FRDG Publication 11/97 An Assessment of the Use of Positive Pressure Ventilation in an Unpressurised Stairwell

FIRE RESEARCH & DEVELOPMENT GROUP

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An Assesment of the Use of Positive Pressure Ventilation in an Unpressurised Stairwell

J G Rimen

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

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ABSTRACT

This report describes a series of trials to assess the effects of Positive Pressure Ventilation (PPV) in the unpressurised stairwell of a four storey industrial building. A repeatable trials fire was lit on the first floor, smoke logging the stairwell, and various venting tactics were tried in the stairwell, both with and without PPV.

It is concluded that the use of a PPV fan can improve conditions in a smoke logged stairwell, improving overall visibility to some extent while having no adverse effect upon the temperatures in the stairwell. Opening an outlet vent on the landing of the fire floor can cause a rapid improvement in visibility on that landing.

AN ASSESSMENT OF THE USE OF POSITIVE PRESSURE VENTILATION IN AN UNPRESSURISED STAIRWELL

MANAGEMENT SUMMARY

Introduction

In 1995 the Fire Experimental Unit (FEU) of the Home Office Fire Research and Development Group (FRDG) were asked to conduct a research project into the likely effects of Positive Pressure Ventilation (PPV) when used in firefighting. The first major part of this work dealt with the use of PPV in a domestic property, which was reported in FRDG Publication 17/96.

This present report deals with the second part of this work; the use of PPV in the unpressurised stairwell of a four storey industrial building.

In the event of a multi-storey building being involved in fire, the stairwell (or stairwells) assumes great importance for the firefighters. It would clearly be advantageous for the firefighters to be able to keep at least one stairwell clear of smoke or, if it has become smokelogged to be able to clear it. Any improvement in visibility that can be achieved in the stairwell will clearly assist them in any search and rescue operations, as well as in finding and dealing with the fire.

It was decided that a series of trials should be undertaken in a suitable building in which repeatable trials fires could be lit. The stairwell would be severely smokelogged and various ventilation tactics would be tried, both with and without PPV.

The Trials

The Fire Service College (FSC) kindly made their Industrial 'A' building available to FEU for fire trials, during periods when it was not being used for the College's training programme. Industrial 'A', specially constructed to withstand repeated fires, represented a fairly typical small to medium industrial building, of four storeys (five floors in total) with a flat roof. The main part of the building was 17.4m. long by 12.1m. wide in plan view, with two of its three internal stairwells projecting outwards beyond these dimensions. (Figure MS1 overleaf)

The stairwell on the north side of the building, which was used for the trials, had a number of possible vent openings - some on each floor - making it suitable for assessing tactical variations.

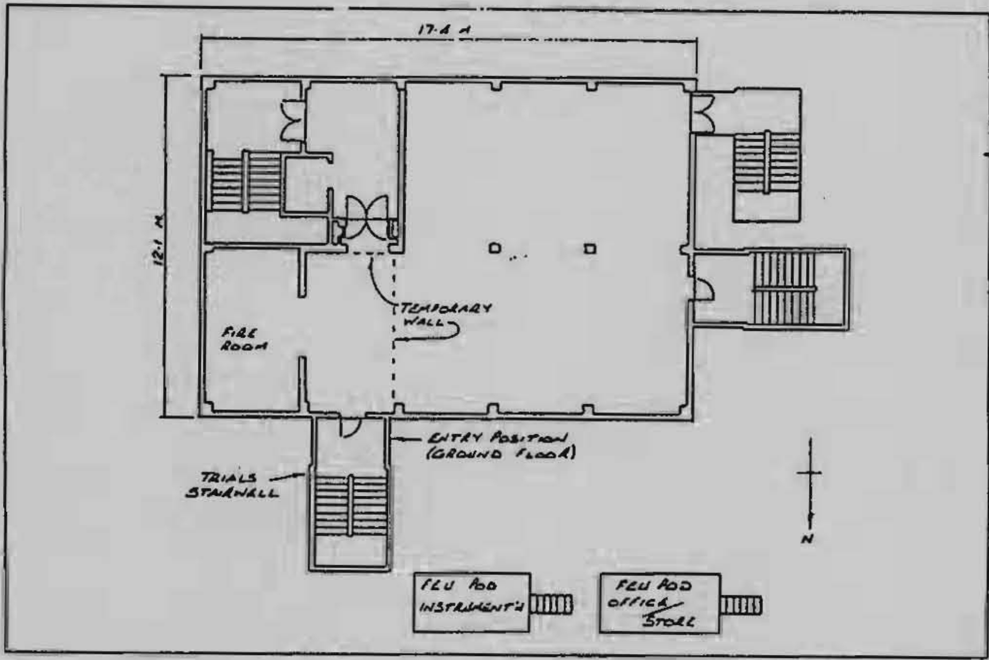

Figure MS1 The Layout of the Trials Building

The small room at the north east corner of the 1st floor of the building was selected as the fire room. The trials fire, a 1.2 metre diameter tray containing firstly 20 litres and latterly 40 litres of heptane fuel, was positioned roughly central in this room. Outside the door of this fire room and some 3 metres away, a temporary wall was constructed by FEU to separate the fire room from the rest of the compartment and provide, in effect, a corridor linking the fire room with the stairwell. The doors between the fire room and corridor and between the corridor and stairwell remained wide open at all times, all other doors and all windows remaining shut, except those selected as vents in the stairwell during particular trials.

A large amount of instrumentation was installed: smoke obscuration meters on three levels, a stairwell video camera and torches to provide a different estimate of smoke obscuration, thermocouple arrays on all floors, in the fire room and in the corridor outside, a thermal radiation flux meter in the fire compartment, a static pressure monitor in the stairwell, a wind velocity meter on the roof of the building and video cameras viewing the fire and the stairwell windows.

In this series of trials the basic aim was to assess any differences that might be made to conditions in the stairwell by the use of a PPV fan, in a given situation. The trials were arranged in pairs, as far as possible, the same tactics being employed in each trial of a pair, except that a PPV fan was employed in one, and natural ventilation only, in the other.

Trial Results

Essentially, there were three kinds of comparisons that could be made. These were:-

a. PPV vs. natural ventilation - while keeping all tactics, timing and conditions as identical as possible.

b. Varying tactics, using PPV - essentially which vent/s to open and when to deploy the fan.

c. Varying tactics, using natural ventilation only.

The general findings of the comparisons of the trials results under each of these headings were as follows:-

PPV vs. Natural Ventilation

In general, PPV improved the visibility in the stairwell to some extent. In some cases the improvement was marked, in others it was fairly slight. In none of the pairs of trials compared with each other did the use of PPV make the visibility in the stairwell worse overall.

Opening the downwind vent on the 1st floor landing (the fire floor) caused a fairly rapid reduction in the smoke obscuration and air temperatures on that landing, both with and without PPV. This effect was generally faster with PPV. In either case, there was no discernible effect on the higher, unventilated landings.

When all of the downwind vents were opened as they were reached, the use of PPV made little difference to the smoke obscuration on any floor except the fire floor (which was cleared rather faster with PPV) until after the fire went out. It then cleared the stairwell faster than natural ventilation.

The temperatures in the corridor were reduced somewhat by the use of PPV, while the fire was burning. In all six scenarios considered, the corridor temperatures were broadly similar when the fan was started and, in all cases, PPV reduced, or maintained, the temperature to below the corresponding natural ventilation temperatures.

The temperatures in the stairwell on the 1st floor and above were reduced more by PPV once the appropriate outlet vent had been opened.

Even though the fire grew once ventilation commenced, and fresh air was introduced, the temperatures in the fire room, also, appear to have been generally reduced when the PPV fan was switched on, while the fire was burning.

Varying Tactics, Using PPV

It would appear that there would be little point in firefighters climbing to the highest level possible before opening a downwind vent. It was found that opening the downwind vent on the fire floor (1st floor) caused a rapid improvement on that landing in terms of visibility, and did not make matters any worse on the higher landings in respect of obscuration or temperatures.

When a vent was opened at the highest level above the fire floor only, and the fan subsequently started, there was a short duration peak in the temperatures on each floor immediately after the fan was started. This peak was most evident on the higher floors (where the firefighters would be). On the 4th floor, at roof level and in some cases on the 3rd floor, the temperatures reached by this peak were somewhat higher than those reached in other trials in which a vent was opened at a lower level. This effect was not experienced, to the same extent, in trials where a vent, or vents, was opened on a lower floor.

Assuming that the aim is to clear the stairwell of smoke as quickly as possible, no reason was found for doing anything other than opening each downwind vent as it is reached, starting with the fire floor.

In the trials in which the downwind vents on the fire floor and 4th floor landings were opened, it was found that visibility improved rather quicker, overall, when the fan was started as soon as the fire floor vent was opened (rather than after the 4th floor vent was opened). The temperatures in the stairwell were also rather lower, overall.

Opening a vent on the fire floor at the opposite end of the corridor, as opposed to opening that in the stairwell and then opening the 4th floor landing vent, was found to improve the visibility in the stairwell faster, while the temperatures in the stairwell peaked rather higher but reduced more quickly, in general. This occurred because the effect was to stop the stairwell being the fire chimney, opening an alternative escape route for the hot smoke and gases.

Varying Tactics without PPV

It would appear, on the evidence of these trials, that there would be little point in firefighters climbing to the highest level possible before opening a downwind vent. Opening vents sequentially, i.e. entry door, 1st (fire) floor, 2nd floor etc., improved visibility in the stairwell rather sooner, but did result in higher temperatures being reached on the 1st and 2nd floors, although they were lower on the 3rd and 4th floor landings and at roof level. Overall, sequential venting would appear to be the better option.

When the outlet vent was remote from the stairwell, on the fire floor near the other end of the corridor, the smoke took slightly longer to clear from the stairwell, and the temperatures experienced in the stairwell were somewhat higher on all landings. This implies that opening both vents (fire floor and 4th floor) in the stairwell may improve the conditions in the stairwell rather faster.

General Conclusions

Guidance on ventilation, in general terms, is given in the 'Fire Service Manual - Volume 2'. This makes it clear that each fire situation, and specifically whether or not to deploy PPV, would need to be considered on its particular merits.

These trials have shown that, while a PPV fan may, usually, be able to improve conditions in a stairwell, or at least in a particular part of a stairwell, it is virtually impossible to predict exactly what the effect of the fan will be in a given situation with any degree of certainty.

For this reason, it would be advisable for a firefighter to say with the fan when deployed on the fireground so that it can be quickly switched off if it was found to be having an adverse effect. Good fireground communications would be essential where a PPV fan was deployed, particularly between the firefighters inside the fire building and fan operator. The continued use of the fan should depend upon the feedback from the firefighters inside the building.

It is clear that in a real situation where firefighters need to ventilate a building in order to search and/or fight the fire, the inlet and outlet openings should be carefully chosen. If natural ventilation, only, is to be used there is no choice about which side of the building will be the inlet - it will be the upwind side. When a PPV fan is available, the same basic rule will still apply. Any natural wind should be used to advantage if possible, and the PPV fan should be thought of as a means of assisting, or augmenting, the natural wind.

In the particular case of a non-pressurised stairwell, it may be considered advantageous to use PPV for one of several, basically different, reasons. These reasons could be:

a. To assist firefighters to reach the fire floor, locate and fight the fire.

b. To clear the whole of the stairwell of smoke.

c. To pressurise an initially clear stairwell in order to keep it clear for use as an escape route, and/or to control the direction of smoke movement (and possibly fire spread).

The results of these trials suggest that if the aim is simply to assist in getting firefighters to the fire, then opening a downwind vent on the landing of the fire floor and then deploying the PPV fan at the ground floor entry door to the stairwell can have a very rapid beneficial effect on that landing. However, this may agitate the smoke higher up the stairwell, causing swirling and assisting its spread through the upper floors.

If the aim is to clear the whole stairwell of smoke, it would seem to be necessary to open an outlet vent, or vents, as high as possible in the stairwell while deploying the fan at the ground floor. However, the trials results showed that, overall, rather faster smoke clearance (and temperature reduction) was achieved by opening a downwind vent at each landing level from the fire floor upwards, while ascending, than by opening the highest (door sized) vent only, with the PPV fan being started once the fire floor vent was open.

If aim is to ensure that smoke does not permeate into an initially clear stairwell, the stairwell could be pressurised by deploying the fan in the ground floor doorway while keeping all vents in the stairwell closed. While reducing the likelihood of smoke entering the stairwell, this could possibly have an unpredictable effect upon smoke movement, and possibly fire spread, in other parts of the building if the use of PPV is uncontrolled. It is advisable here, also, to create an outlet vent before pressurising the stairwell. A small vent on the fire floor will make it possible to keep the stairwell pressurised while clearing smoke on the fire floor. A larger vent would result in lower pressure in the stairwell with the possibility of smoke leaking into it.

While it is clear that the fire will begin to burn more fiercely when the supply of oxygen to a fire is increased by the building being opened up, there was no evidence in these trials that the use of PPV caused the fire to burn any more fiercely than it did with natural ventilation.

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1. INTRODUCTION

In February 1995 the Fire Experimental Unit (FEU) of the Home Office Fire Research and Development Group, based at Moreton in Marsh, were asked to conduct a research project into the likely effects of Positive Pressure Ventilation (PPV) when used in firefighting. Several different scenarios have been, and are to be, investigated. This report covers the third of these - a fire on the first floor of a four storey industrial building, with an adjoining stairwell.

A brief look at the use of PPV in a cellar fire was included in FRDG Report 6/95[1].* A second package of work examined the use of PPV in a simple one room fire in a domestic building (FRDG 17/96)[2]. This continuing work is seen as part of a broader package concerning the ventilation of buildings in general.

An international survey of fire ventilation has also been undertaken (FRDG publication no. 6/94)[3], and practical guidance is given in the recently published Fire Service Manual - Volume 2.[4]

*References are listed on page 53.

2. BACKGROUND

2.1 General

For many years fire brigades have used large fans to assist in clearing smoke and hot gases from buildings which have been involved in fires. Traditionally, fans have only been deployed for this purpose after the fire has been extinguished. It is a usual procedure to ventilate the building after extinguishing and any necessary damping down, in order to both make it possible to see throughout the building, and to gain a more tenable atmosphere for salvage crews, etc., to work in. This ventilation can be achieved by the strategic opening of doors and windows, to let the natural wind blow through the building. However, it has been found over the years that the use of a fan, or fans, can greatly increase the speed of this smoke clearing process.

Fans used in this way can be positioned to blow air into the building (Positive pressure ventilation) to draw air out of the building (Negative pressure ventilation). In either case the fan, or fans, are best positioned to assist any natural airflow through the building. Of these two possibilities, positive pressure ventilation is preferred because it is, in general, rather more efficient. Also, a fan in an inlet opening stays cleaner and is unaffected by the smoke and gases being extracted from the room.

In relatively recent years it has been suggested that fans could be used in some circumstances as an offensive firefighting tool, as well as for the purpose outlined above. This relatively new concept, termed 'Positive Pressure Ventilation' (PPV) was pioneered in the USA, where it is now employed fairly widely, but not universally.

There are two distinct ways in which a fan can be used to blow air into a building: the fan can be positioned right in an open doorway, or it can be positioned at some distance outside the doorway so that its output forms a 'seal' around the doorway. In the former case, the whole of the output of the fan can enter the building, causing a slight positive pressure inside the building, but it is likely that much of the air forced into the building will come straight back out again, over and around the fan, because of the pressurisation (depending upon what other vents or leak paths are open). In other words, there is no control over the direction of air movement. In the latter case, where the fan is sited some distance outside the doorway, hence forming a 'seal' around the doorway, it is much less likely that air will leak back out past the fan. This is particularly so if a suitable outlet vent can be opened at the far side of the building. Hence control of the direction of air flow through the building can be established (although in this case only a proportion of the fan's output enters the building, resulting in slightly less pressurisation).

In recent years, in United Kingdom brigades, the term 'PPV' has come to mean just this latter technique.

The advocates of this relatively new technique, of using PPV as an aggressive firefighting technique, claim that it offers a number of advantages, which may be briefly summarised in general, as follows.

a) Airflow through a fire building can be accelerated by assisting the natural wind, or created where there is little or no natural wind.

b) It may be possible to dictate, within limits, the direction of the airflow through a fire building by the strategic opening or closing of windows and external and internal doors and by the positioning of fans, so controlling the route the smoke will take to the outlet opening.

c) By pressurising part of a building, (remote from the room directly involved in the fire), it may be possible to prevent smoke permeating into that part, as well as reducing the chance of the fire spreading towards that part.

d) The use of a PPV fan can enable firefighters, entering the building with the fan at their backs, to locate the seat of the fire quicker by improving visibility. Also, the airflow from the fan will reduce the chance of the fire spreading towards them, and make the flames 'lean away' from them.

e) The rapid removal of combustion products and their replacement by cooler air will enhance the chances of survival for persons trapped in the fire building.

However, one major potential disadvantage has to be set against all of this: the obvious one, that increasing the supply of oxygen to the fire will accelerate the fire.

Also, it is clear that good, effective fireground communications would be essential if PPV is to be used effectively and safely. The use of a PPV fan in a fire situation would need to be carefully co-ordinated with all other fireground operations. The fan would need to be manned continually during its deployment, and decisions affecting its use based on information from the crews inside the fire building.

The current situation as far as the UK brigades are concerned can be summarised thus. All of the brigades have heard of PPV, and most have studied the technique to some extent, and some are equipping themselves with purpose-built fans, and training their firefighters in its deployment. A small number have purchased PPV fans, mostly for appraisal, and only two brigades are known to have used the technique 'in anger'. The majority of brigades appear to be waiting for others to amass some long term experience before deciding whether to commit themselves to promoting the technique.

On the whole, the technique has so far received a rather cool reception in the UK and this is thought to be due to several perceived difficulties:

a) Supplying large amounts of oxygen to the fire goes against the grain for the average firefighter, seeming to go against basic training.

b) A dearth of 'hard' reliable advice on how, and when to use PPV. (What the brigades want, ideally, is a few simple 'rules of thumb' to assist in making the decision on whether to use PPV in any given situation.)

c) The implications for changes in training that would become necessary if PPV were to be actively encouraged.

2.2 Literature on PPV

While there are a number of articles and papers currently available concerned with the use of PPV as a firefighting tactic, it is not a simple matter for a brigade to come to a balanced judgement on whether or not to promote the tactic. The majority of the articles collated by the FEU, mostly emanating from the USA, are specific, dealing with the use of PPV in a particular situation. Some do attempt to lay down clear guidelines of a general sort governing its use, but the subject is a complex one.

Also, articles about PPV tend to be written only by people who have used the technique successfully and are therefore broadly in favour of its adoption. No articles have been found which specifically advise against the technique, although there are known to be brigades in the USA which do not use PPV, including some very large city brigades. It is not known why they do not.

Over a period of some two years, FEU have collated and studied a large number of articles, reports and papers. These are retained by FEU.

3. TRIALS PLANNING

3.1 General

In planning this series of trials it was agreed that a scenario should be used which could yield information on the likely effects of using PPV in a larger and more complicated building than that used in the previous work. The report FRDG 17/96 'An Assessment of the Effectiveness of Positive Pressure Ventilation in Domestic Properties'[2] describes a series of trials using a single room in a domestic building. Basically, these trials compared the results obtained using PPV with those obtained using natural ventilation only. The present work was intended to facilitate not only comparisons of PPV with natural ventilation, but also to be able to assess various possible tactics, both with and without PPV.

One area known to be of concern to brigades was the case of an unpressurised stairwell in a multi-storey building and the decision was made to conduct trials in such an environment, if possible. Clearly, in the event of a fire in such a building it would be of paramount important to the brigade to be able to clear the stairwell of smoke in order to locate, and gain speedy access to the fire floor. Also, if the stairwell could be cleared sufficiently, and kept clear, it could be used as an escape route for the occupants of the building.

3.2 The Building

A building was needed in which hot, smoky fires could be repeatedly performed, while the interior remained the same throughout the series of trials. This requirement greatly limited the range of buildings which would be suitable.

After discussions with the Fire Service College (FSC), it was agreed that their 'Industrial 'A'' building would be made available to FEU for the proposed trials, provided that the trials could be fitted in to the College's training programme. Because it would not be known very far in advance when a suitable 'window' in the College's training programme would be available, FSC kindly gave FEU permission to install equipment in a stairwell in the building semi-permanently for the overall duration of the trials, whatever that might be.

Industrial 'A', specially constructed to withstand repeated fires, represented a fairly typical small to medium industrial building, of four storeys (five floors in total) with a flat roof (See Figures 1 and 2). The main part of the building was 17.4m. long by 12.1m. wide in plan view, with two of its three internal stairwells projecting outwards beyond these dimensions. (The building is more fully described in Section 5).

The stairwell on the north side of the building which was to be used for the trials, had a number of possible vent openings - some on each floor - making it suitable for assessing tactical variations. (See Figures 3, 4 and 5).

FEU decided to site the trials fire on the first floor, in the 'office' or 'storeroom' in the north east corner of the building. Temporary walls would be constructed outside the single door to this room to form a corridor leading onto the stairwell landing so that as much as possible of the smoke produced would be channelled into the stairwell, while (hopefully) not smoke logging the rest of the building too severely. The position of the main temporary wall would be dictated by the beams at ceiling level across the building, and the 'walls' would need to be fabricated so that they could be quickly installed and made reasonably leaktight, and also quickly dismantled and removed, so that the FSC could still use the building for its exercises.

3.3 The Fire

Little detailed consideration was given to the fire at the initial planning stages, since it was considered that a suitable fire could be readily developed. It was accepted that some preliminary trials would be necessary for this purpose, and it was agreed that a FSC representative should be present to witness these, to ensure that the integrity of the building would not be jeopardised. The fire would be required to:-

a) be easily repeatable and reproducible;

b) be started remotely, and with certainty;

c) produce sufficient visible smoke to completely smoke log the room, corridor and stairwell;

d) raise the 'air' temperatures to realistic levels;

e) burn for long enough for the effects of ventilation to be assessed.

Previous experience suggested that a Heptane fire contained in a standard 34B tray (1.2 metres in diameter) would suffice, although the fire load, and hence the duration of the burn, would need to be determined by preliminary trials.

3.4 Instrumentation

It was agreed that instrumentation would be needed to monitor and continuously log a number of variables throughout each trial. These variables were perceived to be:-

a) smoke obscuration, at all levels in the stairwell;

b) 'air' temperatures at a range of distances from the floor, at a number of sites including the fire room, corridor, each floor of the stairwell and at the extreme top of the stairs where a single door gave onto the roof;

c) thermal radiation flux from the fire, to enable the behaviour of fires to be compared and, possibly, determine the time of extinction;

d) velocity (speed and direction) of the prevailing natural wind;

e) static pressure in the stairwell.

Also, extensive use would be made of video cameras both inside (suitably protected) and outside the building. The video tapes produced would be synchronised and each would record audibly the countdown to events and the comments of the firefighters in the building during the trials.

During the trials the outputs from all of the instruments, except the video cameras, would be logged by FEU's data logger which would be connected to a computer programmed, using commercial software, to display essential monitoring data on monitor screens in a local control room. The data from the trial would be recorded on the computer's hard disk and also, as a back-up, summary information recorded on the disc drive of the data logger. After a trial, the data recorded by the data logger would be transferred into a spreadsheet software package and processed to produce graphical output.

