 51

10.1 Assessment of Advantages and Disadvantages 51
10.2 Ventilation Practice in the USA 53

10.2.1 Tactical ventilation techniques 53
10.2.2 Large industrial buildings 53
10.2.3 Other building types 53
10.2.4 Training 54

10.3 Ventilation Practice in the UK 55
10.4 Scope for Further Application of Venting in the UK 55

10.4.1 Large industrial buildings 55
10.4.2 Other building types 56

10.5 Theory and Research 56
10.6 Summary 57

11 RECOMMENDATIONS FOR FURTHER STUDIES 59

11.1 General 59
11.2 Effectiveness of Tactical Ventilation Procedures 59

11.2.1 Introduction 59
11.2.2 Vertical ventilation 59
11.2.3 Positive pressure ventilation 60

11.3 Development of Procedures 61
11.4 Implementation 61

ACKNOWLEDGEMENTS 62

REFERENCES 64

APPENDICES

A **QUESTIONNAIRES**
B **SUMMARY OF UK CONTACTS**
C **SUMMARY OF US AND OVERSEAS CONTACTS**
D **CASE STUDIES**
E **CONTACT LIST**

1 INTRODUCTION

In September 1993 Warrington Fire Research Consultants (WFRC) were commissioned by the Fire Experimental Unit (FEU) of the Home Office Fire Research and Development Group (FRDG) to undertake research into the area of tactical venting of large-scale fires.

The research was stimulated by a Home Office analysis of fire statistics, which revealed that a relatively small proportion of building fires accounted for a very large proportion of all financial fire losses. The majority of the large fires (and therefore large losses) were occurring in single-storey commercial and industrial storage buildings.

The Joint Committee on Fire Brigade Operations requested a study of ways in which these fire losses could be reduced. This study identified over 30 areas where research might prove beneficial, and these were refined to 8 detailed proposals which were presented to the Committee. The Committee requested the FRDG to pursue three of these projects, one of which was to look at venting as a firefighting tactic.

The tactic of venting is widely used in the USA but is not commonly used or promoted by the UK fire service. Before adopting any change in tactics there is a need to assess the merits of venting in comparison with existing practices. The FEU, therefore, developed a four-stage programme of research to investigate whether fire venting could be of benefit and how it could be introduced safely:

- stage 1 - a survey of the field of venting to determine the true state of the art;
- stage 2 - subsequent theoretical or small-scale experimental studies to investigate the theory in more depth;
- stage 3 - large-scale experimental studies to make practical comparisons between venting and other firefighting tactics;
- stage 4 - development of safe working procedures.

The extent of work involved in each stage of the project would be dependent on the findings of the previous stage.

WFRC were commissioned to carry out stage 1 of the work and the results are presented in this report. The main objectives were:

1. to survey the current extent of knowledge of venting;
2. to ascertain what theoretical, scientific and practical work has been carried out in the field of venting, and to evaluate the results and conclusions of this work;
3. to determine whether the results show that venting is fully understood and to identify areas where further research is necessary;

4. to assess the possibility of using theoretical or modelling techniques to determine the advantages and disadvantages of venting as a fire service tactic;

5. to assess the advice given to firefighters in relation to venting;

6. to produce detailed proposals for subsequent theoretical and experimental studies, where necessary.

It was recognised by the FEU that incorrect venting could be counterproductive and lead to severe fire spread, particularly if backdraught conditions existed. They, therefore, initiated a separate study into backdraught. The venting and backdraught surveys were carried out concurrently over a three-month period. The interaction between tactical venting and backdraught may need further consideration in the light of the results of the two separate studies.

2 BACKGROUND

2.1 Definition of Ventilation

At the outset of this survey a distinction was made between the terms *venting* and *ventilation*. The intention was to distinguish between operations to clear smoke after a fire has been controlled (i.e. prevented from spreading further) and operations at an earlier stage to counter the spread of fire or to assist firefighting and rescue activities. The Terms of Reference offered the following definitions:

> "Venting is a tactic used in firefighting to limit fire spread by creating a suitable way out for the flammable products of combustion. This may involve making a hole in the roof above the fire or the use of openings in other positions."

> "Ventilation is a tactic used during and subsequent to firefighting to clear smoke from a building. This may involve the creation of holes in windows or roofs, or simply opening selected doors, to allow clean air to be drawn into the building, by the fire, by fans or even by natural air movements."

However there is a conflict between the two definitions because smoke ventilation used prior to fire control can improve visibility, allowing earlier access to and easier identification of the fire location, and assist in limiting fire spread.

In the US manuals on firefighter training no distinction is made between venting and ventilation as defined above. Instead, ventilation is described generically as

> "the planned and systematic removal of heated air, smoke, or other airborne contaminants from a structure and their replacement with a supply of fresher air."

For firefighting this will entail the removal of the products of combustion, which may include hot and flammable gases and smoke. This definition encompasses the use of ventilation tactics to limit fire spread but it also covers all types of automatic and manual ventilation. The definition is useful in that it is generally consistent with that used in Book 12, Part 3, of the "Manual of Firemanship", which discusses the removal of combustion products from a building by ventilation. It has been suggested (15)[1] that where the hot gases are at flame temperature the technique should be referred to as *fire ventilation* and where the gases are cooler it should be called *smoke ventilation*. However, there is no intrinsic difference between the activities described by these two definitions and neither differentiates between the timings of ventilation. Therefore, for the purposes of this study, it was felt that greater clarity would be achieved by adopting the following definitions:

[1] Numbers refer to references on page 63.

1. automatic ventilation -

This involves the use of pre-installed roof vents activated automatically, usually at an early stage of the fire, by the fire detection system or fusible link devices;

2. tactical ventilation -

This requires intervention by the fire service to "open up" the building and release the products of combustion.

This usually takes place at a later stage than automatic ventilation but can involve the use of pre-installed vents.

Tactical ventilation could be used at the following stages of the fire:

- after arrival of the fire service but before control is achieved;
- after control but before extinction;
- after extinction.

Tactical ventilation may have an effect on fire spread. This can be either beneficial or detrimental depending on the skill of the firefighters.

For the purposes of this study, consideration was focused on the application of tactical ventilation prior to control and extinction of the fire. Smoke clearance after control will have minimal effect on limiting fire spread. However, the dangers of ventilating oxygen-starved or smouldering fires should be recognised since it may re-initiate fire growth by increasing the oxygen supply.

2.2 Advantages of Ventilation

The most common claims made by the proponents of ventilation are that it:

(1) assists escape by restricting the spread of smoke on to escape routes and extending available egress times;

(2) aids rescue operations by removing smoke and toxic gases, which hinder search activities and endanger trapped occupants;

(3) improves the safety of firefighters by:

- removing the build-up of hot, fuel-rich gases which could develop into a backdraught,
- removing heat, which may contribute to the onset of flashover,

- reducing the concentration of toxic "fire gases" prolonged exposure to which may cause delayed health problems;

(4) speeds attack and extinguishment by:

- removing heat, thus enabling firefighters to enter a building and carry out fire attack earlier,

- removing smoke, thus improving visibility and permitting firefighters rapidly to locate the fire and proceed with extinguishment;

(5) reduces property damage by:

- facilitating earlier access, which, with the correct tactics, will allow for earlier extinguishment and a potential reduction in water damage,

- removing smoke and hot gases, which cause damage both close to and remote from the fire source,

- relieving the heat load on the structure of the building, which could ultimately lead to structural collapse,

- limiting the potential for fire spread in a number of ways including:

  - reducing lateral flame spread at floor level by localising the seat of the fire,

  - reducing lateral flame spread at high level by controlling the width of the fire plume or reducing horizontal spread of flame beneath a roof or ceiling.

The emphasis of this survey (see Section 1) is on the use of ventilation as a means of reducing property loss rather than on improving the level of life safety for building occupants, and further consideration is, therefore, mainly directed towards establishing the validity of claims (4) and (5). However, it is also important to consider the implications for firefighter safety.

Sections 2.3 and 2.4 provide an introduction to the different methods of fire ventilation; a more detailed consideration of the theory, tactics and equipment required for each method is provided in Section 4.

2.3 Automatic Ventilation

Automatic ventilation systems are normally designed to limit the smoke and heat hazards by one of two methods:

(1) confining hot smoky gases in a layer below the ceiling, from which they are vented or extracted, and

simultaneously replacing the air flows beneath the hot gases; or

(2) controlling the pressure distribution in the fire compartment to restrict the flow of hot gases and flames through small openings into adjacent areas.

Automatic systems rely on the natural buoyancy of the fire gases and physical barriers to direct and contain the smoke. Mechanical extraction can be used to supplement the buoyancy-induced movement of the smoke.

Automatic systems are normally designed for life safety purposes although automatic vents are sometimes provided in industrial buildings for property protection purposes.

2.4 Tactical Ventilation Techniques

Tactical ventilation to assist in firefighting operations can use either natural or forced ventilation. Tactical ventilation methods can be divided into three basic categories.

(1) top or vertical - making of openings at high level (usually through the roof) such that the buoyancy of the combustion products enables them to vent vertically;

(2) cross or horizontal- provision of openings in the external walls (e.g. via windows and doors) such that external wind forces and fire gas buoyancy assist in the removal of combustible products;

(3) forced - use of fans, blowers, nozzles or other mechanical devices to create or re-direct the flow of air inside the building so that the fire gases are forced out of the building.

The term *natural ventilation* is used throughout this report to describe collectively the techniques of vertical and horizontal ventilation when they are not assisted by mechanical means.

The use of pre-installed vents, e.g. openable windows on stairways or roof vents, is a form of natural ventilation.

3 SURVEY OF VENTING

3.1 General

A comprehensive information-gathering exercise was undertaken to survey the state of the art of venting worldwide. The key elements of this exercise were:

(1) computer database searches
(2) library visits
(3) questionnaires
(4) UK contacts
(5) USA contacts
(6) other overseas contacts.

3.2 Computer Database Searches

Database searches were carried out using facilities at WFRC and the FEU. At WFRC the following databases were accessed:

(1)	FLAIR	(Fire Research Station (FRS))
(2)	FIREDOC	(US National Institute of Standards and Technology (NIST))
(3)	HSE-LINE	(Health and Safety Executive)
(4)	ISBENX	(Building Services Research and Information Association).

3.3 Library Visits

WFRC has its own specialised fire library and a number of the references were found by database searches in-house. A visit was also made to the specialised fire library of the NIST in Maryland, USA.

3.4 Questionnaires

A simple questionnaire and covering letter were sent to all the UK fire brigades to discover whether they were actively promoting tactical ventilation of fires, what they considered to be the main advantages/disadvantages and whether they had knowledge of any successes or failures involving the tactic. They were also asked if they could provide technical information or assistance.

A similar but more detailed questionnaire and covering letter were sent to the largest 50 fire departments in the USA and to a selection of other fire services worldwide. The USA was targeted for particular attention because tactical ventilation is used extensively throughout that country. The questionnaire was intended to elicit a specific response and provide general views in response to more open questions. The aim was that the whole questionnaire should take no longer than 20 minutes to complete; this was to ensure as high a response rate as possible.

Copies of the questionnaires and the covering letters are provided in Appendix A and the mailing list is provided in Apendix E.

3.5 UK Contacts

Meetings were held with representatives of various UK fire brigades identified as being active in the field of ventilation research and practice, namely Wiltshire, Essex and Bedfordshire. To strike a balance, meetings were also held with a number of large brigades in the North-west that do not actively promote tactical ventilation.

Other specialists in the general field of ventilation and fire science were contacted, namely:

Howard Morgan - FRS
Graham Hansell - Colt International.

Meetings were also held with Paul Grimwood and John Taylor, two practising UK firefighters who have demonstrated a personal interest in the subject of fire venting.

A letter explaining the scope of the study and asking for any comments was also circulated to:

the Fire Brigades Union
the National Association of Fire Officers
the Chief and Assistant Chief Fire Officers Association Operations Committee
the Institution of Fire Engineers.

Meeting were also held with training officers from the Fire Service College and members of the Fire Service Inspectorate (FSI) to discuss their views on the topic.

Contact was made with other interested parties but the number of meetings and extent of correspondence were limited by the short timescale of the project. A list of all the contacts made in the UK is provided in Appendix E and details of the discussions held are given in Appendix B.

3.6 US Contacts

As the tactic of ventilation is used widely in the USA, a visit was considered necessary to discuss the topic with fire departments and specialists in the field. Meetings were held with the following:

National Fire Training Academy, Emmitsburg, Maryland
New York Fire Department
University of Central Florida, Orlando, Florida
Orange County Fire and Rescue Department, Florida
Chicago Fire Department, Illinois
Seattle Fire Department, Washington
John Mittendorf, independent consultant (formerly of Los Angeles Fire Department).

Other organisations were contacted by telephone in an attempt to identify on-going research activities:

National Fire Protection Association (NFPA)
NIST
International Fire Service Training Association (IFSTA)

Details of the meetings are provided in Appendix C and a full list of the contacts made is provided in Appendix E.

3.7 Other Overseas Contacts

Questionnaires were directed to a selection of overseas fire services, covering Europe, Scandinavia and the Far East. A full list of contacts is provided in Appendix E and a summary of the responses given in Appendix A.

3.8 Additional Information

A substantial amount of additional information was collected throughout the course of the study and this material has been retained by the FEU. It included videos, US fire department operating procedures, training literature and promotional material from PPV fan manufacturers.

4 US TACTICAL VENTILATION TECHNIQUES

4.1 General

Comprehensive information on the considerations and requirements for tactical ventilation is available from a number of sources in the USA, including:

(1) IFSTA Manual, "Fire Ventilation Practices" (39);
(2) IFSTA Manual, "Essentials of Firefighting" (40);
(3) "Ventilation Methods and Techniques" by J.W. Mittendorf (34).

In addition to these manuals many of the US Fire departments produce their own training literature and operating procedures, tailored to the particular hazards and building types that they encounter.

The following paragraphs provide an overview and discussion of the general considerations, techniques and requirements for tactical ventilation. The tactics advocated for specific building types are discussed in Section 5 and more detailed guidance is available in the manuals listed above.

4.2 Ventilation Considerations

4.2.1 Introduction

Tactical ventilation is one of a number of tools available to the Officer in Charge when he is formulating a plan of attack on the fire. Typical considerations will involve basic assessment and decision making (see ref. 39):

(1) assessment
- assessing rescue/life hazards
- determining the location and extent of the fire
- identifying the building construction features

(2) decisions
- is there a need for ventilation?
- where is ventilation needed?
- how should ventilation be accomplished?

These are considered in more detail below.

4.2.2 Assessing Rescue/Life Hazards

To assess the rescue/life hazards, reliable information is needed about the number and location of people in the building at the time of the fire. This will assist in determining whether the building should be vented to draw heat and smoke away from the occupied areas or whether it should be vented to attack the main body of the fire immediately.

Similar information is needed on the presence of any hazardous materials. This can also influence how and where the building should be vented.

4.2.3 Determining the Location and Extent of the Fire

It is generally recommended that ventilation should not be carried out until the seat of the fire has been located. Ventilation may increase the fire severity and can draw the fire into uninvolved parts of the building. Precautions should be taken to protect against these effects and this will normally require knowledge of the fire location.

Firefighters need to know how to "read" the signs of a fire, such as the following examples.

- Visible smoke conditions.

  The colour of smoke will provide an indication of the stage of fire development reached and the nature of materials burning.

  The location and speed of smoke escape from the building envelope will assist in determining the location of the fire.

- Heat conditions and fire severity.

  Feeling walls, doors or windows, looking for discoloured or blistered paint, or using infrared detectors, will provide an indication of the fire travel and location on arrival.

US fire departments consider the roof to be an important indicator of fire location and extent of development, particularly in windowless buildings or buildings that are completely smoke logged on arrival. Therefore one of the first actions is to send a team (never less than two firefighters) to inspect the roof. The maxim is that if it is unsafe to put firefighters on the roof then it is almost certainly unsafe to commit firefighters into the building underneath the roof.

4.2.4 Identifying Building Construction Features

A knowledge of the building construction is a critical factor in determining how much time is available for ventilation operations and the most appropriate manner in which to vent the building. Typical features that should be considered during ventilation assessment are:

- the type and age of the building;
- the materials of construction;
- the method of construction, e.g. type of roof;
- the number of stories;

- roof access and roof features, e.g. skylights;
- the security devices on doors, windows etc.;
- the location of stairways;
- the location of openings in relation to prevailing wind directions.

4.2.5 Is there a Need for Ventilation?

Definitive guidance is not available in any training manual and the answer to this question must be based on the heat, smoke and gas conditions within the structure, and the life hazard.

A phrase repeated by many of the US fire officers contacted was "vent early - vent often". It was admitted that such an aggressive approach sometimes results in buildings being vented unnecessarily. However, it is believed that the benefits gained in most instances, in terms of limiting fire and smoke damage, far outweigh the cost of the unnecessary superficial structural damage incurred on the few occasions when the tactic is used needlessly.

The question posed is, "if tactical operations can be carried out safely, why wait for the fire to dictate where and when the building will be vented?".

Most agree that ventilation is unnecessary for small fires, which do not present major smoke or heat problems. There is also a general concensus that horizontal ventilation or PPV should not be used when a potential backdraught situation exists.

4.2.6 Where is Ventilation Needed?

Deciding where to ventilate will depend largely on the objective of the ventilation operation, e.g. to facilitate protection of trapped occupants, assistance in search and rescue, the direct fire attack, etc.. The experience of the ventilation team will often determine the best vent position to achieve the desired objective.

For fire attack the order of ventilation is

(1) offensive - carried out in close proximity to the seat of the fire to improve conditions in that area;

(2) defensive - carried out away from the seat of the fire to limit the potential for fire spread to uninvolved areas.

In the first instance it is recommended that the exit opening should be as close to the seat of the fire as possible. If this is not safe, then an exit hole should be made between the fire and the uninvolved portion of the building. If neither option is practical then defensive tactics such as cutting holes to act as a fire break may be necessary.

4.2.7 How should Ventilation be Accomplished?

Earlier decisions about the objectives of ventilation and where it is needed, together with consideration of building construction, will often dictate the means of ventilation. The major consideration will be whether to use natural or forced ventilation techniques and whether to attempt vertical or horizontal ventilation.

4.3 Ventilation Techniques

The techniques of tactical ventilation are considered under the following headings:

(1) cross or horizontal
(2) top or vertical
(3) forced.

4.3.1 Cross or Horizontal Ventilation

Cross or horizontal uses a combination of external wind forces and fire gas buoyancy to remove combustion products horizontally via openings in the building fabric, e.g. windows and doors.

Structures in which cross ventilation may be appropriate are those in which (see ref. 39):

- the fire is not large enough to necessitate opening of the roof;
- there are windows and doors close to the seat of the fire;
- the fire and the products of combustion are not being carried into the top floor;
- the fire has not entered structural voids or concealed spaces.

It is important, when seeking to initiate cross ventilation for tactical reasons, that the following points should be considered:

- the exit opening should be as close to the seat of the fire as possible and opposite the point from which attack teams will approach the fire;
- ideally the exit point should be on the leeward side of the building; but
- if the fire is on the windward side of the building, creating an opening on the leeward side may spread the fire:
- precautions should be taken to protect internal and external exposures, e.g. combustible wall linings or eaves;

- cross ventilation should not be initiated if backdraught conditions are suspected.

Once appropriate ventilation is established, personnel should take care not to disturb the flow of air adversely by:

- opening up other exit points,
- closing entry points,
- directing fire streams into the vent openings,
- improper placement of salvaged contents.

4.3.2 Top or Vertical Ventilation

Top or vertical ventilation relies upon the buoyancy of the combustion products to vent vertically through openings made in the fabric of the building, usually at roof level, directly above the fire.

Structures in which vertical ventilation may be appropriate are those in which (see ref. 39):

- the fire is in, or has spread to, the roof space;

- horizontal ventilation would be difficult, e.g. windowless buildings with few exterior doors;

- there are tall vertical shafts, e.g. light wells, elevators, etc;

- the fire has entered structural voids or concealed spaces.

Selecting where to ventilate will depend on many factors including:

- the availability of natural openings, such as skylights, louvres, ventilator shafts, etc. use of which will usually be easier than cutting the roof open;

- location of the fire, which will dictate whether offensive or defensive ventilation is required;

- roof construction, which will determine how difficult ventilation may be to achieve;

- wind direction (firefighters should always work with the wind at their back or side);

- roof stability and appearance; a sagging roof or melting, bubbling tar will indicate the location of the fire and provide some indication of the safety of the roof.

Selecting a proper method of ventilating the roof requires a detailed knowledge of the different designs and types of roof construction. A key requirement is to establish the location, spacing and direction of the rafters.

There are three basic types of roof cut (see ref. 32) as summarised below.

- Inspection holes: these are normally triangular cuts with sides about 9" long that are made to observe conditions below and investigate the roof construction.

- Main roof cuts: these are offensive openings made over or as close to the fire as safety considerations will allow. Opinion as to the proper size of the cuts varies; some estimates suggest between 5% and 10% of the floor area but in large buildings this would require impractically large areas of the roof to be opened up. Some of the training manuals recommend initial cuts 1.3m x 1.3m (i.e. 4' x 4'). A more practical approach involves increasing the size of the hole until the smoke stops venting under pressure (see ref. 34).

- Trench cuts: also referred to as "strip-cuts" or "stripping". These are defensive cuts made across the full width of the roof. They are intended to act as a fire-break and stop the horizontal travel of a fire by venting it vertically. As a rule of thumb a cut approximately 1m wide is recommended (see ref. 39). For obvious safety reasons firefighters should cut only the roof covering and decking and not the rafters, purlins or other members that support the roof.

Safety precautions are essential for rooftop operations, some of the important considerations being:

- to provide a secondary means of escape from the roof;

- to maintain a lookout for indications of a weakening structure and prevent personnel from walking on weakened roofs;

- to exercise caution in working around electric wires and overhead cables;

- to stand on the windward side of any openings that are made.

4.3.3 Forced Ventilation

Forced ventilation refers to the use of fans, blowers, nozzles or other mechanical devices to create or redirect the flow of air inside the building so that the fire gases are forced out of the building.

Forced ventilation can be used to supplement natural ventilation or overcome some of its limitations, e.g. counter the effect of wind.

The main advantages of forced over natural ventilation are:

- the ventilation objectives, i.e. smoke removal, restoration of a tenable atmosphere, etc., are achieved more rapidly;
- it is less susceptible to erratic wind conditions;
- it is a more controllable form of ventilation.

The disadvantages of forced ventilation are that:

- it requires the use of a mechanical device, a power source and additional manpower;
- it can increase the intensity of a fire and lead to unwanted fire spread if incorrectly applied;
- in large buildings it requires a very large fan.

The main techniques of forced ventilation are:

- positive pressure ventilation (PPV)
- negative pressure ventilation (NPV)
- water-fog assisted ventilation
- heating ventilation and air conditioning systems (HVAC).

4.3.3 (i) Positive Pressure Ventilation

PPV involves introducing fresh air into a confined space, thus creating a slight positive pressure within the space. It works on the principle that any fluid will move from a region of high pressure to a region of lower pressure if there are no barriers to the flow.

A high-volume flow fan is placed outside the building so that the cone of pressurizing air it produces just covers the entrance opening (usually a door). Where high flows (volumes) are required multiple fans can be used in series (i.e. one behind the other), and where large openings need to be covered fans can be used in parallel, i.e. side by side. Sealing the opening is critical to the success of PPV since a pressure higher than the exhaust pressure must be maintained to prevent reverse flow from occurring.

The selection of the exhaust point is also important. Smoke will tend to move towards and be exhausted via whatever exit points that exist. A discharge point should therefore be provided as close to the seat of the fire as possible. If the fire affected room is on the exterior of the building, and openings such as windows and doors are available, the smoke and fire will follow the path of least resistance directly to the outside. However, if there are no natural openings, or if the fire-affected room is in the interior of the building, an exhaust point to outside may need to be created in another area of the building. Careful consideration must be given to the effect that this may have in drawing fire through uninvolved parts of the building.

In order for PPV to work it is imperative that firefighters do not arbitrarily open windows or make ventilation openings as they inspect the building. This runs contrary to traditional practice in the USA and there has been a need to re-educate firefighters to this way of thinking.

The main perceived advantages of PPV are that:

- most of the work required to set up PPV takes place outside the building;

- it provides a flow of cool, fresh air into the building at the point where firefighters make their entry;

- it achieves many of the benefits of natural ventilation more quickly;

The main concerns regarding the tactic are that:

- it requires considerable practice and training to be used effectively;

- if applied incorrectly it can force smoke and fire toward previously unaffected areas of the building that may contain occupants or firefighters.

4.3.3 (ii) Negative Pressure Ventilation

NPV has been used for many years to draw smoke out of contaminated structures by placing a large fan at an exhaust location (door or window) and opening a ventilation entrance at a strategic location across the room.

Unlike PPV, NPV is rarely used by US firefighters during fire attack for three main reasons:

(1) it requires firefighters to set up the equipment in exit points or within the space being ventilated, which subjects them to the hostile fire environment;

(2) the equipment is not generally designed to handle smoke at high temperatures;

(3) the technique is not considered to be as effective as PPV in removing smoke.

Further consideration of this tactic falls outside the scope of this study.

4.3.3 (iii) Water-fog-assisted Ventilation

Water sprays can be used to push and pull smoke in a building. When the nozzle is opened the fog or spray stream forces air ahead of the pattern, and replacement air is drawn in behind the nozzle. Hence if the stream is directed out through a doorway or window it will tend to draw quantities of heat or smoke with it.

Properly applied fog or spray has been found to be two to four times more effective than smoke ejectors, depending on the angle of the spray pattern and the position of the nozzle in relation to the exit opening.

The main drawback of this technique is that it requires the firefighter to be directly exposed to the environment that he is attempting to clear. Consequently, its application is mainly limited to smoke clearance exercises, not fire attack. Further consideration of this tactic, therefore, falls outside the scope of this study.

