Report on PPV Trials

at Oxford Road, Preston, U.K.

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1. INTRODUCTION

1.1 Ventilation

Ventilation as a fire-fighting tactic has been used since time immemorial. Hence it is nothing new. Venting (the creation of exhaust/inlet ports for the products of combustion) a fire has been done with caution, following much training and consequently has been instrumental in reducing property damage and increasing comfort levels for fire-fighters at virtually every fire. The maxim within the Fire Service has been ‘vent, vent early, but only when safe to do so’. Hence it has always been recognised that caution is the better part of valour but that used correctly, venting is a key tool in the fire-fighter’s toolbox.

Positive pressure ventilation is a method of using high volumetric flow rate fans to increase the pressure within a compartment so that the products of combustion are encouraged to exit the compartment in order to reach a region of lower pressure. Generally speaking, the mobile fan unit is placed approximately 3 metres from the doorway, i.e. outside the building, and the air is directed in through the doorway. Positive pressure ventilation can be viewed as simply an advanced use of natural ventilation techniques.

Positive pressure ventilation is widely utilised in the USA and the concept was first introduced there many years ago. The constructional methods used for buildings in

USA differ widely to those of the UK, so it is difficult to justify the direct application of the ventilation techniques developed there.

However, many local authority Fire Services in Great Britain now use positive pressure ventilation in the post-fire scenario. Most however, are wary regarding the use of positive pressure ventilation prior to the fire being extinguished. This has been termed ‘aggressive positive pressure ventilation’. In fact, at the time of writing, only one of the fifty-seven local authority brigades has routinely adopted this approach.

In contrast to the above paragraph, it has been decided to utilise the terms offensive and defensive in this report, to parallel the Home Office and LFRS, with the following definitions(1);

Defensive – ventilating away from the fire, or after the fire is out.
Offensive - ventilating close to the fire to have a direct effect on the fire itself.

From hereon, positive pressure ventilation will be referred to as ‘ppv’. With regard to domestic ppv use, as it is very unlikely in a single domestic dwelling that a fan will be used away from the fire, the term defensive should be considered to mean use of ppv once the fire has been extinguished.

1.2 The Trials

During the week of 10 – 14 January 2000, Lancashire Fire and Rescue Service, supported by the Department of Built Environment, University of Central Lancashire, undertook a series of ppv trials at Oxford Road, Preston.

The main objectives of the trials were as follows: -

- To examine the possible tactical advantages of offensive ppv
- To improve knowledge and skills in the use of defensive ppv
- To further assess fan selection in terms of fan size
- To produce a comprehensive report, (including stills and video footage), to assist in future training packages and the further development of operational procedures.
- To provide realistic, live fire observation for personnel involved.
- To provide comprehensive data for use in risk assessments.

The trials were originally planned to take place in two-storey properties but were relocated, due to uncontrollable circumstances to single-storey properties.

Plate 1. Oxford Road, Avenham

Each fire experiment room was furnished with the type of materials that would be expected with a real incident i.e. carpets, curtains, sofas, bedding etc. Consequently, the trials were possibly the most realistic, in terms of fire loading, to have been carried out to date in the U.K.

The trials took place over five days. The chosen approach was to carry out each scenario twice, once using standard fire fighting techniques, (defensive) and once using offensive positive pressure ventilation.

Although much quantitative data was gathered, the nature of fire, with its many variables, dictates that qualitative data is very important. Consequently, each volunteer has been canvassed for his or her experiences during the trials. This information is included within the report.

This report is a précis of a more detailed and technical engineering analysis, which is available if so required.

1.3 Positive Pressure Ventilation

Extensive research has been undertaken regarding the subject of positive pressure ventilation and its applications for the Fire Service. Lancashire Fire and Rescue Service and several other Brigades have conducted ‘in house’ experiments to determine the effectiveness of positive pressure ventilation post fire, as a result, the use and safe application at incidents is well documented.

Supporters of the use of ppv offensively claim that it has a number of advantages, such as:

- The enhancement of fire-fighter safety due to the improved atmosphere that positive pressure ventilation can create.

- The rapid improvement of conditions remote from the fire-affected compartment will enhance the chances of survival for persons trapped in a building on fire.

- Fire-fighting operations can be expedited as the improved conditions enable the fire attack to take place quicker.

- The correct use of positive pressure ventilation prevents firespread beyond the fire compartment.

The literature review undertaken for this project demonstrates that although research into positive pressure ventilation has been fragmented, the overall picture is one of support for the technique. There is a distinct lack of formal academic evidence to support this however and consequently many sceptical Chief Fire Officers, this being demonstrated by the reticence of UK Fire Brigades in offensive positive pressure ventilation use. Most of the reports reviewed indicate the need for further research.

Two Fire Brigades have already undertaken offensive ppv experiments, Tyne and Wear Metropolitan Fire Brigade and Greater Manchester County Fire Brigade. The results of the two sets of experiments undertaken by Tyne & Wear indicate that the use of ppv does not seriously intensify fire spread [(2)]. In contrast to this the report of offensive ppv experiments in Greater Manchester indicate a rapid acceleration of the fires involved on operation of the fans [(3)].

Clearly from the differing results produced by two large Metropolitan Brigades the use of offensive ppv warrants further investigation and research. It is universally accepted that without proper training and correct tactical deployment at incidents, ppv could prove potentially fatal for fire fighters and members of the public.

When assessing the use of positive pressure ventilation there is a tendency to forget that pressurisation has been incorporated within building designs for several decades. Heating ventilation and air conditioning systems can be designed so that, in the event of a fire, they can be used as a smoke control system. Separate heat and smoke control systems are also designed for the larger building and for certain industrial applications, therefore the concept of ppv and fire application is not a new one.

1.4 Previous U.K. Research -- Overview

A major concern amongst fire officers and the research establishment in this country is the fact that ppv may prove ineffective when used offensively, possibly even dangerous. Ventilation techniques for domestic dwellings and small industrial units in the UK have relied on the available openings of the building involved in fire, windows, doors, or occasionally roof lights are used when appropriate to exhaust the contaminants. The problem foreseen initially with ppv in UK construction buildings is the lack of available or adequate exhaust points to compensate for the amount of air entering the building from the ventilation units. Flashover, backdraught and firespread were all perceived problems associated with the fans in early assessments.

Early in 1994, Warrington fire research consultants undertook a survey of ventilation when used as a fire-fighting tactic; the report from the survey was published later that year. The report concluded that further research needed to be undertaken on the subject of ppv ventilation since little or no research existed in the UK. As a result of the Warrington report the Fire Experimental Unit at Moreton in Marsh undertook a further research project, this work to be backed up by a survey of the expertise available in the USA and other countries [(4)].

The research results indicated that ppv to be particularly suited to fire attack in small domestic dwellings however, caution was expressed regarding its use (ppv) due to the 'significant amount of additional training' that would be required.

Two trials of note were conducted by the Fire Experimental Unit using the Fire Service College's facilities; the first using fires on the ground floor and the second experiment consisted of fires in a basement.

The results of these experiments demonstrated the need for a systematic ventilation procedure when using ppv. It was found that any compartment where an outside window was not opened was effectively sealed by the ppv, preventing any smoke clearance. Where ppv was not used the compartment cleared gradually, but this did not happen with ppv. The main conclusion from this experiment is that if using ppv for smoke clearance, rooms should be cleared one at a time and once a room is clear of smoke, the windows should then be closed. The report further concludes that these results were due to the limited flow from the portable ventilation units and that ppv was not as effective in clearing rooms with upwind windows.

Another very important point to be concluded from the Experimental Unit's experiments was the fact that ppv can easily be overcome by a strong wind therefore its use is limited to certain scenarios.

A comprehensive research document was produced by J G Rimen (5), which researched the use of positive pressure ventilation in domestic properties. The document describes a series of trials conducted in still air conditions and a further series of trials conducted in a four bedroom detached house. J.G Rimen had listened to the views of Fire Officers and others in the building industry and acknowledged the sceptics who regarded increasing the oxygen content to fires via ppv as dangerous.