4. EQUIPMENT AND PROCEDURES

4.1 General

It was necessary for FEU to bring together a large amount of equipment for these trials. Some was already owned by FEU, some could be readily purchased and some had to be developed. The main items are briefly described below.

4.2 PPV Fan

It was considered sensible to use the same PPV fan which had been used throughout the earlier 'domestic' trials [1,2] This was a 24" Tempest, petrol driven fan (1)* (Figure 6).

This fan had seven blades in a housing 630mm. diameter and 200mm. long. It was powered by a 5HP Tecumseh 4 stroke petrol engine and had a stated throughput of 258 m^3/min. (9,130 $ft.^3$/min.).

The fan had five pre-set elevation, or tilt, positions. In each of these positions a spring-loaded pin located in a hole, at each side of the supporting structure. These holes were numbered 1 to 5, by FEU, to make setting and noting the position simpler during trials. These five positions gave the following tilt angles:

Hole 1 = 21° fan axis above horizontal
" 2 = 15° "
" 3 = 9° "
" 4 = 3° "
" 5 = -3° fan axis below horizontal.

In all trials where the fan would be used, its axis would be tilted upwards at 9° to the horizontal, and the fan would be positioned 2.5m. from the outside of the doorway. In this position it would be expected to seal the doorway in virtually all conditions of the natural wind.

4.3 Smoke Obscuration Meters

FEU had previously purchased two smoke obscuration meters (2) and a third identical one was purchased for use in these trials. Essentially, each meter consisted of two components; a light emitter, and a corresponding light receiver. The receiver would respond only to the emitted light, independent of the level of visible light or radiation from any other source. These two components could be set facing each other, at any

*Superscripts refer to the notes on page 51.

distance (up to 8m.) apart, and could be calibrated over the range 0% to 100% obscuration by introducing a series of filters between them.

Since these instruments could be operated only at around ambient temperatures, FEU designed and procured water cooled jackets to protect them from the hostile environment which would be encountered in the fire trials (3). Three assemblies were constructed. In each, the emitter and receiver, mounted in their separate cooling jackets, were set up on a pair of Unistrut (4) rails, the effective distance between them being 1.0m. After being aligned, each component was bolted solidly to the rails to form a complete unit.

A steel structure was built for each assembly to support it in a horizontal position at an effective height of 1.0m. from the floor (Figure 7). These structures could be quickly assembled and dismantled in a confined space.

These meters were first tried in a series of pavement light trials [1], when it was found that the smoke produced by some oil fuels (diesel oil, in particular) left a greasy film on the windows of the cooling jackets, which affected the instrument's readings.

In order to prevent any possibility of this occurring during the fire trials (in which the fuel was to be Heptane), window protection devices were designed and constructed. These consisted of a short tube and surrounding plenum chamber which fed a very small flow of air across the surface of each window, resulting in a small flow of air away from the window. Air was fed to these devices from a small electric blower (5), via a purpose-made flow restrictor/deflector and silicon rubber tubing (6). This expedient was effective in keeping the windows clean during the subsequent trials, while having no discernible effect upon smoke behaviour or the results obtained.

4.4 Stairwell Visibility Torches

Since the smoke obscuration meters could only monitor fairly small volumes in three selected positions in the stairwell, it was decided to develop a separate independent method of assessing visibility in the stairwell as a whole. It was perceived that a video camera near the bottom of the stairwell, angled to 'look' upward through the narrow central 'slot' between the stairways, could detect a lighted torch on each of the above floor levels, and adjacent to the door onto the roof, if the torches were aligned with the slot.

A small CCD video camera (7), fitted with a fisheye lens giving a field of view of 110° (8) was mounted atop the central handrail at the first half floor level in the stairwell. This camera was protected, both from high temperatures and from moisture by a stainless steel air-cooled jacket with a circular 'oven-glass' window (9). During all trials cool air was circulated through this protective jacket from outside the building by an electrically driven air blower [5].

A firefighter's torch [10] was attached to a bracket just below the handrail on each floor level of the stairwell, some 0.6m. above the floor in each case, and also just inside the door leading onto the roof. All five torches were aligned with the central 'slot', to be visible to the camera when lit.

The torches were switched on, and their lenses wiped clean, immediately before each trial commenced and were switched off afterwards.

This device yielded useful data on the general extent of visibility throughout the trials.

4.5 Thermocouple Arrays

A total of eight thermocouple arrays were prepared, to monitor air temperatures at each floor level in the stairwell, immediately inside the door at the top of the stairs which gave access to the roof, in the fire room and in the corridor. Each of these arrays consisted of a length of steel Dexion angle section with a bolted on 'foot' where necessary to maintain them in a vertical position. To each of these, a number of 'K' type thermocouples [11] were fixed with soft iron wire, their hot junctions at known heights from the floor.

The arrays for the stairwell each contained seven thermocouples, equally spaced vertically at 0.3m. (1'0") centres, the lowest being 0.3m. from the floor. The arrays for the fire room and corridor were similar, but contained one more thermocouple each, at 2.44m. (8'0") from the floor.

In all cases the hot junction end of the thermocouples were some 25mm. from the supporting structure. Their cables were run down to the floor level inside the angle section and, where necessary, the array was orientated to protect the thermocouples and their cables from direct thermal radiation (the cables were also wrapped for further protection). The cables terminated at their lower end in a ceramic connecting block, suitably protected, at floor level.

4.6 Static Pressure Monitor

To enable an idea of the changes in static pressure in the stairwell during a trial to be gained, a micro-manometer [12] was mounted on the fourth floor of the stairwell. The variable tapping of this instrument sensed the local, stairwell pressure while the 'standard' tapping was connected into a length of small bore silicon rubber tubing to give a tapping in the main compartment, on the fourth floor.

This instrument gave an electrical signal output which continuously compared the two pressures being sensed. Ideally one of these should be a standard atmospheric pressure (which could be considered to remain constant over a short period of time, like a fire trial), but in a real and 'leaky' building there is nowhere where this can be precisely measured; the pressure sensed depending predominantly upon the natural wind. The arrangement described above was considered to be the best that could be achieved in the given situation.

4.7 Thermal Radiation Flux Meter

A single radiation flux meter [13] was mounted on a rigid stand at a height of 0.25m. from the floor. The meter was housed in a diecast aluminium alloy box with just its window protruding, in order to protect its electrical and water connections.

Cooling water was recycled through the meter by a small electrically driven pump [14] via flexible plastic tubes, with a fine filter (0.25mm. mesh) immediately upstream of the meter. The flexible tubes were sufficiently long to allow the pump and its reservoir to be positioned behind the temporary corridor wall, remote from the fire, while the meter would be positioned relatively close to the fire.

4.8 Wind Velocity Meter

This device was essentially an anemometer and vane which would provide continuous wind speed and direction data. The data could be fed directly into the FEU datalogger.

4.9 Video Cameras

In all, four video cameras were used during the trials. Two were set up outside the building, one to the east and the other to the west of the stairwell to record the progress of each trial. They were positioned far enough away from the building to show the ground close to the stairwell and also the top of the roof parapet, to record if and when the stairwell/roof door was opened.

Also, two small CCD video cameras [7] were used inside the building. These were both fitted with a fisheye lens giving a field of view of 110°[8]. Both were housed in a stainless steel air cooled jacket incorporating a circular 'oven glass' window [9] to protect them from high temperatures, and from moisture which could fog the lenses.

4.10 Compartment Dividing Screens

Figure 3 shows the layout of the first floor of the trials building. It can be seen from this that, apart from the north and west stairwells, the floor consists essentially of three compartments: one large open one (some 68% of the total floor area), a small room - to be the trials fire room - opening off the main compartment (some 9% of the total floor area). The remaining area comprises the main stairwell, lift shaft and lobby.

To channel smoke from the fire room into the north stairwell it was necessary for FEU to design and construct a screen, or temporary wall, to separate the fire room from the main compartment. This screen was positioned to form a realistic corridor immediately outside the fire room doorway. It needed to be adequate to withstand high temperatures and direct radiant heat from the fire and also the maximum static pressures that could be generated in the fire room and corridor, which would be dynamically applied over the whole area of the partition. Also, it was necessary to be able to make the screen seal the two spaces from each other, as far as possible, to prevent excessive smoke logging of the main compartment.

This screen needed to be capable of being rapidly assembled, installed and sealed, while being constructed of sections small and light enough to be carried up the stairs of the building. Also, it needed to be capable of being rapidly dismantled and stored without sustaining serious damage, as it was foreseen that it would need to be assembled and dismantled a number of times.

A survey of the building showed that it would be possible for a tall, rigid screen to be erected immediately in front of a main transverse beam below the ceiling level, its top supported against the side of the beam. A set of wooden screens was therefore constructed, each screen being of two parts so that they could be carried up the stairs separately and bolted together on the first floor. These screens were made of 12mm. plywood, each 2.60m. high by 1.22m. wide, except for one narrower one which was fitted on installation to close the gap between the compartments. Their vertical edges were reinforced to enable them to be butted together, and their edges were slotted locally where necessary to clear existing pipes, brackets, etc. A pair of steel clamps were made for, and attached to, each section of the screen. These allowed the screens to be clamped against the vertical face of the beam closest to the fire room. The lower part of the screen was backed up by a temporary wall of concrete blocks, three blocks high, to preclude the possibility of the screens moving when acted upon by the highest predicted static pressure surges.

Once the screens were fixed firmly in position, any gaps apparent around pipes, etc. were plugged with fire blanket material [16], to minimise leaks. Fire curtains of woven glass fibre [17] were then suspended from half driven 4" (100mm.) nails in 2" x 2" (50 x 50mm.) timbers along the top edge of the screen, the curtains having brass cringles along their top edge, at 6" (150mm.) centres. The fire curtains were loaned to FEU by

FSC for the duration of the trials. They were of various sizes, six of them being adequate to cover the screen with generous overlaps.

A similar screen and blanket arrangement was made to cover the double doorway into the lobby since it was found that the existing arrangement leaked smoke quite badly. Again, this was made to be readily clamped into position.

Late on in the trials programme it was decided to modify the temporary partition wall in order to be able to open a 'window' in the south end of the partition to allow smoke to escape from the corridor into the main compartment, to simulate a window at the opposite end of the corridor from the stairs. (Shown in Figure 4).

To achieve this, a rectangular opening was cut in the partition; 0.86m. wide by 1.02m. high, its lower edge 1.47m. from the floor and its vertical edge 0.22m. from the southernmost end of the partition. This gave an opening of approximately the same surface area as that of a single stairwell window, with a broadly similar centre height. A removable 'window' was made to be a close fit in this opening, and both parts were permanently covered with fire curtain material. This 'window' was fixed into the opening by a bolt and ring such that it could be quickly removed by pulling on a rope from the doorway at the far end of the main compartment. When used in the more usual way, this 'window' was closed, and a second fire curtain was suspended over this section of the partition.

4.11 External Cable and Air Supply Support

It was decided that all cabling and air cooling tubes connected to the instruments in the stairwell should be run outside of the building, as far as possible. This was for two reasons: (a) to keep the interior of the stairwell clear of obstructions and trip hazards, and (b) because it was not known what temperatures might be reached inside the stairwell.

Cables from all instruments needed to be run from the instrumentation pod to each level in the stairwell. Also, cooling air tubes were needed to service the smoke obscuration metres on floors 1, 2 and 4, and the video cameras on the ground and 1st floors.

In order to achieve this, a steel structure was made by FEU to support the necessary cables and tubes outside the building. The structure was fabricated so that its components could be carried up the stairs and assembled on the roof. Essentially, a horizontal beam was cantilevered over the parapet of the roof and a steel chain suspended from this beam extended to the ground, where it could be 'anchored' with concrete blocks. This chain was positioned a little to the north of the windows on the west side of the stairwell, to enable the windows to be fully opened without obstruction, and far enough out from the wall to avoid the cables chafing against the concrete in high winds.

The fixed pane of wired glass - immediately below the opening part - in each window on the west side of the stairwell was removed and replaced by a sheet of aluminium alloy, each sheet tailored to the needs of that particular floor, to allow cables and tubes to enter the building, while at the same time achieving a reasonable seal against smoke.

Air blowers to supply air to the smoke obscuration meters and video cameras were houses in a weatherproof box against the west wall of the stairwell. A plastic tube was run from one of the blowers to the 4th floor level, clipped to the chain at regular intervals. This tube incorporated double connectors at the necessary levels for silicon rubber tubes [6] to enter the stairwell. All cabling was run from the instrumentation pod, along an overhead gantry to the chain, and was clipped to the chain in a similar way.

The initial connecting up of this arrangement was somewhat awkward, it being necessary to work through the open windows - a temporary structure had to be made to straddle the smoke obscuration meters in order to be able to reach the tubes with both hands - but once connected it worked well for the duration of the trials.

4.12 Thermal Insulation Materials

Two kinds of material were purchased to protect the instruments, cabling and rubber tubes in the fire room/corridor area. Previous experience, notably in the domestic building, suggested that these materials would be suitable and adequate for the purpose. These materials were:

(a) Ceramic felt blanket [16] which exhibited very low thermal conductivity over the range of temperatures experienced. Rolls of this material were purchased in both 13mm. (½") and 25mm. (1") thicknesses. Both could be easily torn or cut with scissors to the shapes required. This material was used to wrap, or cover, all cables and tubes from the instruments, and was also pressed into any gaps in the screens to minimise leaks. It was loosely tied in position with soft iron wire, where necessary.

(b) Aluminium baking foil, which exhibits extremely low surface emissivity, was used either singly or over (a) above, to protect cabling and tubing. This could be torn into suitable strips and loosely wrapped around items, again being fixed with soft iron wire where necessary.

These materials performed their function adequately during the trials, and no instrument failures due to overheating were experienced.

4.13 Standard Trials Fire

The intention was to develop a repeatable fire which would raise the 'air' temperatures in the fire room, corridor and stairwell to realistic levels and produce sufficient smoke (a smoke obscuration meter reading of 100% on each floor level in the stairwell was the aim). However, the severity and, in particular, the duration of the fire were limited so as not to increase the residual heat in the fabric of the building unduly. Since it was necessary to complete several trials in a day, it was important that the room could cool sufficiently between trials to ensure similar temperature conditions at the start of the next trial.

The fuel was Heptane (18) since this had proved suitable in previous trials [2], and it was considered that a standard 34B tray (1.2m. in diameter) would give a suitable surface area of fuel, this being about the largest that could be reasonably accommodated and used in the fire room. The Heptane was floated onto a 15mm. deep water base, in the tray.

The duration of the test fire was determined by the depth of fuel, and the burn rate of the fuel. However, while it was possible to establish a burn rate for a given fuel in a given tray, outdoors, which would be reasonably repeatable, it was found in previous trials [2] to be impossible to achieve good repeatability in a fire room. (The time taken to burn a given volume of fuel could vary by up to some 70%). This was due to differences in the degree of oxygen depletion, which varied with the strength and direction of the prevailing wind as well as the temperature of the fuel and the room. The only ventilation in the fire room, direct to the outside of the building, was via five circular holes, each some 150mm. in diameter and 300mm. from the floor. Three of these holes were in the east wall and two were in the north wall. They could all be partially closed by sliding concrete slabs.

The fires were started remotely, from the instrumentation pod, using an electrically triggered detonator. This small 'firework'(19), 75mm. long and 25mm. in diameter, was fixed inside the lip of the firetray by a steel clip. It was triggered by an FEU made switchbox incorporating a removable safety key, and powered by a standard D.C. power supply.

Some preliminary trials were necessary in order to determine the quantity of Heptane to be burnt in each trial. A FSC representative was present to witness these preliminary trials and to approve the repeated use of the resulting trials fire.

In the first of these preliminary trials, 7 litres of fuel were used. This proved insufficient and in the subsequent trial 14 litres were used, which again proved to be insufficient. Finally, it was agreed, following a third trial that 20 litres of Heptane appeared to give the required temperatures and degree of smoke logging, with a fire duration of around 6 minutes. 20 litre Jerry cans were used to carry the fuel to the firetray. The same can filling procedure was adhered to throughout all trials since it was easy and relatively quick to fill the cans by eye - with a bilge pump [20] from a 200 litre drum - with acceptable repeatability. This method of fuel handling obviated the need for time consuming fuel measuring methods to be employed immediately before each trial.

Later, after trial no. 24, it was again decided to increase the fire load to 40 litres (2 Jerry cans) in subsequent trials, after analysis of the results of the earlier trials showed that the fires were going out too soon after the higher vents were opened to be certain of the overall effects of PPV.

4.14 Fireground Communications

It had to be accepted that radio communication would not be viable during trials because of the possibility of interference with the trials instrumentation. For this reason FEU's hard wired Diktron communication system [23] was used throughout for two-way communication between the researchers, and between one of the firefighters and the instrumentation pod during trials. All communications could be recorded onto video tape.

Also, a public address system was used to alert all personnel in the area of the trials building, and to broadcast the countdown at the start of each trial.

4.15 Safety Procedure

A safety procedure was evolved, covering the storage and handling of all fuel and detonators and the sequence of operations to be employed throughout the series of trials. This included the handling of the safety key without which the fire ignition circuit could not be triggered. Also, an emergency fire lighting kit was assembled, to be placed outside the building for use if a trial fire went out prematurely, leaving unburnt fuel in the building.

5. FIRE TRIALS

5.1 General

FEU maintained close contact with the FSC Programmes Office to determine when the Industrial 'A' building might become available for trials. Because of the estimated time necessary for FEU to set up equipment and instrumentation and test all instruments, and then remove it again, it was agreed that a 4 day period would be the minimum worthwhile.

The trials were completed in four separate sessions:

13 ~ 16th January 1997 (trial nos. 1 ~ 11 inc.)
28 ~ 31st January 1997 (trial nos. 12 ~ 24 inc.)
1st and 2nd April 1997 (trial nos. 25 ~ 32 inc.)
14th ~ 16th April 1997 (trial nos. 33 ~ 40 inc.).

5.2 The Building

Industrial 'A' was one of FSC's specially constructed buildings, made to withstand repeated fires. It represented a fairly typical small to medium sized industrial building of four storeys (five floors in total), with a flat roof. (Figures 1 ~ 5 inc.). The main part of the building was 17.4m. long by 12.1m. wide with two of its three internal stairwells projecting outwards beyond these dimensions to the north and west. The internal layout of each floor of the building was essentially similar. On all floors the reinforced concrete structure of the building in the main compartments (not the stairwells or lobby) was protected by a system of thermal shock resistant refractory tiling [21].

On all floors except the ground floor there were large wired glass windows along each side of the main compartment which contained openable panels hinged horizontally so that the top of the movable part moved inwards while the bottom moved outwards. These windows could be latched shut or opened until the glass was almost horizontal. There were similar windows on each side of the north and west stairwells, except at the third floor level where, instead of windows, a door at each side gave access onto a balcony which ran completely around the building at this level. When fully open, the windows gave an opening 1.15m. wide and 0.84m. high.

Figure 5 shows, approximately to scale, a vertical cross section through the north stairwell, which was to be used for the trials. This Figure shows the ground floor entry door, outward opening, on the west side of the stairwell. There was a window, identical to all others in the stairwell on the east side, opposite the door. The door at the extreme top of the stairs afforded the only means of access onto the roof of the building.

Within the stairwell, the stairs ascended clockwise (ie. the outer wall was on the climber's left hand side). In the centre of the stairwell the flights of stairs were separated by a gap of 100mm. forming, in effect, a slot 100mm. wide by 2.0m. long, in plan view, affording a line of sight up through the entire height of the stairwell. There was a continuous steel handrail with banisters at this inner edge of the stairs, running from top to bottom while, on the outer walls, short separate lengths of handrail were fixed at each flight. Figure 4 gives a horizontal cross section through this stairwell. At each floor level a single doorway, 0.74m. wide by 2.0m. high connected the stairwell landing to the main compartment, the door opening outwards onto the landing.

The fire room was the relatively small compartment on the first floor, in the north east corner of the building. This compartment had wired glass windows in its east wall, all of which could be securely fixed shut. Above the windows, a built-in sparge pipe system could project fan shaped water sprays against the inner surface of all of the glass, to protect it in the fire situation. The actuating valve for this sparge pipe system was sited in the first floor lobby.

There were five holes through the outer walls of this compartment, three in the east wall and two in the north. These were 150mm. in diameter and situated 300mm. from the floor. They could be partially closed by means of sliding concrete slabs.

There was a heavy sliding door to separate this compartment from the main compartment. This doorway, 1.45m. wide by 1.95m. high, was kept fully open throughout all trials.

FEU installed a temporary partition wall in the main compartment for the trials (Figure 4). This is briefly described in Section 4.10.

5.3 Description of Trials Set-up

5.3.1 General

The FSC kindly agreed that FEU could install their instrumentation in the north stairwell and leave it there undisturbed for the entire duration of the trials. Also, the small compartment on the first floor could be used between trials to store any equipment used, during trials, in this and the main compartment. All doors into these two areas were kept closed and marked 'Out of Bounds' during the periods between FEU's trials, while FSC used the building for its own training programme. Also, FEU's pods, one for instrumentation and one for use as an office/store, were parked for the duration of the trials in an agreed position (Figure 1), and all cabling, tubes etc., were left in positions, except in the main compartment.

The positions of all instruments, during the trials, are described below.

5.3.2 Inside the Building

Figures 4 and 5 give an idea of the position of equipment and instruments inside the building. The temporary partition wall (Section 4.10) was assembled with its top edge supported and clamped against the side of the main ceiling beam and its lower edge against a temporary wall of concrete blocks, in the position shown, to form a corridor connecting the fire room and the stairwell. The double doorway between the corridor and the lobby was partitioned off in a similar way. Both were sealed, as far as possible, using fire blanket material.

The firetray, of 1.20m. diameter, was positioned towards the north end of the fire room and a little off-centre, as shown, to avoid splashing from the window-protecting water sprays. The igniter cable entered the room via one of the ventilation holes in the north wall of the room.

The fire room thermocouple array (Section 4.5) was positioned near the inner (south west) corner of the room, as far from the fire as was reasonably practicable. The array was orientated so that the hot junctions of the thermocouples were facing away from the fire, thus being shielded from direct radiation, so as to record air temperatures only. The cables, suitably protected, ran along the floor, across the south end of the room and out of the building via the first ventilation hole. The array could not be placed against the outside wall because of the likely effect of the window-protecting water sprays.

The fire room video camera (Section 4.9) and thermal radiation flux meter (Section 4.7) were positioned close together immediately outside the doorway of the fire room, in the corridor, each 2.1m. from the fire tray. Their cables and air or water cooling pipes, suitably protected, ran at low level from the instruments across the corridor and through a small slot in the base of the partition, at its south end, and across the floor of the main compartment to the nearest ventilation hole, adjacent to the FEU pods. The flux meter water recirculating pump and its reservoir were placed in the main compartment.

The thermocouple array in the corridor was positioned close to the partition and out of the direct radiation from the fire, as shown. Its cables were laid around the edge of the corridor behind the flux meter and video camera and out through the ventilation hole furthest from the fire. They were protected (Section 4.12) throughout their length.

During each series of trials a hosereel with hosereel gun [22] attached entered the fire room through a ventilation hole in the north wall and was coiled down immediately outside, and to the left of, the fire room doorway. This was essentially a safety precaution although it was also used for putting the water base into the fire tray, and occasional topping up. The hosereel was charged at all times when fuel handling and trials were in progress.