4.3.3 (iv) Heating Ventilation and Air Conditioning Systems

Some high-rise buildings in the USA are designed so that, in the event of fire, the conventional HVAC systems can be used as a smoke control system. The operation of the systems is based on the principle of pressurization. For example, by extracting air from the fire floor and introducing air into the floors above and below, it is possible to create a pressure difference between the floors such that any airflows, via small leakages between the floors, occur in the direction of the fire-affected floor, not away from it.

Although there is usually an option for the fire department to override the automatic control and employ the system tactically, US experience suggests that these systems are too complex, difficult to control and of limited use for this purpose.

4.4 Ventilation Requirements

<u>4.4.1 Organization and Personnel</u>

In his book Paul Grimwood (32) usefully explains the US team-based approach to firefighting. Firefighters are specifically assigned to fulfil certain roles on arrival at an incident. The procedures are clearly defined in standard operating procedures (SOPs) for each department. The basic concept is for the engine company to effect the water supply and attack the fire, while the ladder company adopts the roles of forcible entry, search and rescue, ventilation and controlling utilities. Where multi-storey buildings are concerned (not usually more than six storeys) the standard operating procedures will require a roof team in position at a very early stage in the operation, usually within 2 min of arriving on the scene. The size of this team is variable and depends on an individual department's manning levels. However, in metropolitan areas anywhere from two to five firefighters will make up the initial roof team. Their primary function is to:

(a) visibly check the rear (and sides, where necessary) of the building for trapped occupants;

(b) make a visible assessment of the internal light wells for potential rescues;

(c) report their position, and the status of such areas, to the incident commander.

Their secondary function will be to ventilate the roof, on the orders of the incident commander. It is argued by many departments that the key to success lies in an early placement of the roof team.

US fire departments provide a high level of first attendance. Typical examples given for large industrial building were:

Orange Co., Fl.	2 engines	@ 3 men each
	1 aerial appliance	@ 3 men each
	1 batallion chief	
		Total 10 men
Chicago	2 engines	@ 5 men each
	2 trucks	@ 5 men each
	1 batallion chief	
		Total 21 men
Los Angeles	3 engines	@ 4 men each
	2 trucks	@ 5 men each
	1 batallion chief	
		Total 23 men

The larger departments recommend a minimum of four men per truck, i.e. two teams of two men, one for search and rescue the other for ventilation.

Even within the USA the lack of a ladder company in suburban and rural fire departments has been given as an excuse by many for not performing the functions normally accomplished by a truck company, which include ventilation. However, it is claimed that the lack of equipment, not the lack of a vehicle, is the critical factor and that ventilation can be carried out even with limited manpower, provided the fire ground organisation is good.

4.4.2 Equipment

The typical equipment carried on most trucks will include:

- PPV fans (for those departments which support the tactic). Los Angeles provides three per truck, other departments contacted provide two.

- Pike poles, used to remove tiles, and break ceilings below roofs.

- Axes, one for each member of crew.

- Rotary saw (petrol-driven) with carbide-tipped blade, for cutting through metal cladding, usually 2 off.

- Chain saw (petrol-driven) for general cutting, usually 2 off.

5 TACTICAL VENTILATION FOR COMMON BUILDING TYPES

5.1 General

A discussion is presented below of the important considerations, techniques, benefits and hazards associated with ventilation in specific building types. The discussion is based on information obtained at meetings with US fire departments and from guidance offered in the US training manuals. An assessment of the relevance of this information to the UK situation is also provided.

5.2 Single-storey Warehouse/Industrial Building

5.2.1 Considerations

Construction

Industrial buildings in the USA incorporate many different construction features. The most common forms of construction are:

steel frame	-	a substructure of steel, covered with corrugated steel or aluminium panels;
concrete	-	usually "tilt-up" construction comprising concrete slabs, tilted up into place to form external walls; sometimes concrete blockwork is used in place of slabs;
brick	-	ordinary brick construction, often with parapet walls;
roof	-	the most common roof construction is a plywood and "tar" (bitumen) system over a metal or timber framework. Heavyweight timber roof joists are considered to be safer for ventilation operations than either lightweight timber or steel structures since they are less prone to early failure and collapse.

A major influence in many cases on the choice of ventilation technique is the lack of windows or doors for cross-ventilation purposes. If vertical ventilation is deemed necessary, the ability to vent and the choice of where to vent will depend on the nature of the roof construction, i.e. whether it is lightweight or heavyweight. If the construction is lightweight it is often considered too dangerous to carry out offensive ventilation directly above the fire and defensive ventilation (e.g. trenching) may be used instead.

In the USA many large storage buildings are sprinklered but automatic ventilation systems are not common. Most of the other features are similar to those of comparable buildings in the UK.

Location of Fire

A number of fire scenarios were prepared in advance of the meetings between WFRC and US fire departments to provide a basis for discussion. In relation to single-storey warehouse buildings three fire locations were considered for discussion purposes:

(a) fire against end wall
(b) fire in centre of building
(c) unidentified fire location.

Special Hazards

Most industrial/storage occupancies are large open areas with minimal sub-division and this can lead to rapid fire spread throughout the building.

The contents of the building may be hazardous and it may not be desirable to vent the fire gases to the outside.

Roof collapse, particularly of lightweight truss roof constructions, can occur in a short period of time. Collapse of timber roof structures usually occurs where the bottom chord or webbing has burnt through. Total failure of metal roof structures can occur at around 600°C when the steel begins to lose its strength.

5.2.2 Tactics

(a) Fire against an End Wall

Most fire departments did not feel that PPV fans would be capable of generating sufficient airflow in a large industrial unit for effective horizontal ventilation and recommended roof ventilation instead.

Roof ventilation involves cutting a hole in the roof as close to the seat of the fire as safety will allow. The minimum size suggested for a first cut is 4' x 6'. The actual size required in a given situation is determined by the pressure of the smoke released. If the smoke is venting under pressure, the ventilation opening should be increased until the smoke vents "lazily". To save time it is normally better to increase the size of the original hole than to cut new holes.

If necessary, a defensive trench or strip cut, 3' to 4' in width, can be made to restrict lateral fire spread. Offensive cuts should always be made before defensive cuts. If offensive cuts are not possible, then attention should be switched to defensive ventilation operations.

Orange County Fire and Rescue were the only department to recommend the use of PPV in this situation. They suggested that an exit opening should be made at the top of the end wall adjacent to the fire and that PPV fans should be set up at the opposite end of the building to establish forced horizontal ventilation. This approach may be feasible where windows and doors are conveniently located or holes can be cut in the external walls; however, where walls are constructed of concrete or brick and window/door openings are limited, it is unlikely to be appropriate and vertical ventilation may be required. The advantage of cross ventilation over vertical ventilation is that it eliminates the need to commit firefighters to potentially dangerous roof operations.

For situations where the fire has self-vented at one end of a building but conditions within the building remain poor, one department recommended vertical ventilation at the non-fire end of the building. It was claimed that the possibility of drawing fire from one end of the building to the other was minimal because an opening already exists above the fire. The purpose of creating a hole at the non-fire end is to improve conditions for firefighters entering the building at locations removed from the fire.

The interaction between sprinklers and vent efficiency was discussed. One department suggested that in situations where sprinklers were limiting vent efficiency, and visibility inside the building was continuing to deteriorate, the sprinklers should be turned off. This is not a recommendation found in any of the training manuals and should be treated with some caution.

(b) Fire in Centre of Building

Vertical ventilation was recommended for fires located in the centre of the building. PPV was not recommended on the grounds that it could spread the fire to unaffected areas of the building.

The tactic, again, is to vent as close as possible to the seat of the fire and increase the size of the hole until the smoke is observed to vent "lazily".

(c) Unidentified Fire Location

The general advice is not to vent until the location of the fire is known and this applies especially to the use of PPV.

As for any ventilation operation the recommendation is to make systematic observation cuts in the roof to determine the location of the fire and the extent of fire spread. It is recommended that the first cut be made at one end of the building and the second cut at the opposite end. If flames are visible through both the holes the immediate action should be to abandon roof operations since this would indicate extensive fire spread.

If smoke is observed through one hole only, further observation cuts should be made, advancing from the non-fire to the fire side of the building.

Once the fire is located, appropriate ventilation operations should be carried out, as described in (a) and (b) above.

Where the location of the fire cannot be identified and conditions in the building continue to deteriorate it is recommended that an offensive cut be made in the centre of the building. At worst this may draw a fire from one end of the building to the vent in the centre. However, the potential benefit is that at least half of the building should be saved as firefighters will be able to gain access to the building and extinguish the fire.

5.2.3 Discussion

There is strong anecdotal evidence from US fire departments that offensive ventilation, over the seat of the fire, will speed fire attack and extinguishment.

The US experience suggests that tactical ventilation will raise the smoke layer in the building by at least 1m. This is likely to improve visibility but may have little significant effect on limiting smoke damage, unless ventilation is carried out before significant smoke logging occurs. It should be relatively straightforward, using conventional smoke ventilation theory, to estimate the effects of different vent sizes on reducing both the smoke-layer depth and the temperature at different stages of fire development.

The effectiveness of offensive ventilation in limiting lateral flame spread at either high or low level is not clear. Practical experience tends to suggest that creating a hole directly over the fire will create a chimney effect, drawing air in the direction of the opening, localizing the seat of the fire at ground level and drawing the flames toward the vent at roof level. Theoretical and practical studies are required to demonstrate and quantify this effect.

US experience suggests that steel-clad or aluminium-clad roofs will often vent themselves prior to the arrival of the fire service. In this situation offensive ventilation is likely to be unnecessary and attention will instead be focused on defensive ventilation operations with the intention of preventing fire spread to adjacent structures or compartments. A similar change of tactics may also be necessary when dealing with lightweight roof constructions; the available operating time on such roofs is very short owing to the danger of roof collapse, making offensive operations close to the fire perhaps unsafe.

The hazards of operating over the fire are a major concern to UK firefighters. Such concerns may well be justified but they should not necessarily preclude the use of tactical ventilation for defensive purposes. An example of such a tactic is pre-venting an exposed occupancy to minimise or eliminate the spread of fire. Consider a double-bay warehouse in which the two bays are separated by a wall that extends to roof level but is breached by an opening or lack of fire stopping. A strip cut made in the roof of the unaffected bay, adjacent to the opening, will as the fire travels through the opening draw flames, heat and smoke up and out of the building.

The dilemma facing firefighters is that the shift towards more lightweight building constructions increases not only the need for offensive ventilation but also the risks associated with such operations. The safest solution for the fire service may be to abandon the compartment of origin and concentrate on protecting the adjacent areas.

5.3 Two-storey Warehouse/Industrial Building

5.3.1 Considerations

Construction

In the USA the construction of two-storey industrial buildings is generally similar to that of single-storey structures. However, two-storey buildings are likely to contain more windows, especially at the lower level where rooflights will be ineffective.

Location of Fire

Two fire locations were considered for discussion purposes:

(a) ground floor
(b) upper floor.

Special Hazards

The considerations are the same as for a single-storey building.

5.3.2 Tactics

(a) Fire on Ground Floor

Where the fire is confined to the ground floor, vertical ventilation is not normally attempted. Because of the increased likelihood of ground-floor windows in a two-level structure, horizontal ventilation becomes the preferred option. In large open buildings it is important to identify the location of the fire and create an exit opening as close to the seat of the fire as possible. This will minimise the potential for increased fire spread within the building. It is important to ensure that hoselines are charged before ventilation is initiated so that an immediate attack can be made on the fire as conditions clear.

Some departments suggest that PPV can be used to complement the horizontal ventilation on the lower floor and/or to pressurize the floor above, thus reducing the potential for smoke logging and fire spread to the upper level.

It is suggested that, where the upper level is already smoke logged on arrival, PPV can be used to clear the area of smoke, and that any openings created for this purpose should be resealed after the smoke has been cleared in order to maintain the pressurization effect. This is considered to be a dangerous tactic unless charged hoselines are available on the upper floor. Although not a direct form of fire attack, this application of ventilation, where effective, may minimise the potential for smoke damage on non-fire floors.

If the fire breaks through from the lower to the upper level a tactical change to vertical ventilation is recommended to minimise the extent of fire spread on the upper floor.

(b) Fire on Upper Floor

The recommended tactics for tackling a fire on the upper floor are the same as those described above for single-storey buildings. Vertical ventilation is the preferred option for most cases as it provides for the release of combustible products over the seat of the fire.

5.3.3 Discussion

It is difficult to determine how extensively the tactic of cross ventilation, in a form similar to that described above, is applied by the UK fire service. It seems unlikely that firefighters could gain access to some buildings or tackle punishing fires without any form of ventilation.

Cross ventilation appears to be less controversial than vertical ventilation from the point of view of the increased risk to firefighters. However, without the assistance of PPV, the tactic can be reliant on favourable wind directions for its success. If the fire is on the windward side of the building then creating exit points on the leeward side will increase the risk of fire spread. It is difficult to reconcile the potential benefits of gaining quicker access and earlier fire extinguishment against the risk of drawing the fire toward the advancing firefighters, whose only option for aggressive attack is then to approach from the leeward side of the building.

The other option is to employ PPV fans. However, the use of multiple fans to pressurize large spaces has difficulties, especially in adverse wind conditions, and further investigation is needed before any conclusions can be drawn regarding their suitability.

5.4 Small Commercial Units

5.4.1 Considerations

Construction

Shop units are diverse in their size, height and construction features. A common type of structure in the USA is a "strip store" arrangement, which consists of multiple occupancies, side by side, sometimes sharing a common attic.

They are mostly flat roofed (plywood and "tar" (bitumen) system) with exterior concrete block walls. Separating walls between units are usually fire resisting.

Location of Fire

Two fire locations were considered for discussion purposes:

(a) fire confined to shop unit;

(b) fire extending into ceiling void.

Special Hazards

Common attic voids provide an open channel for fire spread. Experience has shown that, in shop units where the separating wall extends to roof level, there is a real possibility of fire "hopping" the separating wall unnoticed.

Access to the shop units from the rear is normally very difficult for security reasons.

The shop fronts are normally large glazed openings, which because of the nature of the glass tend to prevent self-venting at an early stage.

5.4.2 Tactics

(a) Fire Confined to Shop Unit

Where the fire has not breached the ceiling, horizontal ventilation may be an option. To minimise the backdraught potential, great care should be taken to vent the shop front at its highest point before entry is attempted or any other openings are made at low level. The problem with horizontal ventilation is that it may be difficult to create an entry point at the rear of the unit and establish a through flow of air. This problem will be compounded where there is an adverse wind direction.

One department advocated the use of PPV of the fire source but this is expected to present the same problems as natural cross ventilation, and the potential for spreading fire via the common attic space also needs further investigation.

It is, therefore, often considered more appropriate to initiate vertical ventilation directly above the fire. If the fire has not taken hold in the ceiling void, a well-positioned hole is expected to prevent horizontal flame deflection. Having established an offensive hole it may be appropriate to make precautionary defensive strip cuts at roof level to protect the adjoining shops.

(b) Fire Extended into Ceiling Void

Even where the fire has extended into the ceiling void prior to arrival, the first efforts should still be directed to creating an offensive hole as close to the seat of the fire as possible. Where this is not practical, it is likely that strip ventilation will be needed ahead of the fire to form a break in the horizontal direction of travel. Two strips may be necessary to limit fire spread in opposite directions.

Some departments suggest that PPV fans could be used to pressurize adjacent stores and limit the potential for smoke ingress or fire spread. Once again, this is not ventilation to assist fire attack but ventilation to limit property damage.

5.4.3 Discussion

The arrangement of shop units in the manner described above is typical of many small collections of shops in the UK. For large covered shopping malls there is an increasing tendency to provide dedicated automatic smoke control systems with an override facility for fire service control. However, tactical ventilation may still be employed to good effect in these circumstances.

Collapse of the walls or the roof is considered less likely in this type of structure than in large industrial buildings, so that offensive roof-top operations may be safer to undertake. Defensive operations will almost certainly be safer because catastrophic failure of large sections of the roof is unlikely.

In the UK, the tactics discussed above could also be applied to fires in terraced houses, where the fire has or is likely to spread into the loft space.

5.5 High-rise Buildings (Seven Storeys or more)

5.5.1 Considerations

Construction

The height, layout and construction of high-rise buildings in the USA vary considerably, so in the interests of simplification two generic layouts were considered during discussions:

(a) open-plan accommodation with unconnected stairs;

(b) divided accommodation with stairs connected by a corridor.

Location of Fire

Two fire locations were considered for discussion purposes:

(a) fire above neutral pressure plane (npp);

(b) fire below npp.

Special Hazards

High-rise buildings present a number of problems for ventilation, e.g. limited access points, delayed evacuation, and the dangers of falling debris, smoke and fire spread through vertical shafts, communication difficulties, etc..

One of the most important influences on smoke movement in a high-rise building is the "stack effect". This is the vertical movement of air through a building caused by a difference in temperature between the air inside and that outside the building. In simplistic terms, if a tall shaft in a high-rise building is vented at the roof and street levels, and the air inside is hotter than the air outside, air will flow in at the bottom and out at the top, creating an upward flow. Conversely, if the air inside is cooler than the air outside, the flow will be in the opposite direction. Somewhere in between, normally around the mid-height of the building, a neutral pressure plane (npp) will be established where the flow is neither in to, nor out of, the structure.

The consequence for venting a building is that, if an opening is created below the npp, it may draw air into the building and spread smoke throughout the interior. Venting above the npp will allow smoke to escape.

Wind presents added difficulties as it can raise or lower the npp and will have a significant influence on the feasibility of cross ventilation.

The buoyancy of the smoke as it rises within the building will also influence ventilation decisions. Once the temperature of the smoke matches that of the surrounding air, the smoke will stratify and natural ventilation will become difficult. The smoke will then begin to bank down and spread throughout floors above the fire floor.

5.5.2 Tactics

Two hypothetical fire locations were considered during discussions with US fire departments, one above and the other below the npp. Their response indicated that little, if any, consideration is given to the location of the fire relative to the npp; practical difficulties in locating the npp in real fire situations and a reluctance to use natural ventilation techniques may partly explain this.

Although the ventilation manuals discuss natural ventilation techniques, there is little evidence that they are commonly used.

Typical reasons for not using horizontal ventilation include:

- the hazards of breaking thick plate glazing at high level (small pieces of glass can be carried long distances on the wind and may easily kill a person);
- the difficulty of breaking windows when the fire is between the firefighter and the window;
- concerns about stack and wind effects spreading smoke through a building.

The problem of smoke stratification was most commonly quoted as the main reason for not relying on natural vertical ventilation via stairshafts.

The general opinion was that in high-rise buildings the timing and location of natural ventilation will largely be dictated by the fire, the prevailing conditions and which windows break first.

Those departments that had adopted the use of PPV considered it to be a very useful technique for achieving controlled ventilation in high-rise buildings.

It is claimed that, by positioning fans at the ground level entrance to the stairshaft and by opening a door to the fire floor, those fans can be used to pressurize the stairshaft and ventilate the fire floor:

(a) in open-planned structures, via windows that have been opened or broken by personnel or the fire;

(b) in divided structures, either:

- via windows in the fire compartment; or

- via the opposing stairshaft by an opening at roof level.

The use of PPV fans for pressurizing firefighting stairs will provide obvious benefits to firefighters, limiting the ingress of smoke from the fire floor when the door to the stair is closed and diluting any smoke in the shaft when an opening is available at the top of the stairshaft.

However, the timing and coordination of PPV with rescue and fire suppression operations requires careful consideration, especially where ventilation is directed up a stairwell. Ventilation must be delayed until all occupants above the fire floor are either evacuated or moved to an area of refuge. Similar attention must be given to the safety of firefighters who may be in the stairway.

5.5.3 Discussion

There seems little reason to doubt the US firefighters' claims that natural ventilation will often be ineffective in very tall buildings and easily overcome by wind and stack effects. However, there is a need to explore the limits for application of PPV techniques in the manner described above. Computer-based analysis, using existing models (see Section 9) should be sufficient for this purpose.

5.6 Low-rise Apartments (less than Seven Storeys)

5.6.1 Considerations

Construction

In the USA these types of building generally have multiple floors and enclosed central hallways that provide access to numerous rooms within the building. The hallways may be of considerable length and may incorporate fire doors at various intervals.

For discussion purposes a distinction was made between single- and multiple-stair buildings.

Location of Fire

The fire location considered was an accommodation unit.

5.6.2 Tactics

The problems associated with natural ventilation in high-rise buildings are less relevant to low-rise buildings.

Wind effects can still present a problem for cross ventilation where the fire is in an accommodation unit on the windward side of the building. However, it will not be as difficult to break a window from outside the building as the windows will be within the range of an aerial ladder. Hence, where smoke conditions in the stairs and hallway are reasonably clear, and the wind direction is favourable, horizontal ventilation alone is likely to be adequate.

Where the stairs or hallways are smoke logged because wind or fire is forcing smoke into the building, vertical ventilation of the stairwell(s) should be the first priority. In single-stair buildings this can be achieved by creating an opening at roof level in the stairwell. In multiple-stair buildings it may be possible to use the wind effects to direct an air flow through one stairway, along the hallway on the fire floor and up out of the opposing stairway. This will channel smoke toward one stair and maintain the other clear of smoke at all times. It is claimed that smoke stratification is not normally a problem in low-rise buildings and that this channelling effect can be achieved without the use of PPV fans. However, fans can be used to augment the effect.

Once the stairs and hallways have been cleared, attention will be turned to the offensive ventilation of the fire. If the fire is on the top floor, vertical ventilation is likely to be most appropriate method, and if the fire has spread to the attic, defensive strip cuts may be required to limit horizontal spread. If the fire is below the upper floor, and the wind direction is favourable, then horizontal ventilation should be utilized. PPV is recommended by some to assist or replace natural ventilation.

5.6.3 Discussion

The apartment building described above is similar in layout to many low-level, multiple-occupancy dwellings in the UK. The concept of directing smoke and heat into a stairway that may be being used for escape purposes is likely to be alien to UK firefighters. This again highlights the importance of coordinating ventilation tactics with other activities.

The benefits of this approach are that it can provide firefighters with good access to the fire-affected floor and that it tends to reduce lateral spread of fire from a stairway into dwellings at other levels. Since the fuel load in stairways and corridors is minimal, the risk of fire spread via these routes should be low.

The risks of putting men on roofs to open up the stairway, when the fire is below the upper floor, are considered to be relatively low in this type of building.

5.7 Two-storey Residential House

5.7.1 Considerations

Construction

A large number of the single family dwellings in the USA are timber frame "balloon" constructions, which provide open passageways to the attic within the exterior walls. Roof constructions are also different to those found in the UK in that ply or felt construction is common and there is a less prolific use of slates or roofing tiles.

Location of Fire

Two fire locations were considered for discussion purposes:

(a) fire in bedroom on upper level;

(b) fire in kitchen on lower level.

Special Hazards

The timber construction of these houses can necessitate rapid intervention by the fire department, involving aggressive ventilation techniques, if the building and its occupants are not to be lost.

5.7.2 Tactics

(a) Fire in Bedroom on Upper Level

Where the fire has not extended into the attic, PPV is generally considered to be the most appropriate ventilation method. This involves placing a fan at the front door to the house and creating an opening in the fire room. Efforts are made to ensure that openings are not made in other areas of the building as this will reduce the effectiveness of PPV. The exit opening is not created until the hoselines are charged and in place for an attack on the fire. Once the opening is made, the fan speed is increased.

Where the fire has extended into the attic, roof ventilation will usually be undertaken; this can be augmented by the use of a PPV fan. A water attack on the attic fire would be made by breaking a hole in the ceiling and directing the spray up from below, to drive the fire up an out of the hole in the roof. Water sprays would not be directed into the roof opening but might be directed across the vent to assist the ventilation process.

Prior to the development of PPV techniques, roof ventilation was the tactic commonly employed where the wind direction prevented cross ventilation. PPV is now considered to be a safer alternative.

(b) Fire in a Kitchen at the Lower Level

PPV techniques would again be utilised. In this situation the exit opening would be created in the kitchen and care would be taken not to make any openings to the outside in other rooms.

5.7.3 Discussion

US firefighters consider the use of PPV to be even more appropriate to UK constructions than to US ones, as UK houses generally offer better fire containment.

On the basis of demonstrations witnessed by WFRC personnel, both in the USA and in Spain, PPV is considered by WFRC to offer significant potential benefits in terms of clearing smoke quickly and reducing the potential for flashover.

The Spanish demonstrations also tentatively illustrated conversion by PPV of a pre-backdraught condition into a well-ventilated fire with no signs of a backdraught having occurred (ref. 41).

Concerns have been raised about the possibility of PPV causing occupants or firefighters to be trapped between the fire and an exit opening. These concerns are valid for fires in rooms that are not on the perimeter of the building and from which an opening direct to the outside cannot be made. However, such a situation is unlikely to arise in a typical single family dwelling.

The Spanish trials also illustrated potential problems in combining water-fog attack with PPV and further research is needed to explore the interaction between the two.

5.8 Summary

Warehouse/industrial buildings

In most cases US firefighters consider vertical ventilation to be more suitable than horizontal ventilation in single storey buildings. However, in multi-storey buildings they may attempt to cross ventilate floors below the top floor either naturally or with the aid of PPV fans.

Although there are differences in the construction of US and UK industrial buildings, it is not felt that vertical ventilation operations on UK buildings would be any more or less dangerous than those on US buildings. Lightweight constructions appear to be as common in the US as they are in the UK, especially in newer buildings.

US buildings are less likely to have pre-installed ventilation systems which may explain the greater emphasis placed on tactical ventilation. Timber roof constructions may also increase the need for early tactical ventilation in the US.

US experience suggests that steel or aluminium-clad roofs, which are common in the UK, will often vent themselves prior to the arrival of the fire service and that defensive rather than offensive operations will often be more appropriate.

Given the shift towards lighter-weight building construction, the practice of putting firefighters on roofs may become more dangerous and alternative means of tactical venting, e.g. from aerial appliances or using pre-installed vents, may need to be considered.

Small Commercial Units

In small shop units, as for large industrial buildings, the US preference is for vertical rather than horizontal ventilation. The first objective is to create an opening as close to the fire as possible and the second is to limit fire spread using "trench" cuts.