A series of trials were undertaken in a ‘mock’ detached dwelling, the primary objective being to determine basic rules for the use of ppv at incidents. The results obtained during the trials were recorded using a data logger and the results subsequently analysed.

The report concluded that an inlet / outlet ratio of 2 / 1 is the ideal ratio for the use of ppv and this is what Brigades should aim for. If this ratio is unable to be obtained then it would be still advantageous to have the inlet opening larger than the outlet opening. Experiments undertaken also suggest an optimum distance of 1.0m from the inlet opening for the fan and that it was not necessary to seal the opening with the fan, this last conclusion contradicts current working practises which have been adopted from other research. Another conclusion from the report indicates that the most efficient method of using the ppv fan is when it is placed so that air is projected horizontally into the building.

The research conclusions indicate that ppv has the capability of rapidly improving the environment at fires, but can also make things worse and that it is virtually impossible to predict with any certainty the effect of the fan in a given circumstance. This particular conclusion from the report was used to back up the evidence of those individuals opposed to the adoption of ppv for fire service operations.

Others adopted a totally opposing opinion within the UK fire service for ppv application as a result of J.G Rimen's report. The report states that 'each fire situation, and specifically whether or not to deploy ppv, would need to be considered on its particular merits', in other words risk assessment. Those in favour of ppv use argue that a ventilation fan is just another piece of equipment available to the incident commander and with adequate training and correct incident assessment, it (ppv) is safe to use.

Fire Authorities in the UK have acknowledged the training requirement for ppv; two metropolitan Brigades have conducted fire experiments to assess the training implications and effectiveness of ppv.

Tyne and Wear Metropolitan Fire Brigade acquired the use of two derelict semi-detached properties; these were subsequently used for tactical ventilation trials in real fire situations during November 1996. The properties used were identical in construction and layout, which enabled fires to be repeated and compared.

Cribs were placed in various rooms within the houses and holes drilled in the walls at various heights to facilitate thermocouples. Temperature readings for all the exercises were recorded and used to compare the effect of ppv in different locations of the houses. Wooden pallets, straw, diesel and paraffin produced the heat and smoke for the experiments with maximum temperatures reaching around 800°C.

The experiments from Tyne and Wear are summarised as follows [(6)]:

- Experiments carried out indicated ppv would overcome wind strengths of 8-10m/s, the experiments carried out by the experimental unit at Moreton showed ppv to be ineffective against a 2m/s wind.
- Ppv did not seriously intensify or spread a fire however some localised flaming did occur.
- Ppv improves visibility in a short time scale.
- Ppv reduces temperatures dramatically in a short period of after application.
- Effective use of ppv improves the working environment and reduces the risk of flashover.

The Tyne and Wear report recommends the defensive use of ppv and appears positive regarding the use of ppv offensively.

On 1st May 1998 Greater Manchester Fire Service carried out a series of tests using disused terraced properties. The objectives for the tests were to document and develop the behaviour of fire using offensive positive pressure ventilation, the results to be used for the formulation of Brigade training policy. The tests were carried out with assistance from the University of Central Lancashire, who produced the report(7) from which this information is drawn.

Three main tests were carried out; a bedroom fire, with a vent made prior to application of the fan, a bedroom fire without a vent, a lounge fire with vent made after application of the fan.

Equipment from the University Of Central Lancashire was used to measure temperatures, gas compositions and fire growth in a similar manner to the Tyne and Wear experiments. Video cameras erected outside the buildings observed the smoke movement from the exhaust points whilst a thermal imaging camera was used to show heat transfer and fire spread internally.

With these tests the fire was not confined to a crib and sufficient materials were present to support flashover. The fire load consisted of upholstered furniture and chipboard that were arranged to simulate the furniture and fittings of a typical room.

During all the tests, the application of PPV produced higher temperatures within the fire compartment after an initial decrease. It should be mentioned, however, that two of the tests were deliberately arranged so that ppv was used incorrectly.

In the first test, the compartment (internal) door was open until it was considered the fire had almost reached the fully developed stage, and then the door was closed. The graph indicated that the fire had become strongly ventilation controlled by these actions, dropping from a temperature of 700^0c to just over 200. The room was then vented, by breaking the window and opening the internal door, prior to applying the ppv fan.

The same criticism can be applied to each of the tests carried out i.e. it cannot be concluded that ppv accelerated the fire any more than natural ventilation alone would achieve.

During all the tests a visible ‘flashback’ was reported on application of ppv. The timing of this event for each test is unclear and no evidence is apparent on the graphs. No reference had been made to this effect before and consequently it is an interesting area for consideration.

There are a number of possible reasons for this effect:

- The fire may be undergoing transition from growth to fully developed, this transition is rapid; the fire wants a large volume of oxygen which results in lengthened flames. The fire nearly always becomes ventilation controlled at this stage.
- The fire compartment pressure due to buoyancy is in excess of that in the doorway.
- There is too restrictive a vent to outside; the fire had nowhere else to go.
- The fire was affected by wind from outside.

The data from Tyne and Wear does highlight a small localised increase in temperatures after ppv application, but does not mention the possibility of a ‘flashback’ on initial application, the report does acknowledge the potential danger of offensive use.

In July 1998, Tyne and Wear Fire Brigade carried out a further set of trials at the Fire Service College. The trials were conducted in conjunction with the Fire Experimental Unit of the Home Office. The brief for these tests was to establish the effects of ppv on a casualty situated between the fire and the vent, and the effect of ppv on fire spread, two issues perceived at the time to be holding ppv use back.

The report[8] of the trials, produced by the Fire Research and Development Group, concludes; ‘ppv produced no measurable difference in fire spread from that observed under natural ventilation alone. However ventilation, whether natural or forced, did appear to increase fire spread.’

This was an interesting conclusion which again conflicts with the findings from GMC.

Note: the performance of positive pressure ventilation fans has improved rapidly since their inception. Many of the early trials used fans that were of low output and consequently some results may be misleading.

1. **Preston Fire Trials**

2.1 The Properties

The properties used for the trials were a connected block of single-storey, two and three bedroom flats, built circa 1970. The block was scheduled for demolition the week following the trials. The properties had been donated for use by Collingwood Housing Association.

The construction of the properties was mainly of concrete, which proved ideal for repeatable experiments.

Plan drawings of the properties are included in Appendix A

2.2 Equipment and Technical Apparatus

Appliances and general firefighting equipment was provided by Lancashire Fire and Rescue Service.

Positive pressure ventilation fans were supplied by FSE Ltd. The company supplied a range of fans for use but for consistency the same fan, (18” Tempest) was used throughout the trials.

Technical measuring apparatus was supplied and controlled by the University of Central Lancashire.

Each experiment house was instrumented using thermocouples (temperature measurement), and a gas analysis probe. Thermal imaging equipment was also utilised inside and outside the properties. A digital camera was used to create a photographic record of events.

Wind velocity for each experiment was measured with a Vane Anemometer. The wind conditions were gusting light throughout the week, consequently the wind was considered to have had a negligible effect and are ignored in the analysis below.

3 Experiments

3.1 Overview

The experiments were to take place over three days, Tuesday, Wednesday and Thursday. Each experiment was repeated using both defensive tactics and offensive tactics. It had been decided that time was available to carry out three experiments per day. Consequently, the third experiment each day was set aside to enable a repeat experiment to be carried out in light of what had happened on the first two experiments.

Due to a very high level of interest shown by the media, it was decided that the final day, Friday, should be considered as a press day to allow demonstrations and interviews to take place. The reason for this was to ensure that the experiments could take place Tuesday, Wednesday and Thursday without interruption. Some experimenting however did take place on the Friday and is included in this project.

The experiments are described in the order that they took place. Included in the description are the graphs drawn from thermocouple and gas data, and the visual observations of the fire-fighters involved.