The smoke obscuration meters (Section 4.3) were positioned on the 1st, 2nd and 4th floor landings, in the positions shown. They were a close fit between the corridor/stairwell wall and the first stair, and were positioned as close to the west wall of the stairwell as practicable in order to keep the stairwell as clear of obstruction as possible (for firefighters in self-contained breathing apparatus to be able to pass, in conditions of zero visibility). The cabling and air supply pipes to the meters were fed into the stairwell via the fixed part of each adjacent window (Section 4.11). The air tubes inside the building were all of silicon rubber[6] which is rather more resistant to high temperatures than other rubber or plastic tubing.

The stairwell thermocouple arrays on the 1st, 2nd and 4th floors were fixed to the support structures of the smoke obscuration meters. The array on the 3rd floor, where there was no smoke obscuration meter, was in a similar position, just clear of the door onto the balcony. Those on the ground floor and just inside the roof door were central in the stairwell. In all cases, except for the ground floor, their cables were led out of the stairwell via the nearest 'window'. The cables from the ground floor array were taken out of the building via a hole bored low down through the frame of the entry door.

The stairwell video camera (Section 4.4), in its protective air cooled jacket, was mounted on the inner handrail on the first half landing of the stairwell (Figure 5). This camera was tilted to view upward through the central 'slot', so that it could detect lighted torches fixed to the banisters, just below the handrail on each floor level landing and immediately inside the roof door. The cables and cooling tubes from this camera were led down and out through the ground floor door frame. The torches[10], mounted on the banisters just below the handrails, were firefighter's intrinsically safe, self-contained torches, each containing three 1.5v. batteries.

5.3.3 External to the Building

FEU positioned two pods, each 4.4m. long by 2.2m. wide alongside the north side of the building. They were set down onto their legs with their windows facing the building, some 5.5m. distant from the main part of the building. They remained in this position for the duration of the whole series of trials. (Figure 1). One housed the instrumentation, data logger, computer, video monitors and recorder, etc., and the other was used as an office and equipment store. Also, FEU's horse box was parked at the east end of the building and use as a store for larger, heavier items.

Mains power was supplied to the pods from a weatherproof socket box installed for the FEU on the outside of the east wall of the stairwell. From the instrumentation pod an overhead cable tray was erected to carry cabling to a vertical chain by the side of the stairwell entry door (see below).

All of the necessary cabling and pipework from the instruments in the stairwell were run up the outside of the building as far as possible in order to: (a) avoid the hostile environment and risk of damage, and (b) to avoid trip and fouling hazards for the firefighters, moving in zero visibility. (Section 4.11)

On each floor level, except the 3rd floor, the moving part of the stairwell windows was hinged horizontally at its centre line so that when opened its top edge moved inward while its bottom edge moved outward and, being balanced, it would stay in any selected position. Below each of these opening windows was a single fixed pane, the same width and half the height of the opening part. This fixed pane was removed prior to the trials and replaced by a sheet of aluminium alloy through which small local holes were bored to allow the necessary cable connectors and tubes to pass through, on each floor. Any remaining gaps were then plugged with fire blanket material. A similar arrangement was made on the 3rd floor; here a small fixed pane low down by the side of the balcony door was replaced by a pre-drilled metal panel.

The wind station[15], used throughout to measure and record wind speed and direction, was set up centrally on the flat roof of the building. It was mounted atop a 7.0m. long tube which could be mounted vertically into a hinged tripod stand. Guy ropes were attached to the tube just below the wind station, and the whole was arranged so that the tube could readily be lowered into a horizontal position. This was necessary because of the need to check and maintain the windstation (at least some of the trials would be carried out in midwinter and any icing would cause the instrument to malfunction).

Two external video cameras were set up for the trials, one at each end of the building and some 40m. distant from it. They were each positioned to be able to 'see' all of the windows on their side of the stairwell. Also, the one at the east end of the building could detect when the door onto the roof opened, while that at the west end could 'see' the ground floor entry door.

The FEU's fire appliance, ALT 469H was positioned some 40m. to the west of the building where the pump operator could see the stairwell entry door. The pump was kept running, and manned, during all fuel handling operations and trials.

Prior to all trials, a set of emergency tray igniting equipment was set out well away from the entry door, in case of a failure of the electrical igniter, or the fire going out prematurely. This consisted of a lance, a small sealed can of petrol, matches, a propane blowtorch, a drip tray and a steel bucket full of gravel with a steel tube inserted for extinguishing the lance. Several foam filled fire extinguishers were placed in prominent and strategic positions.

5.4 Trials Programme

5.4.1 General

In this series of trials the basic aim was to assess any differences that might be made to conditions in the stairwell by the use of a PPV fan, in a given situation. The trials were arranged in pairs, as far as possible, the same tactics being employed in each trial of a pair, except that a PPV fan was employed in one, and natural ventilation only, in the other.

The timing of events (entry, vent opening, etc.) was kept identical, as far as possible, within each pair of trials, and also across broad groups of trials where it was considered that it may be advantageous to be able to make broader overall comparisons of tactical approaches.

In all trials the fire was on the first floor, the firefighters entered by the stairwell door at a pre-determined time after the start of the fire, and made their way up the stairs. All of the stairwell windows were initially closed, as were the doors from the stairwell into the building at each floor level except for the door at the 1st floor, fire room, level which remained wide open throughout. All other doors and all windows remained closed throughout all trials, unless specifically mentioned.

In the list of trials undertaken, all trials that were commenced are listed although, of the total of 40, only 32 yielded valid data. (See Section 6.3.1) The reason for doing this was to avoid any possibility of confusion which changing 'trial numbers' might have caused: a trial number had to be allocated to each package of data at the outset of a trial, before it was known whether the trial would yield valid data.

5.4.2 List of trials undertaken

The trials undertaken are listed in Table 1. This list gives a very brief description of the procedure adopted in each trial.

5.5 Trials Procedure

This Section describes the general, overall, method adopted in going about this programme of trials. The detailed procedures adopted by the firefighters varied somewhat from trial to trial, different tactics being tried to clear the stairwell of smoke and heat. However, the underlying procedures were identical throughout the trials.

A team of six experimenters was necessary to perform the trials. Their duties were as follows.

a) Project Officer - co-ordinate the work - observe - time events - detonator safety key - operate the PPV fan.

b) Two persons in the instrumentation pod - countdown - data recording from all instruments - video recording.

c) One person - man the fire appliance - operate the window drenchers.

d) Two firefighters - fuel the firetray and place detonator - enter during the fire and carry out agreed tactical procedure.

205 litre drums of Heptane fuel, for use in the trials, were stored in the Fire Service College's fuel compound, which was well away from all buildings and kept locked for safety reasons. The first task on each day of trials was to pump sufficient fuel for the day's trials from a drum into 20 litre Jerry Cans. These Jerry cans of fuel were then stored in the locker of the trials fire appliance which would be on the side of the vehicle remote from the trials building.

The appliance was then driven into its position, some 40m. distant from the stairwell door, and a hosereel was run out along the ground to the north end of the fire room, where it was taken up and through one of the ventilation holes, and coiled down adjacent to the fire room door. This hosereel was kept charged throughout as a safety precaution, and was also used for topping up the water base in the fire tray when necessary to maintain its level at 15mm.

The external video cameras and stands to display the trial numbers were set up, positioned so that between them they could 'see' all windows in the stairwell, the ground floor door and the roof parapet adjacent to the door at the top of the stairs giving out onto the flat roof of the building.

The emergency fire lighting kit was laid out just beyond the west end of the building. This consisted of a small sealed can of petrol, matches, a propane blow torch, an igniting lance, a steel bucket containing gravel and a steel tube for extinguishing the lance, a small drip tray and a dry powder fire extinguisher. This kit was necessary to enable the firefighters to light the fire tray in the event of an electrical detonator failing, or to re-light it if it went out prematurely leaving unburnt fuel in the tray.

Prior to each trial all instrumentation was switched on and a series of checks was undertaken to ensure that all instruments and recorders were functioning correctly. All of the video camera windows, stairwell torches and smoke obscuration meter windows were cleaned, the detonator firing circuit was checked, and a final check was made that all doors and windows in the building were shut, except the first floor doors between the fire room, corridor and stairwell which remained fully open at all times.

Immediately before each trial the fire appliance pump was engaged and kept running for the duration of the trial. A Jerry can, or cans (see later) of Heptane fuel was placed just outside the stairwell door along with a dry powder extinguisher and a bucket containing: a detonator with shorting link fitted, the safety firing key and a pair of wire cutters. The firefighters entered the building with these items and climbed to the 1st floor, where they fuelled the tray, fitted the detonator to the tray rim and finally cut the shorting link. They then made their way out of the building, handing the safety firing key to the to the project officer upon emerging, who then closed the door securely.

Both firefighters now donned self-contained breathing apparatus (BA) and one connected a Diktron communication system[23] into his facemask so that he was in 2-way communication with the instrumentation pod. (Radio communications could not be used because there was a danger that the signals might interfere with the instrumentation.)

At the same time, the pump man, also in 2-way Diktron communication with the instrumentation pod, entered the lobby on the south side of the building and stood by to turn on the fire room window drenchers. All Diktron communications were recorded onto all of the four video tapes produced during each trial. This was subsequently most useful since it made it possible to readily synchronise all tapes and also provided a commentary from one of the firefighters during each trial.

When the firefighters were ready, the safety firing key was connected into the firing box and the countdown towards ignition was commenced over the Diktron and PA systems. At 'zero' the fire was ignited, stopwatches were started, and an event marker signifying 'time=0' was imposed onto all instrument recordings. Once it was confirmed that the fire was alight the 'pump man' turned on the window drenchers to a pre-determined mark and then returned to the appliance pump, closing all doors behind him, before the firefighters entered the building.

The firefighters and project officer waited outside the stairwell door until the agreed door opening time (1 minute in the first three trials and 2½ minutes thereafter). Again, an audible countdown indicated the time to open the door and the firefighters entered immediately, the entry door being wedged wide open.

The firefighters now carried out their pre-determined tasks in accordance with a countdown from the instrumentation pod. The countdown was intended to ensure as far as possible that, for example, a window on the 4th floor would be opened at the same time, relative to the fire starting, in each of a pair of similar trials. Also, the countdown was helpful to the firefighters in pacing themselves in the stairwell. (The target times were decided after the first few trials and were intended to be realistic bearing in mind that the firefighters were moving about in an unfamiliar building in conditions of zero visibility.) Once all tasks had been completed the firefighters returned to the ground floor and came out of the building.

In the trials where the PPV fan was used, the fan had been previously positioned 2.5m. from the entry doorway, with its axis tilted back 9° to the horizontal. The fan operator either watched for evidence that the pre-determined vent had been opened or, if he could not see the vent from his position, awaited confirmation from the instrumentation pod before starting the fan.

During all trials, all instruments and, where applicable, the PPV fan were left running and recording until the smoke obscuration level recorded by all three meters had fallen to, or near, zero, by which time the air temperatures in the stairwell were generally low enough not to have caused any problems.

In all trials, except two of the later ones (nos. 36 and 37), the vents opened by the firefighters were the windows in the stairwell, the doors - in place of windows - giving onto the balcony at the 3rd floor level, or the door giving onto the flat roof of the building. In these other two trials, a window sized opening, was opened in the temporary partition, at its inner (south) end, while all vents in the stairwell, except the entry door, remained shut. During these two trials the windows along both sides of the main 1st floor compartment were all fixed open as far as possible before the trial commenced. The 'window' in the partition was removed, upon a countdown relayed from the instrumentation pod, by an experimenter pulling on a rope, which released a bolt on the 'window', from the doorway of the west stairwell. This experimenter came out of the building immediately the 'window' had been removed.

After each trial the building was opened up to the natural wind as far as possible and left for at least two hours to allow the temperatures of the surfaces of the walls and ceiling in the fire room and corridor to return to similar to the initial temperature. The PPV fan was also used to assist this between trials cooling.

Throughout the programme, pairs of trials with and without the PPV fan were conducted, as far as possible, one after the other in order to ensure that the prevailing natural wind conditions would be as similar as possible.

The quantity of heptane fuel burnt in each trial was, initially, 20 litres, giving an average time to extinction of 5 mins. 33 secs. This was subsequently changed, in trial no. 25 onwards to 40 litres, which gave an average time to extinction of 8 mins. 59 secs.

6. RESULTS OF TRIALS

6.1 General

The data obtained from the instruments in and around the building was recorded, where possible, by the FEU's data logger throughout all trials. The duration of each trial - in effect, how long to keep recording - was decided by the experimenters in the instrument pod. They kept a close watch on the measured smoke obscuration values on each floor and stopped all instruments recording when all of these obscuration values had fallen to below 10%.

The data from all instruments then needed to be processed, using the FEU's computer and printer to make it reasonably handleable. This proved to be a time-consuming process. In general, the data was printed out in graphical form, the computer selecting the scales upon which to plot each variable in each location. Then, after these plots had been examined, they were re-plotted to common scales for each location, to enable broad comparisons to be made between the data from the various trials.

Other data which could not be similarly logged and plotted (visibility of stairwell torches from the first half landing, smoke movement outside the building and any comments from the firefighters) was recorded on video, all tapes being labelled and stored for subsequent manual analysis.

6.2 Data Processing

6.2.1 General

After each of the two main series of trials all of the data currently to hand was processed. Similar sets of graphs were plotted for each trial. These plots are described below and, as an example, the set of plots obtained from trial no.40 (natural ventilation, only) is reproduced as Figures 8 to 20 inclusive.

6.2.2 Smoke obscuration

The results from the three smoke obscuration meters on the stairwell landings on the 1st, 2nd and 4th floors were all plotted on a single sheet, the 1st floor trace being black, the 2nd floor red and the 4th floor green. Obscuration was plotted on the vertical axis, from 0 to 100% and elapsed time, from zero (ignition) to 25 minutes on the horizontal axis. (Figure 8).

6.2.3 Stairwell Visibility Torches

The video tapes were studied to ascertain the time, relative to ignition, when each torch first became visible, and then remained visible. These times were listed for each trial. (Table 2).

6.2.4 Temperatures

In all, seven temperature graphs were produced for each trial, one from each thermocouple array. Each graph had seven colour coded traces plotted on it (two, from the fire room and corridor, had eight) recording the air temperatures at 1, 2, 3, 4, 5, 6 and 7 feet from the floor level (also at 8 feet in the fire room and corridor).

These graphs had temperature plotted on the vertical axis and time, measured from ignition, on the horizontal axis. In their final version these plots had a common temperature scale for each position, from trial to trial. The time scales were also made the same, the longest necessary for any trial, for each of the two series of trials in order to facilitate ready comparison. (Figures 9 ~ 15, inc.).

6.2.5 Thermal Radiation Flux

A single graph was produced for each trial showing how the radiation incident upon the meter varied over the duration of the trial. In all cases flux, in kilowatts per square metre was plotted against time from ignition. (Figure 16).

6.2.6 Static Pressure

A single graph was produced for each trial to show how the static pressure varied over the duration of the trial. In all cases the static pressure in Pascals was plotted against time from ignition (Figure 17). Event markers were subsequently manually superimposed onto the plots to enable estimates of average pressures, between certain events (vents opening etc.) to be made.

6.2.7 Wind Speed and Direction

Two separate graphs were produced for each trial, one plotting wind speed in metres per second, and the other wind direction. Although the normal Meteorological Office convention was used throughout (north=0°, clockwise= +ive, so that east=90° etc.), this had to be modified in the processing for any trial during which the wind direction passed through north, to enable the computer to calculate the average wind direction over the duration of the trial. In these cases (trial no.40, Figures 18 and 19, is one) north through east to south = 0° ~ + 180°, and north through west to south = 0° ~ -180°. This worked provided that the wind did not pass through south (the normal convention worked when it did not pass through north).

The average wind speed over the duration of the trial was also calculated and the two averages, speed and direction, were manually combined in the form of a vector diagram, superimposed on a sketch of the stairwell to a scale of 1cm = 1m/sec. These vector diagrams made it simple to readily perceive the average wind conditions during each trial, so that comparisons could be made. (Figure 20).

6.2.8 Video evidence

Video tapes from the four cameras were all labelled and stored in chronological order so that any tape could be readily viewed while analysis was in hand. All tapes contained an audio recording giving the countdown to ignition so that they could be synchronised with all other data, and the firefighter's comments.

In each trial two tapes showed the outside of the stairwell, one each side, a third showed the fire and a fourth showed the stairwell torches. (Section 4.9).

6.3 Analysis of the Results

6.3.1 Changes During the Trials

At the outset of the trials the intention was to conduct pairs of trials with and without the use of PPV to assess any differences possibly caused by the fan. Also, it was considered that if conditions remained reasonably constant it would be possible to make comparisons between the effects of employing different tactics, both with and without PPV. In short, it should be possible to compare the results of any trial with those of any other.

In the event, it proved to be impossible to make fair comparisons across all trials. The trials results had to be separated into two groups because the fire load, and hence duration, was changed after trial no.24. Direct comparisons could therefore only be fairly made within each group.

In trials no.1 ~ 24 inc. the fire load was 20 litres of heptane, which gave an average fire duration of 5 mins. 33 secs., and a range of from 4 mins. 29 secs. to 7 mins. 40 secs. In trials no 25 ~ 40 inc. 40 litres of Heptane were burnt, which gave an average fire duration of 8 mins. 59 secs., and a range of from 7 mins. 50 secs. to 10 mins. 28 secs. (The reasons for these somewhat surprisingly large ranges are discussed in Section 11.2).

The first opportunity that FEU had to process and study any trials data in detail occurred after trial no.24, since there had only been a one week break between the first two trials sessions, due to availability of the building. At this time it became clear that the fire was, on occasion, going out too soon after, and in some cases even before, the designated vent was opened. This meant that the effects of the PPV fan could not be fairly ascertained.

It was decided at this stage to:

(a) ignore the results from any trial in which the fire went out within 30 seconds of the last vent being opened, and

(b) approach the College for permission to double the fire load.

It was agreed to double the fire load, and no similar problems were subsequently experienced.

In analysing results, use was made predominantly of the later, extended trials, direct comparisons being possible between all trials in this group (nos. 25 ~ 40 inc.), except for those in which the fire went out prematurely (see below). Some selected pairs of trials from the earlier group (nos. 1 ~ 24 inc.) were also compared with each other, although more importance is attached to the results of the later, extended trials.

In all, eight trials failed to yield any data. The fire went out prematurely, before all of the heptane fuel was consumed, in five cases. These were trials no.5, 26, 29, 33 and 39. In each of these cases the trial had to be aborted and the fire was re-ignited by the firefighters using a petrol soaked lance to burn off any remaining fuel safely. In two cases, trials no.12 and 19, the door on to the roof at the extreme top of the stairs opened slightly of its own accord. The latching of this door was subsequently modified to preclude the possibility of this happening again. In trial no. 32 the PPV fan failed to operate properly and it was therefore decided not to use the results of this trial. In this case the fan's motor failed to develop full power. It was suspected that 'dirty' petrol may have been to blame, although an overhaul by the manufacturers' approved agents failed to improve its running. An identical PPV fan was borrowed from the Fire Service College for use in subsequent trials. All of the aborted trials were subsequently repeated, different trial numbers being allocated to them.

6.3.2 General Observations

In order to determine the maximum instantaneous air temperature recorded at any time, at each thermocouple array position, the results of trials 25-40 inc. were examined. The heights selected for examination were 3 feet (0.91m.) and 6 feet (1.83m.) since these represent approximately the height of a firefighter's head when kneeling or crawling, and when standing or walking. These temperatures are given in Table 3, and Table 4 gives the maximum temperature recorded at any time in any trial.

The initial study of the trials results and discussion with the firefighters involved indicated that, in general, the temperatures encountered in the stairwell were not sufficiently high to cause distress to the firefighters and did not cause them any undue inconvenience at any stage, provided that they did not loiter unduly in the hottest areas. It was therefore felt that the temperatures did not pose a serious problem for the firefighters in this particular situation, where their objective was to proceed up the stairs to vent at, or above, the fire floor level.

The greater problem was perceived to be the lack of visibility due to smoke obscuration, as it was this which would limit the firefighter's rate of ascent and impede their actions. For this reason, the greater emphasis in analysing results was placed upon smoke clearance in the stairwell, any effects upon temperatures being considered of secondary importance. (Nevertheless, the temperature variations gave a good guide to the air movement, and so were an important part of the results while they were being analysed.)

6.3.3 Comparisons of Trials Results Which Were Possible

Essentially, there were three kinds of comparisons that could be made. These were:-

a. PPV vs. natural ventilation - while keeping all tactics, timing and conditions as identical as possible. (Section 7., below)

b. Varying tactics, using PPV - essentially which vent/s to open and when to deploy the fan. (Section 8., below)

c. Varying tactics, using natural ventilation only. (Section 9., below)

A fourth comparison - fan position - was also tried, setting the fan right in the doorway as opposed to the 'standard' position (for these trials) of 2.5 metres away, but in fact no complete and reliable comparison was possible. This was because, in the relevant trials, the fire went out too soon relative to the vents being opened.

These three categories of comparisons are examined separately below. In the following Sections, all times given are from ignition, unless otherwise stated.

In each category, a summary of the results of each comparison is given immediately after the relevant comparison.

7. PPV v. NATURAL VENTILATION

7.1 Comparisons That Could Be Made

In this Section the following scenarios are considered.

Scenario 1. Open roof door, only. (Trial no. 25 vs. trial no. 27).

Scenario 2. Open both 4th floor windows, only. (Trial no. 38 vs. trial no. 40).

Scenario 3. Open the downwind window on the 1st floor and 4th floor, only. Start the PPV fan, when the 4th floor window is open. (Trial no. 28 vs. trial no. 30).

Scenario 4. Open the downwind window on the 1st floor and 4th floor, only. Start the PPV fan once the 1st floor window is open. (Trial no. 30 vs. trial no. 31).

Scenario 5. Open the 1st floor 'window' at the opposite end of the corridor to the stairwell, and the 4th floor downwind stairwell window. Start the PPV fan once the 1st floor 'window' is open. (Trial no. 36 vs. trial no. 37).

Scenario 6. Open the 1st, 2nd, 3rd and 4th floor downwind windows as they are reached. Start the PPV fan once the 1st floor window is open. Trial no. 34 vs. trial no. 35).

7.2 Scenario 1.

The entry door was opened at 2 mins. 30 secs. and the roof door was opened at 5 mins. 36 secs. The PPV fan was started immediately the roof door was opened, where applicable.

In general, PPV improved the visibility in the stairwell, and completely cleared it faster than natural ventilation after the fire went out. The stairwell torches confirmed that PPV cleared the stairwell faster. Also, PPV reduced the temperatures on the 2nd and higher floors after the roof door was opened.

7.3 Scenario 2.

The entry door was opened at 2 mins. 30 secs. and both 4th floor windows (one each side of the stairwell) where opened at 5 mins. 21 secs. The PPV fan where applicable, was started immediately the windows were open.

In general, PPV improved the visibility in the stairwell somewhat. This was confirmed by the stairwell torches. Also, PPV reduced temperatures quite markedly in the stairwell and corridor almost immediately.