In general UK constructions are not dissimilar to those in the US and similar tactics, with due consideration to the safety implications for firefighters, may therefore be appropriate. In the UK, these tactics could also be applied to fires in terraced houses, where the fire has spread or is likely to spread into the loft space.

High Rise Buildings

A detailed comparison was not undertaken but, from the discussions held, it does not seem that typical US construction varies widely from the UK.

In the US, although the ventilation manuals discuss natural ventilation techniques there is little evidence to suggest that ventilation is commonly used because of difficulties created by pressure and wind effects in and around the tall buildings.

US experience suggests that in these buildings the timing and location of natural ventilation will largely be dictated by the fire, the prevailing conditions and the windows which break first.

Those departments, which had adopted the use of PPV considered it to be a very useful technique for achieving controlled horizontal ventilation and for pressurizing firefighting stairs.

It is likely that US experiences of fire development in high rise buildings will be similar to those in the UK and that the tactics employed there will be transferable to the UK.

Low Rise Apartments

The layout of low-level, multi-occupancy buildings in the US appears to be very similar to those found in the UK. In some areas of the US the buildings are timber framed structures but in others, as in the UK, they are of masonry construction. Both types of structure are commonly vented which implies that the nature of the construction is not a critical factor in determining the need for ventilation.

Tactics for dealing with fires below the top floor involve clearing approach routes before attacking the fire. Where corridors are smoke logged, smoke and heat is directed into a stairway and vented at roof level. This may be achieved naturally but some departments utilise PPV fans to assist the process.

On the top floor vertical ventilation as close to the fire source as possible is recommended with trench cutting used as a precautionary or complimentary tactic where necessary.

In the UK the concept of directing smoke into a stairway that may be being used for escape purposes will be alien. Although it may be argued that because the fuel load in these areas is low the risk of fire spread will also be low, careful consideration would need to be given to co-ordinating ventilation tactics with other fireground activities.

Two Storey Residential House

Timber frame construction for single family dwellings is very common in the US and there is less prolific use of slates or roofing tiles. The timber construction can lead to rapid fire spread and may explain the US tendency toward early ventilation.

Notwithstanding this there is some experience to suggest that ventilation tactics are used on brick built structures with tiled roofs.

Prior to the development of PPV techniques, roof ventilation was the tactic most commonly employed. It has been suggested that vertical ventilation was even used for dealing with fires on the lower floor, when adverse wind directions prevented horizontal ventilation.

Those departments which promote the use of PPV claim that it has transformed the way in which they deal with fires in residential occupancies and that there is now no need to ventilate via the roof unless the fire has spread into the attic space.

There is a strong belief in the US and increasing awareness in the UK that PPV techniques would be particularly suited to dealing with fires in the types of houses found in the UK.

6 FIRE VENTILATION IN THE UK

6.1 Summary of Questionnaire Response

Questionnaires (see Appendix A) were sent out to 66 UK fire brigades by the FEU and 47 responses were received.

Only seven brigades (15%) stated that they currently promote the use of tactical fire ventilation. A small number of brigades (6%) are currently evaluating fire venting. The policy in others (6%) is that the Officer in charge should have the option to vent if he considers it appropriate.

Most of the brigades that do promote fire venting have no structured training programme or training literature. Instead they rely on the Manuals of Firemanship and manufacturers' publications.

The main advantages of fire venting were considered by the brigade to be:

(a) improved working conditions for firefighters (45%);

(b) limitation of lateral fire spread (51%).

The disadvantages were considered to be :

(i) an increased risk to firefighters during roof operations (35%);

(ii) that, not used properly, it may result in an increase of fire intensity/spread and hence an increase in damage (40%).

A small number of respondents felt that the increase in manpower required (6%) and the nature of UK building construction (4%) were disadvantages.

Not surprisingly, when asked to suggest further sources of information some UK fire brigades (16%) suggested fire departments in the USA. However, UK brigades were also suggested, such as Wiltshire, Bedfordshire and Essex, named respectively by 11%, 4% and 4% of respondents.

6.2 Meetings with the UK Brigades

Opinion within the UK fire service differs as to the extent of ventilation application. Representatives of the FSI suggested that ventilation is a tactic regularly employed by the UK fire service during fire attack but that the extent of application depends very much on the experience of the Officer in Charge and the nature of the building and the fire. Training officers at the Fire Service College, on the other hand, believed that it is only used as a last resort when other tactics have failed or complications arise.

A common theme in many of the discussions was a growing recognition that practising firefighters would benefit from more education in the fundamentals of fire growth and development and that this would engender a better understanding of basic fire phenomena, such as flashover, backdraught, rollover, etc.. This was an opinion shared by representatives from Greater Manchester, Merseyside, West Yorkshire, Lancashire and Cheshire. They agreed that a positive move towards tactical fire ventilation would mean a fundamental change in firefighting tactics and training requirements.

UK firefighters recognise that there are significant benefits to be gained from ventilation, and that this has been proven on occasions when fires have self-vented, e.g. at Windsor Castle.

However, there is still a major concern over the safety of committing firefighters to roof-venting operations. The brigades did not wholly accept the US experience of ventilation and felt there was a need to explore US tactics in more detail and establish how these relate to injuries, fatalities and fire losses. The indication was that before adopting more aggressive ventilation tactics the UK fire service would require hard evidence, if possible supported by statistics, that ventilation achieves better results than current methods and does not give rise to more injuries or fatalities.

There is a strong concensus that automatic ventilation provides a positive benefit to firefighters. However, there also appears to be a need for better training in the use of pre-installed systems that have manual overrides for firefighters.

There are ongoing programs of operational research in Wiltshire, Bedfordshire, Essex and Grampian to evaluate PPV tactics. Interest appears to have been stimulated during visits to the USA and Sweden by senior officers. However, once again there is a strong view that experience from the USA must not be taken at face value and that more research into the effectiveness of their tactics should be conducted.

Amongst the brigades there is more interest in developing expertise in the use of PPV than in aggressive natural ventilation techniques.

The Swedish firefighting technique of offensive fog attack, augmented by flashover training, is also generating much interest.

6.3 Other Contacts

A meeting was held with Howard Morgan of the Fire Research Station to ascertain whether there is any ongoing research into tactical ventilation methods. He confirmed the generally held belief that little scientific effort is directed toward gaining a better understanding of firefighting tactics. He has recently completed a study of ventilation tactics for basements but the report has not yet been made available.

Contact was also made with Graham Hansell of Colt Technology, who again confirmed that most of the theoretical research effort is directed toward gaining a better understanding of the principles of automatic ventilation design, an example being the joint research project between Colt International and FRS into the effect of sprinkler sprays on vent efficiency.

Lt. Cmdr. Bamforth of RN Pheonix was contacted because it was understood that the Royal Navy were evaluating the use of PPV for fighting shipboard fires. The US Navy have been using the tactic for some time, but primarily only for smoke clearance and clean - up. The Royal Navy are only at the preliminary stage of formulating a research programme.

In respect of an industry contribution, exploratory meetings were held with Steve Marsh of Godiva who market Hale-USA products and Mike Lamoureux/David Appleton of Groupe Leader who market the Ram Fan which is also produced in the USA. Both companies, and others, are active in promoting PPV and some useful background information was obtained. At this early stage of gaining experience with PPV in the UK it appears that brigades are getting technical information and training notes from the USA via the industry.

7 FIRE VENTILATION IN THE USA AND OVERSEAS

7.1 Summary of Questionnaire Response

7.1.1 US Response

Twenty-five of the questionnaires circulated to the 50 largest fire departments in the USA were returned (see Appendix A).

All those who responded stated that tactical fire venting was used as a common tactic in residential buildings and single-storey industrial/commercial buildings. However, only 20 fire departments (80%) claim to use fire venting as a tactic in high-rise buildings.

The circumstances in which tactical ventilation would be used were as follows:

(a) for removal of heat and smoke from the structure (56%);

(b) where better working conditions for firefighters are required (36%);

(c) where backdraught or flashover conditions exist (20%).

The timing of tactical ventilation was often quoted as being dependent on the circumstances and objectives of fire venting. Almost half the fire departments (40%) stated that ventilation should coincide with interior water attack. A smaller number (16%) suggested that it should be initiated before water attack to reduce the risk of backdraught. One return suggested that fire venting could be employed at any stage during the fire but did not specify under what circumstances.

Several circumstances were considered inappropriate for fire venting, the main ones being:

(A) where the roof/building is unsafe (32%);

(B) where the fire area is small (32%);

(C) where interior water attack is not yet available (24%);

(D) where the exhaust path will increase occupant/ firefighter exposure (28%).

All the fire departments confirmed that they make holes in the roof to achieve fire venting. Approximately 30% raised some objection to the use of at least one of the following: wall openings, powered devices and installed vents.

The three main benefits of fire venting in large buildings were claimed to be:

(1) better conditions for firefighters (72%);

(2) decrease in property loss (56%);

(3) reduced risk of backdraught and flashover (48%).

The two main disadvantages of using tactical ventilation were that:

(i) it poses a danger to crews working on weakened structures (64%);

(ii) when not used properly, it could result in an increase in fire intensity/spread (72%).

84% of the fire departments provide some form of training to their firefighters; 36% provide training to recruits and 44% provide continuous training. One fire department suggested that they carry out all ventilation training "on-the-job".

Theoretical training is conducted in classrooms or dedicated training academies. Ten fire departments (40%) conduct practical training in buildings due for demolition and nine fire departments (36%) conduct practical training at the fire training ground.

Details of case studies and further contacts are given in Appendices D and E.

7.1.2 Overseas Response

Only five questionnaires were returned from contacts outside the UK and the USA. These responses came from Honolulu, Hong Kong, New Zealand, Finland and Sweden. Details of their responses are contained in Appendix A.

In Sweden the tactic of fire venting is used only for larger single-storey industrial and commercial buildings. The suggestion is that firefighters would attempt to seal up a smaller building and put the fire out with an interior attack, an approach similar to that adopted in the UK.

7.2 Meetings with US Fire Departments

US firefighters maintain that ventilation operations require a great deal of training, co-ordination, planning and skill. Many believe that a failure to ventilate early will result in a more passive approach to firefighting, which relies on external rather than internal fire attack.

The general philosophy is to vent quickly - if ventilation is delayed until it is obvious that it is required then it will probably be too late to carry it out safely or effectively.

They strongly believe that ventilation significantly reduces the potential for flashover- and backdraught-related injuries. All the US fire departments contacted directly were extremely surprised that the UK fire service only employ ventilation as a last resort. They could not envisage how firefighters could enter buildings and tackle fires effectively without early ventilation. Some even claimed that fire attack teams would refuse to enter buildings unless they were confident that ventilation operations were underway.

It is interesting to note that, although tactical ventilation is practised countrywide, opinions on the merits of PPV vary from one department to another. The larger, older fire departments, such as New York and Chicago have tried but are reluctant to adopt PPV whereas many of the expanding departments, e.g. Pheonix and Los Angeles, are more willing to change.

Because there is no national policy-making organisation for the US fire service, the onus lies on individual fire departments to carry out their own practical research. Although the situation is different in the UK, a similar trend is emerging with individual brigades conducting their own trials and exchanging information.

Discussions about specific ventilation tactics are summarised in Section 5.

7.3 Other Contacts

Contact was made with the NIST and the NFPA but neither were able to provide information or are currently undertaking any research in the field of tactical ventilation.

The IFSTA is about to publish an update of its 1980 manual on ventilation tactics, and were kind enough to make a manuscript available for this study.

Research aimed at establishing the effectiveness of PPV is being carried out at the University of Central Florida. This team is also developing a water simulation technique for training firefighters in the principles of PPV. Further research is being undertaken to develop a computer model of the hydraulic analogy of airflow used in the practical simulation. Further details are provided in Appendix C.

The Swedish fire service have, for the past two years, been conducting research into the use of controlled explosive charges for making holes in roofs. The device essentially comprises flexible explosive fitted into a framework that concentrates the force of the explosion in a defined position. A test group of firefighters has been trained in the use of the explosive devices and a one-year trial is about to commence. It is expected that the device will reduce the amount of time firefighters spend on roofs creating openings.

8 BASIC THEORY OF VENTILATION

8.1 Ventilation Research

8.1.1 Introduction

On the basis of the literature search that WFRC has undertaken, it is clear that the vast majority of theoretical and scientific research has been directed toward developing a better understanding of ventilation for the purposes of designing automatic ventilation systems. Very little attention has been focused on practical research into the ventilation of fires as a firefighting tactic.

In the USA the benefits of conventional vertical and horizontal ventilation are unquestioned and standard operating procedures have evolved through many years of experience. It appears that a need has never been felt to prove or demonstrate the merits of the approach through theoretical or practical research. It is interesting, however, that the relatively new technique of positive pressure ventilation (PPV) is stimulating debate in the USA and worldwide. Research is being undertaken to gain a better understanding of the benefits and disadvantages of this in practical firefighting situations.

8.1.2 Early Research

It is known that studies of roof venting were carried out about a century ago in Vienna (3), when a model theatre was built to see if fire on the stage could be confined by roof ventilation.

In a recent report for the National Research Council, Canada, which summarises the available research results on ventilation, Kim (1) suggests that roof venting for fire safety was first discussed by Sestack (2) in 1957. However, others (11) claim that rigorous fire ventilation research was begun after a disastrous fire destroyed the General Motors factory in Livonia, Michigan, in 1953.

The General Motors factory was a large single-storey structure with a flat roof, under which heat and smoke were trapped, preventing firefighters from approaching. General Motors subsequently initiated an experimental modelling study (12) with the Illinois Institute of Technology (IIT), to establish roof ventilation requirements for industrial plants of this type. The results provided much of the basis for the later development of the NFPA report 204M "Guide for Smoke and Heat Venting" (28).

Some early theoretical research into ventilation was also carried out by Yokoi (8,9) in Japan, who developed expressions for the flow of fire gases from vented roof reservoirs.

In the UK, throughout the 1960's, the Fire Offices' Committee Joint Fire Research Organization, in collaboration with Colt Ventilation and Heating Ltd (now Colt International), supported a programme of theoretical and experimental research into automatic ventilation. In 1960 P.H. Thomas and co-workers (4) reported on theoretical work on convection flow due to temperature difference and on experimental work using scaled models. The experiments demonstrated that the shape of a vent was not important and that its position within a small contained area was of only minor importance.

In 1963 Thomas et al. (5) developed correlations for the calculation of the temperature beneath a ceiling, the heat vented and the mass of air flowing into and out of a compartment, for different vent sizes, expressed in terms of the dimensions of the room and the size of the fire. However, the theory was limited to the early stages of fire growth.

Thomas and his co-worker Hinkley produced a further paper (Technical Paper No. 10) to present the research results in a form that could be applied to the design of practical roof venting systems (5a). Calculations and nomograms were provided for the design of systems to deal with three types of fire: small fires, large but not fully developed fires and fully developed fires.

Building on the work of Thomas et al., the practical considerations regarding the design and positioning of roof screens, the types and positioning of vents, exposure hazards and the compatibility of vents and sprinkler installations were addressed by Langdon Thomas and Hinkley in 1965 (6). They described simple methods for calculating approximate vent sizes for the purpose of firefighting and the control of special hazards. They also discussed the exposure hazard associated with roof vents and provided calculations for determining the depth of smoke screens required to form a smoke reservoir for a given vent area.

The first large-scale tests aimed specifically at investigating the effectiveness of vents in limiting horizontal fire spread in large buildings were conducted by Heselden and Theobold in a single-storey building 1.5m x 4.5m, and reported in 1969 (7); these tests also studied the use of water curtains. It was found that ventilation alone did not prevent the spread of fire from one timber crib to another spaced 0.3m away; and it was concluded that neither ventilation nor water curtains used in isolation would prevent fire spread but that a combination of the two could significantly limit the spread of fire.

In 1972 Keough (16) conducted a series of large-scale experimental fire tests in an aircraft hangar 13m high, with fires of up to 1.8MW m^{-2} of floor area, to study the design of automatic roof ventilation systems in single-storey buildings.

8.1.3 Recent Research

Recent research has concentrated on computer modelling, on refinement of the original theories developed in the early 1960's and on the application of ventilation to more complex building structures, e.g. shopping centres and atrium buildings.

Computer modelling is discussed in more detail in Section 9 but it should be explained here that the models fall into two categories: zone models and more complex field models. A number of zone models have been developed but there are a lack of experimental data with which to validate these, mainly owing to the high cost of full-scale testing. Field models offer more promise but at the moment their use is limited by the considerable demands they place on computational resources and the lack of validation work carried out.

Bengston and Hagglund (20) have used a zone model to study fire venting and compared the calculated results with the experimental results of Keough (16), they concluded that the two were in agreement. FRS and Colt International have been working together to develop a model to investigate the interaction between automatic ventilation and sprinkler operation (See Section 8.1.4). A range of other zone models has been developed but their application and validation in respect of fire ventilation is not known.

The interest in computer modelling has stimulated the development of alternative thermal plume theories, many of which are more complicated than the original "small" and "large" fire plume theories presented by Thomas et al. (5). Hinckley (21) compared several of the plume theories against the available experimental data for vented fires and found that the simple empirical equation for large-fire plumes presented by Thomas et al. (5) gave a better fit than some of the other correlations that appeared to be more soundly-based theoretically. It was also found that the large-fire plume theory could be applied to much smaller fires than had previously been believed.

In view of this Morgan (23) produced design guidance for venting gases in single-storey buildings that used only large-fire plume theory and was, in effect, a more convenient version of Thomas and Hinkley's Technical Paper No.10 (5a).

Law (22) also developed a correlation for the flow of fire gases from a vented roof reservoir using experimental data obtained from scale modelling of a shopping centre by Morgan et al. (24 and 25). Morgan later brought together much of the practical and theoretical research into a guide to the design of smoke control systems in multi-level shopping centres (26).

More recently, Morgan and Hansell have been investigating the theory behind the use of ventilation as a smoke control technique in atrium buildings (27).

8.1.4 Sprinklers and Ventilation

A long-standing question concerning the interaction between automatic ventilation and sprinkler operation is whether sprinklers affect the efficiency of smoke vents or smoke vents affect sprinkler operation. The concerns are that:

(1) the introduction of air associated with ventilation would lead to increased combustion and would so increase the severity of the fire that sprinkler control would not be possible;

(2) sprinkler discharge would cool the fire gases and thereby reduce the ventilation efficiency.

In the early 1970's Heskestad (10) carried out a number of model experiments to investigate sprinkler water demand, visibility conditions and fuel consumption in single-storey buildings containing both sprinklers and automatic roof vents. The results indicated that, in cellulosic fuel fires, vents and draft curtains caused an increase in water demand, only slightly delayed loss in visibility and increased fuel consumption. The results were more favourable for a series of large heptane fires, where vents reduced the water demand slightly and markedly improved visibility conditions. The Factory Mutual Research Corporation (FMRC), who conducted this and other research into the issue (13,14), now strongly suggest that automatic ventilation in sprinklered buildings is, at best, of limited value and can often be detrimental. The US guide (28) is ambivalent about the fitting of roof vents to sprinklered buildings.

Waterman (11), on the other hand, suggested that the presence of automatic vents would complement rather than impair the protection afforded to large single-story buildings by automatic sprinkler systems. He argued that automatic vents will work even if the sprinkler system is defeated by human error or negligence or mechanical damage, and that they will also substitute for manual roof venting upon the arrival of the fire service. His conclusions were based on 45 medium-scale experiments in a building 23m x 7.5m x 5m.

Kim (1) reported on a literature search in venting and sprinkler operations conducted by the IIT Research Institution (IITRI) (17), which found that the effects of ventilation on sprinkler control had been judged both positive and negative in past reports. It was noted that roof venting gave positive results in most full-scale tests and that where negative effects were claimed the results were often obtained either with perimeter venting or from studies employing models with suspected scaling inadequacies.

Heselden (29) carried out a similar review in 1984 with similar results. He suggested developing a numerical model of the system based on "simple engineering relationships" as obvious difficulties had been encountered with experimental work carried out on a reduced scale, full-scale tests being very expensive.

To expedite this a consortium including FRS and Colt International based in Ghent has recently carried out further experimental work and developed a new mathematical zone model (18) to investigate the importance of different factors. It is claimed that the model shows automatic ventilation to produce no delay of practical importance with fast-growing fires and relatively unimportant in determining the size of the fire when the first sprinkler operates. Although there are some exceptions to this rule, typically for slow-growing fires, the delay in sprinkler operation is claimed to be more than offset by the advantages of a clear atmosphere. Characteristically, however, the results of the Ghent tests have been criticized (19) and more experimental validation of the theoretical work is undoubtedly required.

The debate about smoke ventilation and sprinkler interaction continues today. Recent reports (19) of a seminar organized by FRS and Brandforsk (The Swedish fire research board), attended by delegates from both Europe and the USA, suggest that there is still no common ground and engineers still have an incomplete toolkit with which to work.

8.1.5 PPV Research

It has been reported (32) that, prior to about 1980, large fans had been used to push smoke out of buildings during salvage, smoke clearance and clean-up operations. During the 1980's fire departments and fan manufacturers in the USA developed the technique of PPV for use during fire attack. A chronological overview of the published work in this area is provided by Ziesler et al. (44). Limited test evidence is available to support claims that the tactic will significantly reduce the levels of smoke, carbon monoxide and heat within a building when applied correctly. Further practical research in this area is ongoing (see Section C.4).

The majority of research into the practical application of PPV has been carried out by US fire departments but few of the results have been published.

8.2 Ventilation Theory

It is beyond the scope of this report to provide a detailed description of the scientific theory of ventilation. This has already been covered by others. The seminal work in this field is documented in FRS Technical Paper No.7 (5) and a useful synopsis of the current theories is provided by Hinkley in the US Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering (38).

Although the way in which hot combustion products will flow and mix with air is a complex phenomenon, influenced by many factors, it has been shown that a simplified "zone" model is often appropriate for automatic ventilation design.

The simple plume and zone theory is likely to be suitable for establishing the potential benefits of natural ventilation tactics.

However, the existing models are unlikely to be suitable for exploring the effects of powered systems or horizontal ventilation, especially where the smoke is being discharged via a low-level vent. In such instances cross-flow mixing and dilution processes will be more important; these are more difficult to model theoretically and may require the use of field models or network models (see Section 9).

There are significant gaps in the theory that do not facilitate straightforward modelling of ventilation effects, most notably;

- the effect on lateral fire/flame spread at roof and floor level,
- the interaction between water attack, ventilation airflows and fire chemistry in relation to the backdraught problem.
- mixing and smoke movement by PPV and horizontal ventilation.

A significant improvement in the theoretical understanding of ventilation is not expected in the near future. The continued development of field modelling is considered to offer the most promise.

9 MODELLING OF FIRE VENTILATION

9.1 General

Two forms of modelling are considered appropriate for developing a better understanding of tactical ventilation:

(1) theoretical;

(2) physical.

A discussion of the merits of each approach is provided in the following Sections.

9.2 Theoretical Modelling

Because of the complexity of the problem, the majority of theoretical models require a computer based solution.

Computer models have been developed that can predict fire development in both single-room and multi-room/multi-floor situations. The models differ in sophistication with regard to their physics and mathematics for different building geometries and applications.

9.2.1 Field Models

Field models solve a set of partial differential equations from the principles of fluid mechanics. The compartment or space is divided into a grid of small cells (typically thousands) and the fundamental equations of mass, momentum and energy are solved at each cell. In principle, such models will allow the user to determine the conditions at any point, in a compartment of any shape or size. However, the scope for their application is currently limited by their need for powerful computing resources and the length of time required to complete a simulation (typically one or two days for a single-room scenario). There is also a lack of validation for both small and large scale problems. There are also difficulties in simulating the flaming region.

9.2.2 Zone Models

Zone models, whereby a compartment is divided into a number of distinct zones (usually two) of uniform properties, offer a simpler solution. Although the zone models involve significant simplification, some of them have been validated against full scale fires in large buildings and the results suggest that they are reasonably accurate for small fires i.e. of the order of 5 MW (43). The results for large fires are less encouraging, mainly because most of the experimental results that led to the formulation of plume models were conducted on a laboratory scale. Further research and validation is needed to establish the bounds of application for each of the models.

Whilst computer zone models may be useful for investigating the effect of ventilation in the early stages of a fire, e.g. for the design of automatic ventilation systems, the accuracy of their application to large fires requires further development.

9.2.3 Network Models

Network models employ mass balance equations and flow equations, and may include additional equations for smoke concentration and temperature. Fire is usually described in terms of its temperature and smoke production characteristics as a function of time. Typical input data are meteorological data (air temperature and wind speed), building characteristics (height, leakage areas) supply of ventilation air, fire characteristics and indoor air temperatures.

Models can be either transient or steady state but for ventilation purposes a transient model will be more appropriate. These models offer scope for investigating the bounds of application of PPV in multi-room, multi-level buildings. However, as with all the modelling approaches considered, the accuracy of predictions and the range of validity of the models available needs to be established in the context of large fires.

9.3 Physical Modelling

The destructive nature of large fires means that full scale modelling can be costly. Alternative approaches involve the use of scale modelling or simulation modelling.

9.3.1 Scale Modelling

Scale modelling has received extensive application during the development of much of the existing ventilation theory.

It has been shown (see reference (5)) that provided the main method of heat transfer is by convection (i.e. heat transfer by conduction and radiation is small) and the main flow is turbulent relations may be derived between the temperature and velocity at points in a model and the convective heat input and characteristic height dimension of the model. It has also been shown by experiment that these relationships obey scaling laws.

Reduced-scale modelling is generally accepted as a reasonable basis for the development of ventilation theory but, as for computer modelling, there is still a need to validate the results against data obtained from full-scale experiments, particularly where large fires are being considered.

It is difficult to envisage how this type of modelling could be adapted to include the effects of firefighting water sprays and thus facilitate a comparison of the ease of firefighting with and without ventilation.

9.3.2 Simulation Modelling

The University of Central Florida have developed a simulation model for tactical ventilation (see Appendix C). For this, small scale models of structures are constructed of thin, clear acrylic. Heated air is simulated by injecting red coloured water at a rate corresponding to the rate of air expansion caused by a localised fire in a single room. The air flow from the fan for PPV is simulated by blue-coloured water injected at a scaled rate corresponding to the actual air flow of the fan. The simulation is conducted either on a water table or in a deeper transparent tank.