3.2 Events of 10th January 2000

The Monday of the experiment week was given over to preparation. The venue was visited for the purpose of carrying out a final assessment of the site. The following tasks were carried out:

- A final health and safety risk assessment check
- An initial inspection by the technical support team
- Collection of furniture from storage
- Preparation of the first experiment house for technical apparatus
- Collection of fire-fighting equipment

3.3 Events of 11th January 2000

3.3.1 Experiment 1A

Scenario – defensive positive pressure ventilation

Fire crews arrive to find a well-developed front room (lounge) fire. The objective of the fire crews is to enter the premises through the rear door wearing breathing apparatus, and extinguish the fire using standard operating procedure.

Objective:

To develop a well-established single room fire and to measure the temperatures in and around the fire compartment. To measure the temperatures and gas levels in a bedroom adjacent to the fire compartment. To establish the effects of defensive positive pressure ventilation fire-fighting tactics on such a fire.

A fire was started in a sofa in the lounge. The fire loading in the lounge was similar to that which would be expected in a real situation. Once the fire was lit, the fire was allowed to develop until such time as was considered necessary before fire crews were instructed to enter and tackle the blaze. Within the house, only the door to the lounge and the door to the bedroom were open. All external doors and windows were closed.

Parameters

T_0	Entry	Attack	Vented	Fan on	Vent(m^2) Inlet	Outlet
15^0c	210sec	240sec	380sec	400sec	1.6	0.62

Results/Analysis

Refer to graphs 1A1 – 1A5

Fire compartment temperatures peaked at around 1000^0c and then decayed rapidly, probably due to the fire becoming ventilation controlled. The fire intensified slightly when the rear door was opened. On application of water the temperatures within the fire compartment reduced only minimally, hovering around 500^0c. Temperatures within the bedroom reached more than 500^0c. Compartment temperatures only dropped rapidly when the fan was applied.

The thermocouple tree indicates that the neutral plane, (base of smoke layer), was somewhere in the region of 900-1200mm from floor level at the most intense period of burning.

The gas analysis shows that the atmosphere would not have sustained life until ventilation commenced. CO levels (measured in the bedroom at bed height), reached 28000 parts per million – the highest levels reached during these experiments. Once the fan was applied the CO levels dropped rapidly and the O_2 levels increased from 10% to 20% within 30 seconds.

Visual Observation

Flames were apparent in the early stages, but appeared to be subdued by the smoke levels. On venting, there was a large quantity of grey smoke. The rate of exhaustion of this smoke increased markedly on application of the fan.

Observation of the post-fire scene showed that there was much combustible material remaining in the fire compartment.

3.3.2 Experiment 1B

Scenario – offensive positive pressure ventilation

Fire crews arrive to find a well-developed front room (lounge) fire. The objective of the fire crews was to enter the premises through the rear door wearing breathing apparatus, and extinguish the fire using offensive positive pressure ventilation tactics.

Objective:

To develop a well-established single room fire and to measure the temperatures in and around the fire compartment. To measure the temperatures and gas levels in a bedroom adjacent to the fire compartment. To establish the effects of offensive positive pressure ventilation fire-fighting tactics on such a fire, and compare the results to those of the previous experiment.

A fire was started in a sofa in the lounge. The fire loading in the lounge was similar to that which would be expected in a real situation. Once the fire was lit, the fire was allowed to develop until such time as was considered necessary before the fire compartment was vented and the fan was applied via the rear door. Fire crews were then instructed to enter and tackle the blaze. Within the house, only the door to the lounge and the door to the bedroom were open. All external doors and windows were closed.

Parameters

T_0	Vented	Fan on	Entry	Attack	Vent(m^2) Inlet	Outlet
16^0c	230sec	240sec	260sec	290sec	1.6	0.47

Results/Analysis

Refer to graphs 1B1 – 1B5

Again the fire appears to have developed rapidly although temperatures were lower, peaking at around 750^0c, than in Experiment 1A. The fire was in decay when fire-fighting operations began. No fire growth occurred on venting or applying the fan. The fire has appeared to die down on its own accord, possibly due to the lack of ventilation causing a smothering effect, the fire was probably smouldering and the smoke mixture in the compartment was possibly very fuel-rich, although when the fan was operated there wasn't sufficient energy in the fire to create ignition. It is possible that backdraught conditions were achieved here and if the fan had been applied moments earlier then perhaps a backdraught would have occurred.

Some cooling was apparent on application of the fan, particularly at the probes on the entrance to the bedroom and on the thermocouple tree on the internal fire compartment doorframe. The neutral plane appears to have not reached a level quite as low as test 1A, reaching somewhere between 1200 – 1500mm from the floor.

The gas analysis shows a similar profile to the previous experiment, with a dramatic improvement of conditions on application of the fan. CO levels peaked at approximately 15000 parts per million. The improvement in O_2 levels was slower than in the first experiment.

Visual Observations

The fire fighting crew reported smoke coming back down the hallway, towards the fan. This may be the cause of the slower improvement in gas levels. It was thought that this might be due to the exhaust vent being to small, creating an overpressure in the compartment. The vent ratio was 3.4:1 in favour of the inlet.

3.3.3 Experiment 1C

Scenario – offensive positive pressure ventilation

The previous experiment, 1B, was repeated this time using a larger vent size. The reason for this was to see if the vent restriction was the cause of the smoke returning down the corridor.

Parameters

T_0	Vented	Fan on	Entry	Attack	Vent(m^2) Inlet	Outlet
16^0c	230sec	240sec	260sec	295sec	1.6	1.0

Results/Analysis

Refer to graphs 1C1 – 1C5

A similar fire profile was achieved although this time the fire intensified on venting and application of the fan. The intensification in terms of temperature was only in the region of 75^0c. The rate of growth due to this was, although observed for only a short period, no greater, perhaps even less, than the original growth rate prior to venting

The neutral plane came somewhere between 600 – 900mm, lower than in the previous test. On application of the fan, the neutral plane appears to have risen, perhaps as high as 1500mm.

The gas analysis showed a quicker improvement in conditions. The vent ratio for this test was 1.6:1,

Visual Observation

No report was made of smoke or flame in the corridor. The conditions on the approach to the fire compartment were cooler and very much clearer than in the previous experiment. The fire fighters were very impressed with the operation.

3.4 Events of 12th January

3.4.1 Experiment 2A

Scenario – defensive positive pressure ventilation

Fire crews arrive to find a well-developed bedroom fire. The objective of the fire crews is to enter the premises through the rear door wearing breathing apparatus, and extinguish the fire using standard operating procedure.

Objective:

To develop a well-established single room fire and to measure the temperatures in and around the fire compartment. To measure the temperatures and gas levels in the hallway adjacent to the fire compartment. To establish the effects of defensive positive pressure ventilation fire-fighting tactics on such a fire.

A fire was started in bedding materials in the bedroom. The fire loading in the bedroom was similar to that which would be expected in a real situation. Once the fire was lit, the fire was allowed to develop until such time as was considered necessary before firecrews were instructed to enter and tackle the blaze. Within the house, only the door to the lounge and the door to the bedroom were open. All external doors and windows were closed. Temperature probes were fitted to the vent.

Parameters

T_0	Entry	Attack	Vented	Fan on	Vent(m^2)	
					Inlet	Outlet
17^0c	1125sec	1155sec	1180sec	1195sec	1.6	0.67

Results/Analysis

Refer to graphs 2A1 – 2A5

Comparatively low temperatures were achieved with this fire (360^0c). Due to the nature of the combustible materials the fire growth rate was much slower than that achieved on the previous day.

The neutral plane was clearly exhibited on the graphs, being between 900 – 1200mm from the floor. The high temperatures recorded at the vent are thought to be due to localised burning observed at the window frame by the fire fighters.

Low gas levels were also exhibited. The combustible materials were predominantly bedding and the mattress of the bed.

Visual Observations

This experiment was visually observed from the hallway by the author using Breathing Apparatus. The application of the fan, even when the fire was extinguished, had a dramatic effect on conditions. There was an instant cooling effect, a fire compartment immediately after a fire attack is very hot and humid. There was also a dramatic improvement in visibility; ppv created a far more comfortable environment for the fire fighters.

3.4.2 Experiment 2B

Scenario – offensive positive pressure ventilation

Fire crews arrive to find a well-developed bedroom fire. The objective of the fire crews was to enter the premises through the rear door wearing breathing apparatus, and extinguish the fire using offensive positive pressure ventilation tactics.