7.4 Scenario 3.

The firefighters entered at 2 mins. 30 secs. The downwind window on the 1st floor landing was opened at 3 mins. 9 secs. and the downwind window on the 4th floor landing was opened at 4 mins. 26 secs. The PPV fan, where applicable, was started immediately the 4th floor window was open.

In general, PPV improved visibility slightly on the 2nd and 4th floor landings both before the fire went out and after although the visibility up the centre of the stairwell was not improved to any significant degree. The temperatures in the fire room and corridor peaked earlier and slightly higher when PPV was used, but also started to reduce earlier and reduced slightly faster after the fire was out. In the stairwell, PPV appeared to make little difference to temperatures on the 1st floor, but reduced all temperatures faster on the 2nd and higher floors, from when the fan was started onwards.

7.5 Scenario 4.

The firefighters entered at 2 mins. 30 secs. The downwind window on the 1st floor landing was opened at 3 mins. 9 secs. and the PPV fan, where applicable, started at 3 mins. 17 secs. The downwind window on the 4th floor landing was opened at 4 mins. 26 secs. (Note: this is identical to the preceding Scenario 3, except for the timing of the introduction of the PPV fan.)

In general, the visibility was improved to some limited extent by the use of PPV on the 2nd and 4th floor landings, but appeared to make it rather worse on the 1st floor for some 2-3 minutes while the fire was burning. Visibility improved faster, once the fire was out, with PPV. This mixed overall effect is borne out to some extent by the evidence from the stairwell torches, which show:

1st half landing to 1st floor : not available
1st half landing to 2nd floor : natural vent. better
1st half landing to 3rd floor : natural vent. better
1st half landing to 4th floor : PPV better
1st half landing to roof level: not available

With regard to temperatures, the use of PPV had a beneficial effect upon the temperatures on the stairwell landings, particularly on the 2nd and higher floors while the fire was burning, and may have also had a marginal cooling effect in the corridor.

7.6 Scenario 5.

The firefighters entered at 2 mins. 30 secs. The 1st floor 'window' - at the southern end of the corridor - was opened at 3 mins. 06 secs. The PPV fan, where applicable, was started at 3 mins. 26 secs., and the downwind 4th floor landing window was opened at 4 mins. 23 secs., (Note: this is virtually identical to Scenario 4, except that the 1st floor window was at the opposite end of the corridor.)

PPV improved visibility on the 2nd and 4th floor landings, but took rather longer to clear the 1st floor landing completely (similar down to 20% obscuration, then some three minutes longer to reach 4%). However, the 2nd and 4th floor landings were cleared some five minutes and four minutes earlier, respectively. The stairwell torches indicated that PPV cleared the smoke faster to all floors for which evidence was available, except the 2nd floor. The effect of PPV upon the temperatures in the stairwell were quite marked, the temperatures reducing faster at all levels, particularly so on the 2nd floor and above. As an example, on the 2nd floor landing, the temperatures had dropped to about 30°C within two minutes of the fan being started, whereas with natural ventilation this took five minutes longer.

7.7 Scenario 6.

The firefighters entered the stairwell at 2 mins. 30 secs. They opened the window on the downwind side of the stairwell at each floor level as they came to it. The 1st floor landing window was opened at 3 mins. 02 sec., and the PPV fan, where applicable, was started at 3 mins. 06 sec. The 2nd floor window was opened at 3 mins. 33 secs., the 3rd at 4 mins. 11 secs. and the 4th at 4 mins. 50 secs.

PPV improved the visibility in the stairwell quite markedly. Also temperatures in the stairwell were, in general, reduced by the use of PPV, particularly on the 2nd floor and above.

7.8 General Findings

In general, PPV improved the visibility in the stairwell to some extent. In some cases the improvement was marked, in others it was fairly slight. In none of the pairs of trials compared with each other did the use of PPV make the visibility in the stairwell worse, overall.

Opening the downwind vent on the 1st floor landing (the fire floor) caused a fairly rapid reduction in the smoke obscuration and air temperatures <u>on that landing,</u> both with and without PPV. This effect was generally faster with PPV. In either case, there was no discernible effect on the higher, unventilated landings.

When all of the downwind vents were opened as they were reached, the use of PPV made little difference to the smoke obscuration on any floor except the fire floor (which was cleared rather faster with PPV) until after the fire went out. It then cleared the stairwell faster than natural ventilation.

The temperatures in the corridor were reduced somewhat by the use of PPV, while the fire was burning. In all six scenarios considered, the corridor temperatures were broadly similar when the fan was started and, in all cases, PPV reduced, or maintained, the temperature to below the corresponding natural ventilation temperatures.

The temperatures in the stairwell on the 1st floor and above were reduced more by PPV once the appropriate outlet vent had been opened.

Even though the fire grew once ventilation commenced, and fresh air was introduced, the temperatures in the fire room, also, appear to have been generally reduced when the PPV fan was switched on, while the fire was burning.

8. TACTICAL VARIATIONS WITH PPV

8.1 Highest Possible Vent, only Vs. All Downwind Vents As They Are Reached

In trial no.25 the firefighters entered at 2 mins. 30 secs., climbed to the roof level and opened the roof door at 5 mins. 37 secs. The PPV fan was started eleven seconds later, at 5 mins. 48 secs.. In trial no.34 the firefighters entered at 2.30 and opened each downwind vent as they came to it: 1st floor window at 3 mins. 02 secs., 2nd floor window at 3 mins. 33 secs., 3rd floor balcony door at 4 mins. 11 secs., and 4th floor window at 4 mins. 50 secs. The PPV fan was started once the 1st floor window was opened, at 3 mins. 06 sec.

The differences in effect upon the smoke obscuration were small on both the 2nd and 4th floors throughout, the slight differences noted would make very little difference to firefighters in the stairwell. However, there was a marked difference on the 1st floor landing, the obscuration reducing to below 10% almost instantly when the fan was started, in trial 34. The visibility up the centre of the stairwell from the 1st half floor landing was better (clearing sooner) to all floors, in trial no.34, in which all vents were opened sequentially.

The temperatures in the stairwell were generally somewhat lower in trial no.34, although the earlier onset of the final reduction was due simply to the fact that the fire went out sooner. If the 'fire out' event lines were aligned on the graphs - one slid over the other - the temperature reductions from this event onwards were broadly similar). In trial 25 (top vent, only) a peak in temperatures moved up through the stairwell immediately after the fan was started, this was most in evidence on the higher floors. This was not experienced in trial no.34, when vents were opened sequentially.

There appeared to be a clear benefit in ventilating the fire floor as soon as possible.

8.2 Highest Possible Vent, Only Vs.1st and 4th Floor Vents.

In trial no.25 the firefighters entered at 2 mins. 30 secs., climbed to the roof level and opened the roof door at 5 mins. 37 secs. The PPV fan was started eleven seconds later, at 5 mins. 48 secs.. In trial no.28 the firefighters entered at 2 mins. 30 secs., and opened the downwind windows, on the 1st floor at 3 mins. 10 secs. and on the 4th floor at 4 mins. 28 secs. The PPV fan was started at 5 mins. 01 sec.

Overall, smoke clearance from the stairwell was faster in trial no. 28, in which the 1st and 4th floor vents were opened. Obscuration on the 1st floor was reduced faster in trial no. 28. However, on the 2nd and 4th floors there was little difference, the 2nd floor being slightly better in trial no. 28, but marginally worse during the later stages on the 4th floor. The visibility from the 1st half landing up the centre of the stairwell was better (cleared sooner) to all floors, except the roof level, in trial no. 28.

Regarding temperatures, the results of trial no. 28 were rather better although the differences in the temperatures experienced in the stairwell were generally fairly small, except for those on the 1st floor. Here, the temperature reduced sooner, and remained lower, in trial no. 28. There was little practical difference on the 2nd and 3rd floors, but on the 4th floor and at the roof level the maximum temperatures were slightly lower in trial no. 28.

8.3 Open All Downwind Vents, Fan on at 1st Vs. 1st and 4th Floor Vents, Fan on at 4th.

In trial no. 34 the firefighters entered at 2 mins. 30 secs. and opened each downwind vent as they came to it: 1st floor window at 3 mins. 02sec., 2nd floor window at 3 mins. 33 secs., 3rd floor balcony door at 4 mins. 11 secs., and 4th floor window at 4 mins. 50 secs. The PPV fan was started once the 1st floor window was open, at 3 mins. 06 sec. In trial no. 28 the firefighters entered at 2 mins 30 secs. and opened the downwind windows, on the 1st floor at 3 mins. 10 secs. and on the 4th floor at 4 mins. 28 secs. The PPV fan was started once both windows were open, at 5 mins. 01 sec.

The smoke obscuration was cleared rather faster on all three monitored landings in trial no. 34, in which each downwind window was opened as it was reached and the PPV fan started once the 1st floor window was opened. The greatest difference occurred on the 4th floor. Also, the visibility from the 1st half landing, up the centre of the stairwell was better (cleared sooner) to all levels, except the 1st floor which cleared ten seconds later. The temperatures in general reduced rather faster in trial no. 34, except for short periods on the 1st and 4th floors during which the differences were fairly slight.

8.4 Open 1st and 4th Floor Vents, Only: PPV on at 1st Floor Vent Vs. PPV on at 4th Floor Vent.

In both trials, nos. 28 and 31, the procedures were identical and the timings virtually identical. The only difference was the time at which the PPV was started. In each trial the firefighters entered at 2 mins. 30 secs. The 1st floor downwind window was opened at 3 mins. 10 secs. (3-09 in no. 31), and the 4th floor window at 4 mins. 28 secs., (4-26 in no. 31). In trial no. 28 the PPV fan was started at 5 mins. 01 sec., after the 4th floor window was opened, whereas in trial no. 31 the fan was started at 3 mins. 17 secs., just after the 1st floor window was opened.

Overall, the obscuration was reduced a little faster on each of the monitored landings in trial no. 31, in which the PPV fan was started earlier (once the 1st. floor vent was opened). The visibility from the first half landing up the centre of the stairwell was better (cleared sooner) to all floors in trial no. 31.

The temperatures on the stairwell landing were generally lower at any time on all floors, in trial no. 31. The only exception to this was during the earlier stages on the 3rd. floor landing, when the temperatures at all levels were slightly higher until about the time the 4th. floor vent was opened.

Again there appeared to be a clear benefit in ventilating the fire floor as soon as possible.

8.5 Effect of the 1st (fire) Floor Vent Being at the Opposite End of the Corridor.

A 1st floor and 4th window were opened in both of these trials. The procedures were effectively identical and the timings very similar. The difference was that, while in trial no.31 the normal downwind 1st floor stairwell window was opened, in trial no.36 a purpose-built 'window' of similar size (same cross-sectional area) was opened, remotely, at the opposite end of the corridor (into the main compartment of the building, which was itself ventilated as well as possible, all windows being open). The timing was as follows. The firefighters entered the stairwell at 2 mins. 30 secs. The 1st floor window was opened at 3 mins. 09 sec. (3mins. 06sec. in trial no.36). The PPV fan was started at 3 mins. 17 secs. (3mins. 26 secs. in trial no.26), and the 4th floor window was opened at 4 mins. 26 secs. (4 mins. 23 secs. in trial no.26).

The reduction in obscuration on the 1st floor was very similar in the trials, being very rapid in both. However, on the 2nd and 4th floors the smoke clearance was markedly faster in trial no.36 (1st floor vent at the opposite end of the corridor to the stairwell). This would be expected since the PPV fan, once operating, would allow little or no smoke to enter the stairwell. However, comparing the visibility from the 1st half landing up the centre of the stairwell gives a more confused picture: this cleared faster to the 1st and 2nd floors in trial no.31; to the 4th floor was faster in trial no.36, while no such comparison was possible for the 3rd floor or roof level.

The temperatures in the corridor reduced sooner in trial no.36. (The 1st floor vent was closer to the door of the fire room in this trial and the expected effect of the PPV fan, at the bottom of the stairwell would be to impeded the movement of hot smoke towards and into the stairwell.) However, on the 1st floor the temperatures were similar and even slightly higher in trial no.36. On the upper floors the temperatures, in general, peaked rather higher in trial no.36, but then reduced faster once the fan was working.

8.6 General Findings

It would appear that there would be little point in firefighters climbing to the highest level possible before opening a downwind vent. It was found that opening the downwind vent on the fire floor (1st floor) caused a rapid improvement on that landing in terms of visibility, and did not make matters any worse on the higher landings in respect of obscuration or temperatures.

When a vent was opened at the highest level, only, above the fire floor and the fan subsequently started, there was a short duration peak in the temperatures on each floor immediately after the fan was started. This peak was most evident on the higher floors (where the firefighters would be). On the 4th floor, at roof level and in some cases on the 3rd floor, the temperatures reached by this peak were somewhat higher than those reached in other trials in which a vent was opened at a lower level, at any time while the firefighters were in the stairwell. This effect was not experienced, to the same extent, in trials where a vent, or vents, was opened on a lower floor (fire floor or intermediate floor).

Assuming that the aim is to clear the stairwell of smoke as quickly as possible, no reason was found for doing anything other than opening each downwind vent as it is reached, starting with the fire floor.

In the trials in which the downwind vents on the fire floor and 4th floor landings were opened, it was found that visibility improved rather quicker, overall, when the fan was started as soon as the fire floor vent was opened (rather than after the 4th floor vent was opened). The temperatures in the stairwell were also rather lower, overall.

Opening a vent on the fire floor at the opposite end of the corridor, as opposed to opening that in the stairwell, and then opening the 4th floor landing vent, was found to improve the visibility in the stairwell faster, while the temperatures in the stairwell peaked rather higher but reduced more quickly, in general. This occurred because the effect was to stop the stairwell being the fire chimney, opening an alternative escape route for the hot smoke and gases.

9. TACTICAL VARIATIONS WITHOUT PPV

9.1 Highest Possible Vent, Only Vs. All Downwind Vents, as They Are Reached.

In trial no.27 the firefighters entered at 2 mins. 30 secs., climbed to the top of the stairs and opened the roof door at 5 mins. 36 secs. In trial no.35 the firefighters entered at 2 mins. 30 secs., ascended the stairs and opened each downwind window as they came to it: 1st floor window at 3 mins. 02 sec., 2nd floor window at 3 mins. 33 secs., 3rd floor window at 4 mins., 11 secs., and the 4th floor window at 4 mins. 50 secs.

The smoke obscuration was cleared better, overall, in trial no.35, in which the downstream window on each landing was opened as it was reached, according to the smoke obscuration meters. The visibility up through the centre of the stairwell showed little overall difference between the two trials.

The temperatures attained in the corridor were markedly higher in trial no.35, in which the vents were opened sequentially. (The fire burned more fiercely and went out sooner). On all floors the temperatures peaked, and decreased, sooner in trial no.35, although they reached rather higher values on the 1st and 2nd floors. On the 3rd and 4th floors and at the roof level the higher temperatures were experienced in trial no.27, and they remained high for longer.

9.2 Effect of The 1st Floor Vent Being at The Opposite End of The Corridor.

A 1st floor and a 4th floor window were opened in both of these trials. The procedures were effectively identical, and the timings very similar. The difference was that while in trial no.30 the normal downwind 1st and 4th floor stairwell windows were opened, in trial no.37 a purpose-built 'window' of similar size and shape (same cross-sectional area) was opened remotely at the opposite end of the corridor (into the main compartment of the building which was itself ventilated as well as possible, all windows being open). The timings were as follows. The firefighters entered the stairwell at 2 mins. 30 secs. The 1st floor window was opened at 3 mins. 09 sec. (3 mins. 06sec. in trial no.37), and the 4th floor window was opened at 4 mins. 26 secs. (4 mins. 23 secs. in trial no.37).

There was virtually no difference in the smoke clearance between the two trials. In both, the 1st floor landing cleared very quickly as soon as the 1st floor window was opened, irrespective of which end of the corridor this was, while the 2nd and 4th floor landings did not clear to any useful degree until after the fire went out. However, the visibility from the first half landing, up through the centre of the stairwell, improved, in general, rather faster in trial no.30, in which both vents were in the stairwell. The peak temperatures experienced in the stairwell were higher on all landings in trial no.37, in which the 1st floor vent was remote from the stairwell.

It would appear that, in trial no.37, once the 1st floor window was opened, an airflow was set up from the entry door to the 1st floor window causing less hot smoke, overall, to enter the stairwell, the flow being in the opposite direction in the corridor. Once the 4th floor landing window was opened this flow would be spoilt and the stairwell would subsequently act as a chimney.

9.3 General Findings

It would appear, on the evidence of these trials, that there would be little point in firefighters climbing to the highest level possible before opening a downwind vent. Opening vents sequentially, ie. entry door, 1st (fire) floor, 2nd floor etc., improved visibility in the stairwell rather sooner, but did result in higher temperatures being reached on the 1st and 2nd floors, although they were lower on the 3rd and 4th floor landings at roof level. Overall, sequential venting would appear to be the better option.

With regard to the position of the fire floor vent; when this vent was remote from the stairwell, on the fire floor near the other end of the corridor, the smoke took slightly longer to clear from the stairwell, and the temperatures experienced in the stairwell were somewhat higher on all landings. This implies that opening both vents (fire floor and 4th floor) in the stairwell may improve the conditions in the stairwell rather faster.

10. EFFECT OF PPV ONCE THE FIRE IS EXTINGUISHED

There appears little doubt that, once the fire is out, residual smoke can, in general, be removed from the stairwell faster using PPV than by natural ventilation alone. A Study of the results of all trials comparing the use of PPV with natural ventilation (including the earlier, short duration, ones), shows that the obscuration continued to fall, after extinction, faster when the fan was deployed. Also, there was a corresponding increase in the rate of 'air' temperature reduction.

However, it should be borne in mind that, in the trials, only vents on the downwind side of the stairwell were opened whereas in a real situation, in such a stairwell, firefighters would almost certainly open the vents on both sides when using natural ventilation to clear the stairwell.

Once the fire had been extinguished there would be nothing to prevent firefighters ascending the stairwell to open vents on the worst affected floor levels. The trials showed that opening a downwind vent on a particular landing had a relatively rapid effect, on that landing - when PPV was used. Therefore, if sequential smoke clearance were undertaken (one floor level at a time), the sequence could be determined by the firefighters according to the particular requirements of the situation.

DISCUSSION ON TRIALS

11.1 General

The whole series of trials was a learning process for FEU. It was not known at the outset how long it would take for the firefighters to climb the stairs, in conditions of zero visibility, to reach and locate each possible vent. In the first few trials the firefighters were asked to proceed in a 'natural' realistic manner and to open the specified vent as soon as they reasonably could. The resulting times were noted and, after consultation with the firefighters, were used as target times in subsequent trials where the same tactics were employed. During these subsequent trials a countdown was given over the Diktron system to one of the firefighters, leading up to each vent opening. This assisted the firefighters to pace themselves to some extent, although it was not the intention to cause them to hurry unduly. It was accepted that the times of vent opening would be most unlikely to be identical in a pair of similar trials. However, the differences, in the event, were small and were considered to be insignificant.

It was unfortunate that it was not discovered that the duration of the fire needed to be extended until after trial no. 24 had been completed. This was due to the fact that no results were available for study until after these trials had been completed. There had only been a one week period during which trials were not being undertaken during the period since trials began, and this was not sufficient to process the data and plot results for any of the trials (the emphasis was on preparation for the next trials period). Upon examining the data obtained, after trial no. 24, the decision was made not to use for analysis the results of any trial in which the fire went out within 30 seconds of the last vent being opened. This effectively meant not using the results of any trial prior to trial no. 25 for direct comparisons, although the information gained from them significantly influenced the choice of scenarios and conduct of the subsequent trials.

11.2 Variation in Rate of Burning of Trials Fires

That the average rate of burning of the fire varied quite widely from trial to trial is evident from the differences in the fire duration (see Table 2). When 20 litres of heptane was burned the fire durations varied from 4 mins. 37 secs. to 7 mins. 40 secs., and when 40 litres was burned it varied from 7 mins. 50 secs. to 10 mins. 28 secs. These extremes represent a large range of differences, which can only be explained by the vagaries of the natural wind and its effect in the fire room. One might expect that during the 2.5 minute period (trial no. 4, onwards) after ignition and before the ground floor stairwell door was opened there was a tendency for the fire to become oxygen starved to some extent, and the rate of burning to reduce as a result. The only way that fresh air could enter the fire room, before the entry door was opened , was from outside the building, via the holes in the outer, north and east, walls. However, there was no evidence of any relationship between the natural wind average velocity (direction and speed) and fire duration. Also, variations in the initial temperature of the fire room may have affected the fire's duration, the fuel burning faster when warmer.

However, once the stairwell entry door was opened, fresh air could also enter the building by this means and it appears likely that the subsequent ventilating tactics in the stairwell may have had some effect upon the duration of the fire. Certainly, the longest duration fires occurred when only the highest vents (roof door on 4th floor landing windows) were opened as outlet vents.

Also, the measured radiation flux varied widely, in all cases, during a single trial. In general, the fires appear to have died down during the period from 2 minutes to 5 minutes after ignition and then to subsequently increase in ferocity to about their original level. The lowest point in the flux meter reading occurred, in general, after the entry door was open, and the flux did not increase markedly until this door had been open for a minute or so.

However, it was considered that these variations would be unlikely to affect the overall trials results in any fundamental way: burning the same quantity of the same fuel each time could be expected to liberate similar quantities of smoke and heat, overall.

11.3 Effect of The Natural Wind

All that can be said with certainty about the effect of the natural wind upon smoke clearance in these trials is that it was not predictable. During each trial the wind was measured at a point which was roughly central above the building, and 7 metres above the roof (and hence well above the raised structure housing the lift winding gear). Wind speed and direction, continuously recorded over the duration of each trial, were averaged and combined to give an average velocity during each trial, and this was compared with the other data obtained from that trial. No clear relationships were evident, and it was concluded that the actual airflows around the building, and hence in the vicinity of the vents and doorways were complicated by the building itself.

This implies that accurate information on the current average wind speed and direction in the general area of an incident may be of little use to firefighters in assessing the likely effect on local, tactical, smoke clearance within a building, where tall buildings are involved, or in an area surrounded by tall buildings, trees, etc. It would be of more direct value to them to know how the air is moving in the immediate vicinity of the possible vents, but, in practice, this can generally only be ascertained by a 'suck it and see' approach.

11.4 Positions of The Smoke Obscuration Meters

The positions of the three smoke obscuration meters in the stairwell were dictated by their size and shape and that of the stairwell landings. They could not be positioned where they would impede access to the main compartment from the stairwell on any floor, nor on the 3rd floor where they would have impeded access to the balcony. They needed to be placed as close as possible to the wall at one side of the landings where they were deployed to enable the firefighters to pass them in conditions of zero visibility. This meant that they were quite close to the window, though below the opening part. It was inevitable that in some trials this adjacent window would be used as a vent, when the wind was such that it was on the downwind side of the stairwell, and in others the window on the far side of the stairwell would be used as the vent, in which case the smoke obscuration meter would be remote from the vent. It had to be accepted that the positioning of the smoke obscuration meters was not ideal, and there was no way of knowing whether this made any significant differences to the trials results.

11.5 Relationship between Results from Smoke Obscuration Meters and Stairwell Torches

In general the results from these two, quite different, measuring systems correlated with each other but did yield rather different information. The smoke obscuration meters each sampled a relatively small volume on each of the three selected landings, while the torches gave more of an overall picture, monitoring the smoke logging up through the centre of the stairwell.