Although at this stage the simulation method has been only calibrated against the large-scale fire tests undertaken by UCF and OCFRD, it is claimed that the real time and simulation time of events compare very well. The simulation technique is particularly useful for classroom training as it provides a cost effective, safe and visually interesting representation of events. It is also a flexible tool for demonstrating the effects of errors in judgement, e.g. incorrect selection of an exhaust point. However, further research is required before the simulation technique can be used as a predictive tool.

The main limitations of the technique in its present form are that:

(1) it cannot realistically simulate buoyancy effects and is, therefore, of limited use for natural ventilation or multi-storey applications;

(2) it cannot be used to simulate flashover or backdraught effects;

(3) it does not account for environmental effects such as wind and humidity.

Further research is being undertaken at UCF to develop a computer model of the hydraulic analogy for air flow. It is claimed that a simplified form of field modelling approach can be applied to the water system. No details of the research were available at the time of the visit but is expected that a preliminary model will be developed early next year.

Similar models have been used in the past (5) to provide a representation of roof ventilation. The models contained a brine solution and the flow of hot gases form a fire at floor level was simulated by the flow of coloured water having a lower density.

Such models are undoubtedly useful for demonstration or teaching purposes but they are considered to be of limited use for predictive or investigative research.

10 CONCLUSIONS

10.1 Assessment of Advantages and Disadvantages

The following tables summarise the extent of anecdotal and theoretical support for the general claims made about tactical ventilation.

The views expressed by US firefighters relate to situations in which the tactic of ventilation is applied correctly. Automatic ventilation is not considered.

Table 1 considers life safety issues and Table 2 considers property protection issues.

Table 1-Summary of Support for Tactical Ventilation
Life Safety Issues

CLAIMS MADE ABOUT TACTICAL VENTILATION	BASIS AND STRENGTH OF SUPPORT FOR CLAIM	
	Expressed views of US fire fighters	Theoretical /Test
ADVANTAGES		
Aids rescue operations	●●●	-
Reduces backdraught potential	●●●	-
Reduces flashover potential	●●●	-
Reduces concentration of toxic gases	●●	-
Assists escape	●	-
DISADVANTAGES		
Exposes firefighters to roof collapse	●	-
Increases backdraught potential	○	-
Increases flashover potential	○	-

●●● Strong support
●● Support
● Limited support
○ No support
\- Evidence not available

Table 2-Summary of Support for Tactical Ventilation Property Protection Issues

CLAIMS MADE ABOUT TACTICAL VENTILATION	BASIS & STRENGTH OF SUPPORT FOR CLAIM	
	Expressed views of US fire fighters	Theoretical /Test
ADVANTAGES		
Relieves effect of heat on building structure	●●●	●●●[1]
Raises smoke layer (improving visibility & fire identification)	●●●	●●[2]
Lowers temperatures (facilitates earlier entry & fire attack)	●●●	●●[2]
Limits smoke damage to contents	●●●	-[3]
Reduces potential for breaching fire compartment boundary	●●●	-
Reduces potential for water damage	●●	-
Reduces lateral flame spread at roof level	●●	-
Reduces lateral flame spread at floor level	●	-
DISADVANTAGES		
Increases rate of burning	●[4]	●●●[5]
Involvement of other exposures (e.g. external facia, adjacent buildings)	○	-
Increases fire spread within building due to air currents created	○	-

●●● Strong support
●● Support
● Limited support
○ No support
\- Evidence not available

[1] See reference 45.

[2] Theoretical studies of automatic ventilation suggest that these benefits would be achieved but no explicit studies of tactical venting have been undertaken to quantify the level of benefit.

[3] The effectiveness of limiting smoke damage will depend largely on the extent of smoke build-up prior to ventilation and the nature of the contents.

[4] Not considered to be a practical problem by US firefighters because water attack will be available.

[5] There is theoretical and experimental evidence to support an increase in the rate of burning but there is no evidence to indicate whether or not this is an operational disadvantage.

10.2 Ventilation Practice in the USA

10.2.1 Tactical Ventilation Techniques

The following conclusions are based on discussions held with US fire departments and questionnaire responses.

(1) The general maxim is "vent early-vent often", but not before hoselines are charged.

(2) The three most commonly applied techniques of tactical ventilation are:

- vertical ventilation, achieved by making holes in roofs;
- horizontal ventilation, achieved by opening/ breaking doors and windows;
- PPV, achieved by using high-volume-flowrate fans to direct the flow of smoke.

(3) Natural vertical and horizontal ventilation techniques are used extensively throughout the USA in the early stages of fire attack. The use of PPV is not universal and research by fire departments is ongoing.

10.2.2 Large Industrial Buildings

The following conclusions relate to large industrial buildings, which were the main focus of attention for this survey.

(1) There is a strong belief amongst US fire departments that vertical ventilation is the most appropriate method of venting large single-storey industrial buildings.

(2) The scope for horizontal ventilation is normally limited by the availability of openings and the danger of spreading fire through the building.

(3) Opinion differs over the use of PPV. Some feel that the large volumes of these buildings and the lack of convenient openings limit its practical application.

(4) In multi-storey industrial buildings vertical ventilation is used only if the fire involves the upper floor. Cross ventilation is employed to deal with fires on the lower floors. Some departments use PPV to supplement cross ventilation. PPV fans are also sometimes used to pressurize other floors and limit smoke ingress.

10.2.3 Other Building Types

Table 3 summarises the tactical ventilation techniques most commonly used in different types of premises and fire situations.

Table 3-Summary of Expressed US Preferences for Tactical Ventilation

BUILDING TYPE	FIRE LOCATION	USEFULNESS OF VENTILATION TECHNIQUE		
		VERTICAL	HORIZONTAL	PPV*
LARGE INDUSTRIAL (Single-storey)	-	●●●	●[1]	○
LARGE INDUSTRIAL (Multi-storey)	On upper level	●●●	●[1]	○
	On lower level	○	●[1]	●[2]
COMMERCIAL SHOP UNIT	In ceiling void	●●●	○	●[2]
	Below ceiling	●●●	●	●●[3]
HIGH-RISE	-	○	○	●●●[4]
LOW-RISE (Compartmented)	-	●●	●	●●●[4]
SINGLE FAMILY DWELLING	In loft	●●●	○	●●[5]
	Below loft	●●[6]	●●	●●●

●●● Very useful
●● Useful
● Of limited use
○ Not normally used

* Views of those fire departments that promote the tactic.

1 Lack of openings limits usefulness.
2 Used to pressurize adjacent compartments and limit smoke ingress.
3 Used to complement horizontal or vertical ventilation.
4 Used to pressurize stairs or direct smoke into vertical shafts.
5 Used to complement vertical ventilation.
6 Not used by departments that promote the use of PPV.

10.2.4 Training

(1) Training manuals describing standard procedures for tactical ventilation are available in the USA (see Section 4). Many departments produce their own training literature tailored to the types of buildings and hazards that they encounter locally.

(2) Venting is ingrained in the US system of firefighting but they recognise that there are risks involved and place particular emphasis on practical and classroom training in the following areas:

(a) understanding fire development and behaviour;

(b) methods of building construction;

(c) communication;

(d) co-ordination of ventilation with fire attack;

(e) anticipation of fire escalation.

10.3 Ventilation Practice in the UK

(1) Ventilation is not a tactic used in the early stages of fire fighting. However, many UK firefighters have experienced its benefits whilst attending fires that have self-vented.

(2) It is difficult to obtain a clear picture of how frequently ventilation is employed during fire attack. Most brigades state that they do not promote the tactic but that it is used by some experienced officers when they are confident of the outcome of their actions and firefighting jets are in position.

(3) Cross ventilation (e.g. using openable windows on stairways) is commonly practised but vertical ventilation is not widely used. The practice of vertical ventilation from aerial appliances is being developed by some brigades.

(4) A small number of brigades are conducting trials in the use of PPV, although reports of its use during firefighting operations are limited.

(5) Although tactical ventilation techniques are not commonly used in the UK, many brigades have expressed a strong interest in the potential benefits, especially using PPV techniques.

10.4 Scope for Further Application of Venting in the UK

10.4.1 Large Industrial Buildings

(1) Tactical ventilation of large single-storey industrial buildings may provide operational benefits. However, the lightweight nature of modern building constructions makes them hazardous to work on and vulnerable to collapse. In this situation it is essential that safe working procedures are developed, e.g. the use of aerial appliances.

(2) In view of the potential risks that vertical ventilation poses to firefighters, consideration should be given to the provision of pre-installed vents for the purposes of assisting firefighting and limiting property damage.

(3) Trench or strip cutting could provide a means of reducing fire spread and would not involve firefighters in hazardous operations directly above the fire.

(4) Scope for the application of PPV techniques in large industrial buildings may be limited.

10.4.2 Other Building Types

(1) Defensive trench or strip cutting could be more extensively used in commercial units and terraced properties where there is a risk of concealed horizontal flame extension at roof level. Defensive operations are considered to be safer

than offensive ones because they are carried out away from the seat of the fire, in advance of fire spread.

(2) There may be scope for the use of PPV fans in high- rise buildings to pressurize stairways and corridors and afford protection against the ingress of smoke.

(3) In low-rise residential buildings consideration should be given to the benefits of channelling smoke into stairways.

(4) PPV appears to be a method of tactical ventilation that would be well suited to compartmented buildings and residential premises.

(5) US fire departments place great emphasis on training specifically aimed at ventilation techniques; and before a more widespread introduction of tactical venting in the UK, detailed procedures and training would need to be developed.

10.5 Theory and Research

(1) The majority of scientific, theoretical and experimental research has been directed toward developing a better understanding of ventilation for the purposes of designing automatic systems. Very little research has been undertaken to quantify the benefits of tactical ventilation.

(2) The basis of support for tactical ventilation is largely anecdotal, stemming from operational firefighting experience in the USA. However, it is considered likely that existing theoretical and experimental research could assist in validating many of the claims made about tactical ventilation, particularly vertical ventilation.

(3) The scientific theory of venting hot gases from a stratified smoke layer is generally well established although further research is required to reconcile the different plume theories, e.g. point source and large fire theories, spill plume theories, etc..

(4) The theoretical understanding of cross ventilation and forced ventilation situations, where considerable mixing of fresh air and smoke is likely to occur, is not well established.

(5) Theory to describe the interaction between venting and water attack, and the potential implications in backdraught and flashover situations, is not well established.

(6) There are no theoretical models to describe the effect of ventilation on lateral fire spread at roof or floor level. Large-scale experimental data may exist but specific analysis has not been undertaken.

(7) Operational research into the application of PPV is currently being undertaken by fire services in the UK, USA,

Sweden and Spain. This tactic is being hailed as a safer alternative to traditional ventilation tactics in many situations but no theoretical studies have been undertaken to support this claim.

10.6 Summary

Natural vertical and horizontal ventilation techniques are used extensively throughout the USA in the early stages of fire attack but the use of PPV is not universal and operational research is ongoing. The tactics are ingrained in the US system and it appears that a need has never been felt to prove or demonstrate the merits through theoretical or practical research.

In most buildings, especially large single storey structures, US firefighters tend to favour roof ventilation. There are situations in which horizontal ventilation is recommended but the practical difficulties of achieving effective ventilation are often quoted. In two storey residential houses there is a growing recognition that PPV may be the tactic of the future.

The general advice is to vent early and often, provided that it can be achieved safely and that charged hoselines are available to counter any consequential increase in fire severity. Training literature on ventilation tactics exists in the USA and particular emphasis is also placed on practical and classroom training to instill in firefighters an understanding of fire behaviour and the methods of building construction.

In the UK it is difficult to obtain a clear picture of how frequently ventilation is employed during fire attack. Most brigades state that they do not promote the tactic but that it is used by some experienced officers when they are confident of the outcome of their actions. However, many UK firefighters have experienced the benefits of ventilation whilst attending fires which have self vented and a strong interest is developing in the use of such tactics, especially PPV.

Tactical ventilation, and in particular PPV, is not a panacea for all problems but simply another tool at the disposal of the Officer in Charge. Subject to further research, aimed at quantifying the potential operational benefits and developing safe working practices, it is felt that there is scope for more extensive application of ventilation tactics in the UK.

In large industrial buildings it may not be safe to commit firefighters to offensive roof top operations and consideration may need to be given to the use of aerial appliances, pre-installed vents or defensive operations instead. (Defensive operations are considered to be safer than offensive ones because they are carried out away from the seat of the fire.)

Defensive trench or strip cutting could also be more extensively used in commercial units and terraced properties where there is a risk of concealed horizontal flame extension at roof level.

In high-rise buildings there may be scope for the use of PPV fans to pressurize stairways and corridors and afford protection against the ingress of smoke. US experience suggests that there is little scope for natural ventilation in many instances because of the difficulties created by wind and stack effects.

In low-rise residential buildings consideration should be given to the benefits of channelling smoke into stairways, even though this may be alien to UK firefighters. PPV appears to be a method of tactical ventilation that would be well suited to this type of compartmented building and especially two storey residential premises.

US fire departments place great emphasis on training specifically aimed at ventilation techniques and before a more widespread introduction of tactical venting in the UK, detailed procedures and training schemes would need to be developed.

The majority of scientific, theoretical and experimental research has been directed toward developing a better understanding of ventilation for the purposes of designing automatic systems. Consequently, the theory of venting hot gases from a stratified smoke layer is generally well established but the theory of cross ventilation and forced ventilation, where considerable mixing of fresh air and smoke is likely to occur, is not well understood. Theory to describe the interaction between venting and water attack, and the potential implications in backdraught and flashover situations, is also not well established.

There are no theoretical models to describe the effect of ventilation on lateral fire spread at roof or floor level. Large scale experimental data may exist but detailed analysis has not been undertaken.

11 RECOMMENDATIONS

11.1 General

On the basis of this study it is considered that further work is required to:

(a) demonstrate the effectiveness of tactical ventilation procedures;

(b) develop procedures appropriate to UK conditions;

(c) provide firefighter training and ensure safe implementation.

Recommendations for achieving the above are provided below.

11.2 Effectiveness of Tactical Ventilation Procedures

11.2.1 Introduction

To establish the merits of ventilation procedures and to provide guidance on venting requirements (i.e. vent areas or fan flow rates) the following theoretical and experimental work is recommended. For the reasons outlined in 10.4.1, consideration has been limited to the tactics of vertical ventilation and PPV.

11.2.2 Vertical Ventilation

Of the possible benefits resulting from vertical ventilation it is considered that the following are the most important and require further investigation:

(1) smoke removal;

(2) temperature reduction;

(3) reduction of roof-level fire spread.

(i) Modelling

Items (1) and (2) above may be analysed in a relatively straightforward manner and existing zone models should be used to investigate the vent areas required to reduce compartment temperatures and raise the smoke layer for a range of fire and building sizes.

Zone models have generally been developed for small fires and physical tests/demonstrations would be required to validate the models for large fires. These tests would also serve to provide firefighters with a practical demonstration of the possible benefits of ventilation.

(ii) Testing

There are currently no models available that will allow the influence of ventilation on lateral fire spread to be evaluated. It is therefore recommended that this be investigated within the programme of large-scale fire tests.

The test programme should provide a basis of comparison between the ease of firefighting activities in vented and unvented conditions. Whilst there is a substantial amount of information available on the venting of small fires (e.g. 5MW) there are few data in relation to well developed fires. It is therefore considered desirable to carry out tests involving fires of 10MW or more. The tests could be carried out in a small warehouse building due for demolition and should be used to investigate the relationship between vent area and fire size. The precise nature of the tests would be dependent upon the findings of the modelling study.

The ability of ventilation to prevent flame spread at high level (e.g. along a terrace of houses or shops) could be investigated using tests involving a room of similar size to that found in a small house (i.e. of the order of $10m^2$).

(iii) Cost-benefit analysis

A cost-benefit analysis should be undertaken as a basis for determining the worth of pre-installed roof vent systems in large industrial buildings. This should establish whether there are significant property protection benefits to be gained from the installation of vents for firefighting purposes.

11.2.3 Positive Pressure Ventilation

Many US fire departments question the use of PPV in large volumes and modelling for these applications is likely to be difficult. It is therefore recommended that investigations into the use of PPV systems be concentrated on residential properties and other buildings comprising small rooms or compartments.

Of the possible benefits resulting from PPV it is considered that the following are the most important and require further investigation:

(1) smoke removal;

(2) temperature reduction.

Fire spread could be increased by the incorrect use of PPV and there is a need to establish in what circumstances this may be significant.

(i) Modelling

Simple zone models are not appropriate to the analysis of PPV and it is recommended that, initially, network flow models be used to investigate the movement of smoke and heat that may occur with different configurations of fan placement and exhaust location.

PPV fans are regularly used to pressurise stairways and other areas not yet affected by fire. The effectiveness of fans used in this manner could readily be investigated using network models.

(ii) Testing

To investigate the conditions under which fire could be spread by PPV operations, it is recommended that full-scale tests be carried out. PPV is widely used in residential buildings in the USA and it is suggested that tests in two-storey houses would represent the most appropriate focus for initial studies. In particular, the investigation should seek to establish whether and in what circumstances fire may be spread to occupied rooms by the application of PPV.

11.3 Development of Procedures

A working group, consisting of fire officers from UK brigades that regularly use ventilation techniques, should be formed to establish a transfer of practical experiences and review the implications of using tactical ventilation procedures.

It is recommended that a number of experienced UK fire service personnel spend some time with US fire departments to study the practical application of tactical fire ventilation techniques.

On the basis of the theoretical, testing and operational studies, the scope for the use of tactical ventilation in the UK should be established and procedures should be developed for general implementation.

11.4 Implementation

It is recommended that before tactical ventilation is introduced to the UK on a widespread basis practical trials should be carried out by a limited number of brigades.

The use of roof venting and PPV does have potential safety implications both for the firefighters and the building occupants. It is therefore essential that detailed training schemes are developed and implemented prior to the general application of tactical fire ventilation techniques.

ACKNOWLEDGEMENTS

Acknowledgements are due to the following:

All members of the FEU, John Foster, DO. W. Follet and StnO. J. Fay (seconded fire officers) for their assistance

Members of the FSI, HMI Pearn and HMI Wells.

All the UK fire brigades that responded to the questionnaire and the following representatives:

CFO J. Craig	Wiltshire
DCO N.Wright	Wiltshire
SDO A. Stone	Essex
DO T. Stratford	Essex
ADO R. Shepherd	Bedfordshire
StnO A. New	Bedfordshire
ACO C. Smith	Greater Manchester
DO I. Massie	Merseyside
DO T. Vinn	West Yorkshire
DCO P. Holland	Lancashire
DCO R. Hunt	Cheshire
DCO M. Saunders	West Yorkshire
Mr P. Grimwood	London Fire and Civil Defence Authority (LFCDA)
Mr J. Taylor	North Yorkshire
ADO R. Van Stratten	Fire Service College
DO J. Lowe	Fire Service College
ACO P. Whitehouse	Fire Service College

Other specialists in the UK for their assistance:

H. Morgan	Fire Research Station
G. Hansell	Colt Technology
S. Marsh	Godiva
M. Lamoureux	Groupe Leader
M. Appleton	Groupe Leader

All the US fire departments that responded to the questionnaire and the following representatives:

Chief D. Burns	New York City Fire Department
Captain C. Growley	Orange County Fire and Rescue Department
Lieutenant Gibbons	Chicago Fire Department
Lieutenant O'Donnell	Chicago Fire Department
Chief Divis	Chicago Fire Department
Chief Snyder	Chicago Fire Department
Captain Vickery	Seattle Fire Department
Deputy Chief Campbell	Seattle Fire Department
Deputy Chief Rose	Seattle Fire Department

Other specialists in the USA for their assistance:

Mr H. Wood	Federal Emergency Management Agency
Miss P.S Ziesler	University of Central Florida
Dr. F. Gunnerson	University of Central Florida
Mr J. Mittendorf	

All overseas fire departments that responded to the questionnaire and the following representatives :

Mr. H. Bjornstron	Stockholm Fire Training College
Mr. J. Enjin	Swedish Rescue Services Board
Mr. P. Ronnlund	Swedish Rescue Services Board

REFERENCES

1. Kim, A.K., "A Review of Venting of Compartment Fires to Aid Firefighting", Internal Report No. 627, National Research Council Canada, April 1992.

2. Sestack, E.J., "Roof Venting for Fire Safety", Quart. National Fire Protection Association, 50, pp. 212-215, 1957.

3. Lawson, D.I.,"Discussion of paper 'Fire Venting in Single-storey Industrial Buildings' by P.J. Hinckley and G.J. Langdon Thomas", *The Institution of Fire Engineers Quarterly*, 23, p. 394,1963.

4. Thomas, P.H., Simms, D.L., Hinkley, P.L, and Theobald, C.R., "Roof Venting of Burning Enclosures: Part II. Venting Fires of Constant Heat Output", Fire Research Note No. 419, Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization, London, February 1960.

5. Thomas, P.H., Hinkley, P.L., Theobald, C.R., and Simms D.L., "Investigations into the Flow of Hot Gases in Roof Venting", Fire Research Technical Paper No.7, HMSO, London, 1963.

5a Thomas, P.H., and Hinkley, P.L.,"Design of Roof-venting Systems for Single Storey Buildings ", Fire Research Technical Paper No.10, HMSO, London, 1964.

6. Langdon Thomas, G.J, and Hinkley, P.L., "Fire Venting in Single Storey Buildings", Fire Note 5, Ministry of Technology and Fire Offices' Committee Joint Fire Research Organization, London, 1965.

7. Heseldon, A.J.M., and Theobald, C.R., "The Prevention of Fire Spread in Buildings by Roof Vents and Water Curtains; Part 1. Fire Experiments", Fire Research Note No. 791, Ministry of Technology and Fire Offices' Committee Joint Fire Research Organization, London, 1969.

8. Yokoi, S., "A Study of Dimensions of Smoke Vent and Fire Resistive Construction", Report No. 29, Building Research Institute, Tsukuba, Japan, March 1959.

9. Yokoi, S., "Study on the Prevention of Fire Spread by Hot Upward Current", Report No.34, Building Research Institute, Japan, November 1960.

10. Heskestad, G., "Model Study of Automatic Smoke and Heat Vent Performance in Sprinklered Fires", Technical Report FMRC Serial No. 21933 RC74-T-29, Factory Mutual Research Corporation, Norwood, Ma., 1974.

11. Waterman, T., "Fire Venting of Sprinklered Buildings", *Fire Journal*, Vol.78., No.2, National Fire Protection Association, March 1984.

12. Busby, A.L., and Pigman, G.L., "Roof Ventilation Requirements for Industrial Plants", Final Report Project No. L565., Armour Research Foundation (IITRI), Chicago, Ill, 1955.

13. Factory Mutual Research Corporation, "Fire Tests of Palletized and Racked Tire Storage", FMRC Report Serial No. 19037, July 1970.

14. Factory Mutual Research Corporation, "Fire Protection Adequacy for Foamed Polysytrene Egg Carton Float Storage", FMRC Report Serial No. J.I. OEIRI-RR, May 1980.

15. Morgan, H.P., "Roof venting - similarities between large and small scale calculations", *Fire Prevention*, No. 198, pp. 32-33, April 1987.

16. Keough, J.J., "Venting fires through roofs: experimental fires in an aircraft hanger", Commonwealth Experimental Building Station (Australia), Report UP 344, October 1972.

17. Illinois Institute of Technology Research Institute, "Fire Venting of Sprinklered Buildings", Report for Fire Venting Research Committee, IITRI Project J08385, 1982.

18. Hinckley, P.L., "Sprinkler operation and the effect of venting; studies using a zone model ", Building Research Establishment (BRE), BR213.

19. *Fire Prevention*, "Debate on smoke vents and sprinkler action continues", *Fire Prevention* No. 251, p. 9, July/ August 1993.

20. Bengston, S., and Hagglund, B., "A Smoke-Filling Simulation Model and its Engineering Applications", *Fire Technology*, Vol. 20, No. 2, pp. 92-103, May 1986.

21. Hinckley, P.L., "Rates of Production of Hot Gases in Roof Venting Experiments", *Fire Safety Journal*, Vol. 10, No.1, pp. 57-65, October 1986.

22. Law, M., " A Note on Smoke Plumes from Fires in Multilevel Shopping Malls", *Fire Safety Journal*, Vol.10, No.1, pp. 197-202, October 1986.

23. Morgan, H.P., "A Simplified Approach to Smoke Ventilation Calculations", BRE Information Paper, IP 19/85, 1985.

24. Morgan, H.P., and Marshall, N.R., "Smoke Control Measures in a Covered Two Storey Shopping Mall having Balconies as Pedestrian Walkways", BRE CP 11/79, Borehamwood, 1979.

25. Morgan, H.P., Marshall, N.R., and Goldstone, B.M., "Smoke Hazards in a Covered, Multi-level Shopping Mall; Some Studies using a Model 2-storey Mall", BRE CP 45/76, Borehamwood, 1976.

26. Morgan, H.P. and Gardner, J.P., "Design Principles for Smoke Ventilation in Enclosed Shopping Centres", BRE 186, Building Research Establishment, 1990.

27. Morgan H.P., and Hansell G.O., "Atrium Buildings: Calculating Smoke Flows in Atria for Smoke-control Design", *Fire Safety Journal*, 12, pp. 9-35, 1987.

28. National Fire Protection Association, "Guide for Smoke and Heat Venting", NFPA 204M, Quincy, Ma., 1982.

29. Heselden, A.J.M., "The Interaction of Sprinklers and Roof Venting in Industrial Buildings: the Current Knowledge", BRE Report, 1984.

30. Ziesler, P.S., " Laboratory Simulation of Positive Pressure Ventilation", MSc thesis, College of Engineering, University of Central Florida, Orlando, Florida, 1993.