Objective:

To develop a well-established single room fire and to measure the temperatures in and around the fire compartment. To measure the temperatures and gas levels in the hallway adjacent to the fire compartment. To establish the effects of offensive positive pressure ventilation fire-fighting tactics on such a fire, and compare the results to those of the previous experiment.

A fire was started in bedding materials in the bedroom. The fire loading in the bedroom was similar to that which would be expected in a real situation. Once the fire was lit, the fire was allowed to develop until such time as was considered necessary before the fire compartment was vented and the fan was applied via the rear door. Fire crews were then instructed to enter and tackle the blaze. Within the house, only the door to the lounge and the door to the bedroom were open. All external doors and windows were closed.

Parameters

T_0	Vented	Fan on	Entry	Attack	Vent(m^2) Inlet	Outlet
17^0c	1715sec	1725sec	1745sec	1775sec	1.6	0.67

Results/Analysis

Refer to graphs 2B1 – 2B4

The fan appears to have been applied as the fire growth rate was accelerating and does not appear to have increased this rate noticeably. There was a rapid decrease in the hallway temperatures on application of the fan, although this cooling rate was arrested momentarily. Maximum compartment temperatures reached 800^0c.

The thermocouple tree shows a similar result to that of earlier experiments, in that the neutral plane rose. In this case the rise was very clear, from between 900 – 1200mm to between 1200 – 1500mm on application of the fan.

Surprisingly low gas levels were recorded again in this fire, but the decrease in gas levels followed the same profile as the hallway temperatures. Vent temperatures dropped at some probes and increased at others, with no clear pattern.

Visual Observation

This experiment was visually observed from the hallway by the author. Conditions in the hallway prior to positive pressure ventilation were hot and very smoke-logged. On application of the fan the corridor became cooler and clear very quickly. This made the approach to the fire compartment comparatively straightforward.

At some point between the fan being used and the fire being attacked, flames were observed coming out of the fire compartment and across the hall at head height. Indications of fire spread outside the fire compartment were identified due to this and the graphs also record data that could be attributed to such an event.

3.4.3 Experiment 2C

Scenario – offensive positive pressure ventilation

The previous experiment, 2B, was repeated this time using a larger vent size.

Parameters

T_0	Vented	Fan on	Entry	Attack	Vent(m^2) Inlet	Outlet
17^0c	575sec	585sec	730sec	800sec	1.6	0.89

Results/Analysis

Refer to graphs 2C1 – 2C4

The fire demonstrated a similar development curve as experiment 2B. The fire appears to have reach steady state, possibly following the onset of flashover. There was no significant growth rate increase on application of the fan, which would be expected if the fire were at this stage fully developed. Maximum temperatures reached 800^0 c, consistent with flashover.

The thermocouple tree showed a steady neutral plane, even after application of the fan, again, to be expected with a fully developed fire. Hallway temperatures dropped significantly (150^0c) but then appeared to begin to increase.

Gas analysis was inconsistent, and difficult to quantify, but it appears that the fan reduced gas levels initially, but then the gas levels began to increase again.

Visual Observation

Observers inside the building stated that the ‘flashback’ effect of the previous experiment had not been in evidence and that conditions in the hallway had improved considerably on application of the fan. Observers from outside at the vent witnessed a large amount of flame and smoke issue shortly after the fan was applied.

3.5 Events of 13th January

Experiment 3A

Scenario – offensive positive pressure ventilation

Fire crews arrive to find a fire in the middle bedroom. They use offensive positive pressure ventilation tactics but ventilate the wrong compartment.

Objective:

To develop a well-established single room fire and to measure the temperatures in and around the fire compartment. To measure the temperatures and gas levels in the hallway between the fire compartment and the compartment where the vent is situated. To establish the effects of offensive positive pressure ventilation fire-fighting tactics on such a fire to that has been incorrectly vented.

Parameters

T_0	Vented	Fan on	Entry	Attack	Vent(m^2) Inlet	Outlet
16^0c	195sec	210sec	430sec	455sec	1.6	0.67

Results/Analysis

Refer to graphs 3A1 – 3A4

The application of the fan appears to have slightly reduced the growth rate of the fire, although the fire has continued to grow after the fan was applied.

In the hallway, the temperature has risen on application of the fan, as expected. A similar effect was exhibited at the vent, although the effects are perhaps more exaggerated.

The thermocouple tree shows an initial drop in neutral plane level, prior to the neutral plane quickly re-establishing its original level.

The gas levels were adversely affected by the fan, increasing dramatically on application.

Visual Observation

A char stick (narrow stick of timber), was placed in the hallway for this test, at ceiling height, to help gauge any potential fire spread. Following the fire, the stick was found to be severely charred, indicating direct flame impingement from the fire or self-ignition due to temperatures it was exposed to.

The increase in smoke issuing from the vent was clearly evident when the fan was applied.

3.5.2 Experiment 3B

Scenario – offensive positive pressure ventilation

Fire crews arrive to find a fire in the middle bedroom. They use offensive positive pressure ventilation tactics this time ventilate the correct compartment. This scenario was used in an attempt to use positive pressure ventilation offensively to its best effect, using the lessons learned during the week. The scenario was similar enough to the previous experiment to allow reasonable comparisons to be drawn.

Objectives:

To develop a well-established single room fire and to measure the temperatures in and around the fire compartment. To measure the temperatures and gas levels in the hallway adjacent to the fire compartment. To establish the effects of offensive positive pressure ventilation fire-fighting tactics on such a fire.

Parameters

T_0	Vented	Fan on	Entry	Attack	Vent(m^2) Inlet	Outlet
16^0c	500sec	515sec	560sec	590sec	1.6	0.5

Results/Analysis

Refer to graphs 3B1 – 3B4

The fire appears to have peaked at around 550^0c, and then reduced slightly, steadying at around 400^0c. This is possibly due to the fire becoming ventilation controlled. The fan, although generating an increase in temperatures did not appear to increase the growth rate in the fire compartment to any greater rate than it had exhibited prior to peaking.

Hallway temperatures increased initially with the fan but then dropped rapidly prior to fire attack.

Gas levels dropped dramatically on fan use. Again, some of the vent probes showed a drop in temperature whilst others increased.

Visual Observation

Exterior observation showed a dramatic increase in the volume of smoke and flames when the fan was applied. Again, fire-fighters observed vastly improved conditions inside the house.

3.5.3 Experiment 3C

A experiment was carried out to assess the effectiveness of various fans (18” and 21” Tempest) in the smoke clearance of a staircase enclosure.

The staircase was smoke logged by burning sofa cushions. It was then vented at the head and the time each fan took to clear the staircase of smoke was taken. The experiment was measured visually only and consequently is of limited value, however it was agreed by all observers that the 21” fan was obviously the most effective for this purpose.

An interesting point to note was that the smoke was cleared very quickly with both fans, demonstrating the usefulness of ppv in the post-fire situation.

3.6 Events of 14th January

As previously stated, the day was set aside for the press, and several demonstrations were carried out, utilising offensive ppv tactics. It is worthy of note that each of these demonstrations were carried out successfully.

In the afternoon, time became available to run some tests of the effect of ppv on chip-pan fires. Instrumentation was unavailable for these tests, however events were recorded from inside the houses on thermal video.

The basis of these tests was to demonstrate the effectiveness of ppv by using a fan to ‘hold-back’ the effects of a chip-pan fire when water is applied. This was arranged using a cup attached to a stick passed through a hole drilled in the kitchen wall.

The fan was started, and allowed to pressurise the house. The chip-pan was alight at this stage. At a given signal the water was poured in resulting in the well-documented result.

When the fan was used, the flash flames from the kitchen were prevented from entering the house further and the majority were exhausted through the open kitchen window.

This was an unscientific, but nevertheless impressive demonstration for all who observed. The results can be viewed clearly on the thermal images, which are in the process of being transferred to standard videotape, along with the video footage of all the experiments of the week.

4. Experiment Analysis

4.1 Introduction

The analysis is presented separately for each day of the tests. Conclusions drawn from the analysis are included in section 5.