The video camera, mounted centrally on the handrail of the first half landing (some 3.2 metres above ground floor level), was position to 'see' directly each of the five torches fixed to the handrail at each landing level. This system could only tell whether a certain torch was visible at any time; if not, it could not tell why not (relatively thin smoke all the way between the two, or a local thin layer of dense smoke at some level between the two, for example). The results showed that the torches were often visible to the camera intermittently, sometimes for a period of several minutes, before they remained continuously visible. This would appear to indicate that the smoke in the stairwell was swirling.

The results from the stairwell torches were useful in that they did show that, overall, the use of PPV did clear the stairwell of smoke faster than natural ventilation in all pairs of 'similar' trials (including the earlier trials, for which no direct comparisons were made. See Table 2).

11.6 Effect of Pressurising The Stairwell.

Throughout the trials it was the conditions in the stairwell, alone, that were being examined. However, in a real incident there may be other considerations to be taken into account by the officer in charge. For example, Section 8.4 shows that, in a pair of trials where downwind vents were opened on the 1st and 4th floors and the fan started when the 1st floor vent was opened in one, but not until the 4th floor vent was opened in the other, the earlier fan deployment improved the conditions in the stairwell faster. However, this early use of the PPV fan, before a vent at high level has been opened, may pressurise the stairwell to a greater extent (it did in the trials) and cause more smoke to leak from the stairwell into other parts of the building, around doors, etc. or through open internal doorways, particularly on the higher floors. Depending upon the particular circumstances, it may be necessary for firefighters to ascend to the upper floors to ensure that internal doors are closed before pressurising the stairwell, in which case they may also be able to open external vents at high levels in the stairwell.

11.7 Positions of Possible Vents.

When a stairwell such as that used in the trials, with a window or balcony door, at each side, on each landing, is to be cleared of smoke by means of natural ventilation, only, it is most likely that firefighters would open both vents on any landing, since, if any wind is blowing, it would be likely that one would be upwind and the other downwind, to some extent. However, such stairwells are probably less common than those with possible vents at one side, only. For this reason, only the vents at one side of the stairwell, the apparently downwind side, were opened in the majority of trials, both with and without PPV.

12. CONCLUSIONS

12.1 General

Guidance on ventilation, in general terms, is given in the 'Fire Service Manual - Volume 2[4].

Brigades should look upon the PPV fan as simply another tool in their armoury. It is a tool whose use needs to be carefully considered in any given situation. It has the capability of rapidly improving the situation in some instances, but it can also make things worse. Brigades have used natural ventilation to good effect for many years, and there is a vast pool of experience within the brigades in this field. However, brigades have much less experience of using forced ventilation offensively, while the fire is burning. The PPV fan provides, in effect, an extension to this basic technique, giving the firefighters some further options.

Each fire situation, and specifically whether or not to deploy PPV, would need to be considered on its particular merits. These trials have shown that, while a PPV fan may, usually, be able to improve conditions in a stairwell, or at least in a particular part of a stairwell, it is virtually impossible to predict exactly what the effect of the fan will be in a given situation with any degree of certainty. For this reason, it would be advisable for a firefighter to stay with the fan when deployed on the fireground so that it can be quickly switched off if it was found to be having an adverse effect.

Good fireground communications would be essential where a PPV fan was deployed, particularly between the firefighters inside the fire building and fan operator. The continued use of the fan should depend upon the feedback from the firefighters inside the building.

It is clear that in a real situation where firefighters need to ventilate a building in order to search and/or fight the fire, the inlet and outlet openings should be carefully chosen. If natural ventilation, only, is to be used there is no choice about which side of the building will be the inlet - it will be the upwind side. When a PPV fan is available, the same basic rule will still apply. Any natural wind should be used to advantage if possible, and the PPV fan should be thought of as a means of assisting, or augmenting, the natural wind.

12.2 Findings from The Trials.

12.2.1 Comparing The Use of PPV with Natural Ventilation.

In general, PPV improved the visibility in the stairwell to some extent. In some cases the improvement was marked, in others it was fairly slight. In none of the pairs of trials compared with each other did the use of PPV make the visibility in the stairwell worse, overall.

Opening the downwind vent on the 1st floor landing (the fire floor) caused a fairly rapid reduction in the smoke obscuration and air temperatures on that landing, both with and without PPV. This effect was generally faster with PPV. In either case, there was no discernible effect on the higher, unventilated landings.

When all of the downwind vents were opened as they were reached, the use of PPV made little difference to the smoke obscuration on any floor except the fire floor (which was cleared rather faster with PPV) until after the fire went out. It then cleared the stairwell faster than natural ventilation.

The temperatures in the corridor were reduced somewhat by the use of PPV, while the fire was burning. In all six scenarios considered, the corridor temperatures were broadly similar when the fan was started and, in all cases, PPV reduced the temperature to below the corresponding natural ventilation temperatures, or maintained them at very similar levels.

The temperatures in the stairwell on the 1st floor and above were reduced more by PPV once the appropriate outlet vent had been opened.

Even though the fire grew once ventilation commenced, and fresh air was introduced, the temperatures in the fire room, also, appear to have been generally reduced when the PPV fan was switched on while the fire was burning.

12.2.2 Comparing Tactics Using PPV.

It would appear that there would little point in firefighters climbing to the highest level possible before opening a downwind vent. It was found that opening the downwind vent on the fire floor (1st floor) caused a rapid improvement on that landing in terms of visibility, and did not make matters any worse on the higher landings inrespect of obscuration or temperatures.

When a vent was opened at the highest level, only, above the fire floor and the fan subsequently started, there was a short duration peak in the temperatures on each floor immediately after the fan was started. This peak was most evident on the higher floors (where the firefighters would be). On the 4th floor, at roof level and in some cases on the 3rd floor, the temperatures reached by this peak were somewhat higher than those reached in other trials in which a vent was opened at a lower level, at any time while the firefighters were in the stairwell. This effect was not experienced, to the same extent, in trials where a vent, or vents, was opened on a lower floor (fire floor or intermediate floor).

Assuming that the aim is to clear the stairwell of smoke as quickly as possible, no reason was found for doing anything other than opening each downwind vent as it is reached, starting with the fire floor.

In the trials in which the downwind vents on the fire floor and 4th floor landings were opened, it was found that visibility improved rather quicker, overall, when the fan was started as soon as the fire floor vent was opened (rather than after the 4th floor vent was opened). The temperatures in the stairwell were also rather lower, overall.

Opening a vent on the fire floor at the opposite end of the corridor, as opposed to opening that in the stairwell, and then opening the 4th floor landing vent, was found to improve the visibility in the stairwell faster, while the temperatures in the stairwell peaked rather higher but reduced more quickly, in general.

12.2.3 Comparing Tactics Using Natural Ventilation

It would appear, on the evidence of these trials, that there would be little point in firefighters climbing to the highest level possible before opening a downwind vent. Opening vents sequentially, ie. entry door, 1st (fire) floor, 2nd floor etc., improved visibility in the stairwell rather sooner, but did result in higher temperatures being reached on the 1st and 2nd floors, although they were lower on the 3rd and 4th floor landings and at roof level. Overall, sequential venting would appear to be the better option.

With regard to the position of the fire floor vent, when this vent was remote from the stairwell, on the fire floor near the other end of the corridor, the smoke took slightly longer to clear from the stairwell, and the temperatures experienced in the stairwell were somewhat higher on all landings. This implies that opening both vents (fire floor and 4th floor) in the stairwell may improve the conditions in the stairwell rather faster.

12.3 Implications for Brigades.

In the particular case of a non-pressurised stairwell, it may be considered advantageous to use PPV for one of several, basically different, reasons. These reasons could be:

a. To assist firefighters to reach the fire floor, locate and fight the fire.

b. To clear the whole of the stairwell of smoke.

c. To pressurise an initially clear stairwell in order to keep it clear for use as an escape route, and/or to control the direction of smoke movement (and possibly fire spread).

The results of these trials suggest that if the aim is simply to assist in getting firefighters to the fire, then opening a downwind vent on the landing of the fire floor and then deploying the PPV fan at the ground floor entry door to the stairwell can have a very rapid beneficial effect on that landing. However, this may agitate the smoke higher up the stairwell, causing swirling and assisting its spread through the upper floors.

If the aim is to clear the whole stairwell of smoke, it would seem to be necessary to open an outlet vent, or vents, as high as possible in the stairwell while deploying the fan at the ground floor. However, the trials results showed that, overall, rather faster smoke clearance (and tempereature reduction) was achieved by opening a downwind vent at each landing level from the fire floor upwards, while ascending, than by opening the highest (door sized) vent only, the PPV fan being started once the fire floor vent was open.

If the aim is to ensure that smoke does not permeate into an initially clear stairwell, the stairwell could be pressurised by deploying the fan in the ground floor doorway while keeping all vents in the stairwell closed. While reducing the likelihood of smoke entering the stairwell, this could possibly have an unpredictable effect upon smoke movement, and possibly fire spread, in other parts of the building if the use of PPV is uncontrolled. It is advisable here, also, to create an outlet vent before pressurising the stairwell. A small vent will make it possible to keep the stiarwell pressurised while clearing smoke on the fire floor. A larger vent would result in lower pressure in the stairwell with the possibility of smoke leaking into it.

While it is clear that when the supply of oxygen to a fire is increased, by the building being opening up, the fire will begin to burn more fiercely, there was no evidence in these trials that the use of PPV caused the fire to burn any more fiercely than with natural ventilation. The overall average times to extinction with and without PPV were virtually identical.

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NOTES

1. 'Tempest Power Blower' style TGB 244 (24") incorporating 5HP. Tecumseh petrol engine (unleaded), purchased from Fireater Ltd., Fireater House, South Denes Road, Gt. Yarmouth, Norfolk NR30 3QP.

2. 'Visible Emissions Monitor' - model 250, supplied by Skil Controls Ltd., Greenhey Place, East Gillibrands, Skelmersdale, Lancs.

3. Manufactured by Aston Magna Engineering Ltd., Units 86-92 Northwick Park Business Centre, Blockley, Moreton-in-Marsh, Glos. GL56 9RF, to FEU drg. no. FEU-1-248 and associated drawings.

4. Unistrut 40x40, supplied by City Electrical Factors Ltd., Unit 5, Western Road Industrial Estate, Stratford-on-Avon, Warks. CV37 0AH.

5. Leister Longlife Blower - single phase, supplied by Welwyn Tool Co. Ltd., 4 South Mundells, Welwyn Garden City, Herts. AL7 1EH.

6. Silicon tubing. 12.7mm.IDx19.1mm.OD. non-reinforced. (Product code:39 603.13) supplied by Arco M.T.M. Ltd., Unit 8A/8B, Point 4, Second Way, Avonmouth, Bristol BS11 8DF.

7. Sony DXC-102.P. colour CCD video camera, supplied by Sony (UK) Ltd., Sony House, South Street, Staines, Middx. TW18 1BR.

8. Pentax 4.8mm fl.8 - A1 lens, supplied by Pentax (UK) Ltd., South Hill Ave., South Harrow, Middx. HA2 0LT.

9. Housing components manufactured by P. J. Hare (Tooling division), Great Western Road, Cheltenham, Glos. GL50 3QW to FEU drawing no. FEU-1-102 and associated drawings. Assembled and commissioned by FEU.

10. Bardic - 3 cell - intrinsically safe, manufactured by Chloride Standby Systems Ltd., William St., Southampton, S09 1XN.

11. Type K. thermocouple, extension cable, PVC coated, fitted with mini K type plugs and sockets. Cable 16/0 2VX screened drawin. 300mm. tails each end. All supplied by Minta International Ltd., Cadick Road, Knowsley Industrial Park (south), Knowsley, Prescot, Merseyside L34 8HP.

12. FCO 143 range analogue Micromanometer - model 2 range ± 1/10/10 Pascals 0-12 M/S., supplied by Furness Controls Ltd., Beechin Road, Bexhill, East Sussex TN39 3LJ.

13. Medtherm heat flux transducer type 64010, supplied by Parr Scientific Ltd., 594 Kingston Road, Raynes Park, London.

14. DAB pump 'Jet 100m' - 110V.-50Hz.-KG.16.5 supplied by Specialist Pumping Services, Walkers Yard, Castle Road, Kidderminster DY11 6TH.

15. Wind speed and direction indicator, type D.600/120., supplied by Vector Instruments Ltd., Marsh Road, Rhyl, Clwyd.

16. Lo-con felt insulation, (96 Kg/M^3), supplied by Warren Bestobell Ltd., Unit 11, Severnside Trading Estate, Textilose Road, Trafford Park, Manchester M17 1LL.

17. Woven glass fibre curtains loaned by the Fire Service College: manufacturer and source unknown, and stated to be now unobtainable.

18. XL Heptane supplied by Chemitrade, Station House, 81-83, Fulham High Street, London SW6 3JW.

19. Reduced flame Roman candle, electric ignition - '1231-A.-2second GERB.' supplied by Le Maitre (Sales) Ltd., 6, Forval Close, Wandle Way, Mitcham, Surrey CR4 4NE.

20. Bilge pump, model HD supplied by Plastic Pumps Ltd., Unit 3, 60, High Street, Hampton Wick, Kingston-upon-Thames, Surrey KT1 4DB.

21. Protective refractory tiling supplied by Penn Refractories Ltd., Dudley Road, Lye, Stourbridge, West Midlands.

22. Akron Marauder hosereel gun, set to give a 45° inc. spray cone.

23. Diktron line communication system with headset microphone. Diktron Developments, Highgate Square, Birmingham, West Midlands B12 0DT.

REFERENCES

1. FRDG publication no. 6/95 'An Assessment of the Effectiveness of Removable Pavement Lights when Fighting a Basement Fire'. J G Rimen

2. FRDG publication no. 17/96 'An Assessment of the Use of Positive Pressure Ventilation in Domestic Properties'. J G Rimen

3. FRDG publication no. 6/94 'A Survey of Fire Ventilation'. A Hay, Warrington Fire Research Consultants

4. Fire Service Manual - Volume 2 - Fire Service Operations. 'Compartment Fires and Tactical Ventilation'. HMSO

TRIAL NO.	METHOD (Firefighter Briefing)	ACTUAL EVENT TIME (Ignition = t=o.)	FAN USED
1	Firefighters enter at t=1-00. Go to highest level. (Roof door) at realistic pace, open roof door. PPV fan on once roof door open.	Entry = t=1-00 Roof door open at t=5-36. Fan on at t=5-51	Yes
2	As no.1, but no PPV	Firefighters enter at t=1-00. Open door at t=5-36.	No
3	As nos. 1 and 2, but PPV on at entry.	Firefighters enter at t=1-00. PPV on at t=1-18. Open roof door at t=5-36.	Yes
4	Enter at t=2-30. Open roof door at t=5-36. PPV fan on when top door open	Firefighters enter at t=2-30. Open roof door at t=5-36. PPV fan on at t=5-44.	Yes
5	Void. The fire went out prematurely. (Repeated as No.6)		
6	Enter at t=2-30 PPV on at t=2-30 Open east window on: 1st, 2nd, 3rd. (door) and 4th floors, while ascending.	Firefighters enter at t=2-30. PPV on at t=2-36. 1st open at t=3-02. 2nd " at t=3-33. 3rd " at t=4-11. 4th " at t=4-50.	Yes
7	As no.6, but no PPV	Firefighters enter at t=2-30. 1st open at t=3-05. 2nd " at t=3-47. 3rd " at t=4-30. 4th " at t=5-12.	No
8	Enter at 2-30, PPV on at t=2-30. Open <u>both</u> windows (or doors) on 1st, 2nd, 3rd and 4th floors, while ascending.	Firefighters enter at t=2-30. 1st - E - opened at t=3-01 " - W - " 3-18 2nd - E - " 3-48 " - W - " 3-58 3rd - E - " 4-32 " - W - " 4-37 4th - E - " 5-08 " - W - " 5-16.	Yes

Table 1. List of Trials *(Sheet 1 of 5)*

TRIAL NO.	METHOD (Firefighter Briefing)	ACTUAL EVENT TIME (Ignition = t=o.)	FAN USED
9	As no.8, but no PPV.	Firefighters enter at t=2-30. 1st - E - opened at t=2-59 " - W - " 3-10 2nd - E - " 3-47 " - W - " 3-55 3rd - E - " 4-32 " - W - " 4-35 4th - E - " 5-08 " - W - " 5-16.	No
10	Enter at t=2.30 PPV on at t=2-30 Open downwind windows on 1st and 4th floors, only	Firefighters enter at t=2-30 PPV fan on at t=2-37 1st -W - opened at t=3-09 4th -W - " at t=4-26	Yes
11	As no.10, but no PPV	Firefighters enter at t=2-30 1st -W - opened at t=3-06 4th -W - " at t=4-23	No
12	Void - top (roof) door opened slightly		
13	Enter at 2-30, open both 4th floor windows at t=5-36. PPV fan on when windows are open.	Firefighters enter at t=2-30 Open both 4th floor windows at t=7-22. Fan started at t=7-36.	Yes
14	As 13, but no PPV.	Firefighters enter at t=2-30 Both 4th floor windows open at t=7-25.	No
15	Enter at t=2-30 Open downwind balcony door (3rd floor) at t=5-36. PPV fan on when door open	Firefighters enter at t=2-30. 3rd floor - w. door open - 5-38. PPV fan on at t=5-43.	Yes
16	As no.15, but no PPV fan	Firefighters enter at t=2-30. 3rd floor (W) door open - 5-37.	No
17	Enter at t=2-30. Open both 3rd floor (balcony) doors at 5-36. PPV fan on when doors are open.	Firefighters enter at t=2-30. 3rd floor doors open at 5-37. PPV fan on at 5-43.	Yes
18	As no. 17, but no PPV fan.	Firefighters enter at t=2-30. 3rd floor doors open at 5-37.	No

Table 1. List of Trials *(Sheet 2 of 5)*

TRIAL NO.	METHOD (Firefighter Briefing)	ACTUAL EVENT TIME (Ignition = t=o.)	FAN USED
19	Void - Top door opened prematurely - at start - (modified for future trials)		
20	Enter at t=2-30. Open 1st floor downwind (W) at t=3-12 open roof door at 5-36. PPV fan on when 1st floor window is open.	Firefighters enter at t=2-30. 1st floor window opened at 3-12. PPV fan on at 3-19. Roof door opened at 5-36.	Yes
21	Repeat of no.20, but with windows open in main compartment. On 2nd, 3rd and 4th floors..	Firefighters enter at 2-30. 1st floor window open at 3-12. PPV fan on at 3-20. Roof door opened at 5-36.	Yes
22	As no. 20, but no PPV fan and inspect main compartment smokelogging	Firefighters enter at 2-30. 1st floor window opened at 3-12. Roof door opened at 5-36.	No
23	Enter at 2-30: PPV fan into doorway, open 1st floor downwind window at 3-12. Open roof door at 5-36. PPV fan on when 1st floor window open.	Firefighters enter at 2-30. 1st floor window opened at 3-13. PPV fan - <u>in doorway</u> - on at 3-27. Roof door opened at 5-36.	Yes
24	Enter at 2-30: PPV fan into doorway. Open roof door at 5-36. Start PPV fan when roof door is open.	Firefighters enter at 2-30. Roof door opens at 5-36. PPV fan - <u>in doorway</u> - on at 5-43.	Yes
25	Enter at t=2.30: roof door open at 5-36 PPV fan on when door open.	Firefighters enter at 2-30. Roof door fully open at 5-37. Fan on at 5-48.	Yes
26	Void - fire went out prematurely		
27	As no.25 but no fan.	Firefighters enter at 2-30. Roof door open at 5-36.	No
28	Enter at 2-30: open 1st floor downwind window at 3-09, 4th floor window at 4-26. PPV fan on when 4th floor open.	Firefighters enter at 2-30. 1st (E) open at 3-10. 4th (E) open at 4-28. PPV on at 5-01.	Yes

Table 1. List of Trials *(Sheet 3 of 5)*

TRIAL NO.	METHOD (Firefighter Briefing)	ACTUAL EVENT TIME (Ignition = t=o.)	FAN USED
29	Void - fire went out prematurely		
30	As no.28, but no fan	Firefighters enter at 2-30. 1st floor open at 3-09 4th floor open at 4-26.	No
31	As no. 28, but fan on when 1st floor downwind window open	Firefighters enter at 2-30 1st floor (E) open at 3-09. PPV fan on at 3-17. 4th floor open at 4-26.	Yes
32	Void - PPV fan malfunctioning		
33	Void- fire went out at 2-38		
34	Enter at 2-30 1st floor downwind window open at 3-02, 2nd floor downwind window at 3-33, 3rd floor door open at 4-11, 4th floor window open at 4-50 PPV on when 1st floor open	Firefighters enter 2-30 1st open at 3-02 PPV on at 3-06 2nd open at 3-33 3rd open at 4-11 4th open at 4-50	Yes
35	As no. 34 - no PPV	Firefighters enter at 2-30 1st open at 3-02 2nd open at 3-33 3rd open at 4-11 4th open at 4-50	No
36	Enter at 2-30 1st floor "window" at S. End of corridor open at 3-06 4th floor downwind window at 4-23 PPV on when 1st floor "window" open	Firefighters enter at 2-30 1st floor "window" open 3-06 PPV on at 3-26 4th floor "window" open 4-23	Yes

Table 1. List of Trials *(Sheet 4 of 5)*

TRIAL NO.	METHOD (Firefighter Briefing)	ACTUAL EVENT TIME (Ignition = t=o.)	FAN USED
37	As no. 36 - no PPV	Firefighters enter 2-30 1st floor "window" open 3-06 4th floor window open 4-23	No
38	Enter at 2-30 Open both 4th floor windows at 5-12 PPV on when windows open	Firefighters enter 2-30 Both 4th floor windows open 5-12 PPV on - 5-21	Yes
39	Void - fire went out (at 3-35)		
40	As no.38 - no PPV.	Firefighters enter 2-30 Both 4th floor windows open - 5-12	No

Table 1. List of Trials *(Sheet 5 of 5)*

TRIAL NO.	TORCH FIRST VISIBLE AT...., ON					FIRE OUT AT	PPV USED
	1ST	2ND	3RD	4TH	ROOF LEVEL		
1	Never lost	5-54	6-14	6-40	9-04	7-20	Yes
2	5-00	5-51	6-10 cont. from 9-55	Unknown - video stopped at 12-55		7-00	No
3	Never lost	6-12	8-16	9-19	10-12	6-27	Yes
4	3-16 cont. from 4-05	5-52	6-03 cont. from 8-40	6-12 cont. from 8-50	9-42	7-40	Yes
5	VOID						
6	2-41	3-55 cont. from 4-17	7-17	8-40	11-00	4-50	Yes
7	3-09	5-08 cont. from 6-49	10-34	12-14	14-32	4-45	No
8	2-45	4-30 cont. from 5-03	7-08	8-22	9-38	4-53	Yes
9	3-03	7-07	12-13	11-28	11-44	4-29	No
10	2-41	4-40 cont. from 5-00	6-25 cont. from 6-45	7-58	9-37	5-20	Yes
11	3-07	6-07	8-44 cont. from 9-30	11-18	12-40	4-37	No

Table 2 *Results from the stairwell torches.* *(sheet 1 of 4)*

TRIAL NO.	TORCH FIRST VISIBLE AT...., ON					FIRE OUT AT	PPV USED
	1ST	2ND	3RD	4TH	ROOF LEVEL		
12	VOID						
13	2-54 cont. from 4-39	7-52	8-14	8-36 cont. from 8-56	8-38 cont. from 10-24	4-45	Yes
14	3-03 cont. from 4-16	7-50	9-32	10-41	11-19 cont. from 11-25	5-23	No
15	4-33 cont. from 5-43	5-56	6-06 cont. from 7-54	9-50 cont. from 14-00	14-36 cont. from 15-16	6-47	Yes
16	5-15	5-58 cont. from 6-10	8-17 cont. from 9-26	13-07 cont. from 13-46	16-05 cont. from 16-44	5-19	No
17	4-54 cont. from 5-39	5-51 cont. from 6-26	6-02 cont. from 6-20	9-14 cont. from 10-13	14-18 cont. from 15-22	6-50	Yes
18	5-16	6-12 cont. from 6-35	7-48 cont. from 8-30	14-14 cont. from 16-30	16-47 cont. from 17-42	5-16	No
19	VOID						
20	2-44 cont. from 3-30	5-36	6-07	6-37	6-58	5-01	Yes
21	2-36 cont. from 3-16	5-37	6-27 cont. from 6-50	6-48 cont. from 7-13	7-47 cont. from 7-57	5-33	Yes

Table 2 *Results from the stairwell torches* *(Sheet 2 of 4)*

TRIAL NO.	TORCH FIRST VISIBLE AT...., ON					FIRE OUT AT	PPV USED
	1ST	2ND	3RD	4TH	ROOF LEVEL		
22	2-38 cont. from 3-19	5-49 cont. from 6-41	7-38 cont. from 8-43	8-45 cont. from 9-03	9-00 cont. from 9-10	4-59	No
23	3-16	5-38	6-02	6-23	6-52	5-27	Yes
24	4-13 cont. from 5-26	5-49	6-57 cont. from 7-12	7-30	7-44 cont. from 7-52	5-36	Yes
25	Never lost	10-05	10-35	10-57	11-08	10-16	Yes
26	VOID						
27	2-44	5-40 cont. from 10-32	5-55 cont. from 11-26	N/A	12-23	9-53	No
28	2-55	8-36	9-26	10-28	11-58	8-31	Yes
29	VOID						
30	Never lost	8-20	9-08	10-05 cont. from 10-29	12-25	8-01	No
31	2-40	4-39 cont. from 8-50	9-32	10-01	N/A	8-50	Yes
32	VOID						
33	VOID						

Table 2 *Results from the stairwell torches* *(Sheet 3 of 4)*

TRIAL NO.	TORCH FIRST VISIBLE AT...., ON					FIRE OUT AT	PPV USED
	1ST	2ND	3RD	4TH	ROOF LEVEL		
34	3-05	3-35 cont. from 8-07	9-08	9-45	10-50	8-33	Yes
35	3-12	9-00	10-57	11-03	13-24	8-27	No
36	3-04	9-08	N/A	7-40	8-04	7-50	Yes
37	3-14	8-43	8-43	N/A	12-44	8-16	No
38	3-32	5-24 cont. from 9-36	5-33 cont. from 10-16	5-46 cont. from 10-48	11-15	9-41	Yes
39	VOID						
40	3-40	10-52	11-21	14-35	15-00	10-28	No

NOTE: In the above table the the times stated, in minutes and seconds from ignition,indicate when the torch on each floor level first became visible. In cases where it subsequently disappeared again, a second time is given, when the torch reappeared to remain visible.