31. Wiltshire Fire Brigade, "Ventilation at Fires", Operational Note 7.27, December 1990.

32. Grimwood, P.T., "Fog Attack, Firefighting Strategy and Tactics - an International View", pub. FMJ International Publications Ltd., Great Britain, 1992.

33. Carlson G., "Truck Work - A Must, Regardless of Manpower", *Fire Engineering*, Vol 136, No.9, p. 6, 1983.

34. Mittendorf, J., "Ventilation Methods and Techniques", pub. Fire Technology Services, El Toro, Ca., 1988.

35. Mittendorf, J.W., "Tempest Positive Pressure Training Manual", Tempest Technology Corporation, 1992.

36. Mittendorf, J. W., "Positive Pressure Ventilation", *Military Firefighter*, pp. 31-37, August, 1991.

37. Mittendorf, J. W., "PPV on the Fireground", *Fire Engineering*, pp. 47-56, August, 1992.

38 Hinkley, P.L., "Smoke and Heat Venting", SFPE Handbook of Fire Protection Engineering, Section 2, Chapter 3, pp 2.33-2.44, Society of Fire Protection Engineers, Quincy, Ma., USA, 1988.

39. IFSTA Manual, "Fire Ventilation Practices/validated by the International Fire Service Training Association", IFSTA 107, 6th Edition, Fire Protection Publications, Oklahoma State University, 1980.

40. IFSTA Manual, "Essentials of Fire Fighting/validated by the International Fire Service Training Association",3rd Edition, Fire Protection Publications, Oklahoma State University.

41. Private correspondance with Howard Morgan of FRS.

42. Morgan H.P., and Bullen, M.L., "Smoke Extraction by Entrainment into a Ducted Water Spray", Fire Research Note No. 1010, FRS, June 1974.

43. Duong, D.Q., "The Accuracy of Computer Fire Models: Some Comparisons with Experimental Data from Australia", *Fire Safety Journal*, Vol. 16, pp. 415-431, 1990.

44. Ziesler, P.S., Gunnerson, F.S., and Williams, S.K., "Simulation of PPV for Research and Training", paper presented at the Fourth International Symposium on Fire Safety Science, Ottawa, Ontario, Canada, June 13-17, 1994.

45. Harmathy, T.Z., and Mehaffey, J.R. (1984), "Failure Probabilities of Constructions Designed for Fire Resistance", Fire and Materials, Vol. 8, no. 2, pp. 96-104.

APPENDIX A
QUESTIONNAIRES ON VENTING OF LARGE-SCALE FIRES

A.1 GENERAL

This appendix contains the questionnaires and covering letters that were sent out to UK and overseas fire departments. An analysis and discussion of the responses is presented in the following sections.

A.2 UK LETTER

"Re Survey of Venting of Large Fires

Under contract to the Home Office Fire Research and Development Group, Warrington Fire Research Consultants are carrying out a survey of venting of large fires for the Fire Experimental Unit.

We will be contacting fire research organisations and fire departments worldwide to canvass opinion and assess the merits of venting in comparison to other firefighting techniques. In order to get a complete picture of what is (or is not) happening in the UK we would be extremely grateful if you could complete the attached questionnaire and return it to us no later than 5th of November.

Before responding it is important that you are aware of the distinction that is being made between ***fire venting*** and ***smoke ventilation*** for the purposes of this survey, and we would draw your attention to the following definitions:

Fire venting is a tactic used during firefighting to limit fire spread by creating a suitable way out for the products of combustion. This may involve making a hole in the roof above the fire, using openings in other positions or using powered systems (e.g. fans).

Smoke ventilation is a tactic used during and subsequent to firefighting to clear smoke from a building. This may involve the creation of holes in windows or roofs, or simply opening selected doors, to allow clean air to be drawn into the building, by the fire, by fans or by natural air movements.

Fire venting is intended to limit fire spread during the fire, **it is not** the same as ***smoke ventilation*** which is intended to clear smoke during and after the fire. We are interested in fire venting only.

Thankyou for taking the time to read this letter and fill in the questionnaire. Your help in this matter is greatly appreciated."

A.3 UK QUESTIONNAIRE

(see following page)

QUESTIONNAIRE ON TACTICAL FIRE VENTING

Please fill in the following details:

Fire Brigade ....

Your name ....

Your rank ....

Your reference (e.g. training officer, operations etc.)...

And answer the following questions:

1. Does your brigade promote the use of tactical fire venting ....YES/NO

2. If YES, what form of training or instruction is given in your brigade and can you provide copies of any technical training notes.
   ....
   ....
   ....
   ....
   ....
   ....
   ....
   ....

3. What do you consider to be the main advantages/disadvantages and risks of fire venting as a tactic?
   ....
   ....
   ....
   ....
   ....
   ....
   ....
   ....
   ....
   ....
   ....
   ....

4. Are you aware of any case histories which demonstrate the success or failure of tactical fire venting?
   ....
   ....
   ....
   ....

5. Are you aware of any other persons/organisations who you consider may be able to provide technical information on tactical venting techniques.
   ....
   ....
   ....

6. If a follow up is required, with whom should we make contact?

   ....

A.4 US LETTER

"Re Survey of Venting of Large Scale Fires

Warrington Fire Research Consultants (WFRC) have been commissioned by the British Government Home Office Fire Research and Development Group to undertake research into the area of venting of large scale fires.

The tactic of venting is, we understand, widely used in the USA but, as you may be aware, it is not a tactic that is commonly used or promoted in Britain. The British Fire Service is now interested in assessing the merits of venting in comparison to other firefighting techniques. It is envisaged that the tactic may be of particular benefit in reducing the fire losses in large fires.

As a first step, we are undertaking a survey to determine the true state of the art. We will be contacting fire research organisations and fire departments worldwide to canvass opinions. Since most of the expertise in this field is in the USA we are sending a brief questionnaire to a number of the larger US Fire departments.

We would, therefore, be most grateful if you could complete the enclosed questionnaire and return it to us as soon as possible. The questionnaire has been drafted so that it should take no longer than 15 minutes to complete.

Before responding it is important that you are aware of the distinction that is being made between ***fire venting*** and ***smoke ventilation*** for the purposes of this survey, and we would draw your attention to the following definitions:

Fire venting is a tactic used during firefighting to limit fire spread by creating a suitable way out for the products of combustion. This may involve making a hole in the roof above the fire, using openings in other positions or using powered systems (e.g. fans).

Smoke ventilation is a tactic used during and subsequent to firefighting to clear smoke from a building. This may involve the creation of holes in windows or roofs, or simply opening selected doors, to allow clean air to be drawn into the building, by the fire, by fans or by natural air movements.

Fire venting is intended to limit fire spread during the fire, **it is not** the same as ***smoke ventilation*** which is intended to clear smoke during and after the fire. We are interested in fire venting only. (Although we are aware that PPV fans are often used for both purposes, we would be grateful if you could concentrate on their usage for fire venting i.e. limiting fire spread.)

Since we are working to a very tight timescale on this project and will be visiting the USA in early November a faxed response before the end of October would be greatly appreciated. If this is not possible please return the questionnaire to us in the self addressed envelope provided.

Thankyou for taking the time to read this letter and fill in the questionnaire. Your help in this matter is greatly appreciated."

A.5 US AND OVERSEAS QUESTIONNAIRE

(See following page)

QUESTIONNAIRE ON TACTICAL FIRE VENTING

Please fill in the following details:

Fire Department ....

Your name ....

Your rank ....

Your responsibility (e.g. training officer, operations etc.)

And answer the following questions:

1. How many full time firefighters are employed by your Department?............

2. Does your Department use fire venting (see definition in accompanying letter) as a common tactic to limit fire spread?

   (a) in residential buildings YES/NO
   (b) in high-rise buildings YES/NO
   (c) in single storey industrial and commercial buildings YES/NO

3. In what circumstances and at what stage is tactical venting of fires used?

....
....
....
....
....
....
....
....
....
....
....

4. In what circumstances is tactical venting of fires not appropriate?

....
....
....
....
....
....
....
....
....
....
....

5. How is tactical venting to restrict fire spread achieved?

(a)	making holes in roof	YES/NO
(b)	use of openings in walls	YES/NO
(c)	powered devices (e.g. PPV)	YES/NO
(d)	installed vents	YES/NO
(e)	other (please specify)	

....
....
....
....

6. What do you consider to be the main benefits of venting fires in large buildings (i.e. not residential)?

....
....
....
....
....
....
....
....
....
....
....
....

7. What do you consider to be the main disadvantages and risks of fire venting as a tactic?

....
....
....
....
....
....
....
....
....
....
....
....
....

8. Does you Department provide technical guidance on tactical fire venting techniques?..YES/NO

If YES, please list any technical guidance documents that are used:

....
....
....
....
....
....

9. Does your Department provide training to its firefighters in tactical venting techniques?..YES/NO

If YES,

(a) what form does this training take?

....
....
....
....
....

(b) where is it carried out?

....
....
....

10. Please list any documented case histories which you feel show the success or failure of tactical venting.

....
....
....
....

11. Has your department carried out any research or trials into fire venting or can you give any details of research carried out by others.

....
....
....
....

12. Please suggest any other persons/organisations who you consider may be able to provide technical information on tactical venting techniques.

....
....
....
....
....
....

If you would like to make any other comments, please enter them below or continue onanother sheet:
....
....
....

Thankyou for taking the time to complete this questionnaire.
Your help in this matter is greatly appreciated.

A.5. SUMMARY OF UK RESPONSE

Copies of the questionnaire shown in section A.3 were distributed to fire brigades in the United Kingdom. Forty-seven were returned and the results of these are summarised below.

To question 1, "Does your brigade promote the use of tactical fire venting?", only 15% of those who returned questionnaires answered "yes", although several brigades stated that venting was considered during operations but was not formally promoted. Two brigades, Essex and West Sussex, said this option was under evaluation. Another two fire brigades stated that the use of tactical fire venting was the responsibility of the Officer in Charge during a fire.

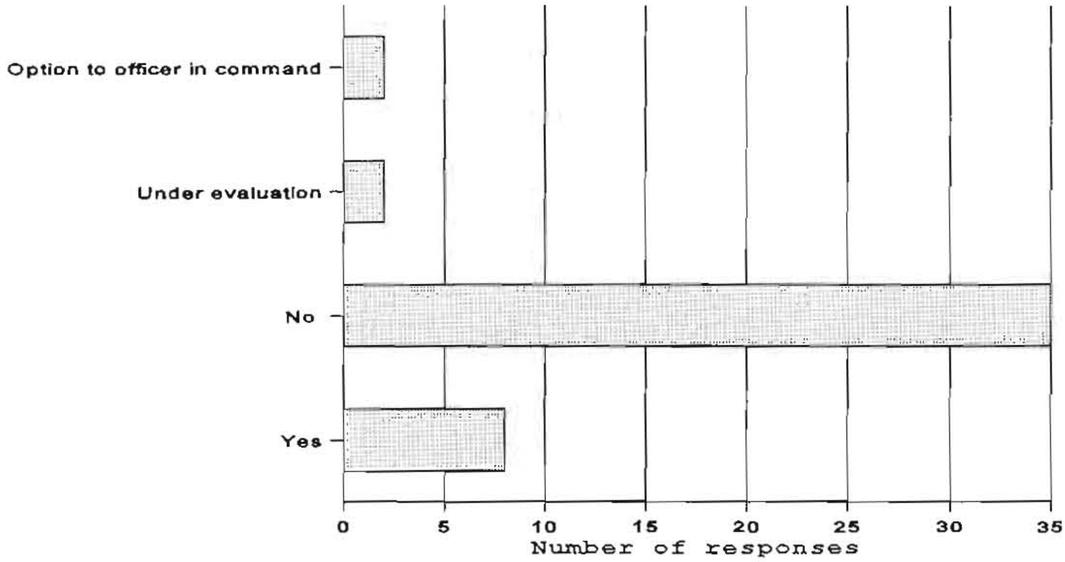


Figure A1
Promotion of Tactical Fire Venting (Response to UK Question 1)

Of those who said that tactical fire venting was promoted, 75% stated in their answer to question 2 that some form of training was provided. Most had no specific training package available and used manufacturers' publications and the Manuals of Firemanship.

To question 3, "What do you consider to be the main advantages/disadvantages and risks of fire venting as a tactic?", the two most popular answers were: "improved working conditions for firefighters" and "the limitation of fire spread". Figure A2 presents the range of advantages mentioned.

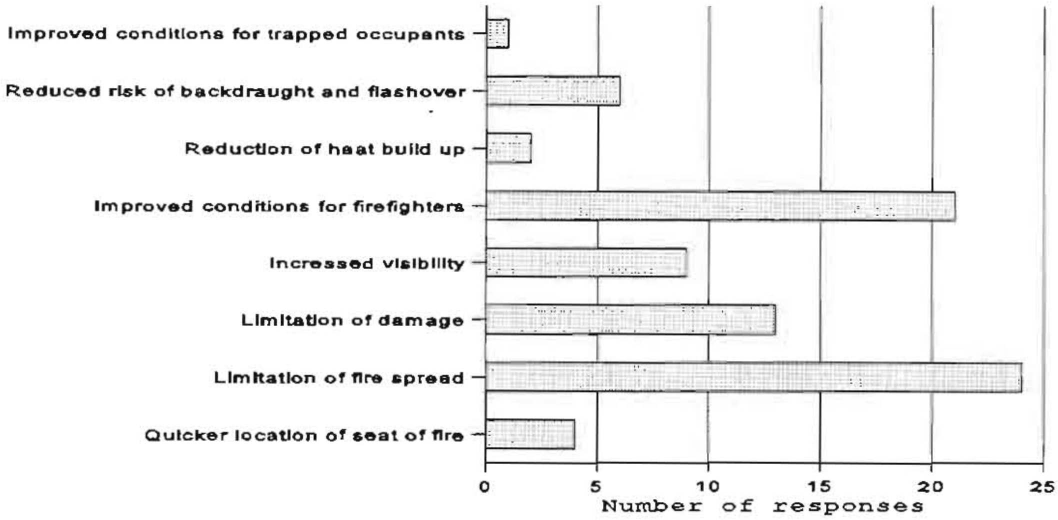


Figure A2
Advantages of Tactical Fire Venting (UK Question 3)

The two most frequently mentioned disadvantages and risks were an increase in fire intensity/spread and an increase in the risk to fire personnel. Overall, the advantages and disadvantages matched the US response except that two brigades considered UK building construction hard to penetrate. Figure A3 presents all the disadvantages and risks mentioned on the returned questionnaires.

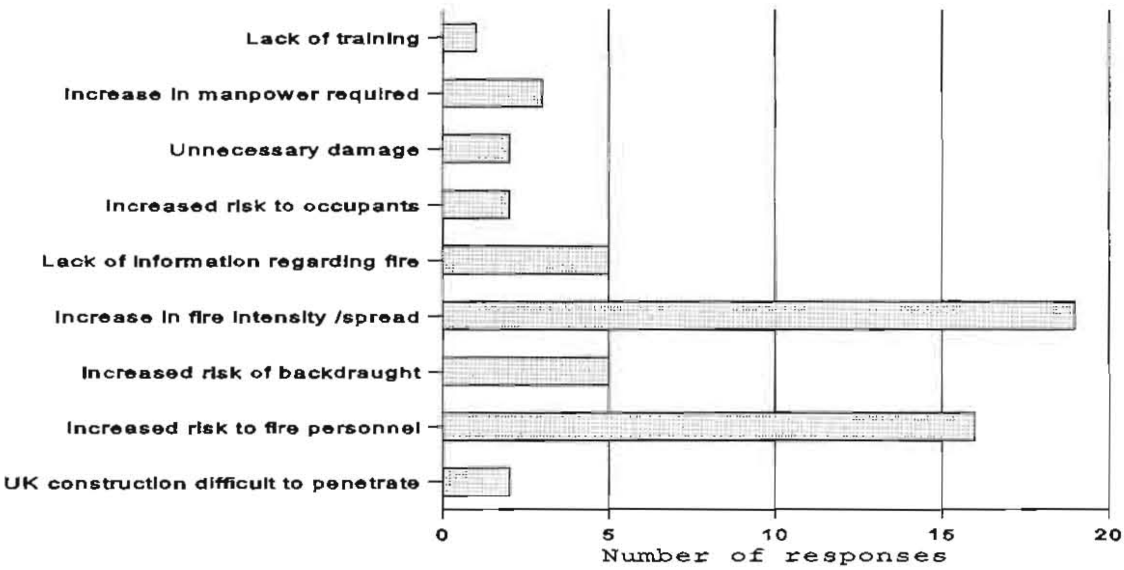


Figure A3
Disadvantages and Risks of Tactical Fire Venting
(UK Question 4)

To question 4, "Are you aware of any case histories which demonstrate the success or failure of tactical fire venting?", no case study was mentioned twice. Seven incidents were named, as follows :

(1) minor incident, Cambridge;
(2) warehouse, Suffolk;
(3) NV Sigard Jarl;
(4) Windsor castle;
(5) cold store, Liverpool (Fire, July 1984);
(6) cold store, Bristol;
(7) Brighton (Fire, Feb 1982).

The response to question 5 is presented in figure A4. This asked for any further persons/organisations who may be able to provide technical information on tactical fire venting techniques. Not surprisingly, US fire departments were suggested most often.

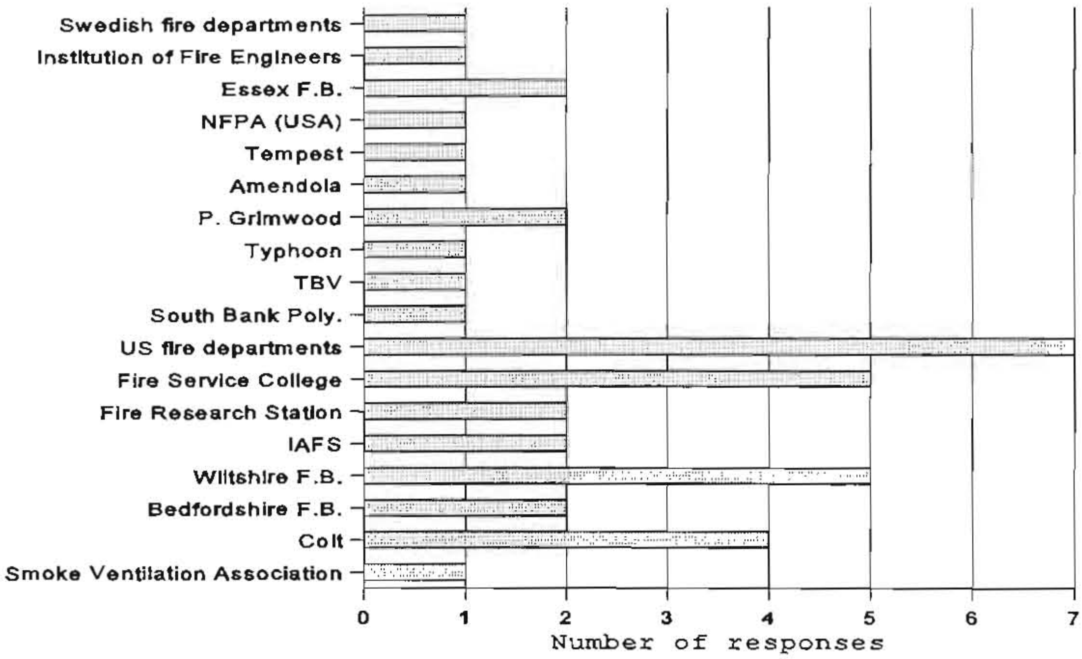


Figure A4
Persons/Organisations Suggested for Further Information
(UK Question 5)

A.6. SUMMARY OF US RESPONSE

Copies of the questionnaire reproduced in section A.5 were distributed to the top 50 fire departments in the USA (listed in Appendix E). Fifty per cent of the questionnaires were returned; a summary of their contents is given below.

Figure A5 presents the results to question 2, which asked if their fire department uses fire venting as a common tactic to limit fire spread in:

(a) residential buildings
(b) high-rise buildings
(c) single-storey industrial and commercial buildings.

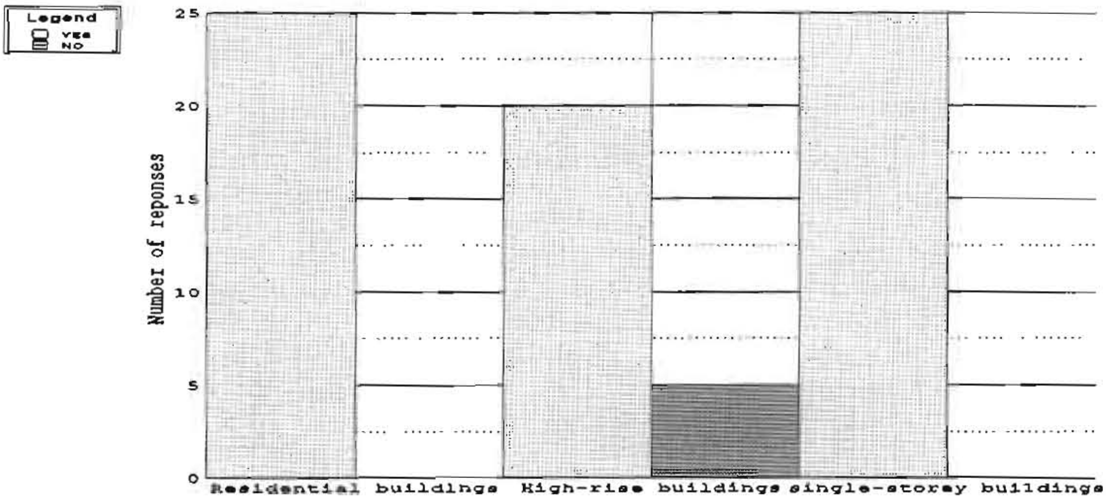


Figure A5
Fire Venting as a Common Tactic in Residential High-rise and Single-storey Buildings
(Response to US Question 2)

Notably, all those who responded stated that fire venting was used as a common tactic in residential buildings and single-storey industrial/commercial buildings. However, 20% of the responding departments do not use fire venting as a common tactic in high-rise buildings.

Regarding the circumstances in which fire venting is used (question 3), most who responded stated that tactical venting is used when heat and smoke trapped within a structure needs to be removed. The second most popular circumstance is where better working conditions for firefighters need to be created. Other circumstances included: where there is a hazard to life or where backdraught conditions exist. Figure A6 presents the range of answers received.

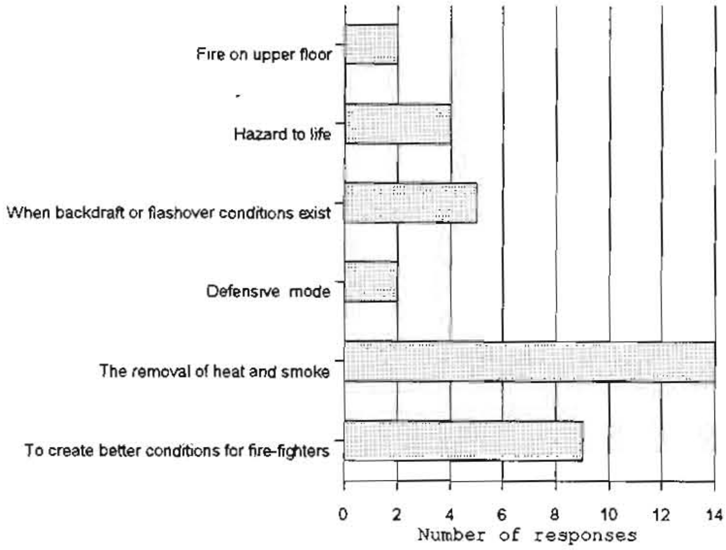
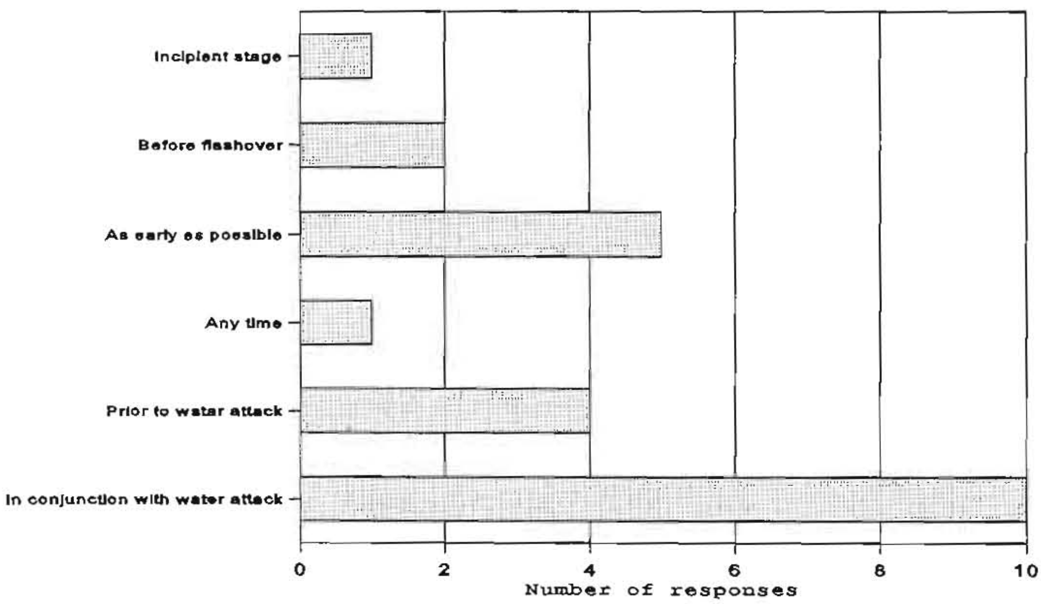


Figure A6
Circumstances in which Fire Venting is Used
(US Question 3)

The stage at which tactical fire venting is initiated depends on the circumstances and the objective of the venting. For instance, respondees said that where a backdraught condition exists, venting should be initiated prior to a water attack. However, it was stated that in most cases venting should not take place until the interior water attack is in place and ready. The results from this aspect of question 3 are summarised in figure A7.

Figure A7
Stage at which Fire Venting is Initiated
(US Question 3)



In response to question 4, a wide range of situations were cited for which tactical fire venting is not considered appropriate.