Throughout this analysis, consideration of effects of wind are not considered due to the fact that the experiments were conducted in light, gusting winds all week and it is believed that consequently the wind had little, if any, detrimental effect on the results.

4.2 Analysis/Synthesis of 11th January Experiments

The absence of fire growth on application of positive pressure ventilation on the second experiment appears, when looking at the experiments as a whole, to be a rare event. It is considered that this fire was strongly ventilation controlled, but had subdued to such an extent that further ventilation had little effect. This was not the case in the first fire, which appears to have self-extinguished -- the reasoning behind this assumption is that the application of water had no cooling effect. There was also plenty of combustible material remaining in the post-fire compartment, as the plate below testifies.

Plate 2 Experiment 1A – Post-fire compartment

With the second fire, the vent was the smallest, and in the highest position. An alternative explanation to the fact that no growth was exhibited is that the vent was too small, and too remote from the burning combustibles to have had a direct affect on the fire. The third test of the first day produced a very similar curve to the second, but with a larger vent. This fire had intensified on venting and application of the fan. Thus, if this is the case, the fan had no detrimental effect and the growth has to be attributed to the vent alone. This correlates with the analysis of the Manchester results and the discussion in the literature review.

Fire crews reported cooler and clearer conditions in the approach to the fire compartment in the second experiment than in the first experiment. The smoke that was observed moving back towards the entry point was probably due to the exhaust vent being restrictive. This, combined with the fact that the fire was still burning probably was the cause of the slower increase in O_2 levels.

Plate 3 Showing Vent for Experiment 1B

This effect was not noted in the third experiment, where the vent was larger. Thus, the restrictive vent, although creating no fire growth, rendered the use of offensive ppv less effective. It is also possible that the adverse smoke flow patterns generated by the smaller vent and fan could lead to fire spread remote from the fire compartment. The plate below shows the difference in effect created by the larger vent size for experiment 1C.

Plate 4 Showing Effect of Larger Vent Size (Experiment 1C)

It is interesting to note that similar fire profiles were achieved on all three experiments even though the fire load materials were different. Although the temperatures and smoke production rates were slightly different, the experiments appear to have produced meaningful results.

4.3 Analysis of 12th January Experiments

The second day's experiments were focused on the bedroom scenario. All three fires were very much slower in developing, but all three accelerated rapidly at a given point, interestingly when the compartment temperature had reached 250 – 300^{0}c.

The second experiment, 2B, was in rapid growth when the fan was applied. The fire was possibly approaching flashover at this point. This fire produced the 'phenomenon' of flashback, with flames projecting back into the hallway from the fire compartment. This phenomenon, which was reported in the Manchester tests, was discussed in the literature review. It was postulated that the fire had become momentarily ventilation controlled, due to the restricted size of the vent, and flames were seeking oxygen as the fire was becoming fully-developed.

It may be that the flames were allowed to exit the fire compartment, against the pressure generated by the fan, due to some inconsistency in the pressure planes at the doorway to the compartment.

The thermocouple tree graph shows a dramatic drop in the temperature of the thermocouple at 1200mm, which is below the height that the flames were seen issuing. This ties in with the theory above, and that the fires rapid growth suddenly required a much greater rate of oxygen uptake

It is therefore suggested that the flashback phenomenon that has been associated with ppv use marks the transition of a growing fire to a fully-developed, ventilation limited fire. As a flashback was not reported for any of the other experiments, consequently its occurrence in this case might well be due to the undersized vent.

It is possible that in the absence of ppv this would lead to rapid fire spread.

Again, application of the fan did not increase the burning rate significantly. Temperatures remote from the fire compartment were improved with positive pressure ventilation, although indications that incorrect use could worsen the situation were noted.

Experiments 2B and 2C appear to suggest that the vent size is the important consideration, as the fire, in under ventilated conditions will be forced to seek oxygen from the inlet, creating a situation where the fire moves towards the fire-fighters. This also indicates that a casualty, situated between the fire and the vent, may be adversely affected by offensive positive pressure ventilation use.

4.4 Analysis/Synthesis of 13th January Experiments

The first fire was a deliberately created scenario where the wrong compartment was ventilated. The effect of the fan on the fire compartment was to create an initial decrease in temperatures, followed by growth. The fire appears to have grown, but at a slower rate than prior to application of the fan. Temperatures and gas levels both increased quite dramatically in areas remote from the fire compartment.

The neutral plane appears to have risen distinctly when the fan was applied, from between 600 – 900mm to between 1200 – 1500mm. This was a momentary effect however; the plane appeared to re-establish its original level. The plane then seems to behave erratically, perhaps suggesting turbulence in the fire compartment.

The behaviour of this fire on the application of ppv, from a practical point of view, had been expected. Pressurising a fire compartment to a greater pressure than that of the area of the vent is obviously likely to encourage the products of combustion to migrate towards the area of lower pressure. The effects may have been worse, had the fire compartment not self-ventilated shortly after the fan was applied. This however, raised an interesting point; that the glazing to a fire compartment will be in a weakened state and pressurisation from a fan could generate self-ventilation, which would generally be beneficial.

Plate5 Experiment 3A, shortly after self-ventilation of the fire compartment. Note: the actual vent is the window to the right of the fire compartment.

The use of the fan when the wrong compartment is vented seems to have a potentially dangerous effect. Both temperatures and gas levels were increased remote from the fire compartment. There were indications that fire would have spread beyond the confines of the fire compartment had the fire not been extinguished at that stage. The graphs indicate that the actions of the fire fighters using the ppv fan probably changed the atmosphere within the building from one of marginal tenability to one where survival was unlikely.

The second experiment, 3B, was a straightforward attempt to utilise ppv to its best effect, with knowledge of the location of the fire. Temperatures had become steady at around 500^0c prior to application of the fan and venting, suggesting ventilation control. Again, on application of the fan temperatures indicate the fire began to grow, and again the growth rate was no greater, possibly lesser than, the original rate.

Plate6 Experiment 3B, Immediately after Venting.

Visual observation indicated that the fire became fully developed, the position of the neutral plane was unclear; the thermocouple tree was positioned at the door but this was only a small room, the thermocouples possibly being affected by direct radiant feedback.

Plate7 Experiment 3B, on application of the fan.

Hallway temperatures dropped rapidly on application of the fan, as did the gas levels in the corridor.

In essence, this fire behaved as had now become expected in that the fire intensified, and the conditions remote from the fire compartment were generally improved.

4.5 Post-fire use

Experiment 3C, and each of the experiments were post-fire ppv was employed, indicates that the post-fire use of positive pressure ventilation is a very effective method of cooling and clearing a property of smoke. Although no comparison was made between the use of a fan and natural ventilation, it is clear, from visual observation and discussion with fire fighters, that the use of a fan is very advantageous for smoke clearance in the absence of very favourable wind conditions.

4.6 Questionnaire

A questionnaire was circulated to all volunteers that participated in the trials.

Of the volunteers who attended the trials and returned the questionnaire, there was a strong consensus of opinion. All respondents were fully confident of the effectiveness of ppv. Some of the volunteers had been sceptical of its use, particularly offensively, and had attended in order to formulate their own opinion. All stated that they would be confident to use ppv offensively in circumstances similar to those of the tests, and consequently that further tests are needed on multi-storey premises.

The same general points were reiterated throughout. Backdraught, firespread and communications were felt to be the key areas. These issues are addressed below.

5.0 Conclusions and Recommendations

The conclusions below can only directly apply to situations similar to the ones covered by these experiments (single-storey domestic premises), although in some instances, assumptions may be drawn regarding the application of ppv to other circumstances.

5.1 Firespread -- Internal

Generally speaking, the fire growth rate was not greatly increased by ppv. In fact it is postulated that the use of a fan creates no greater rate than the use of natural ventilation. There is likely to be, in certain circumstances, an increase in the burning rate but this is due to the airflow causing horizontal fire spread across individual burning items. Any domestic fire where offensive ppv is used would be attacked shortly after the fans application so the rise in temperature etc., in the fire compartment would be short-lived.