The 'fire out' times give the times to the last flame becoming extinct.

Table 2 *Results from the stairwell torches* *(Sheet 4 of 4)*

TRIAL NO.	FIRE ROOM		CORRIDOR		LANDING LEVEL									
					1ST		2ND		3RD		4TH		'ROOF'	
	3'	6'	3'	6'	3'	6'	3'	6'	3'	6'	3'	6'	3'	6'
25	255	420	155	210	36	62	60	68	38	40	33	33	31	33
26	VOID													
27	330	445	185	240	40	65	62	70	48	48	41	41	39	42
28	345	460	185	230	42	60	57	66	40	45	28	30	25	27
29	VOID													
30	315	450	185	240	42	60	56	64	52	53	33	39	31	34
31	310	465	165	240	44	63	54	65	32	33	24	26	24	25
32	VOID													
33	VOID													
34	340	440	195	240	44	67	60	67	35	36	25	29	24	26
35	365	450	215	255	53	78	67	76	44	46	32	38	31	34
36	395	500	155	220	47	68	62	70	28	33	23	25	21	22
37	365	490	160	230	52	73	63	72	52	52	38	45	36	41
38	295	410	155	220	45	72	63	70	38	41	32	34	27	29
39	VOID													
40	395	465	225	255	57	77	78	87	63	67	39	44	42	47

Table 3. *Highest instantaneous temperatures recorded during trials no. 25~40 inc.*

POSITION	6 FEET °C	3 FEET °C	OCCURRED IN TRIAL NO.
Fire room	500	395	36
Corridor	255	225	40
1st floor landing	78	57	35 and 40
2nd floor landing	87	78	40
3rd floor landing	67	63	40
4th floor landing	45	41	27 and 37
'Roof' door	47	42	40

Table 4. *Maximum instantaneous temperatures recorded at any time, in any trial.*

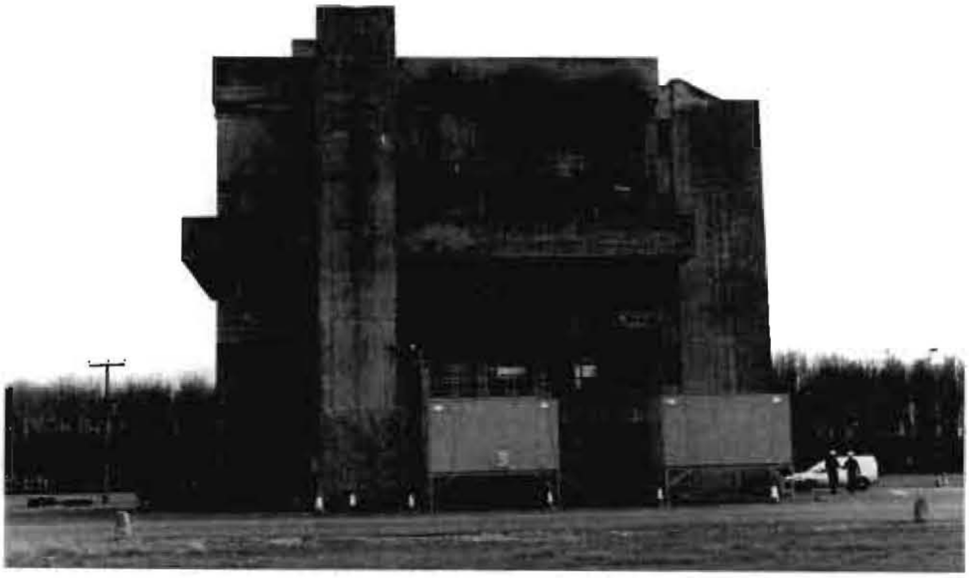


Figure 1 Industrial 'A' Building from the North

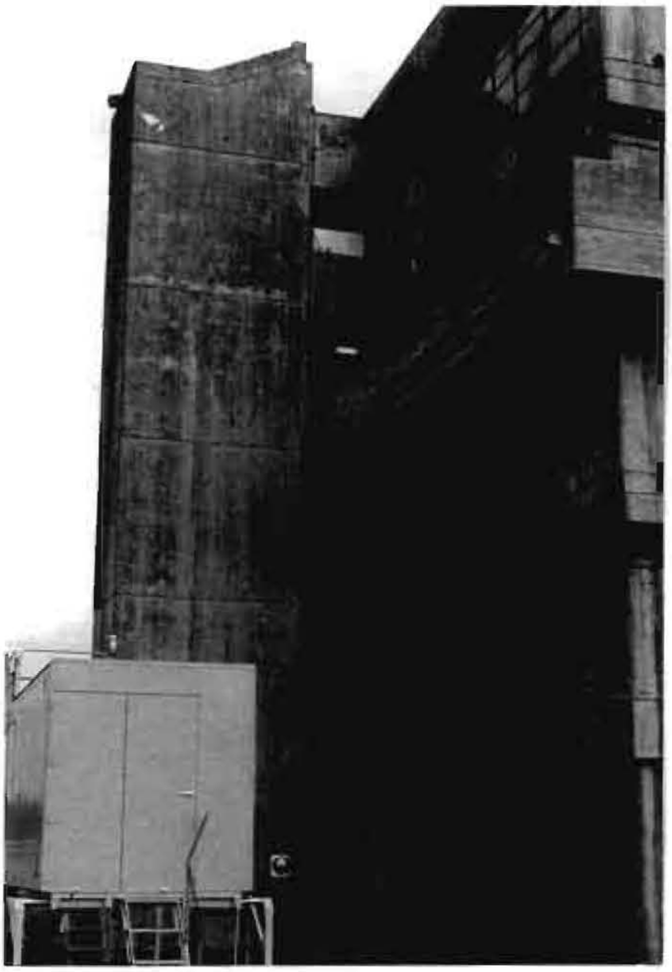


Figure 2 Industrial 'A' Building Showing the North Stairwell Entry Door and Landing Windows