Several of these circumstances are concerned with safety, including where there are unsafe structures, and where the exhaust path would increase exposure to personnel. Eight of the responses stated that it is inappropriate to vent where the fire is small since this would probably create more damage to the property than the fire. Interestingly, one returned questionnaire stated that it was inappropriate to vent where backdraught conditions exist, though in response to question three fire departments had stated that this was a circumstance in which they would vent. Figure A8 shows the wide range of circumstances for which tactical fire venting is considered inappropriate.

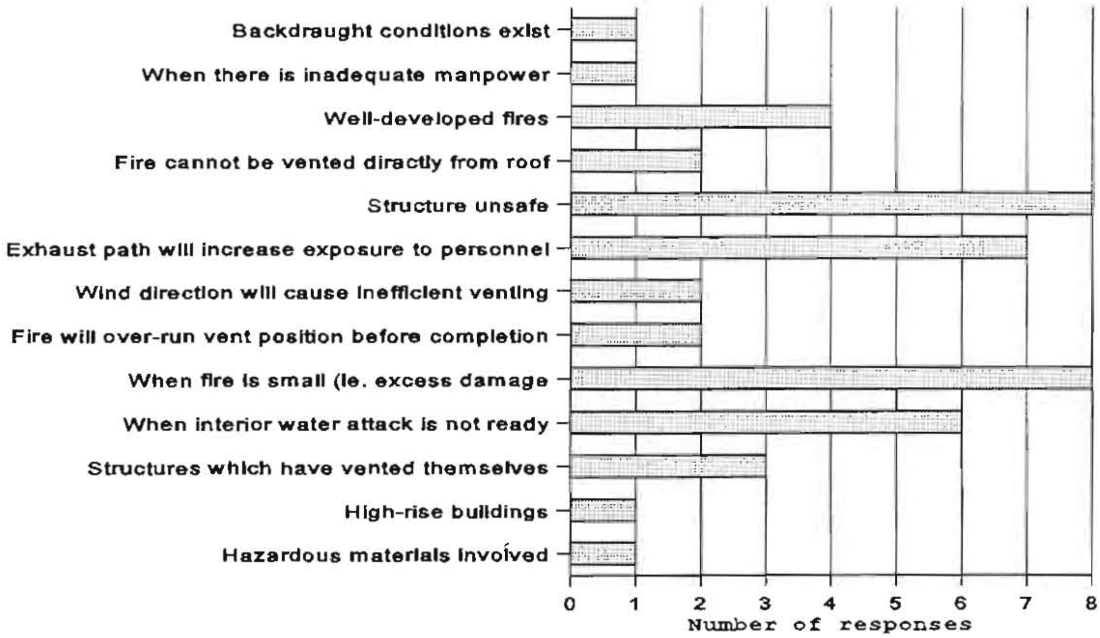


Figure A8
Circumstances which Fire Venting is Considered Inappropriate
(US Question 4)

Question 5 asked how tactical venting to restrict fire spread is achieved:

(a) by making holes in roof
(b) by the use of openings in walls
(c) using powered devices (e.g. PPV)
(d) with installed vents.

All returned questionnaires stated that making holes in the roof was a method used, whereas openings in walls and powered devices were utilised by only 72% of those who returned questionnaires.

Only 68% of fire departments use installed ventilators; this may be explained by the lack of installed vents in some states. Figure A9 presents the results from question 5.

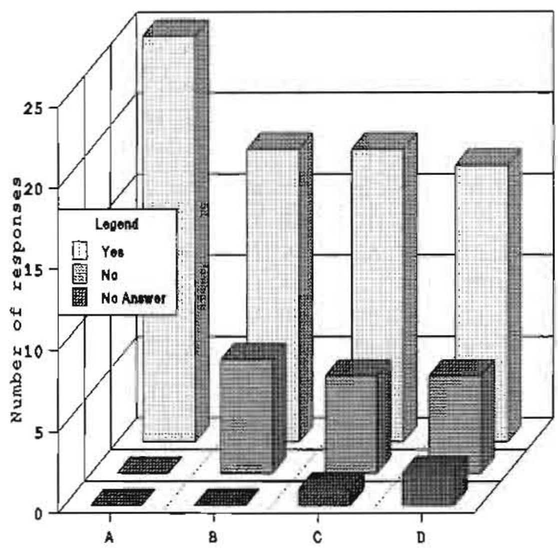


Figure A9
How Tactical Venting is Achieved to Limit Fire Spread
(US Question 5)

In response to question 6, the main benefit of tactical fire venting was stated to be better working conditions for firefighters, which was mentioned by 72% of the fire departments. The limitation of fire spread and reduction in damage were considered to be secondary benefits. Figure A10 presents the full range of stated benefits of fire venting in large buildings.

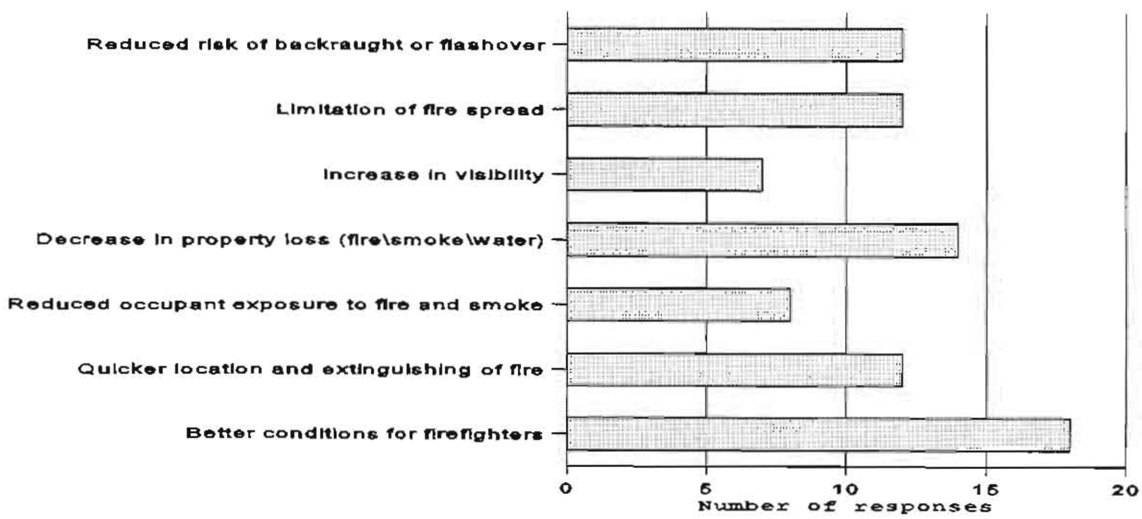


Figure A10

Benefits of Venting in a Large Building
(US Question 6)

The disadvantages and risks of tactical fire venting are presented in figure A11. The disadvantage of tactical fire venting was considered to be the increase in manpower required.

The risks fell into two categories, firefighter safety and misuse of tactical fire venting. It was felt by 74% of the returns that placing firefighters on weakened structures was a considerable risk. The increase in fire intensity/lateral fire spread was considered by 72% as being the biggest risk associated with the misuse of venting.

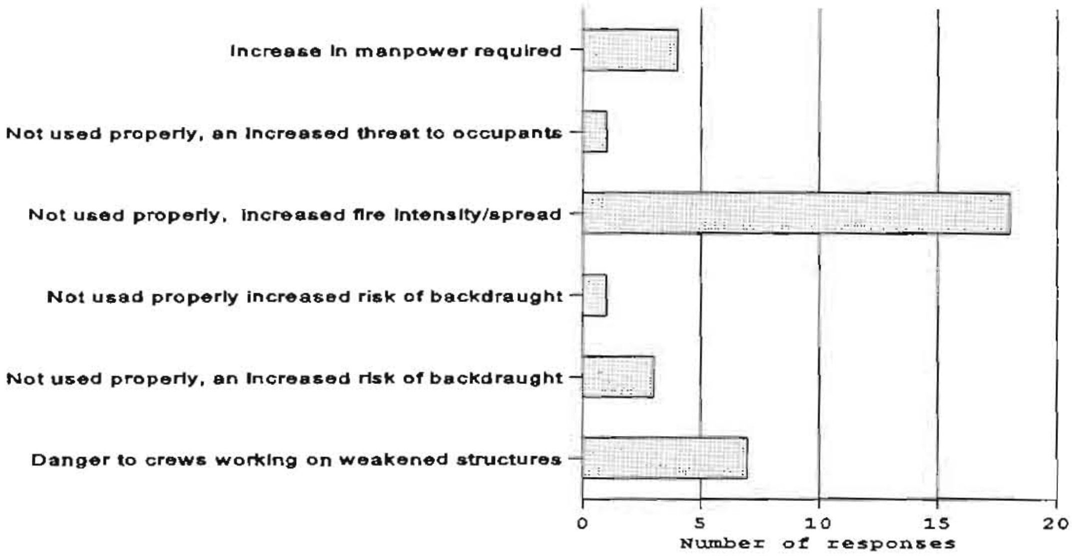


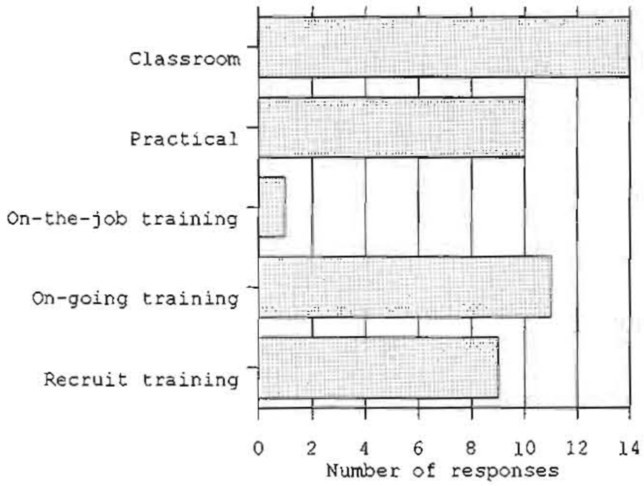
Figure A11
Disadvantages and Risks of Tactical Fire Venting
(US Question 7)

Question 8 asked if any technical guidance was provided. Eighty-four per cent of those who returned questionnaires said that their fire department provided technical guidance on tactical fire venting techniques. Only 8% did not provide technical guidance and two returned questionnaires gave no answer. The most popular technical guidance used are the manuals published by the IFSTA. Other publications used included "Ventilation Methods and Techniques" by J. Mittendorf and specially written training procedures drafted internally by the fire departments.

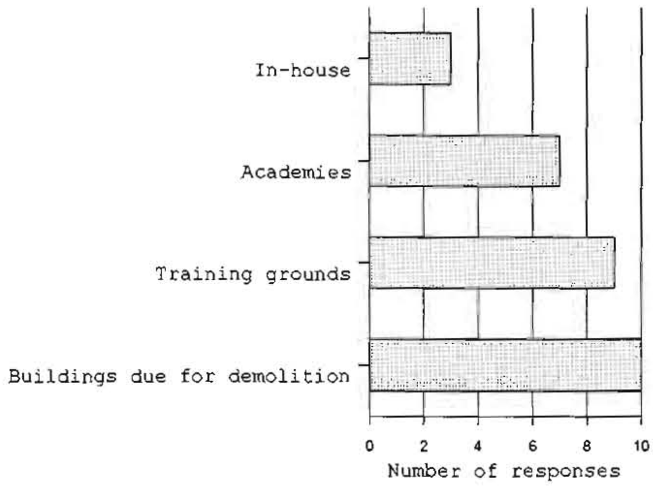
Regarding training of firefighters, question 9 asked the form of training and where it was carried out. Figure A12(a) shows the form the training takes and Figure A12(b) shows where the training is carried out.

Figure A12
(US Question 9)

(a) Form of Training



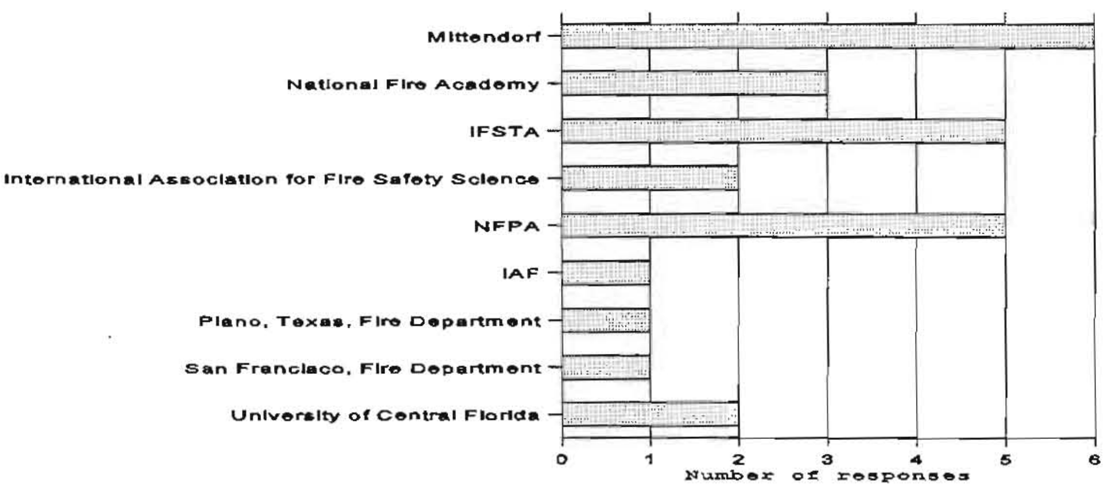
(b) Where Training is Carried Out



One fire department gives no training in fire venting and personnel learn the techniques on-the-job. Interestingly, 40% of fire departments use buildings due for demolition for training purposes, a practice not normally used in the UK.

Figure A13 indicates the other persons/organisations suggested as sources of technical information on tactical venting techniques.

Figure A13



Persons/organisations Suggested as Contacts on Tactical Fire Venting
(US Question 12)

A.7. SUMMARY OF RESPONSE FROM THE REST OF THE WORLD

Copies of the questionnaire reproduced in section A.5 were distributed to fire departments worldwide. Fire responses were received, from Honolulu, Hong Kong, Kuopio (Finland), New Zealand and Sweden. The results are summarised below.

Q2 Does your Department use fire venting as a common tactic to limit fire spread ?

	Yes	No	No Answer
(a)	2	1	1
(b)	2	1	1
(c)	3	0	1

Q3 In what circumstances and at what stage is tactical venting of fires used ?

(a) Circumstances

When heat and smoke need to be removed	3

(b) Time

To coincide with interior water attack	2
As early as possible	1
Before flashover	1

Q4 In what circumstances is tactical venting of fires not appropriate ?

When interior water attack is not ready	2
In well-developed fires	1
Where the building construction is not appropriate	1
When hot rich gases contained within	1
In open fires	1
When fire spread may be uncontrollable	1

Q5 How is tactical venting to restrict fire spread achieved ?

	Yes	No	No Answer
(a)	4	0	0
(b)	2	1	1
(c)	3	0	1
(d)	3	0	1

Q6 What do you consider to be the main benefits of venting fires in large buildings (i.e. not residential) ?

Better conditions for firefighers	2
Quicker location of fire and extinguishing	1
Occupant exposure to fire/smoke reduced	1
Increased visibility	1
Limitation of fire spread	3

Q7 What do you consider to be the main disadvantages and risks of fire venting as a tactic ?

When not used properly there is an :	
increased risk of backdraught	1
increased risk of fire intensity/spread	2
Risk to firefighters on unsafe structures	1

Q8 Does your department provide technical guidance on tactical fire venting techniques?

Yes	No	No Answer
3	1	2

Fire department training procedures	2
Manual of Firemanship	1
Manufacturers' brochures	1

Q9 Does your department provide training to its firefighters in tactical venting techniques ?

Yes	No	No Answer
4	0	0

What form does the training take ?

(a)	Task performance training	1
	Company training	1
	Recruit training	2
	On-the-job training	1
	Practical training	2
	Classroom training	2

Where is the training carried out ?

(b)	At a training ground	2
	In academies	1
	In-house	2

Q12 Please suggest any other persons/organisations who you consider may be able to provide technical information on tactical techniques.

Safety Co. OY (Ltd) Finland	1
Dr. Chow Wan-Ki (Hong Kong Polytechnic)	1
Ventilation equipment manufacturers	1

APPENDIX B
SUMMARY OF UK CONTACTS

B.1 FIRE SERVICE INSPECTORATE

Present at meeting:	HMI Pearn	(FSI)
	HMI Wells	(FSI)
	Mr. J. Foster	(FEU)
	Dr. A. Hay	(WFRC)

Discussions centred around the role of ventilation and educational needs within the UK fire service. The inspectors agreed that ventilation was used primarily for smoke clearance purposes during overhaul and salvage operations and recognised that there is a reluctance on the part of many fire officers to use the tactic in the early stages of fire attack.

HMI Pearn stated that traditional firefighting philosophy is to enter the building and control the fire with a water attack before considering ventilation. HMI Wells, however, stressed that some of the more experienced officers within the service do adopt aggressive, tactical ventilation techniques, particularly when tackling fires in buildings of simple geometry with good compartmentation. He was of the opinion that most firefighters are aware of the benefits of ventilation through experiences of fires that had self vented, a recent example being the Windsor Castle fire. It was claimed that ventilation is a high priority in the mind of the Officer in Charge but that concerns over the safety of his officers will, more often than not, prevent him from committing them to any roof-top operations. Other types of ventilation operation, e.g. horizontal ventilation, are more likely to be utilised but a fear of the unknown will often preclude the use of even these methods in large buildings of complex geometry. In such buildings the main aim is still to bring the fire under control by water attack and containment rather than by "opening up" the building. However, HMI Pearn and Wells both believed that fire officers would employ the tactic more often if they had a better understanding of the theory and techniques. HMI Pearn pointed out that ventilation is traditionally used in residential properties to tackle fires in roof voids.

Concerns were expressed about venting a building with occupants inside, particularly using the PPV method. HMI Pearn stated that the fire service would certainly not vent a building if there were "persons reported". Reference was made to some studies carried out by the FRS Fire Investigation team, which suggested that passers-by opening doors to a building or breaking windows, prior to the arrival of the fire service, had actually worsened the fire and may, in some cases, have contributed to a loss of life.

Notwithstanding the need for better education as part of a ventilation training programme, it was generally felt that practising firefighters would benefit from more education in the fundamentals of fire growth and development and that this would engender a better understanding of basic fire phenomena, such as flashover, backdraught, rollover, etc.. Mr. Foster highlighted John Taylor's report and recent presentations on the Swedish research into flashover, and commented that these had raised an awareness of the education issue within the fire service.

In summary, the inspectors believed that ventilation is a tactic employed by the UK fire service during fire attack but that the extent of application depends very much on the experience of the Officer in Charge and the nature of the building and fire situation.

B.2 WILTSHIRE FIRE BRIGADE

Present at meeting:	DCO N.Wright	(Wiltshire)
	DO W.Follet	(FEU)
	Mr. J. Foster	(FEU)
	Dr. A. Hay	(WFRC)

The meeting in Wiltshire was originally scheduled with CFO Craig; he was unable to attend but DCO Wright was available to discuss Wiltshire's policy on ventilation. CFO Craig later responded in a letter confirming his support for the project but warning of the difficulties in overcoming the traditional resistance to change within the fire service. The meeting and demonstrations concentrated mainly on Wiltshire's experience and application of PPV techniques.

Wiltshire's interest in PPV was stimulated during a visit to the USA in the late 1980's by CFO Craig. In 1990 the brigade produced an operational note entitled "Ventilation at Fires" (31). This note gives the US definition of ventilation, outlines its advantages, discusses the hazards of backdraught and flashover and provides guidance on the main techniques, including vertical and horizontal ventilation, PPV mechanical extraction and water-fog-assisted ventilation.

DCO Wright stated that, at this time, Wiltshire mainly used ventilation techniques post fire control, although he did quote one example of the successful use of PPV during fire attack in a large warehouse fire. Wiltshire are, however, in the process of considering a more aggressive use of ventilation during fire attack. As a brigade, they offer limited training in ventilation techniques during the operational courses that they run at their training centre. Practical training is provided in the use of PPV fans for salvage, smoke clearance and to a limited extent for tactical ventilation. DCO Wright recognised that the depth of training throughout the brigade is limited but maintained that steps are being taken to remedy this.

DCO Wright expressed concerns about the dangers of fire spread in situations where the building geometry or contents are unknown and suggested that firefighters may need to be sent into a building before ventilation tactics are initiated. The point was made that ventilation, and in particular PPV, is not a panacea for all problems but simply another tool at the disposal of the Officer in Charge.

On the subject of large single-storey warehouses, DCO Wright was of the opinion that pre-installed vents are especially advantageous but observed that it is often difficult for the fire brigade to insist on their provision. He did, however, feel that ventilation tactics are likely to be applied more successfully during fires in large premises because the level of attendance, and therefore available manpower, would be greater, the Officer in Charge would have more experience and the chain of command would be better organized. Good communication on the fireground was considered to be an essential factor for successful ventilation.

Following discussions with DCO Wright a demonstration of PPV was provided in a residential burn house. A small room leading off the main downstairs lounge area was filled with synthetic smoke to simulate a fire. By placing a PPV fan at the window to the lounge and opening the front door to the house, which was connected to the lounge via a small entrance hallway, it was possible to demonstrate how PPV quickly cleared the lounge of smoke and then prevented any further ingress of smoke from the fire room. A similar demonstration, simulating a fire in a bedroom, but this time with the PPV fan at the front door and an opening from the bedroom, this illustrated how effectively the technique could clear the affected bedroom of smoke and prevent smoke spread to other parts of the house.

During discussions with the firefighters carrying out the demonstrations, it was ascertained that in a real incident the decision to use PPV would be made by the Officer in Charge but the method of implementation would be left entirely to the firefighters experienced in the use of the fans. It was also suggested that in some instances PPV is being used to clear smoke whilst fires are still being fought. However, it was not clear whether this is taking place after fires are controlled but before they are extinguished.

In addition to having fans on a number of appliances, the rescue tender can be called up by the Officer in Charge to any incident, but for confirmed fire situations an aerial appliance is automatically directed to the incident.

B.3 ESSEX FIRE BRIGADE

Present at meeting :	SDO A. Stone	(Essex)
	DO T. Stratford	(Essex)
	Mr. D. Howarth	(WFRC)

Initial contact was made with CFO John Sherrington at Fire 93, though the FEU were aware, prior to this, of the ongoing work in Essex. A follow-up meeting was held and the main points discussed are presented below.

Almost six years ago Roger Paramor (then CFO) visited Sweden and brought some new ideas back to Essex. The brigade still have many contacts there. The brigade interest covers flashover training, PPV, venting and ventilation.

The brigade's work in flashover training is well advanced and has led them into various methods of controlling fire/risk. They have trained over 1000 firefighters already.

Fans are carried on rescue tenders (two fans) and aerial appliances (1 fan).

Following a visit to the USA by DCO Turner they carried out a series of evaluations of the use of various types of PPV fans. The initial trials involved the use of fans and cosmetic smoke in a smoke house. The results were not particularly impressive.

The brigade's most recent work, in October 1993, was carried out in an unoccupied house in the Basildon area and involved the evaluation of three fans. The trial results indicated that a 24"-blade petrol-driven fan provided the best performance. A video was made to demonstrate the effectiveness of the technique, which is claimed to provide some interesting footage of fire behaviour. A brief report on the trials was made available by SDO Stone. Separate test fires were started in a ground-floor lounge and a first-floor bedroom. The fires, fuelled by a combination of straw and diesel oil, were allowed to smoke log the house almost down to ground floor level. The trials were carried out on a windy day and to simulate worst-case conditions the fans were set up to blow against the wind, contrary to the manufacturer's operating instructions. SDO Stone commented that they were very pleased with the results: the fans cleared the house of smoke within 30s, and the injection of fresh air did not significantly increase the size of the fire or cause any flame spread throughout the house. Indeed, SDO Stone claims that in two instances the introduction of fresh air immediately reduced the risk of flashover.

Further discussions confirmed that in the UK there is no clear distinction between the terms *venting* and *ventilation* and there is no specific interest or training in ventilation as a firefighting tactic.

Essex has a range of large single-storey buildings and, consequently, the brigade claim to have much experience of dealing with fires in this type of building. Several examples of fires in which venting/ventilation was employed were discussed but no reports were available.

Mention was made of the relief to crews where fires had vented unaided and the practice of venting fires from aerials appliances. The latter is considered to be a safe practice and is often employed by firefighters. ACO Barry Unger spoke about the built-in fire protection systems and some of the difficulties that can arise when these are under manual control.

There was a fairly strong view that experience from the USA must not be taken at face value and that more research into the safety and effectiveness of US tactics should be undertaken.

The discussions held with the CFO, DCO and ACOs were both open and informative. The CFO and SDO Stone confirmed that Essex are still progressing with their evaluations but, that on the basis of their experience so far, the use of PPV must be controlled with safety in mind. It is likely that their initial operational policy would involve the use of fans only after fire extinguishment.

Essex have carried out a significant amount of work in this area and they retain an open-minded, enthusiastic approach and would welcome any involvement in further studies.

B.4 BEDFORDSHIRE FIRE BRIGADE

Present at meeting:	ADO R. Shepherd	(Bedfordshire)
	StnO T. New	(Bedfordshire)
	Mr. D. Howarth	(WFRC)

Initial contact was made with officers at Fire 93, though the FEU were aware, prior to this, of the ongoing work in Bedfordshire, mainly in the area of PPV.

ADO Shepherd first saw a PPV demonstration approximately three years ago in London and the brigade have been actively involved for eighteen months. He is assisted by StnO New as operational officer in Luton, where most of the experience has been gained so far. The work is led by operational needs with support from the Chief Officer.

They use a 21" petrol-driven Typhoon fan on the first appliance; a further four fans are being introduced elsewhere in the brigade.

ADO Shepherd confirmed that they initially gave training only in the safe (mechanical) operation of the fan because there was only US and industry experience to draw upon, some of which he said was contradictory. The brigade's experience has grown with practice and operational use and a draft brigade order has been written (a training note is due soon).