Providing the vent size is gauged correctly, and the fire compartment is not breached, the risk of enhanced fire spread appears to be minimal.

However, Experiment 2B gave an indication that if the compartment is breached, there is an opportunity for the fire to break out of the compartment, if the breach leads to an area of lower pressure.

Should the fire compartment be breached, then it is likely that ppv would create a potentially dangerous situation, generating spread to other parts of the building.

It would be possible in future experiments to artificially breach the compartment and consequently examine this possibility. This is therefore recommended as an important area for further research.

5.2 Firespread – External

The application of the fan appeared to observers to generate larger flames than would ordinarily be expected from the exhaust vent. No conclusive evidence is available of this as in many tests flashover conditions were taking place and there is no means of ascertaining the difference caused by the fan, if any.

It is standard practice that where a vent is created it is protected. It is perhaps more critical that this practice is not forgotten where ppv is used.

Thus the protection of vents should be part of the operating procedure for the use of ppv offensively.

5.3 Fire Development

Generally speaking, the fire growth rate was not increased by ppv during these experiments. In fact it is postulated that the use of a fan creates no greater rise in fire growth rate than the use of natural ventilation, other than some local growth due to airflow.

Once a fire becomes fuel-controlled, an increase in vent size becomes unimportant. The fire in effect has sufficient oxygen. This was evident in the experiments above as where the fire did intensify on application of the fan and venting, the growth rate was no greater than that at which the fire had been growing prior to becoming ventilation controlled.

This is a very important issue, as it appears to be the stumbling block for ppv in this country. The hesitance to adopt ppv for offensive use comes mainly from the fear of intensifying an already dangerous situation. If it can be shown consistently, in more controlled conditions, that ppv does not intensify the fire any more than standard ventilation of the compartment, it is more likely to be readily accepted.

In most cases, ventilation caused the fire to resume growth. However, any domestic fire where offensive ppv is used would be attacked shortly after the fans application so the rise in temperature etc., in the fire compartment would be short-lived.

5.4 Vent size

This is an important area for consideration as it proved to be the largest influencing factor on the behaviour of the fire and its products. The widely held belief that the optimum vent size should be 2:1, inlet to outlet, appears to have been borne out by these experiments.

The ‘flashback’ reported by GMC Fire Service was witnessed during Experiment 2B. It appears to have been caused primarily by the exhaust vent being too small in relation to inlet. Where circumstances are such that the above ratio of 2:1 cannot be achieved, it has been suggested that the flashback could be prevented by reducing the speed of the fan and thereby the airflow.

This is an interesting event and it is unclear whether the flashback was caused by the fire searching for oxygen or by an area of low pressure in the region above the compartment door.

It is therefore recommended that the above issue be researched in future experiments.

5.5 Vent choice

This issue has already been mentioned but is worthy of separate discussion. In the scenario of experiment 3B, it was clear that the wrong vent choice caused severe problems for the fire fighters, and potentially for casualties. It is therefore considered straightforward to state that, given a similar scenario, the affected compartment must be vented.

This, of course, is not always a simple matter as it is often not clear as to which room of a house is alight. Venting the wrong compartment could lead to the spread of combustion products to areas unaffected by the fire. It appears that a casualty, or fire fighters, may be adversely affected if the vent choice is wrong.

Thus it is recommended that vent choice be seen as a critical area for the training and command and control of fire fighters.

5.6 Fan positioning

No positioning experiments were carried out however the fan performed well throughout the week without any special consideration being given to the placement of the fan. From this it appears that positioning is not critical – probably due to the fan used being of a high capacity in relation to the size of the property.

Experiments to establish the optimum position would be relatively simple to arrange and necessitates individual experiments for each type of fan purchased.

5.7 Command and Control

This is a critical area and can only be addressed by training. The theory is relatively simple. Locate the fire compartment, vent it and apply the fan. However in the potential confusion of a fireground this is difficult to achieve. Effective communications are crucial, along with a well-trained and disciplined team.

Even at these experiments, with the noise of the scene, achieving the coordinated application of ppv and venting was difficult. Hence ppv demands a heavy requirement for training.

5.8 Defensive (post-fire) ppv

All participants were aware of the benefits of Post-fire ppv use in terms of smoke clearance.

The trials indicate that there is little danger or detriment when post-fire ppv is used (domestic), providing it is used correctly. The signs in some tests that ppv can intensify a fire perhaps raise a concern over the possibility that a fire, not properly extinguished, may regenerate. Consequently it is imperative that the fire is extinguished completely or smouldering materials are covered with a jet prior to application of the fan.

It is concluded that post-fire use of ppv is very effective for smoke clearance and provides little risk providing the fire is satisfactorily extinguished.

5.9 Fire fighter safety

There is no doubt that when ppv is carried out successfully the benefit in terms of fire fighter safety is great. Fire fighters can access the fire in clear, cool conditions, obviously removing many of the inherent dangers of entering, searching for and attacking a fire.

It is probable that the danger from flashover and backdraught are also removed from fire fighting, as it is likely that offensive ppv tactics will ensure that such phenomenon will have occurred (if they were going to occur) as a result of fan use before fire fighters enter the building.

It is recommended that further research be carried out into the effect of ppv on conditions favourable for backdraught.

5.10 Casualty survival

In circumstances were a fire is reasonably well developed, it is likely that a casualty within the fire compartment will be beyond recovery. The fire may intensify on application of ppv but fire fighters attacking the fire earlier, due to the improved conditions, may mitigate this effect.

It has been seen that ppv can improve the tenability of the parts of a building remote from the fire compartment.

The danger to a casualty not located in the fire compartment comes primarily from the products of combustion. Ppv has been seen to rapidly improve gas levels. As such, in many instances the atmosphere in the location of the casualty will become tenable almost as soon as the fan is applied, and the time taken in search and rescue is therefore less crucial.

Due to the improved conditions, a search and rescue team may be able to affect a faster rescue.

5.11 Wind Effects

During the trials the wind appears to have had no adverse affect on the use of ppv. In general the wind speeds were considered to be gusting light throughout the trials. Wind speeds were recorded gusting between 1 – 4 m/s.

5.12 General conclusion

It is clear from these experiments that ppv, when used correctly, can be extremely beneficial to fire-fighting. That said, it is not a simple task to ensure correct use, as there are many variables to consider.

Much knowledge has been gained about the effects of ppv, however, its use cannot be progressed until such time as trials using two-storey properties have been carried out.

To this end, it is strongly recommended that a further series be arranged.

Training is the next area to be addressed once further trials have taken place. Training has been identified as a critical issue for ppv but unfortunately the technique demands a large amount of training input.

Consequently, it would be extremely beneficial if the models created by Lancashire fire fighters were validated during these future experiments, as the value as a research and training tool of such models is enormous. Once reasonable validation has been achieved, there would be no requirement for further full-scale trials, which are unfortunately very heavily resource orientated.