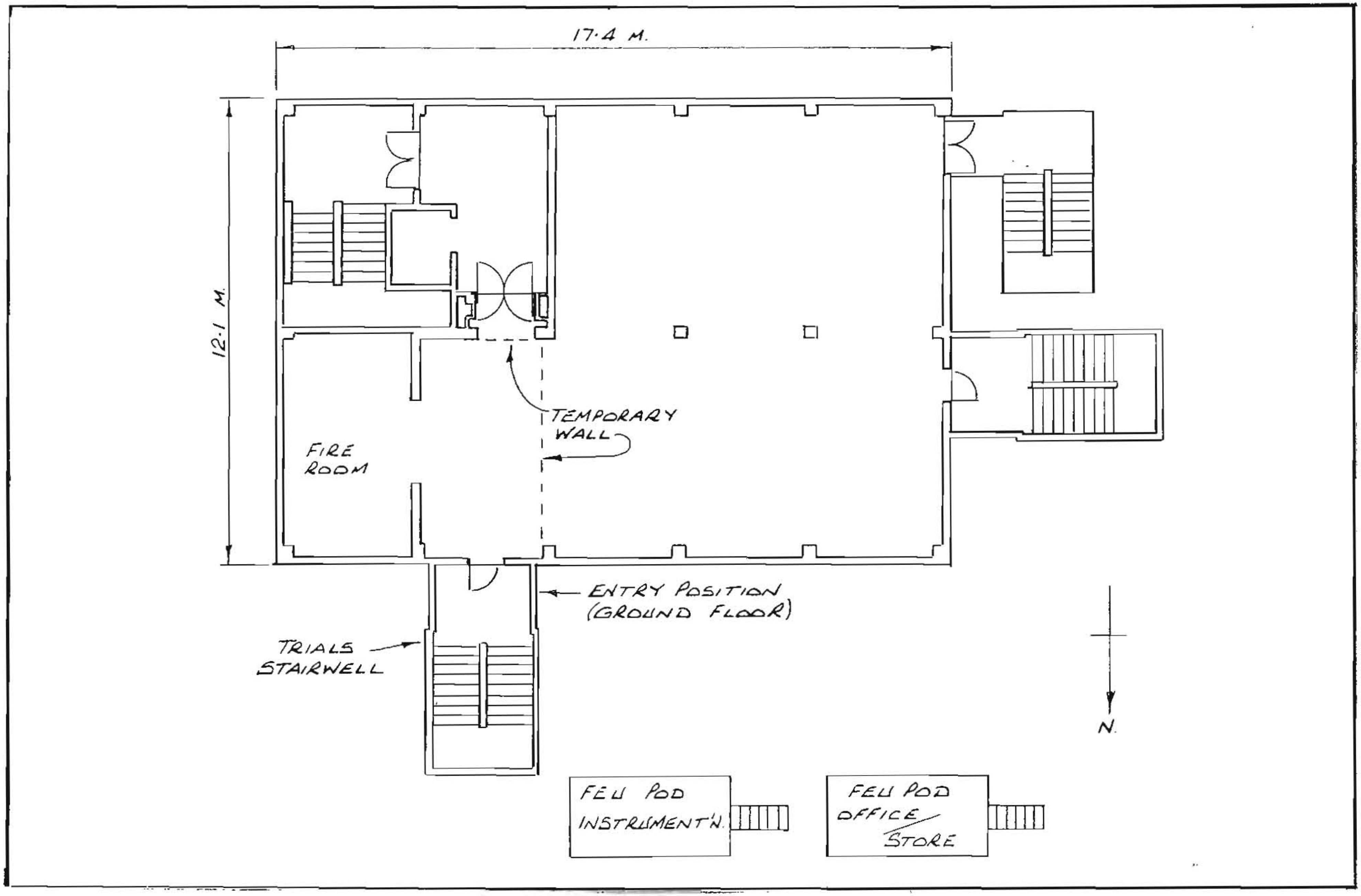


Figure 3 Industrial 'A' Building - Plan Section at First Floor

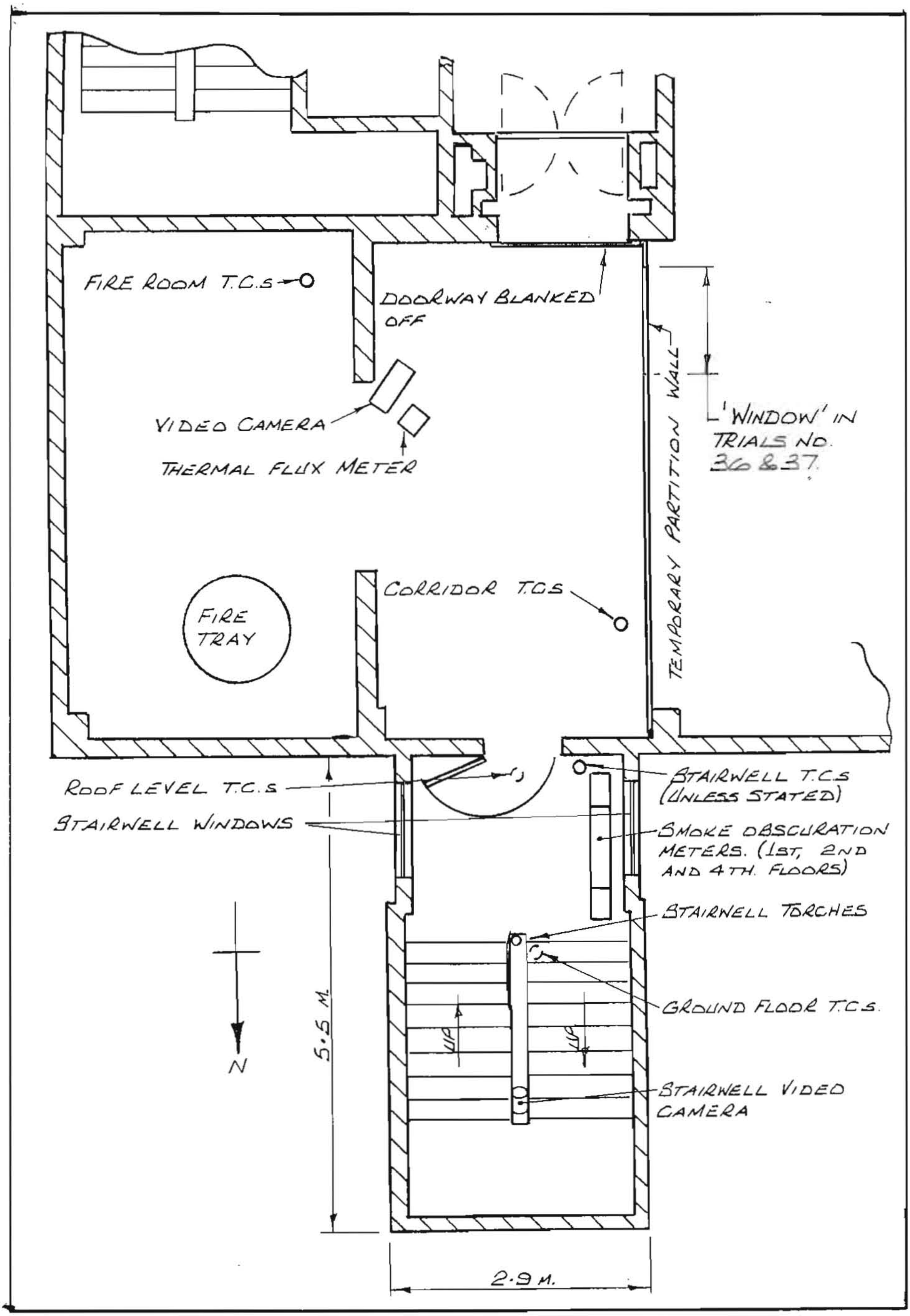


Figure 4 Plan of First Floor Showing Positions of Fire Instruments etc

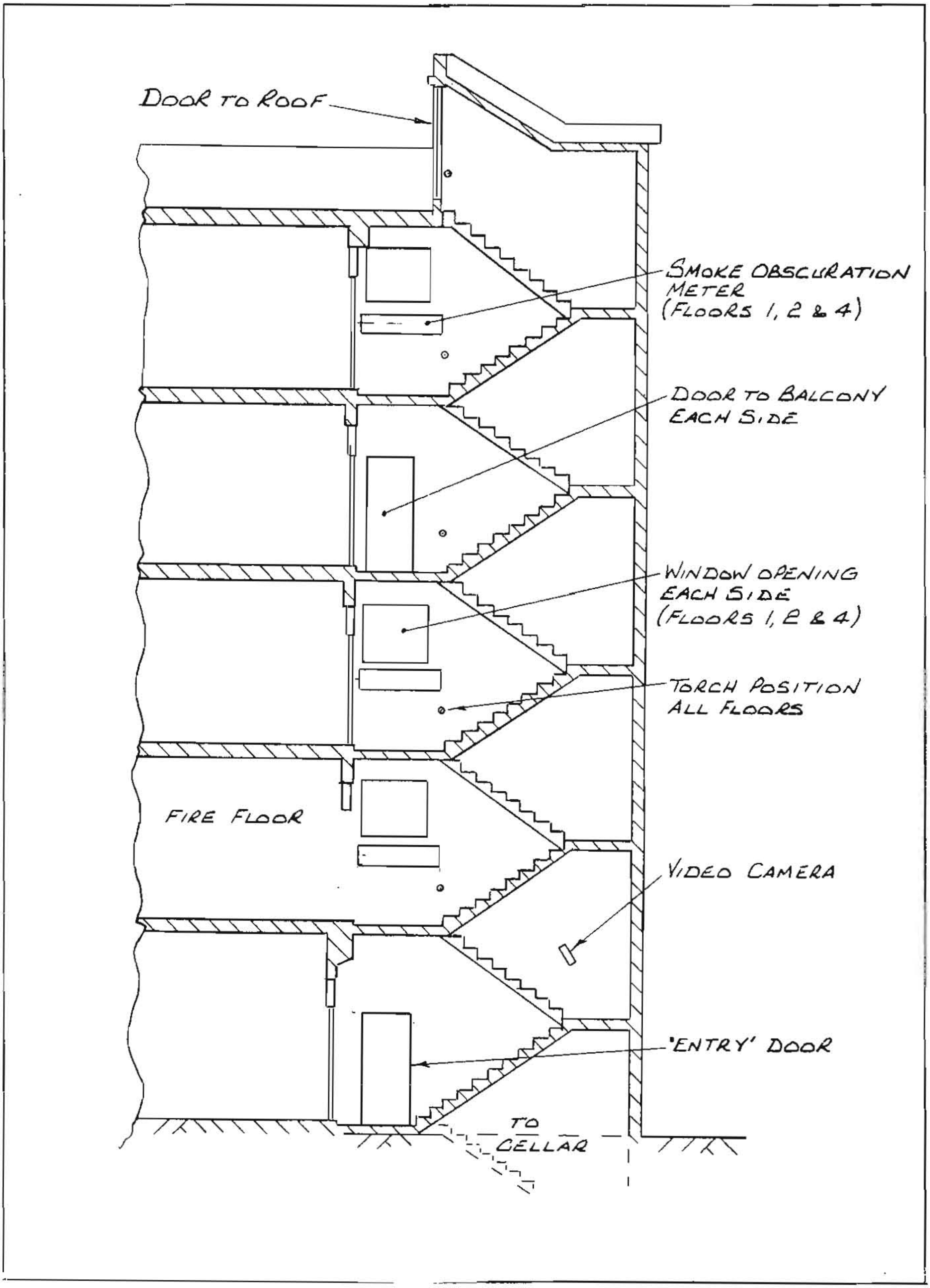


Figure 1 Vertical Section Through the Stairwell

Figure 6 The Tempest 24 " Fan Used Throughout the Trials

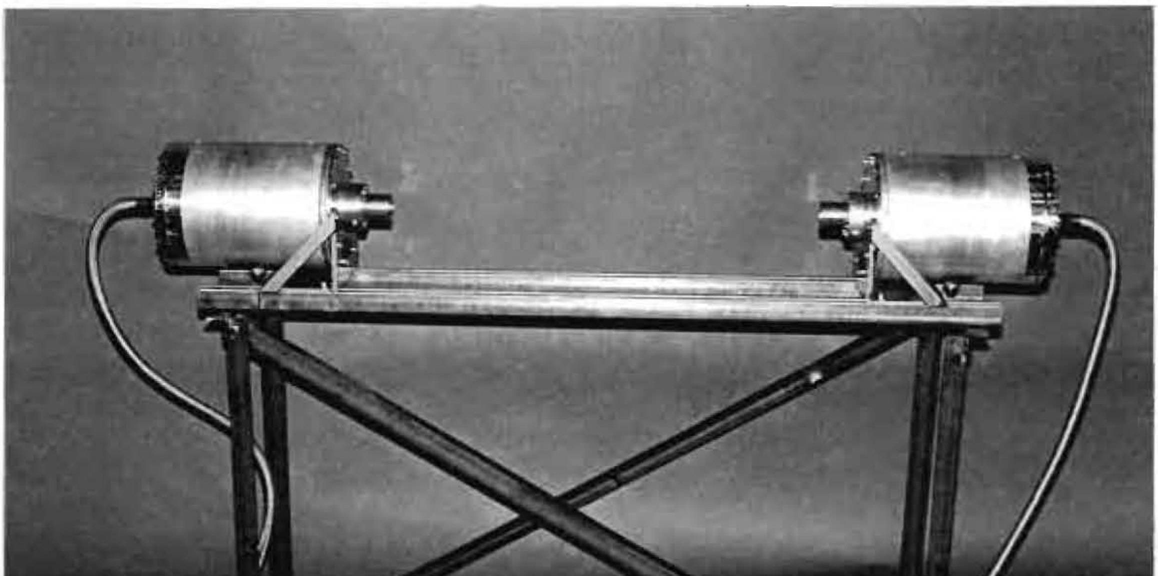


Figure 7 A Smoke Obscuration Meter Assembly

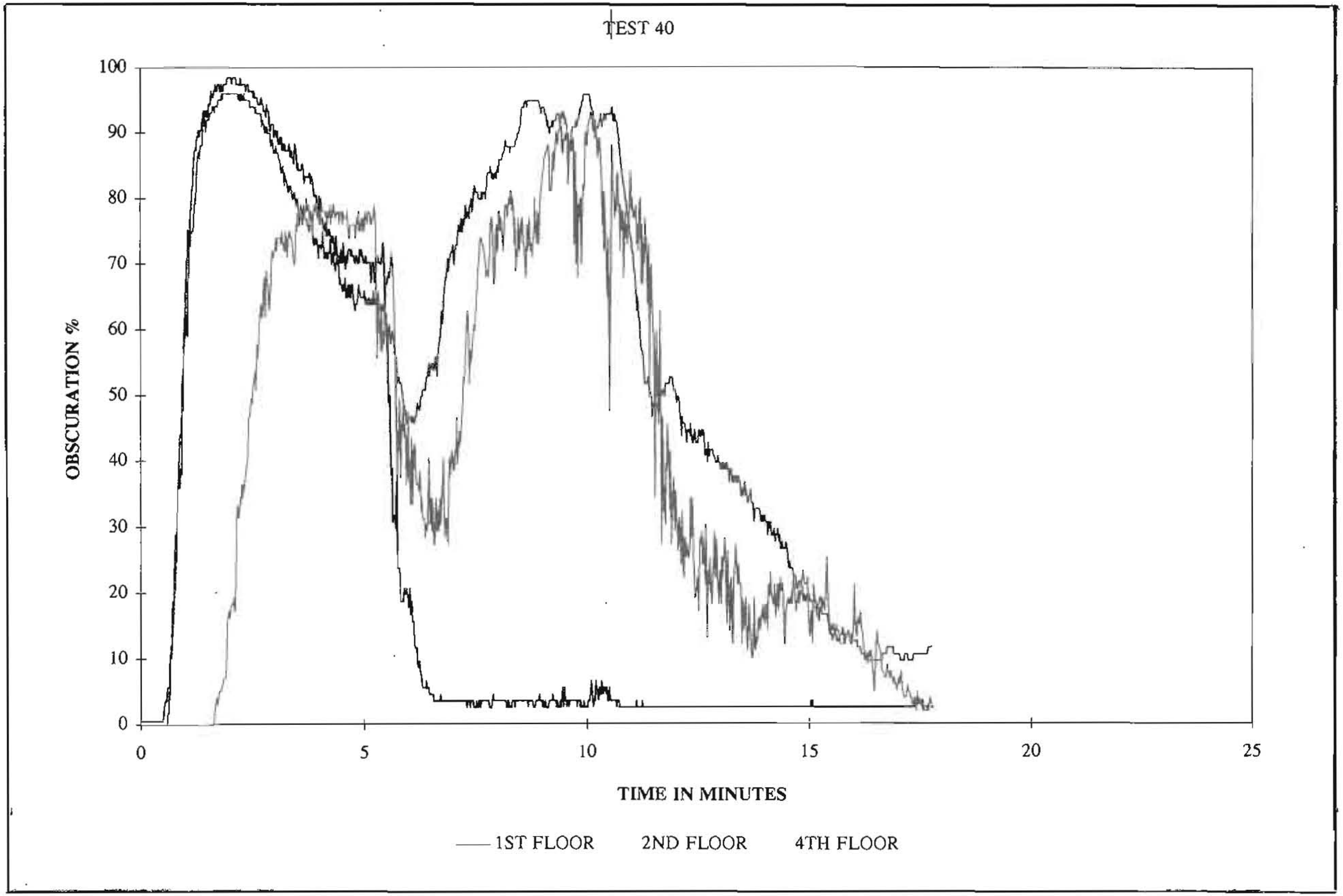


Figure 8 Example of Smoke Obscuration Vs. Time Plot (Trial Number 40)

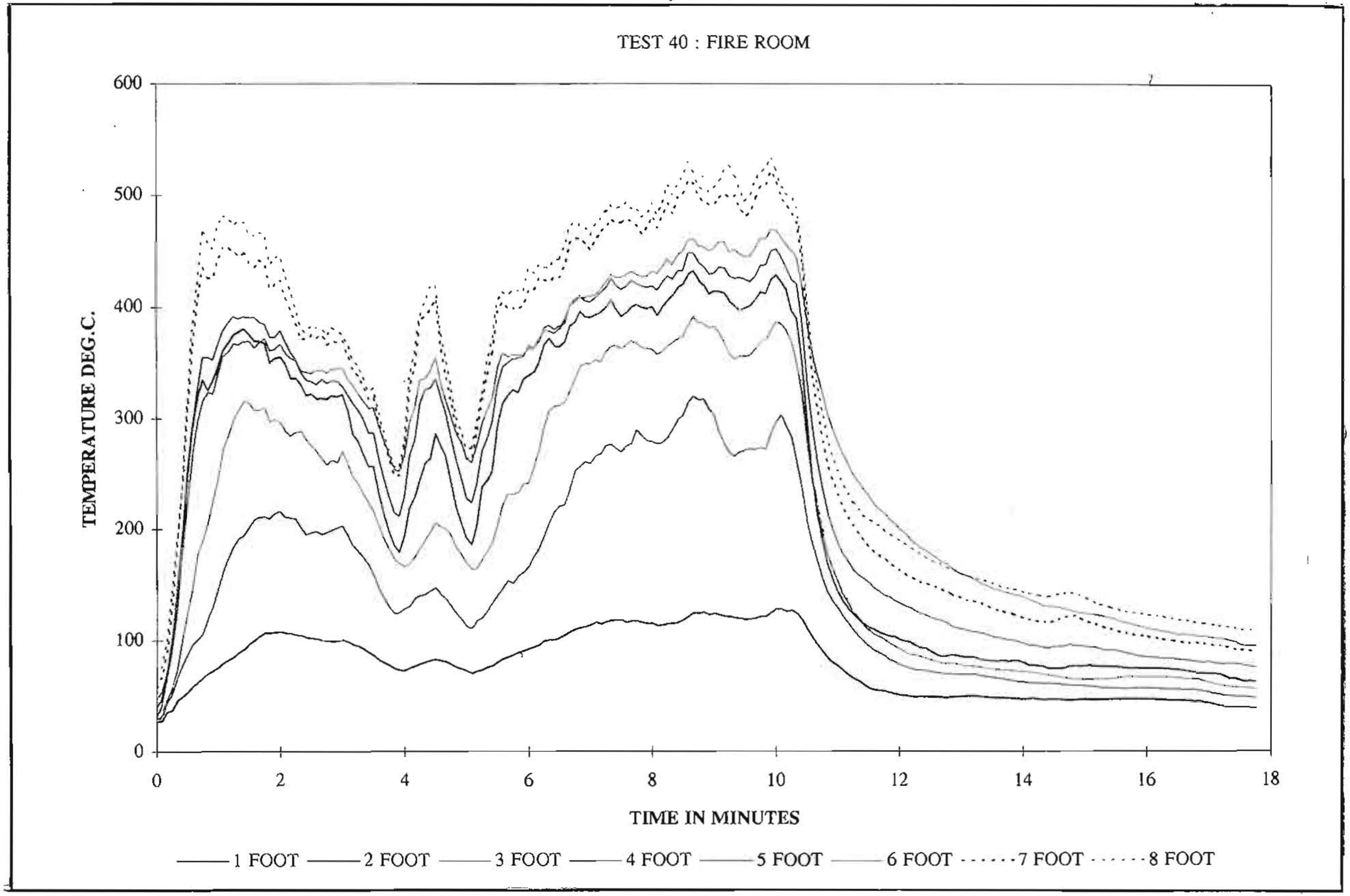


Figure 9 Example of Temperature Vs. Time Plot (Trial Number 40, Fire Room)

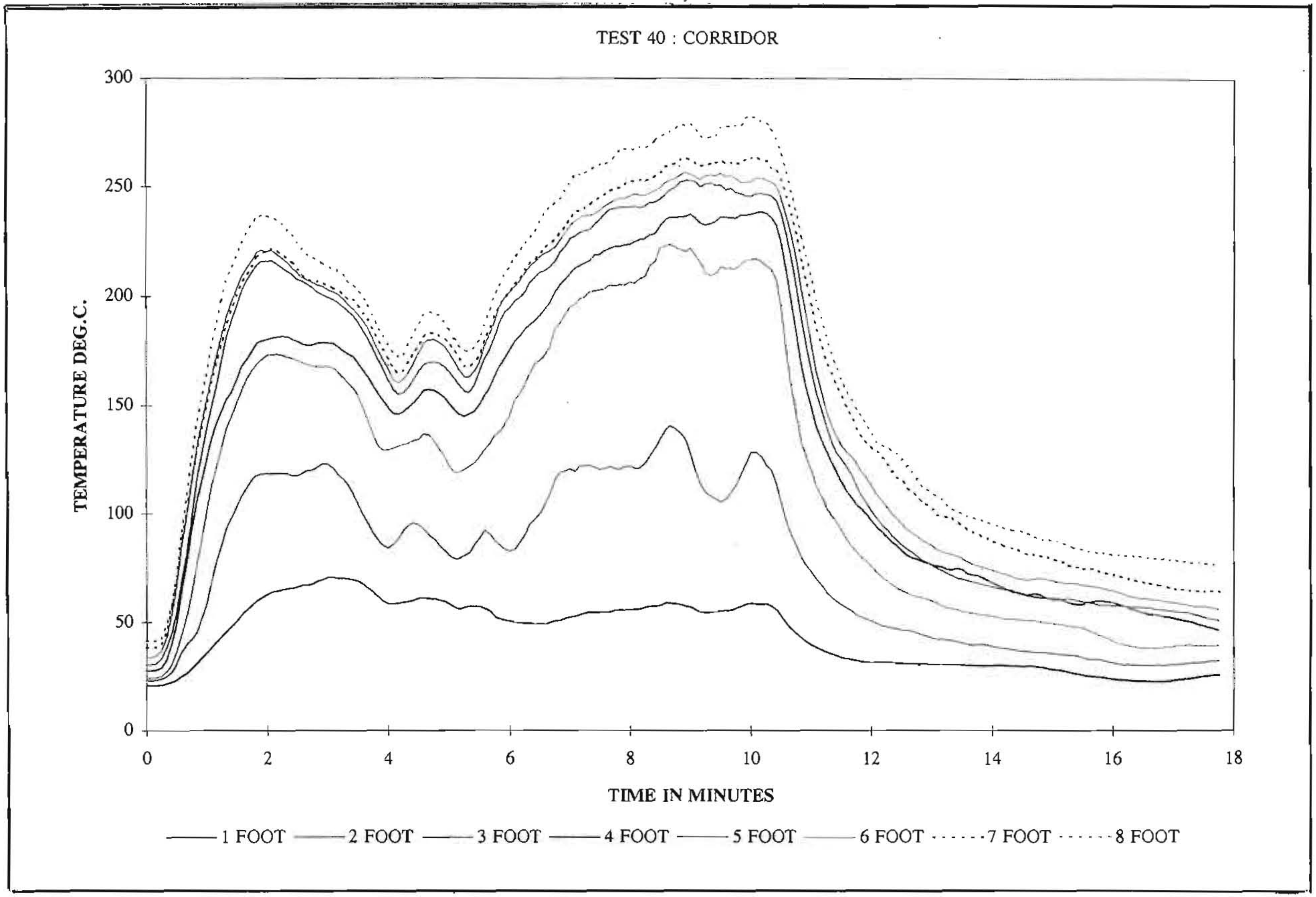


Figure 10 Example of Temperature Vs. Time Plot (Trial Number 40, Corridor)

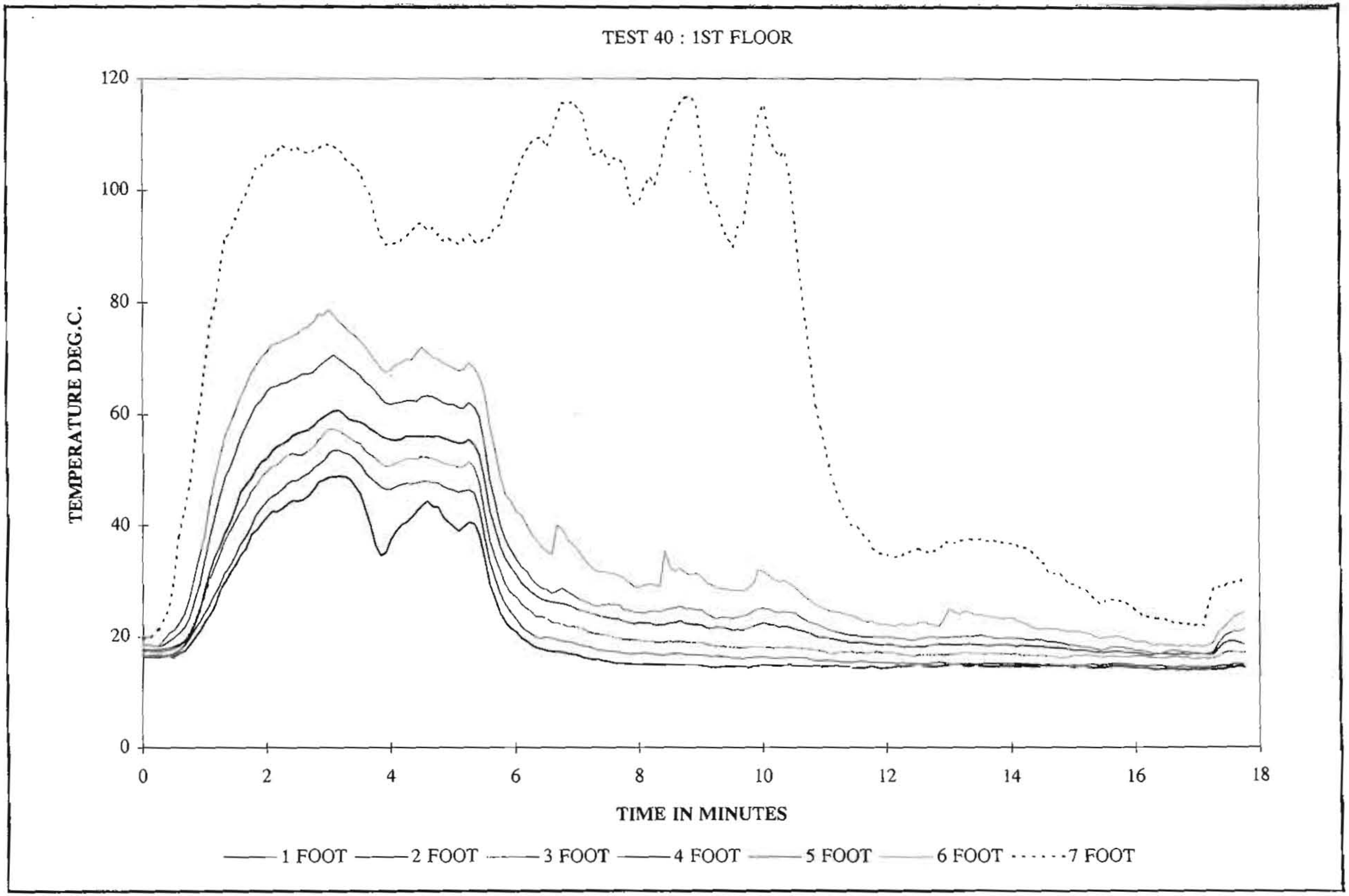


Figure 11 Example of Temperature Vs. Time Plot (Trial Number 40, First Floor)

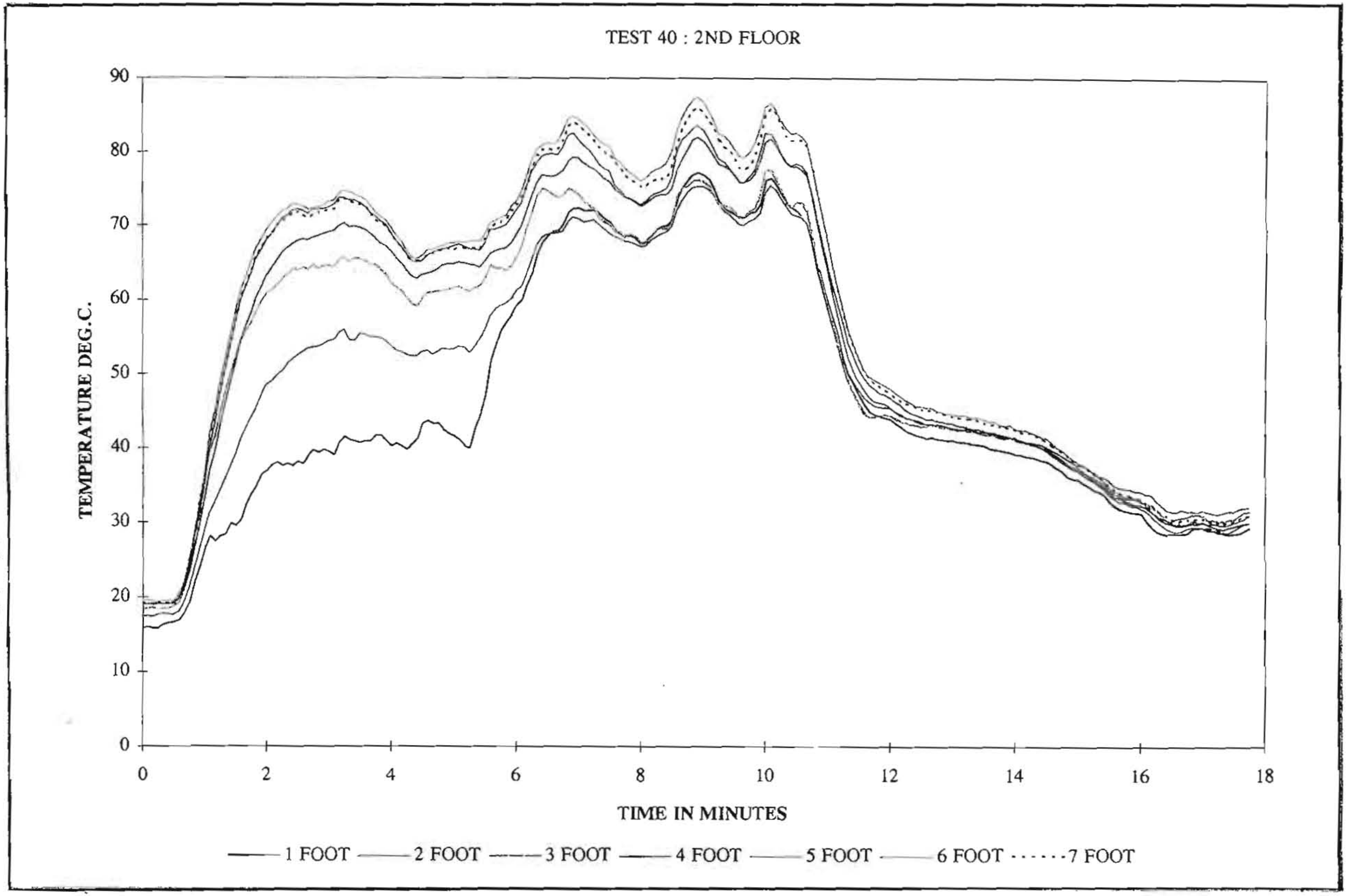


Figure 12 Example of Temperature Vs. Time Plot (Trial Number 40, Second Floor)

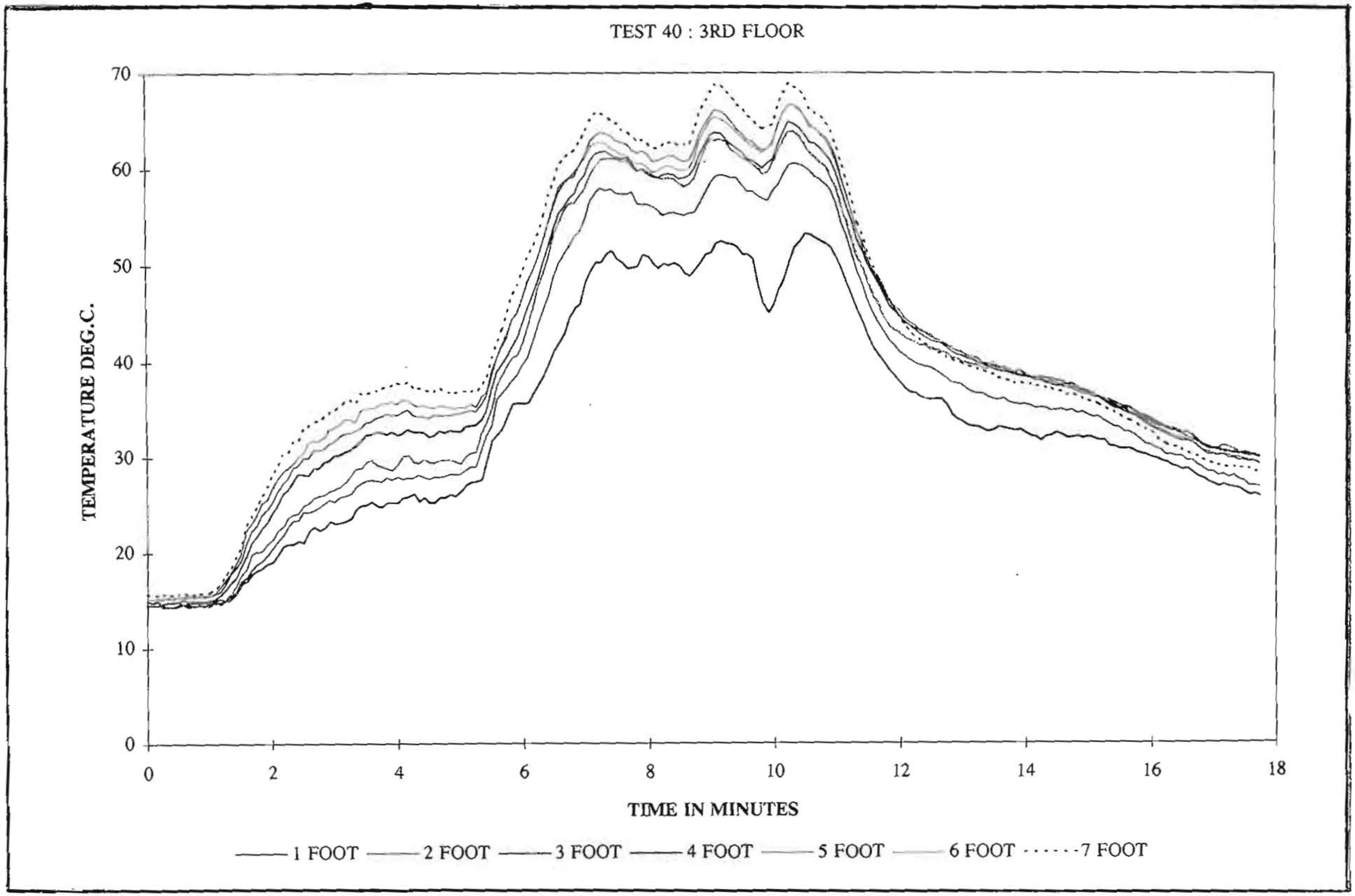


Figure 13 Example of Temperature Vs. Time Plot (Trial Number 40, Third Floor)