ADO Shepherd confirmed that the equipment was seen initially as an aid to smoke clearance, but with experience/confidence in its operation it is now used, as appropriate, for venting once the fire is contained. The brigade do not aggressively promote ventilation as an operational tactic but with the experience gained in selected areas their understanding and confidence in ventilation as a tactic is growing. StnO New gave an overview of his experience gained in Luton and stated that they were also examining rescue techniques supported by PPV.

Both ADO Shepherd and StnO New had some reservations about ventilation above the fire in a single-storey building but this area is being explored in respect of the possibility of using aerial appliances as working platform and identifying the tools required to open a roof or wall. There was a recognition that more could be achieved by pre-planning for specific risks where ventilation would be appropriate.

ADO Shepherd spoke about the importance of progressing logically where a change of accepted practice was sought, making the point that confidence grows with experience and training.

Bedfordshire have produced a report entitled "Introduction to Positive Pressure Ventilation (PPV)", which summarises six phases of evaluation of the use of fans:

Phase I	Equipment and basic ventilation techniques introduced at the station
Phase II	Equipment stowed on appliance for off-station use in training situations

Phase III	Equipment to be used for post-fire ventilation
Phase IV	Equipment to be used where fire situation is known and contained
Phase V	Multi-fan techniques to be used
Phase VI	To be decided; possibly equipment to be used as an aid to search and rescue and aggressive firefighting techniques.

It is understood that the brigade are currently involved in Phase IV.

Bedfordshire welcome a sharing of experience with others and would be prepared to contribute significantly to any future work at national level. They stressed the importance of producing national guidelines in the use of this equipment before an incident occurs, which could devalue the useful work carried out to date at brigade level.

In summary, the meeting afforded worthwhile input from a brigade with tangible experience. Whilst this experience is primarily with PPV it is clear that this has developed their interest in ventilation as a broader firefighting tactic and that this may stimulate work in other areas.

B.5 NORTH-WEST FIRE BRIGADES

Present at meeting:		
	ACO C. Smith (Ops)	Greater Manchester
	DO I. Massie (staff)	Merseyside
	DO T. Vinn (R&D)	West Yorkshire
	DCO P. Holland	Lancashire
	DCO R. Hunt	Cheshire
	Mr. D. Howarth	(WFRC)
	Dr. A.Hay	(WFRC)
	Mr. J. Foster	(FEU)

Following initial contact made at Fire 93, a meeting was arranged with representatives from interested and busy brigades in the North-west who were within close proximity to WFRC. An overview of the project and the research that had been carried out to date in the UK and USA was presented and an open discussion followed.

The definitions of *venting* and *ventilation*, as used in the questionnaires, was brought into question as it was felt that the distinction between the two was ambiguous. After further discussion it was generally agreed that whilst tactical ventilation is not actively promoted there is evidence to suggest that it is practised (in a modified form) within accepted operational procedure and with an emphasis on safety.

Reference was made to the benefits of ventilation, i.e. the relief of smoke and heat, that had been witnessed when fires had vented themselves. However, much concern was expressed about the lightweight structure of certain single-storey buildings, which could lead to early collapse. As a consequence of this it was agreed that the general preference is to use windows and doors for ventilation rather than follow a potentially dangerous practice of putting firefighters on the roof. Several examples were quoted of aerials appliances being used to ventilate safely above the fire but it was otherwise felt that brigades are not equipped or trained to make holes in the roof. Although there is clearly experience of fires having been vented there are few reports to support this.

The benefits of ventilation in extending building tenability and reducing property damage were discussed in relation to the risk of committing firefighters to roofs. The brigades did not wholly accept the USA's experience of ventilation and felt a need to explore their tactics in more detail and establish how these relate to injuries, fatalities and fire losses. The indication was that before adopting more aggressive ventilation tactics the UK fire service would require hard evidence, if possible supported by statistics, to prove that it achieves better results and does not give rise to more injuries or fatalities.

All agreed that a positive move towards tactical fire ventilation would mean a fundamental change in firefighting tactics and training requirements. The relationship between the understanding of fire behaviour and ventilation was discussed and it was agreed that firefighters should be better educated in the fundamentals of fire growth and development, not just at senior officer level.

The use of pre-installed ventilation systems by the fire service during firefighting operations is an area that impinges on fire venting and reservations were expressed about how well this could be achieved in practice. Once again, no written evidence could be quoted of the success or failure of attempts at ventilation using such methods.

West Yorkshire stated that they have some useful experience of PPV in large single-storey buildings, high-rise flats and domestic property, and that they would provide whatever reports were available. The use of PPV to maintain a smoke-free environment on stairs, thus extending escape periods and creating a safe bridgehead for firefighting, generated interest amongst the group.

The manpower and resources available on the fire ground to implement/manage tactical fire venting were discussed and the general opinion was that increasing the emphasis on ventilation would necessitate sacrifices in other areas of activity. This may well be true, since pre-determined levels of attendance appear to be higher, and forcible entry equipment more readily available, in the USA.

The group suggested that lessons could be learnt from past fire experience and from the research carried out by the Health and Safety Executive, TML and Eurotunnel in connection with underground mining and the provisions for the Channel Tunnel.

In summary, the meeting provided a most useful and open exchange of views. The brigade representatives were receptive to new ideas and change provided that they progressed logically with due regard to the safety implications and changes required in operational procedures. They agreed that there is scope to go forward with further work and would welcome an involvement.

B.6 WEST YORKSHIRE FIRE BRIGADE

Present at meeting: DCO M. Saunders (West Yorkshire)
Mr. D. Howarth (WFRC)

WFRC discovered that the West Yorkshire Fire Brigade were evaluating PPV following contact established at Fire 93. DCO Saunders had also visited the New York Fire Department, where he had briefly studied their ventilation tactics.

DCO Saunders feels that the organisation of the New York Fire Department (pump-ladder rescue, etc.), the operational experience and the construction of US property (relatively easy to open up at roof level) explains their use of ventilation as a tactic in the early stages of firefighting. The UK brigades use what is best described as a modified method of ventilation, and he does not see scope for wholly adopting US tactics in the UK.

The risk of collapse in single-storey buildings, the inherent dangers of working on a roof above the fire and the compartmentation of buildings were given as examples of reasons why ventilation may not be appropriate.

DCO Saunders referred to the similarity of ventilation tactics in the USA and Sweden and felt that this could be explained by the fact that Swedish buildings are similar in construction to those in the USA.

On the basis of the information he gained from the USA, DCO Saunders' opinion was that the Americans have more firefighter fatalities but believe their approach saves the lives of building occupants. He stated that the UK adopt a passive approach to ventilation tempered by concerns for the safety of firefighters. He agreed that the American approach was more aggressive.

West Yorkshire had looked initially at Ram-Fan, Tempest, Typhoon and Gilkes for a fan-powered approach to venting/ventilation. They now have a Ram-Fan on the run at Bradford Central. There has been no extensive training because the equipment is under evaluation by experienced firefighters and officers; DO Thomas Vinn is co-ordinating the evaluation. They have 4 months' experience, with some lessons learnt at a large single-storey warehouse and in high-rise flats, although details of the latter were not available.

DCO Saunders strongly believes that the UK fire service needs to pay more attention to training in fire behaviour and firefighting tactics.

Some discussion was held on pre-planning for fires in appropriate risks (e.g. large single-storey buildings) and the ability to manage operationally built-in systems.

In summary, the meeting provided useful information from a busy brigade who would be happy to have an input into any further research or tests.

B.7 GRAMPIAN FIRE BRIGADE

WFRC became aware of Grampian's interest in PPV following a visit to the brigade in September; a contact name was provided by John Foster of the FEU. Further contact was made over the telephone.

The initiative to evaluate PPV came from Sandy Lobban when he was the Deputy Firemaster. StnO Macintosh advised that Grampian Fire Brigade are evaluating petrol-driven fans from Tempest on three pumps and a salvage tender in Aberdeen.

StnO Macintosh said that, whilst they have no depth of experience in tactical fire venting, the brigade have vented buildings during firefighting operations. One such incident involved a mattress and rubbish fire in a derelict building; an internal memo records the following: "The building was heavily smoke logged on arrival and the two BA teams committed to the attack were experiencing difficulty in locating the seat of the fire due to the heavy smoke and debris in the building. Two outside vents on a rear wall were broken out and the PPV fan brought into use. The fan cleared the smoke very quickly enabling the BA teams to quickly extinguish the fire which they could now clearly see."

It was useful to confirm that the brigade are evaluating PPV, and further contact is advised during subsequent stages of the project.

B.8 PAUL GRIMWOOD

A meeting was held with Mr P. Grimwood, a practising firefighter in London, who has also spent a short period of time working as a firefighter in the USA. Since 1979 he has spent much of his time studying international firefighting techniques and has written articles in *Fire* magazine on a regular basis. He has recently published a book entitled "Fog Attack" (32), which explores and compares international firefighting strategies and tactics. The views expressed in his book and during the meeting were his own and not necessarily those of his employers, who gave permission to contact him.

Mr. Grimwood began by highlighting the fundamental differences between the US and UK approaches to firefighting. In his experience US firefighters are, in the tactics that they employ and in their mental attitude, both practically and psychologically more committed to aggressive firefighting than their UK counterparts. He cautioned, however, that this approach has both advantages and disadvantages.

He summed up the fundamental difference in strategy by explaining that US fire departments are organised on a team system to go looking for trouble in the early stages of a fire, whereas the UK firefighters react to trouble as it occurs. In terms of tactical ventilation he felt that the US firefighters have a tendency to over-vent, in that they sometimes vent structures unnecessarily simply because it is standard practice (this claim was strongly refuted by US firefighters contacted during the course of this research). However, he also believes that the UK fire service tend to under-vent in the opposite extreme. He cannot recall any fires where ventilation was used as an *early* tactic by the UK fire service but can quote many examples where failing to ventilate at all has resulted in unnecessary fire damage and even the total loss of a building. He suggests that the correct balance in tactics lies somewhere between the two extremes.

Mr. Grimwood highlighted four essential requirements for successful ventilation operations: communication, co-ordination, precision and anticipation. Any attempt to ventilate a building must be co-ordinated with interior attack and this requires good communications between the different teams and the Officer in Charge. Openings in the structure of the building must be made precisely to ensure that they do not cause fire spread. Anticipation of the effects of ventilation is required so that all the outcomes can be prepared for and the risks covered.

Manning levels and equipment differences between US and UK fire brigades were discussed. Mr. Grimwood observed that manning levels in the USA were generally higher than those in the UK and that consideration would need to be given to increasing the number of firefighters in attendance if there were a move toward ventilation in the UK. More importantly, however, he felt that more hydraulic platforms and more cutting equipment would also need to be made available.

In closing, Mr. Grimwood drew attention to the tactic of fog attack, which he strongly believes is the firefighting tactic of the future. He questioned whether UK fire brigades should be introduced to ventilation before they were made better aware of the benefits of offensive fog attack. He pointed out that the latter tactic would be easier to introduce and that it worked effectively in ventilated rooms.

In summary, Mr. Grimwood made a very useful contribution to the practical aspects of ventilation operations and the important differences between the UK and US fire services. His book contains a number of case studies which assist in developing an understanding of the advantages and disadvantages of ventilation.

B.9 HOWARD MORGAN - FIRE RESEARCH STATION

Howard Morgan is a specialist in the field of smoke movement and smoke control at FRS. He has written many papers on the subject of ventilation theory and research and has published guidance on the design of smoke control systems.

Mr. Morgan confirmed that the theory of venting hot gases from a stratified smoke layer is well established although research is ongoing to reconcile the different plume theories, e.g. point source and large fire theories, spill plume theories.

Having witnessed recent demonstrations of PPV operations in Spain Mr. Morgan stated that he believed it would be relatively simple to adapt the conventional "zone" theory to take account of the additional pressure term due to the fan. This, he believed, could be used to investigate the scope of application of PPV for different geometries and wind conditions. He emphasized that this theory would only apply where the smoke is vented from above a stratified layer and that an alternative theory would need to be developed for cross-flow processes.

On the subject of roof venting operations he did not feel that there was a need to carry out any large scale testing in order to quantify the benefits of ventilation from the point of view of smoke movement. He argued that existing zone model theory would be sufficient for the purpose. He did not feel that CFD models would be appropriate.

Some research (42) has been carried out into a method of air entrainment into a water spray situated in a duct. This has an advantage over other mechanical extraction systems in that it has no moving parts and can be used in fire situations where the high temperature of the gases would render fans inoperable without special protection.

B.10 GRAHAM HANSELL - COLT INTERNATIONAL

Dr. Hansell is consultancy manager for Colt Technology Ltd. UK. He has published a number of papers on ventilation related issues and has undertaken collaborative research with Howard Morgan of FRS.

Dr. Hansell was very helpful and arranged access to the Colt Technology library. In addition to obtaining a number of useful references it was established that Colt have a comprehensive collection of case histories concerning the operation of automatic ventilation of real fires and a significant collection of material describing large scale tests that they have undertaken. Dr. Hansell offered to make the information available if it was required for future studies.

He echoed views similar to those of Howard Morgan on the theoretical understanding of ventilation and also felt that there was no need for further large scale tests.

He outlined the fundamental difference in philosophy between the British Standard Codes of Practice, which are concerned with both property protection and life safety issues, and the Building Regulations, which are primarily concerned with life safety. Automatic ventilation is recommended in the Codes of Practice but it is not a mandatory requirement under the Building Regulations. The onus therefore rests with the building owners to protect their property.

APPENDIX C
SUMMARY OF US AND OVERSEAS CONTACTS

C.1 GENERAL

This appendix summarises the key points arising from the contact made with fire departments and organisations abroad.

Initial discussions were held with the New York Fire Department, the National Fire Academy and the University of Orlando, which enabled a detailed itinerary and schedule of questions to be developed for the main series of interviews held in the USA.

C.2 NEW YORK FIRE DEPARTMENT (NYFD)

Present at meeting: Chief D. Burns (Head of Operations, NYFD)
Mr. J.R. Barnfield (WFRC)

The use of ventilation is ingrained in US system and is second nature to US firefighters. Ventilation is used to control the spread of fire and allow firefighters access to the building. This approach is the opposite of that taken in Europe, which is to confine the fire and control with water. The main use of ventilation in New York is in residential tenements and warehousing up to six storeys high.

In the tenement blocks it is common practice to cut the vent in the roof above the stairway as this can be used to channel smoke and heat away from the fire-affected floor and allow the firefighters to approach from below. Ventilating in this way also tends to reduce the lateral spread of fire from a stairway into dwellings at other levels.

In industrial buildings a hole will be directly above the fire, which significantly improves access to the building.

Roof venting is widely used in low-rise buildings, but is not applicable to high-rise developments. However, horizontal ventilation of high-rise buildings is also rare, as in adverse weather conditions both wind and stack effect can cause smoke to be forced into stairways and other levels.

The normal roof construction with which New York firefighers have to deal is a plywood and "tar" system which is relatively easy to cut through with a carbide tipped circular saw.

The NYFD has lost firefighters in roof venting operations so that great care is required when carrying out activities on the roof. The fire service coverage is good and the arrival time for most fires is of the order of 5 min, at which time it is often possible to achieve roof access with relative safety. The short response time is considered to be crucial to the safety of roof-level activities.

The first activity on arrival is to establish whether it is safe to cut vents into the roof. If so, an initial hole approximately 3' x 3' is cut directly above the fire. This is then increased in size, typically to 4' x 8'. Ventilating in this way would be expected to lift the smoke layer 2' to 3'.

A trench cut across the roof can be a highly effective defensive measure to restrict the lateral spread of the fire. However, considerable skill is required to establish the best position for the trench, which must be out ahead of the fire.

Documented training procedures exist for venting operations considered appropriate to differing forms of construction but these are scattered throughout various training documents.

Aside from the problems of putting men on the roof under dangerous conditions no examples could be identified of ventilation (in low-rise buildings) having made matters worse. The removal of smoke and heat inevitably made entry into the building and firefighting activities easier. However, it is important not to vent if backdraught conditions are suspected.

Effective ventilation requires considerable experience to carry out safely; it is therefore considered that if such procedures are to be introduced in the UK extensive training and slow and gradual implementation of the procedures will be required.

The NYFD has experimented with PPV systems but has rejected their use because of the time required to set them up and because the generation of a positive pressure can cause smoke and fire to spread in unwanted directions.

C.3 Federal Emergency Management Agency - Fire Training Center.

Present at meeting: Mr. H. Wood
Mr. J.R. Barnfield (WFRC)

The opportunity was provided for WFRC to address a class of approximately 25 experienced fire officers, who were attending a command and control course at the academy. The officers were from various states and were able to provide a broad range of views and experience of the use of ventilation procedures.

There was a general consensus that roof venting was desirable wherever safe and practical. The view was expressed and supported by all those present that 100% of US firefighters would take a similar view. However, there were significant differences of opinion regarding the use of PPV.

Most fire departments have their own operational procedures documents and these all cover ventilation methodology.

None of the trainees or tutors was aware of any experimental work on roof venting although a number did know of the work being done on PPV by the University of Central Florida, Orlando.

Many of the class members questioned whether UK fire services could be fully effective in controlling fires without using ventilation techniques. Although a view was expressed that the wider use of timber frame construction in the USA meant that a very rapid intervention was required by the fire department if the building and its occupants were not to be lost. It was considered that the more solid construction used in the UK made aggressive firefighting less necessary.

A number of considerations were identified that are of particular importance with regard to ventilation:

(a) the type of structure;

(b) experience of the behaviour of the different types of structure;

(c) the fact that ventilation above the fire removes heat and smoke, allowing access to the seat of the fire;

(d) that trenching can be used to prevent the lateral spread of fire;

(e) that the lightweight roof construction used in USA is perceived to be much easier to cut through than typical UK roof construction;

(f) that ventilation cannot be separated from fire extinguishing activities.

The extent of roof venting in the various states seems to be more dependent upon local constructional techniques than on differences of principle between the fire departments.

The general policy is to cut a hole above the fire of minimum size 4' x 4'. For trenching, a strip approximately 3' to 4' wide would be cut. The trench, as well as preventing lateral fire spread, can be used to lead the fire in a particular direction. The most effective means of cutting through the roof construction is generally considered to be a chain saw with carbide-tipped blades. However, in some states circular saws are more popular because of the type of construction that predominates. It was not generally felt that the use of axes was an effective means of creating ventilation openings. Clay and concrete tiles are rarely used in the USA but it was recognised that these could make opening up of vent holes particularly difficult.

A particular problem to all firefighters was considered to be the increasing use of very lightweight timber and steel roof truss constructions as these tend to collapse early in the fire.

The objective of ventilation being to clear heat and smoke and allow low level access, it was generally agreed that hoses should not be directed into the vent opening.

Top ventilation is not always practical and in such circumstances consideration is given to breaking out windows and allowing horizontal ventilation. A phrase repeated by a number of the officers was "vent early - vent often" and this seemed to be a common thread in the training of those present. It was, however, stressed that ventilation is intended to enable access to the seat of the fire and has to be coordinated with fire extinguishing activities.

It was accepted that a measure of risk is involved in roof venting but that with appropriate training and experience this risk can be reduced to an acceptable level.

Some, however considered PPV problematic because it has the potential to "blow" the fire towards occupied rooms; it was therefore considered essential, before using PPV:

(1) to take account of the location of the fire;

(2) to take account of the possible location of people within the building;

(3) to ensure that vent openings are established from the fire room(s) to outside before operation of PPV fans;

(4) to avoid where possible vent openings to the outside from occupied areas.

It was also stated by some that the use of PPV can make the damping down process more difficult as the PPV process may force flames into hidden cavities within the structure. However, others felt that this was not a particular problem as there is always a need to check cavities whether or not PPV has been used.

The main benefit of PPV was considered to be the clearance of smoke to enable access for extinguishing and rescue operations in residential buildings. The general view was that PPV should be coordinated (by radio) with the ventilation of the fire compartment (usually by breaking windows) and fire extinguishing operations.

It was stated that PPV (and roof venting) should not be used when there is any suspicion of backdraught conditions.

PPV is used by some departments in large buildings such as warehouses but the general consensus appeared to be that it is of little use in this situation and is best suited to residential and other buildings of a similar size and configuration.

C.4 UNIVERSITY OF CENTRAL FLORIDA (UCF)

Present at meeting: Miss P.S Ziesler (UCF)
Dr. F. Gunnerson (UCF)
Dr. A. Hay (WFRC)

Under the direction of Dr. Fred Gunnerson and Pam Ziesler, senior mechanical engineering students at the University of Central Florida have carried out a series of experimental projects with the Orange County Fire and Rescue Department (OCFRD). One research programme was aimed at evaluating the effectiveness of PPV as a firefighting technique. The objectives were quantitatively to measure temperatures, air quality and visibility during live fire exercises. Using data from three residential fires, a novel technique was developed to conduct underwater, scaled model PPV simulation.

The visit to UCF was timed to coincide with a fire experiment, involving UCF and OCFRD, to investigate the advantages of using PPV in situations where occupants of the building have not made an escape.

Two trials were carried out, one using PPV techniques, the other without. A fire was started in the upper bedroom of a two-storey residential building. The initial fire source was a collection of wooden pallets and straw of approximately $1m^3$. The bedroom also contained a double mattress, an armchair and a sofa to represent a typical fire loading. The windows of the bedroom were boarded up with plaster board. Each trial was carried out in a different bedroom but the layouts and fire loadings of the bedrooms were almost identical.

The upper storey of the building was instrumented with thermocouples at three heights:

(a) adult head height;
(b) child head height;
(c) crawling head height.

Two "dummy" victims were placed in the house: one, an adult dummy on the second floor landing, the second a baby doll, hidden in an under-stair cupboard. Gas analysis equipment and thermocouples were located adjacent to the dummies to facilitate a comparison of the tenability of conditions with and without PPV. An infra-red camera was positioned outside the building to identify any "hot spots" within the building. Video cameras were used to display and record conditions on the inside of the building. Heat-sensitive crayons that change colour with temperature were used on the firefighters' clothing to provide an indication of the temperatures to which they were exposed.

Two different teams of firefighters were used for each trial and neither was familiar with the layout of the building or the location of the dummies prior to their arrival on the scene. The tests generated a great deal of interest and were witnessed by three fire departments and two local T.V. stations.

A full description of the trials and the results will made be available in a UCF report. The preliminary analysis of the results suggests that the victim discovery times were reduced and the survivability times increased when the fans were used.

The results of this and other large-scale tests will be used by UCF to further their novel technique for simulating PPV underwater. For this, scale models of structures are constructed of thin, clear acrylic. Heated air is simulated by injecting red coloured water at a rate corresponding to the rate of air expansion caused by a localised fire in a single room. The air flow from the fan for PPV is simulated by blue-coloured water injected at a scaled rate corresponding to the actual air flow of the fan. The simulation is conducted either on a water table or in a deeper transparent tank.

Although at this stage the simulation method has been only calibrated against the large-scale fire tests undertaken by UCF and OCFRD, it is claimed that the real time and simulation time of events compare very well. The simulation technique is particularly useful for classroom training as it provides a cost effective, safe and visually interesting representation of events. It is also a flexible tool for demonstrating the effects of errors in judgement, e.g. incorrect selection of an exhaust point. However, further research is required before the simulation technique can be used as a predictive tool.

The main limitations of the technique in its present form are that:

(1) it cannot realistically simulate buoyancy effects and is, therefore, of limited use for natural ventilation or multi-storey applications;

(2) it cannot be used to simulate flashover or backdraught effects;

(3) it does not account for environmental effects such as wind and humidity.

Further research is being undertaken at UCF to develop a computer model of the hydraulic analogy for air flow. It is claimed that a simplified form of field modelling approach can be applied to the water system. No details of the research were available at the time of the visit but is expected that a preliminary model will be developed early next year.

C.5 ORANGE COUNTY FIRE AND RESCUE DEPARTMENT (OCFRD)

Present at meeting: Capt. C. Growley (OCFRD)
Miss P. Ziesler (UCF)
Dr. A. Hay (WFRC)

Building construction in Florida differs both from that found in the northern half of the USA and methods used in the UK. Because of the rapid growth in the residential sector, many of the buildings are less than 20 years old. They are generally of timber construction and, because of the warm temperate climate, they are not built to stand the rigours of a cold winter.

For these reasons it was suggested that early, aggressive ventilation is essential if the loss of entire structures was to be prevented.

Capt. Growley queried the low level of injuries apparently sustained by the UK fire service without the use of ventilation. He was of the opinion that ventilation significantly reduced the potential for flashover-and-backdraught related injuries. He was also surprised that firefighters did not encounter problems with "steaming", a term he used to describe the effects encountered when a water spray is directed into the hot upper layer of a fire in an unvented room. Cooling the upper layer is a common tactic used to prevent flashovers but it disturbs the thermal balance in the room by pulling the hot layer down to ground level and generating large volumes of steam. If the only opening into the room is the one through which the firefighters entered, the danger is that the steam and hot gases will vent directly towards them.

The department strongly promote the use of PPV and regard it as a safer, more effective method of venting fires than natural ventilation. It is interesting, however, that PPV is not covered as part of the State-certified basic training course but that natural ventilation is addressed in both a written and practical format. OCFRD rely on individual training by departments and "on-the-job" experience to develop skills in PPV.

When asked about the implementation of tactical ventilation in the UK it was suggested that busy active brigades should be selected and trained on an initial-trial basis (c.f. John Mittendorf C.8). It was felt that this would allow a direct comparison, by experienced firefighters, of venting and the traditional non-venting approach. OCFRD were confident that the benefits of ventilation, particularly PPV, would be self-evident.

They claim to have had no catastrophic problems with PPV and suggest that most of the minor problems they have encountered could be attributed to procedural mistakes. It was argued that, if the tactics are employed correctly ventilation is no more or less hazardous than any other firefighting tactic.

Capt. Growley identified high-rise buildings and windowless buildings as the most difficult to vent. He also agreed with the opinion of many UK firefighters that modern large single-storey warehouses usually vent themselves prior to the arrival of the fire brigade.