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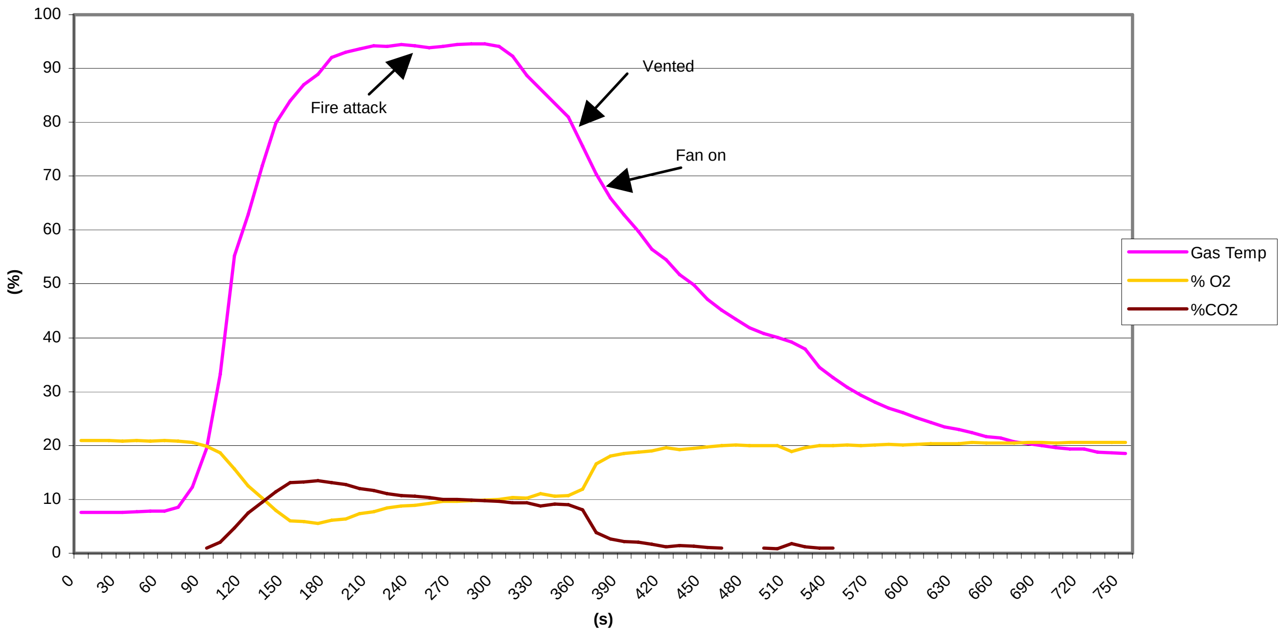
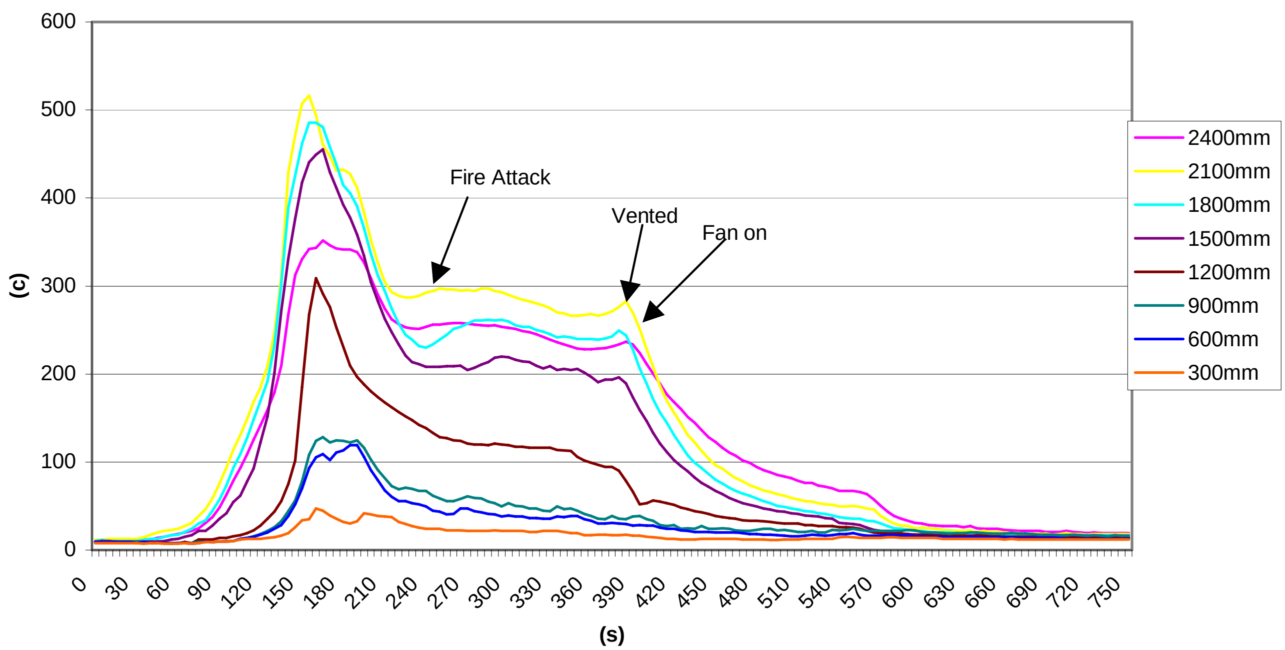
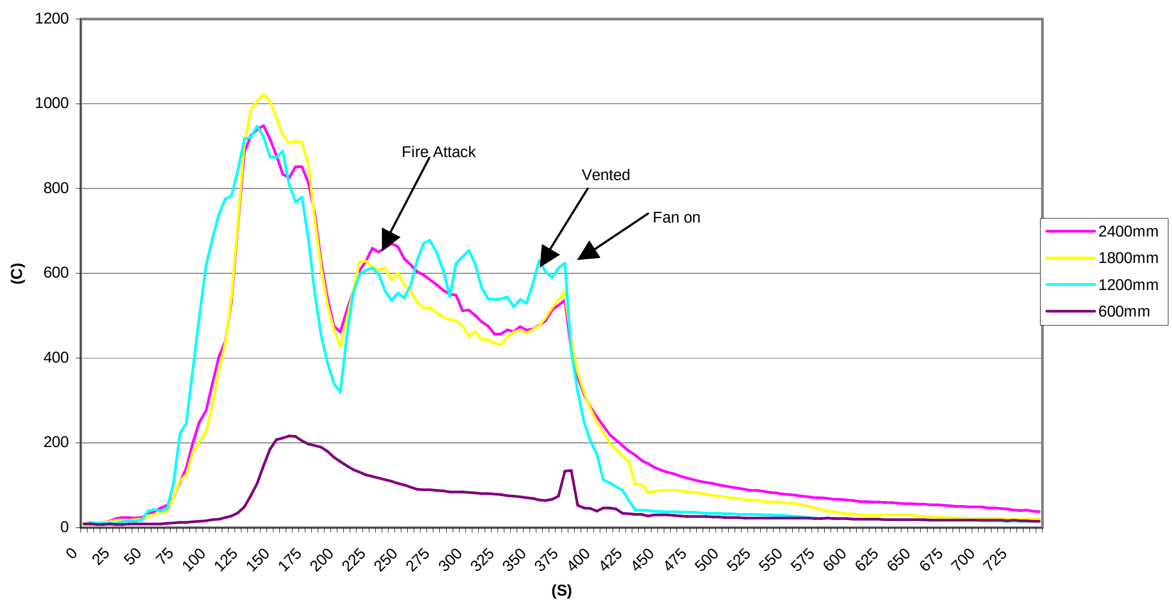


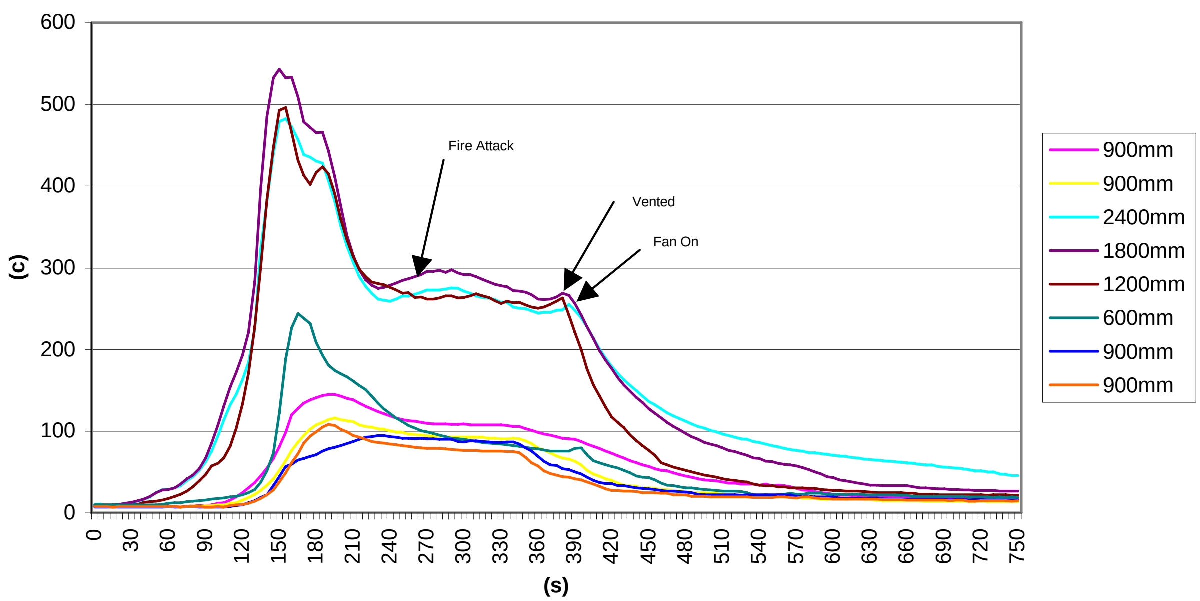
1A2. EXPERIMENT 1A-DOOR



1A1. EXPERIMENT1A-FIRE COMPARTMENT



1A3. EXPERIMENT 1A-BEDROOM



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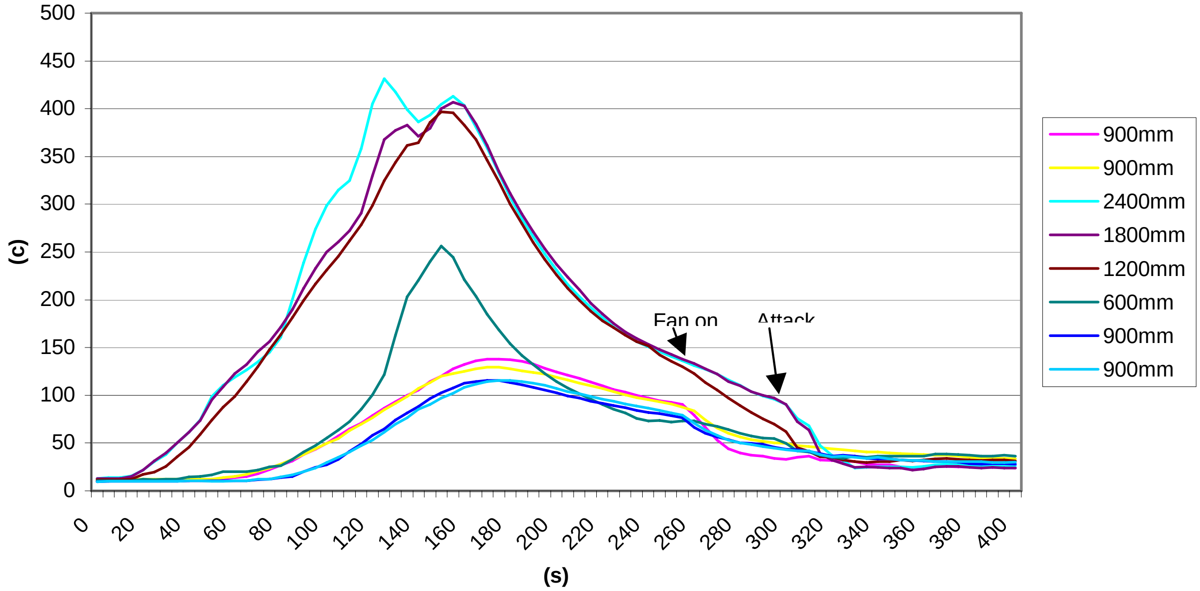

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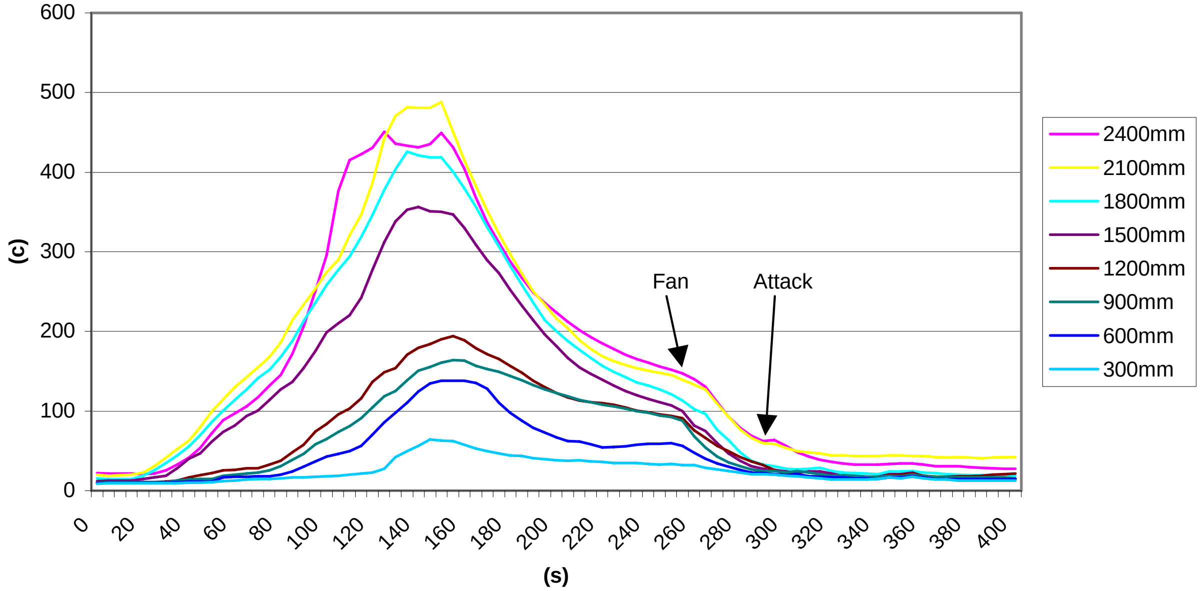

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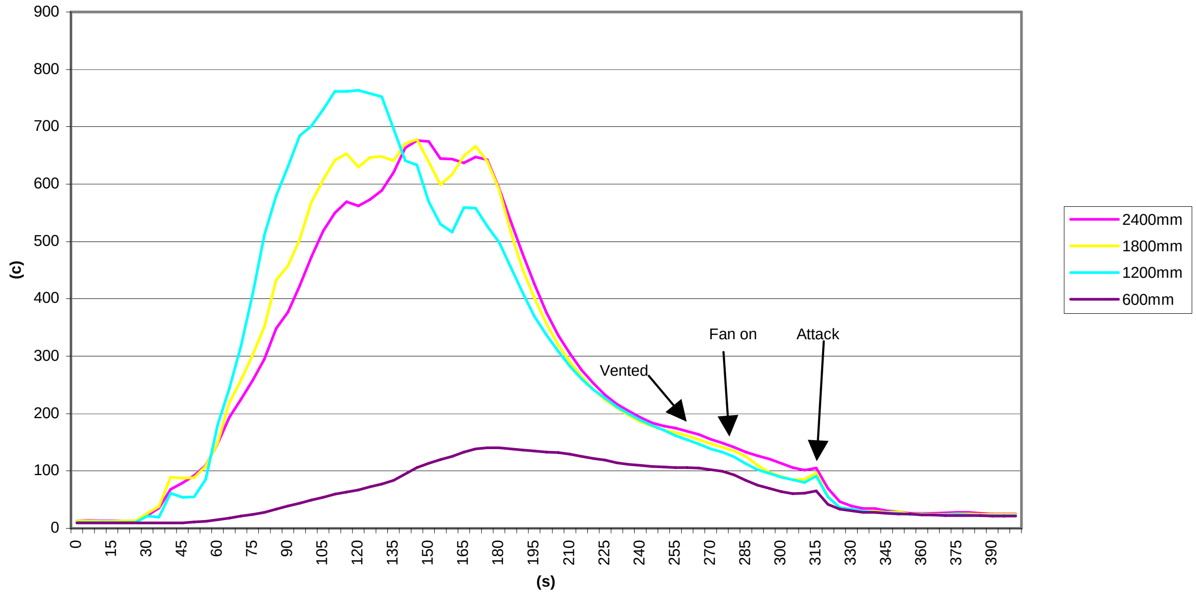

1B4. EXPERIMENT1B-GAS(%)