C.6 CHICAGO FIRE DEPARTMENT

Present at meeting:	Lieutenant Gibbons	(Instructor)
	Lieutenant O'Donnell	(Instructor)
	Chief Divis	(Operations)
	Chief Snyder	(Operations)
	Dr. A. Hay	(WFRC)

A meeting was held with two instructors at the Chicago Fire Training Academy and two operational officers from the downtown Chicago area. Much of the discussion centred around the application of ventilation to the case studies outlined in Appendix D.

As with those of all the US fire departments that were contacted directly, the Chicago representatives were extremely surprised that the UK Fire Service only employs ventilation as a last resort. They could not envisage how firefighters could enter buildings and tackle fires without early ventilation. They even claimed that some fire attack teams would not enter buildings unless they were confident that ventilation operations were underway.

They argued that the truck crews responsible for ventilation should have permission to use their initiative and experience to decide where and how ventilation should be carried out.

The basic training given to firefighters covers the fundamentals of ventilation theory and practice but no specialist training is provided. This is acquired through experience "on-the-job".

The instructors admitted that their aggressive approach has sometimes resulted in buildings being vented unnecessarily. However, they believed that the benefits gained, in terms of limiting fire and smoke damage, far outweigh the superficial structural damage incurred on the few occasions when the tactic should not have been used.

Although the instructors had a cursory knowledge of PPV, the operational officers were not aware of this method of ventilation. After further discussion, they expressed scepticism about the safety and effectiveness of the tactic. It was clear that the Chicago Fire Department do not promote this method of ventilation and, like their UK counterparts, will require convincing evidence of the benefits and safety of it before they do.

C.7 SEATTLE FIRE DEPARTMENT

Present at meeting:		
	Captain Vickery	(Operations)
	Deputy Chief Campbell	(Operations)
	Deputy Chief Rose	(Training)
	Dr. A. Hay	(WFRC)

The representatives of the Seattle Fire Department provided a demonstration of the use of PPV and talked openly about their general philosophy on ventilation.

The difficulties of teaching ventilation to a fire service with little expertise or experience in the tactic were discussed. The US fire officers felt that, whilst experience is required to develop training procedures, the greater need lies in gaining experience in the field. They noted that the number of fires in the USA has decreased and that the depth of experience throughout their department has suffered accordingly. Resources were now being directed to other areas, e.g. using firefighters to provide a medical aid service similar to the paramedic service offered by the ambulance brigade in the UK. They compared the task of retraining their own firefighters for this purpose to that of retraining UK firefighters to vent buildings. The feeling was that it is no more difficult to teach ventilation than any other firefighting tactic and that the important learning exercise occurs after the teaching. They estimated that it would take the UK fire service 10 years to become well practised in the art of fire ventilation.

Attention was drawn to the fact that ventilation has been shown to be a very labour and water intensive process. The introduction of air can increase the fire severity but this was not considered to be a hazard because operating procedures ensure that men and equipment are in place to deal with the situation immediately it occurs. They suggested that maybe the US brigades rely as heavily on ventilation as they do because they are not limited by the manpower available and the ready supply of water. If resources were less readily available then perhaps they would be forced to look at increasing levels of compartmentation and fire resistance.

The general philosophy is to vent quickly: if ventilation is delayed until it is obvious that it is required then it will probably be too late to carry it out effectively. Some defensive venting operations, e.g. a trench cut across a large warehouse, can take as long as 30 min to carry out and may involve a number of roof teams. In Seattle's opinion, it is therefore better to vent offensively and quickly, early on in a fire, than to wait until conditions deteriorate and more time-consuming ventilation is required. In their experience ventilation of large single-storey warehouses has very rarely contributed to fire spread. They argued that it is better to take the initiative and choose the time and the location of ventilation than to wait for the building to vent itself. However, they cautioned that "opening up" a building should never take place before water supply is secured and fire attack teams are ready to enter the building.

The Seattle Fire Department are carrying out ongoing practical research, involving large-scale fires, into the use of PPV as a technique. Their current policy is to use it "where appropriate" and every ladder truck is equipped with two fans.

The differences in opinion within the Seattle Fire Department typify those across the USA. Captain Vickery is a practising firefighter with considerable experience in the application of both natural and forced ventilation techniques. It is understood that he was one of the first people within the Department to become aware of the PPV approach. Characteristically, he was cautious at the outset about the benefits and hazards that it posed but as his experience in using the tool has increased so has his confidence in its application. Familiarization with the technique was achieved firstly through trials with synthetic smoke in fire houses, secondly in smoke clearance applications in derelict buildings and real fires, and finally through aggressive application during fire attack. He considers the scope for its use to be greater in the UK, where buildings tend to have higher degrees of compartmentation and generally less combustible forms of construction than in the USA.

His opinion is shared by Deputy Chief Rose, who heads the training facility and has been responsible for much of the practical research. Seattle recruits learn the basics of ventilation, including PPV, in basic training and some training literature is available. Deputy Chief Campbell (Operations), however, takes a more conservative approach. He feels that PPV is an excellent tool in the right situation and in the right hands. He is more than happy for an officer of the experience of Captain Vickery to use it but is less confident about its use by junior officers. He warns that the effects of PPV are more dramatic than those of conventional ventilation and, therefore, have the potential to cause more of a problem if applied incorrectly. Consequently, Seattle are currently investigating the use of the tool for tackling awkward fire situations, e.g. fires in voids and roof spaces.

The demonstration of PPV involved smoke logging a two-storey fire station with synthetic smoke. By suitable positioning of the fans and opening of windows, two methods of ventilation were illustrated.

The first method involved direct ventilation of the simulated fire room by opening a window within the room. Various combinations of open doors, both to the fire room and in other parts of the building, were used. The trials illustrated that opening more than one door into the source room did not cause smoke to spread out of the room rather than out of the window: the vent to outside invariably represents the path of least resistance for the smoke flow. Similarly, openings to the outside in other parts of the building did not draw smoke from the source room: they merely reduced the efficiency of ventilation from the room. Furthermore, closing the opening to the outside in the source room and opening a window in another part of the building did not draw smoke to that point. Even when a room adjacent to the source was vented, and the source room was not, very little smoke spread between the two rooms. The reason quoted for the limited smoke spread in all instances was that the fan increases the pressure in all parts of the building to approximately the same extent and hence, although air is being pushed into the building it is not inducing any significant flow patterns throughout the building, except from those locations that have a direct connection to the outside.

The second method of ventilation demonstrated how, by opening doors and windows in a logical sequence, smoke could be cleared from different locations in a systematic manner.

In summary, Seattle are a progressive fire department who have traditionally carried out a lot of natural ventilation. As an organisation, they hold an open view on the use of PPV but opinions on the tactic and its application vary within the department. The proponents of PPV view it as a safer means of ventilation in some situations because generally it does not require firefighters on roofs.

C.8 JOHN MITTENDORF

John Mittendorf is a former Battalion Chief with 30 years' service in the Los Angeles City Fire Department (LACFD). He has written numerous articles on ventilation methods and techniques for fire service magazines (36 and 37) in the USA and other countries, and is considered a leading expert in the field. Prior to and since his retirement from the LACFD three months ago he has conducted lectures and seminars all over the USA on building construction, ventilation methods and techniques, truck company operations, and strategy and tactics. He has also published a ventilation manual entitled "Ventilation Methods and Techniques" (34) and has prepared the "Tempest Positive Pressure Training Manual" (35).

Mr. Mittendorf began by summarising the general attitude toward firefighting in the USA. He maintained that in the USA the professionalism of a fire department can be measured by its ability to enter a building and carry out aggressive firefighting. Weak, "stand-back" departments adopt a passive approach to firefighting and will often stay outside a building when they should really be conducting internal operations. It was claimed that aggressive, internal firefighting would not be possible if firefighters were not well trained and disciplined. This view was reinforced by the generalised statement that volunteer or part-time fire departments in rural areas tend to be less well trained and are not as successful at internal firefighting operations.

Mr. Mittendorf argued that the key to successful internal operations lay in good ventilation practice and highlighted three factors which increased the need for ventilation in modern buildings:

(a) a proliferation of the use of petrochemical-based products in buildings;

(b) increased clothing protection being afforded to firefighters;

(c) lighter-weight building constructions.

He claimed that most deaths and injuries in the USA were attributable to toxic gas inhalation and flashover. Although today's structures are generally more airtight, which could increase the backdraught potential, he did not consider backdraught to be a common hazard. Rather he argued, buildings now contain a greater loading of plastic and petrochemical materials which increases both the potential for flashovers and the levels of toxic gas concentrations. Ventilating a structure can mitigate both these hazards.

Firefighters today are better protected both by their clothing and by the use of breathing apparatus. However, both these improvements isolate the firefighter, reducing his sensitivity to the surroundings and his ability to feel and read the developing fire situation. Mr. Mittendorf suggested that this was one explanation for the increase in the number of flashover injuries to firefighters and that more ventilation would counter this problem.

The current building trend, particularly for storage buildings, is for lighter-weight constructions. Mr. Mittendorf was of the opinion that this increased the need for early ventilation because lightweight structures collapse earlier, spreading fire faster. He did, however, warn that lightweight roof constructions, e.g. truss-type roofs, reduce the time available for safe ventilation operations. There is obviously a trade-off between saving property and increasing the risk to firefighters that needs to be considered.

Mr. Mittendorf was critical of the UK fire service's general reluctance to vent early. He claimed that in the USA ventilation was considered to be as important as water attack. The benefits of ventilation are that it:

- relieves the heat load within the building, thus affording some protection against structural collapse

- improves conditions within the building, allowing earlier and more penetrative entry, a more judicious use of water and a more directed attack on the fire.

Controversially, Mr. Mittendorf claimed that the priority between fire attack and search and rescue is changing and that controlling the atmosphere and conditions within the structure is increasingly being viewed as more important than carrying out search and rescue. The view is spreading across the USA that fire attack rather than search and rescue is the first-crew job. He explained that in many situations there would be a negligible difference in completion times between search and rescue operations conducted without difficulties in a smoke logged building and those delayed until the building is ventilated. In addition, ventilation creates a better environment for trapped occupants, reduces the risk of firefighters being added to the casualty list and limits fire spread. Whether efforts are better directed toward fire attack than search and rescue attempts will obviously depend on the particular circumstances of each incident. As with all aspects of firefighting, broad generalizations are usually inappropriate. However, Mr. Mittendorf argued that ventilation should be a priority where sufficient numbers of firefighters were available to carry out all the necessary rescue operations and more efficient use of manpower would be achieved by redirecting efforts toward controlling the fire and relieving the conditions inside the building. This view obviously condones the use of ventilation tactics whilst people are known to be in the building.

Mr. Mittendorf criticized the New York Fire Department philosophy of vent, entry, search which prioritizes search and rescue operations above fire attack. Venting before setting up hose lines he claimed to be a dangerous approach as underlined by the fact that 60% to 70% of firefighter deaths occur in New York. This number cannot simply be explained by the fact that New York is a large city.

Firefighters in Los Angeles are taught the techniques of natural ventilation and PPV in recruit school and this is supplemented with drill training at their stations. Mr. Mittendorf is in the process of writing a truck manual for the Los Angeles Fire Department, which will cover these aspects, but this will not be available for another one to one-and-a-half years.

When asked for recommendations about UK fire service training, Mr. Mittendorf suggested that the most appropriate fires to begin venting would be those in residential properties. His reasoning was that the results of mistakes would be less catastrophic in small buildings than in large ones. For this reason he would not recommend introducing ventilation as a firefighting tactic in large single-storey buildings until experience in its application has been gained in other building types, e.g. simple, compartmented structures.

He did not consider it critical that the UK adopt a system of separate truck and engine companies, provided that the UK fire appliances are equipped and the firefighters manning them are trained for the job.

To introduce PPV he suggested that selected stations in busy, experienced brigades should be trained in the techniques first. The training should begin with drills on the training ground, followed by smoke clearance exercises at real fires. Only after experience has been gained in these areas did he feel that the fans should be used during aggressive fire attack. He was confident that once a small number of brigades were using the tactic this would stimulate an interest in others.

C.9 SWEDEN

The Swedish Fire Service was understood to be heavily involved in research into the areas of flashover training and ventilation tactics, including PPV and the use of explosive devices for making openings in roofs.

At the suggestion of John Taylor, who has developed links with the Swedish authorities, contact was made with Hans Bjornstron, a senior instructor at the Stockholm Fire Training College.

Stn O. Bjornstron explained that the Swedes have been conducting research for the past two years into the use of controlled explosive charges for making holes in roofs. The device essentially comprises flexible explosive fitted into a framework that concentrates the force of the explosion in a defined position. It is claimed that the explosive will make a neat, incisive hole in a roof and that this has been demonstrated many times in the tests that have been carried out. It is believed that the explosive device is an adaptation of similar devices developed for military applications.

A test group of firefighters was trained in the use of the explosive devices last autumn and a one-year trial of their implementation in real fire has just commenced. The devices have been specifically developed for use on tin roofs, which traditionally have been difficult to open using hand tools. Tin roofs are common in the central area of Stockholm and will typically consist of a timber framework covered by a layer of plywood, then a layer of felt, then a layer of tin. It is expected that the use of an explosive device will shorten the amount of time spent by firefighters on roofs.

When tackling a fire beneath a slate roof of similar construction, the slates must be removed so that the explosive frame is in direct contact with the felt underneath. The frame can be used on corrugated steel roofs where the corrugations are not deep; in the event that they are deep the flexible explosive must be removed from the frame and laid on the corrugations.

The impression given by Mr. Bjornstrom was that ventilation is an aggressive tactic used by the Swedish fire service but only after special consideration of the fire situation. The importance of being able to "read" a fire was stressed and the steps being taken by the Swedish fire service to train and educate their members for this purpose, particularly using the flashover container, were highlighted.

This was a view broadly endorsed by Mr. Jan-Erik Enjin of the Swedish Rescue Services Board (Raddnings Verket), who corresponded in a letter. He did, however, point out that the tactic of fire venting tends to be reserved for the larger single-storey industrial and commercial buildings. He suggested that firefighters would often attempt to seal up smaller buildings and put the fire out with an interior attack, an approach similar to that adopted in the UK.

He attributed the success of the latter approach to the Swedish tactic of "offensive fog attack", which combines protective clothing against heat, high-performance fog nozzles and, most importantly, many hours of training and education. The importance of flashover simulator training, where the firefighter learns to recognise the different stages of a pre-flashover fire and the effects of cooling flames, gases or walls, was also stressed.

Mr. Enjin also summarised the findings of some earlier research into the theoretical aspects of PPV. It was suggested that:

- a theoretical model for tactical fire ventilation should be developed;
- new methods of fire ventilation should be investigated;
- a training programme for tactical ventilation should be formulated;
- trials and research should be undertaken to establish equipment requirements.

Future plans include:

- the preparation of a video outlining firefighting techniques for single-storey industrial/ commercial buildings;
- a survey of the use of PPV in the USA to identify the safety margins of the techniques and how it can be used to increase the performance of the firefighter;
- the establishment of a training programme in fire ventilation for the Swedish Fire and Rescue Services.

APPENDIX D
CASE STUDIES

D.1 INTRODUCTION

In order to gain a better understanding of how US fire departments apply ventilation tactics and what factors influence their decision-making process, a list of scenarios covering different fire locations and types of building was formulated. This was accompanied by a list of questions, which were used as a prompt during the discussions held with the US fire departments.

The list of fire scenarios and questions are given below. A summary of the key discussion points at each of the meetings is presented on a scenario-by-scenario basis in Section 5 of this report. Unfortunately, due to the limited amount of time available with each department it was not possible to cover all the scenarios in every meeting. Attention was focused on large single-storey buildings and residential buildings, but each scenario was discussed during at least one meeting.

D.2 FIRE SCENARIOS

1. **Single-storey warehouse/industrial building**

   (a) fire against end wall
   (b) fire in centre of building
   (c) unidentified fire location

2. **Two-storey warehouse/industrial building**

   (a) fire on ground floor
   (b) fire on upper floor

   Consider effects of a mezzanine floor.

3. **Single-storey strip stores**

4. **High-rise office block - open plan**

   Central core versus external stairs only

   (a) Fire above nnp
   (b) Fire below nnp

5. **High-rise flats (apartments) - compartmented >10 storeys**

   Central core versus external stairs
   Single versus multiple stairs

   (a) fire in flat above npp
   (b) fire in flat below npp.

6. **Low-rise flats (apartments) <10 storeys**

   Single versus multiple stair

   (a) fire in flat.

7. **Two storey residential house**

   (a) fire in bedroom on upper level
   (b) fire in kitchen on lower level.

D.3 QUESTIONS

1. What would be the most common form of construction?

2. What level of fire protection would you generally expect?

   - compartmentation?
   - sprinklers?
   - smoke control?

3. What level of first attendance would normally be provided (i.e. number, type of appliances and manpower)?

4. Are there circumstances in which you would not vent?

5. What would the initial deployment tactics be if:

   (a) persons reported;
   (b) no persons reported?

6. What technique of venting would generally be considered most appropriate, natural venting or PPV?

7. Would you consider using PPV and natural venting together?

8. At what stage would you begin venting?

9. What parts of the building would be vented and what size vents would be used?

10. What precautions would be taken to counter the possibility of fire spread associated with venting and how would water, in particular, be used?

11. What "fire signs" would make you reconsider venting?

12. What would you consider to be the main hazards of venting in this building?

    - roof collapse?
    - fire spread?
    - backdraught?
    - increased life threat?

APPENDIX E
CONTACT LIST

E.1 US FIRE DEPARTMENTS CONTACTED

Pheonix Fire Department, Mr A. Brunacini, 520 West Van Buren, Pheonix, Az, 85003

Tucson Fire Department, Mr F. Shipman, 265 South Church, PO Box 27210, Tucson, Az, 85726

Long Beach Fire Department, Mr C.A. Hunter, 211 East Ocean Boulevard, Suite 500, Long Beach, Ca, 90802

Los Angeles City Fire Department, Mr D.D. Manning, 200 North Main Street, Room 920, Los Angeles, CA, 90012

Los Angeles County Fire Department, Mr M. Freeman, 5823 Rickenbacker Road, Commerce, Ca, 90040

Orange County Fire Department, Mr L.J. Holmes, 180 South Water Street, Box 86, Orange, CA, 92666

Riverside County Fire Department, Mr M. Harris, 210 West San Jacinto Avenue, Perris, CA, 92370

San Diego Fire Department, Mr J. Delotch, 525 B Street, Suite 807, San Diego, Ca, 92101

San Francisco Fire Department, Mr J. Medina, 260 Golden Gate Avenue, San Fransicso, Ca, 94102

San Jose Fire Department, Mr R. Osby, 4 North 2nd Street, Suite 1100, San Jose, Ca, 95113

Santa Cruz County Fire Department, Mr D. Locke, P.O Drawer, F-2, Felton, Ca, 95018

Denver Fire Department, Mr R.L. Gonzales, 145 West Colfax Avenue, Denver, Co, 60204

District of Columbia Fire Department, Mr R. Alfred, 613-G-Street, NW, Washington, DC, 20001

Jacksonville Fire & Rescue, Mr C. Clark, 1931 East Beaver Street, Jacksonville, Fl, 32202

Metro-Dade County Fire Department, Mr D. Paulison, 6000 SW, 87th Street, Miami, Fl, 33173

Miami Fire Department, Colonel H. Duke, 273 NW 2nd Street, Fifth Floor, Miami, Fl, 33128

Orange County Fire and Rescue, Mr J. Hunt, 4700 Lake Underhill Drive, Orlando, Fl, 32807

Palm Beach County Fire and Rescue, Mr H. Brice, 50 S Military Trail, Suite 101, West Palm Beach, Fl, 33415

Atlanta Fire Department, Mr D. Chamberlain, 46 Courtland Street, SE, Atlanta, Ga, 30335

Dekalb County Fire Service, Mr J. Boozer, 4400 Memorial Drive Complex, Decatur, Ga, 30032

Honolulu Fire Department, Mr L. Canara, 3375 Koapaka Street, Suite H-42, Honolulu, Hi, 96819

Chicago Fire Department, Mr L.T. Galante, 121 N Lasalle City Hall, Room 105, Chigaco, IL, 60602

New Orleans Fire Department, Mr W.J. McCrossen, 3117 Decatur Street, New Orleans, LA, 70130

Boston Fire Department, Mr M. Pearce Jr., 115 Southampton Street, Boston, Ma, 02116

Anne Arundel County Fire Department, Mr P.C. Haigley, P.O Box 276, Millersville, MD, 21108

Baltimore City Fire Department, Mr H. Williams Jr., 410 East Lexington Street, Baltimore, Md, 21202

Baltimore County Fire Department, Mr E.H. Banister, 700 East Joppa Road, Suite 901, Towson, Md, 21204

Montgomery County Fire-Rescue, Mr R. Granados, 101 Monroe - 12th Floor, Executive Building, Rockville, Md, 20850

Prince George's County Fire, Mr S.T. Edwards, 9201 Basil Court, 4th Floor East, Landover, Md, 20785

Rockville County Fire Department, Mr R.F. Granados, 101 Monroe Street, 12th Floor, Rockville, Md, 20850

Detroit Fire Department, Mr C. Edmunds, 250 West Larned, Detroit, Mi, 46226

Kansas City Fire Department, Mr C.M. Fisher, City Hall, 414 East 12th Street, Floor 22, Kansas City, IL, 64106

St Louis Fire Department, Mr N. Svetanics, 1421 North Jefferson Avenue, Saint Louis, MO, 63106

Charlotte Fire Department, Mr L.L. Fincher Jr., 600 East Fourth Street, Charlotte, NC, 28202

Albuquerque Fire Department, Mr T. Montoya, P.O. Box 2086, 724 Silver SW, Albuquerque, NM, 87103

Clark County Fire Department, Mr L.T. Giles, 573 East Flamingo Road, Las Vegas, NV, 89119

New York City Fire Department, Mr E. MacDonald, 250 Livingston Street, Brooklyn, NY, 11201

Cleveland Fire Department, Mr W. Zimmerer, 1645 Superior Avenue, Cleveland, OH, 44114

Columbus Fire Department, Mr D. Werner, 300 North Fourth Street, Columbus, OH, 43215

Oklahoma City Fire Department, Mr T. Smith, 820 NW 5th Street, Oklahma City, OK, 73106

Portland Fire Bureau, Mr G. Monogue, 55 SW Ash Street, ortland, OR, 97204

Philadelphia Fire Department, Mr H. Harriston, 240 Spring Garden Street, Philadelphia, PA, 19123

Pittsburgh Fire Department, Mr C. Dickinson, 200 Ross Street, 5th Floor, Pittsburgh, PA, 15219

Memphis Fire Department, Mr H.D. Crossvine, 29 South Flicker Street, Memphis, TN, 36104

Nashville Metro Fire Department, Mr J.F. Perry, 416 Russell Street, Nashville, TN, 37206

Austin Fire Department, Mr B. Roberts, 1621 Festival Beach Road, Austin, TX, 76702,

Dallas Fire Department, Mr D. Miller, 1500 Narilla, Room 7AS, Dallas, TX, 75201

El Paso Fire Department, Mr G. Hernandez, 20L South Florence, El Paso, TX, 79901

Fort Worth Fire Department, Mr D.L. Peacock, 1000 Throckmorton Street, Fort Worth, TX, 76102

Houston Fire Department, Mr E. Corral, 1205 Dart, , Houston, TX, 77007

San Antonio Fire Department, Mr Loyosa, 115 Auditorium Circle, San Antonio, TX, 78205

Fairfax County Fire & Rescue, Mr G. Gaines, 4031 University Drive, Fairfax, VA, 22030

Virginia Beach Fire Department, Mr H.E. Diezel, Municipal Center, Virginia Beach, VA, 23456

Seattle Fire Department, Mr C. Harris, 301 Second Avenue South, Seattle, WA, 98104

Milwaukee Fire Department, Mr A.G. Erdmann, 711 West Wells Street, Milwaukee, WI, 53233

E.2 Other Overseas Contacts

Mr D. Jordan, 32 Savanna Drive, Mooroolbark, Victoria 3138, Australia

Mr Paul England, Warrington Fire Research, 2nd Floor, 541 Blackburn Road, Mount Waverley, Victoria 3149, Australia

Major Peter Lim Sin Pang Dipl.Ing., Singapore Defence Force, Central Fire Station, Hill Street, Singapore 0617

Mr M. Baset, Chief Fire Officer, Bomberos, Consorci, Provincial De Valencia, Cami de Mont, Cada 24, 40009 Valencia, Spain

Mr Christer Stromgren, National Rescue Services Board, Civilian Protection Department, Karolinen, S-651 08 Karlstad, Sweden

Mr Owen Kinsella, Director of Operations, New Zealand Fire Service, National Headquarters, P.O. Box 2133, Wellington, New Zealand

Gunnar Haurum, Commandant, Statens Brandskole, Kongevejen 207, 2830 Virum, Denmark

Mr L. Pajulatiti, Director, Emergency Services College, Hulkcontrie 83, 70820 Kuopio, Finland

Mr Erwin Nowak, Osterreichiscer Bundesfeurwehrverband, A-1080 Wien, Lenaugasse 17, Austria

Miss Isabelle Magotte, Chief Inspector, National Fire Inspectorate, Rue Royal 66, B1000 Brussel, Belgium

Dieter Farrenkopf Dipl. Ing., Ober Brandirektor, Feurwehr Hamburg, Westphalensweg 1, 2000 Hamburg 1, Germany

Mr S. Hogan BE. C.Eng MIEI, Fire Adviser, Dept. of the Environment, Fire Services & Emergency Planning Section, Custom House, Dublin 1

Lam Chek-yuen QFSM CPM JP FBIM, Director, Hong Kong Fire Services Dept., 1 Hong Chong Road, Tsiui Sha, Tsui East, Kowloon, Hong Kong

Mr G. Herkemij, Chief Inspector, Ministry of Home Affairs, Schedeldoekshaven 200, P.O. Box 20011, 2500 EA The Hague, Netherlands

Direktoratet For Brann-og Eksplosjonsvern, Nedre Langgt 20, 3100 Tonsberg, Norway