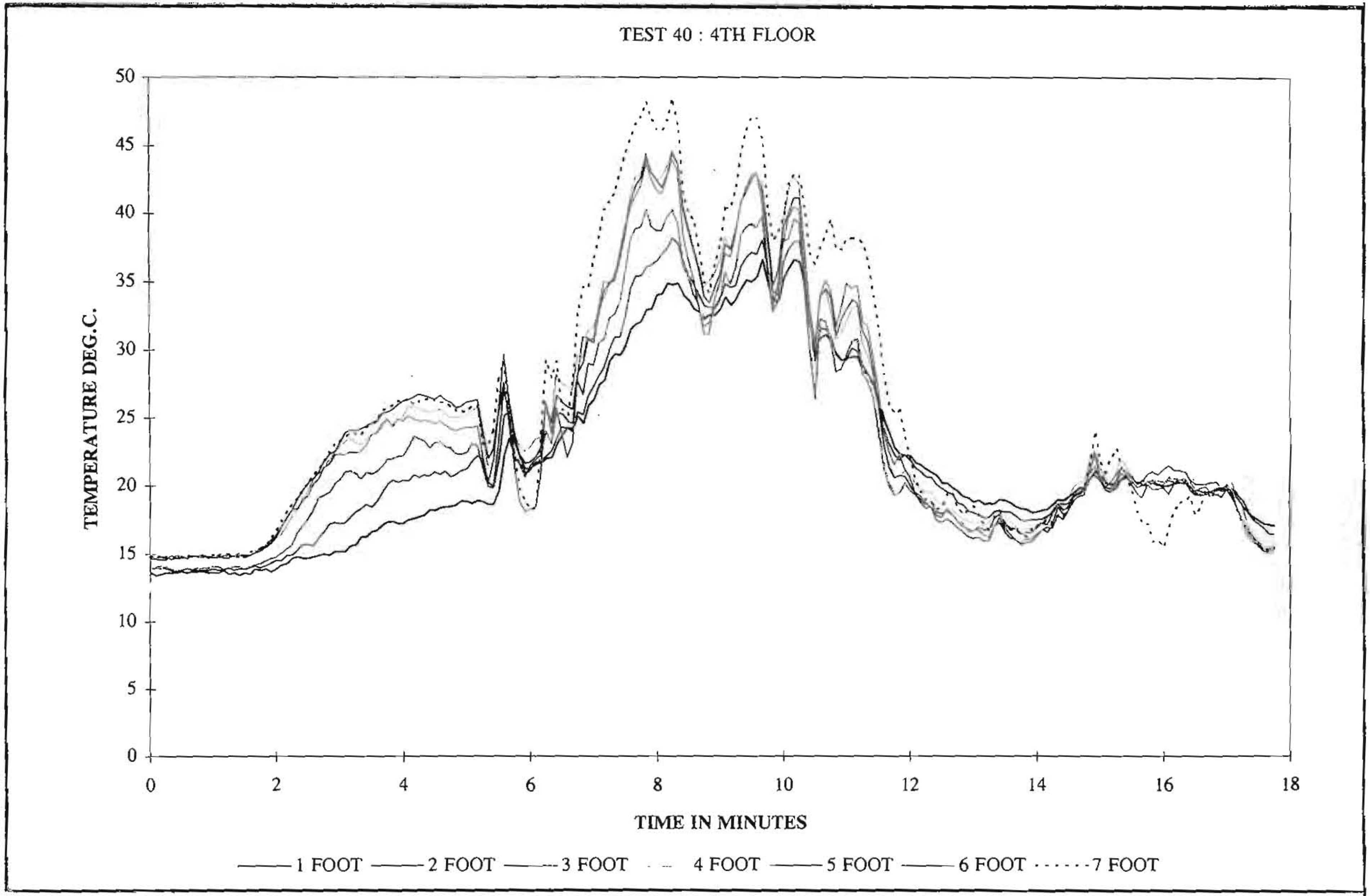


Figure 14 Example of Temperature Vs. Time Plot (Trial Number 40, Fourth Floor)

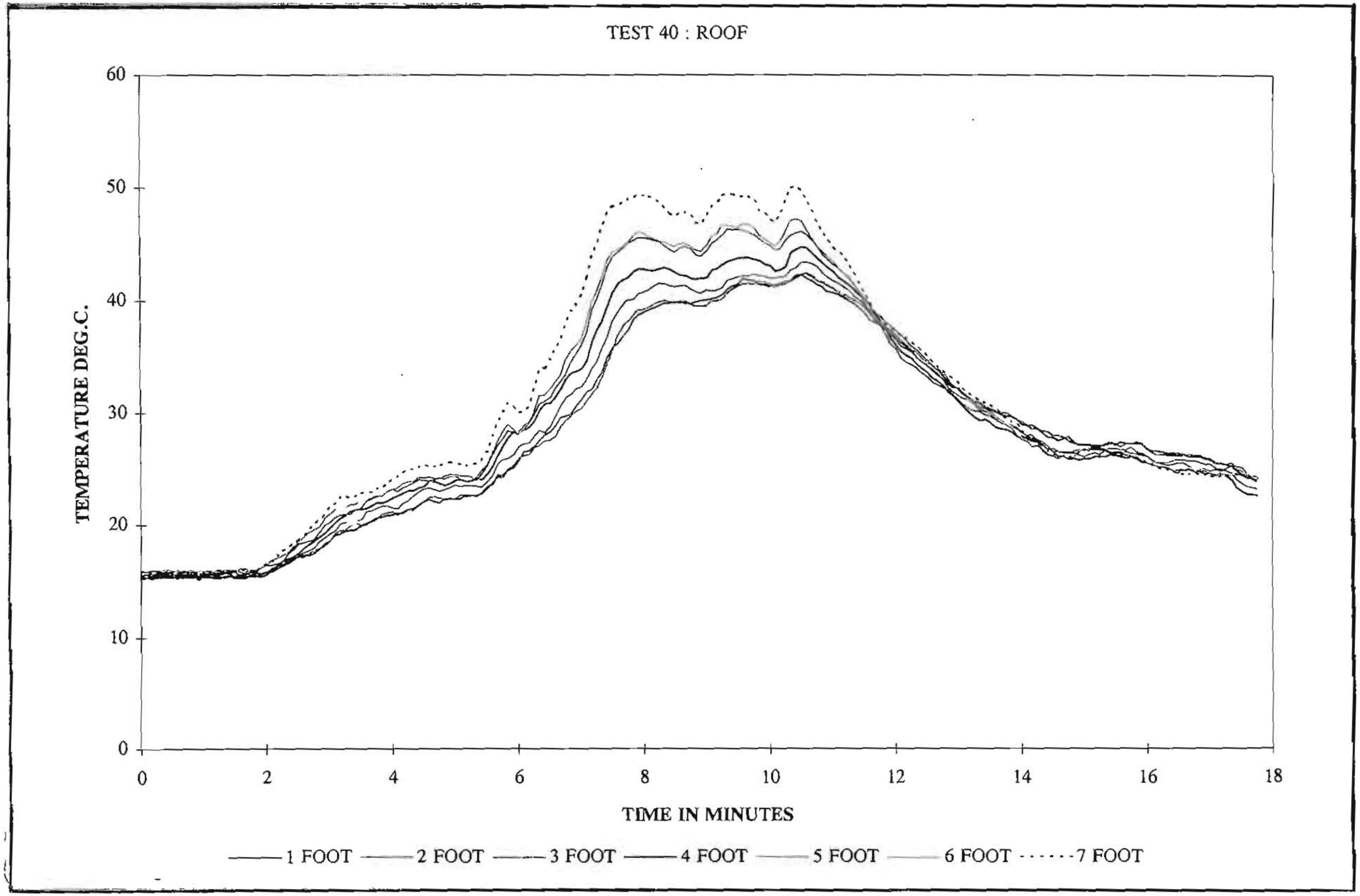


Figure 15 Example of Temperature Vs. Time Plot (Trial Number 40, Roof Level)

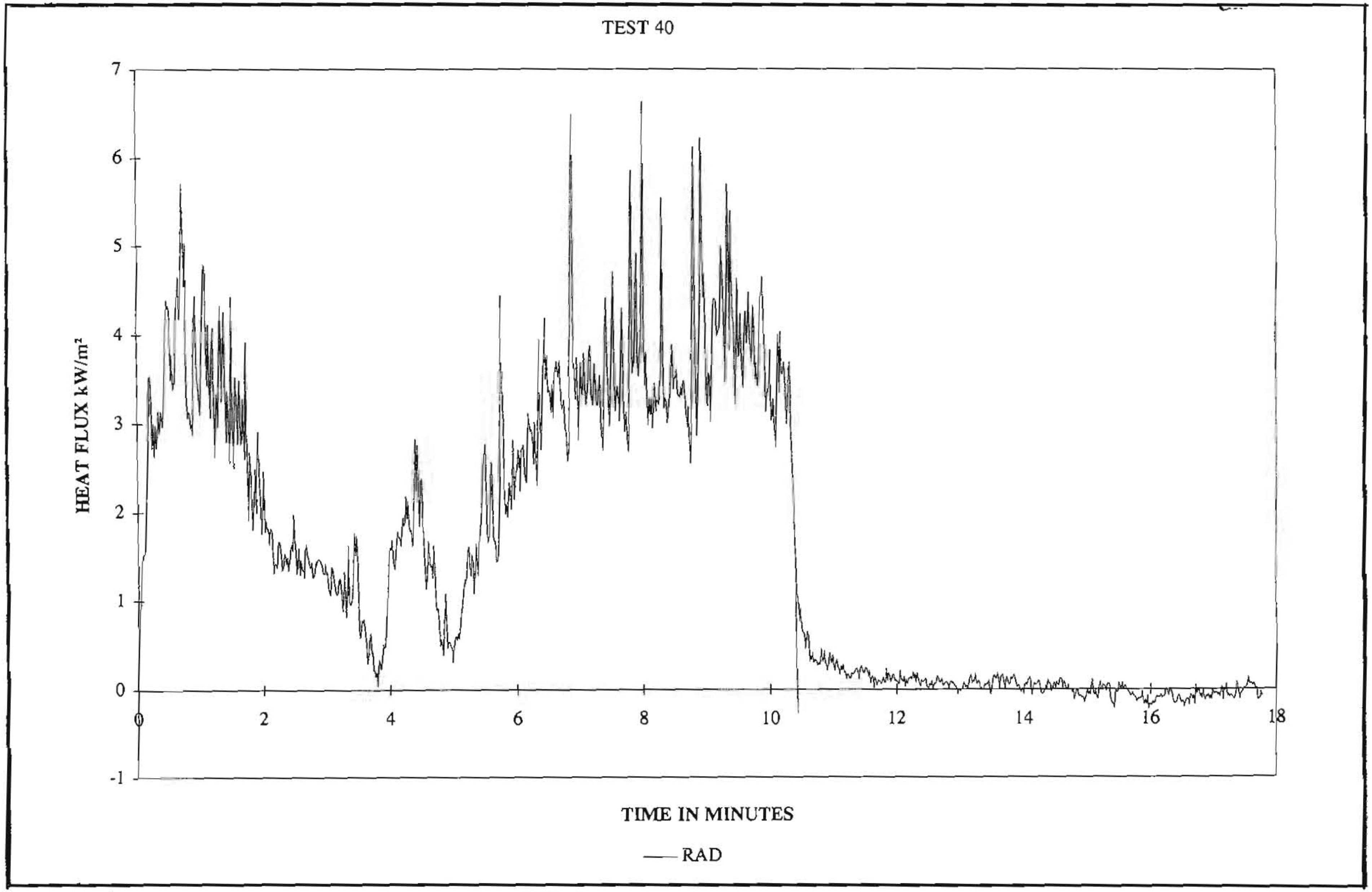


Figure 16 Example of Thermal Radiation Flux Vs Time Plot (Trial Number 40)

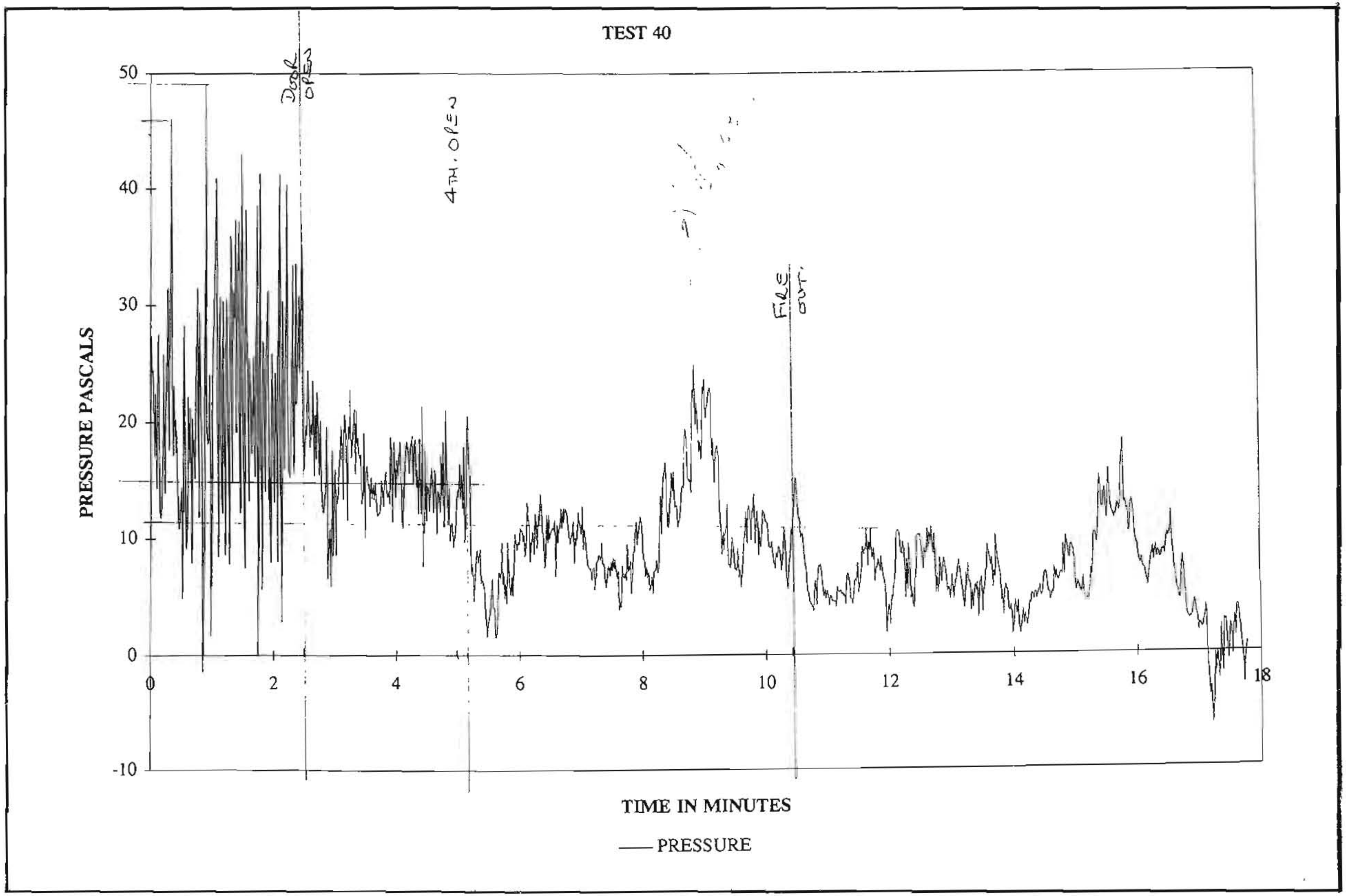


Figure 17 Example of Static Pressure Vs Time Plot (Trial Number 40)

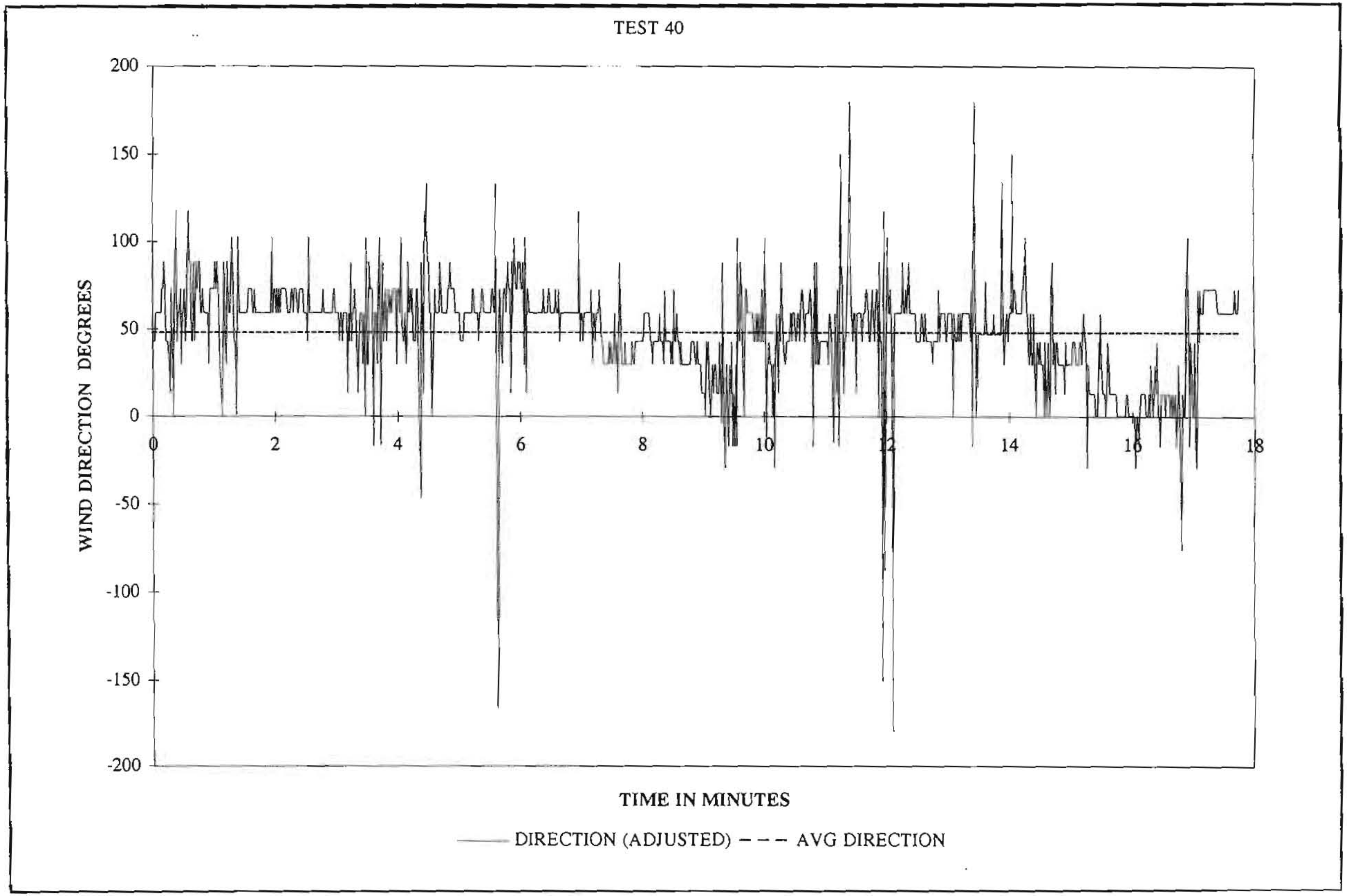


Figure 18 Example of Wind Direction Vs. Time Plot with Average Value Superimposed (Trial Number 40)

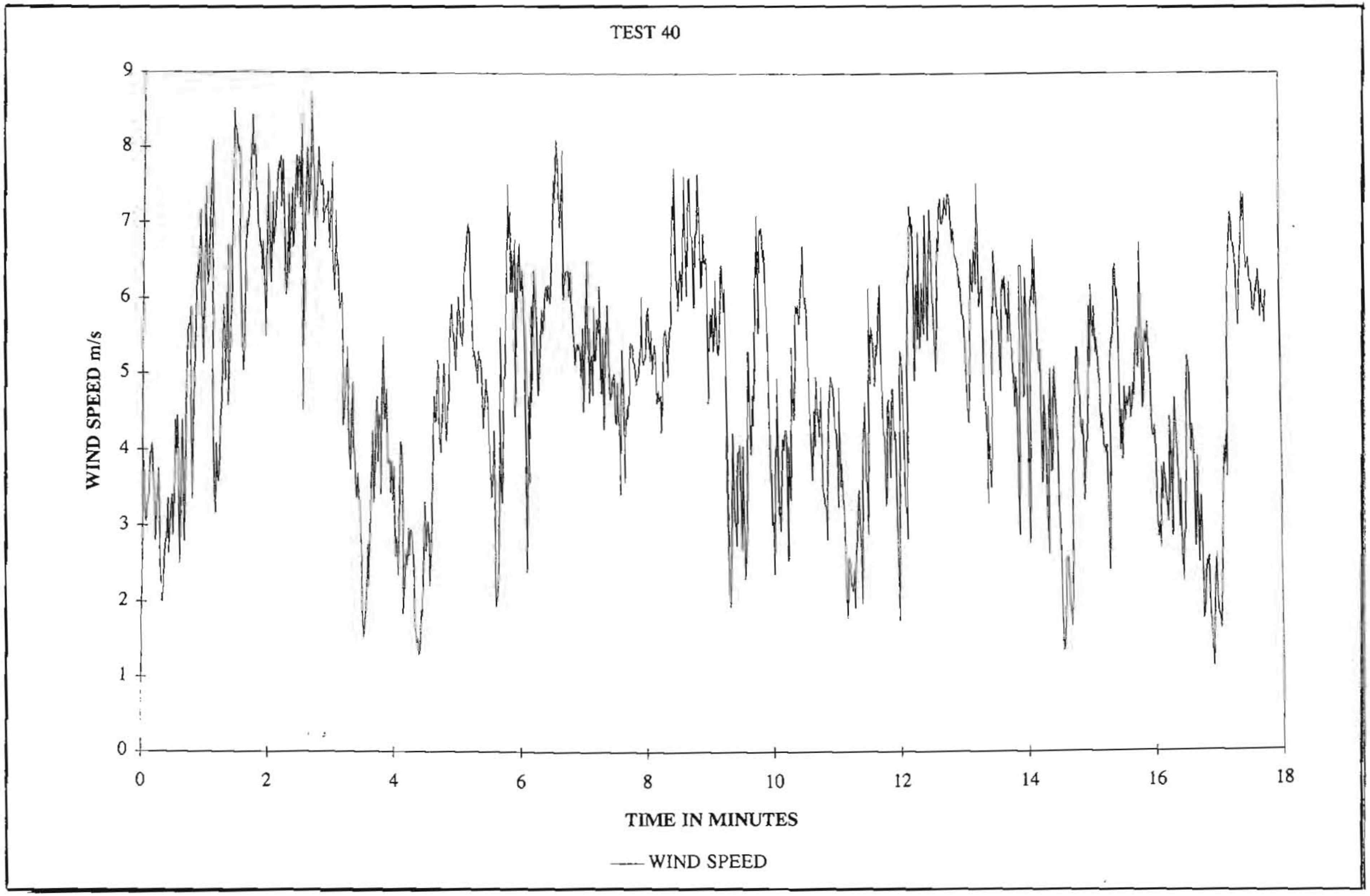


Figure 19 Example of Wind Speed Vs. Time Plot (Trial Number 40)

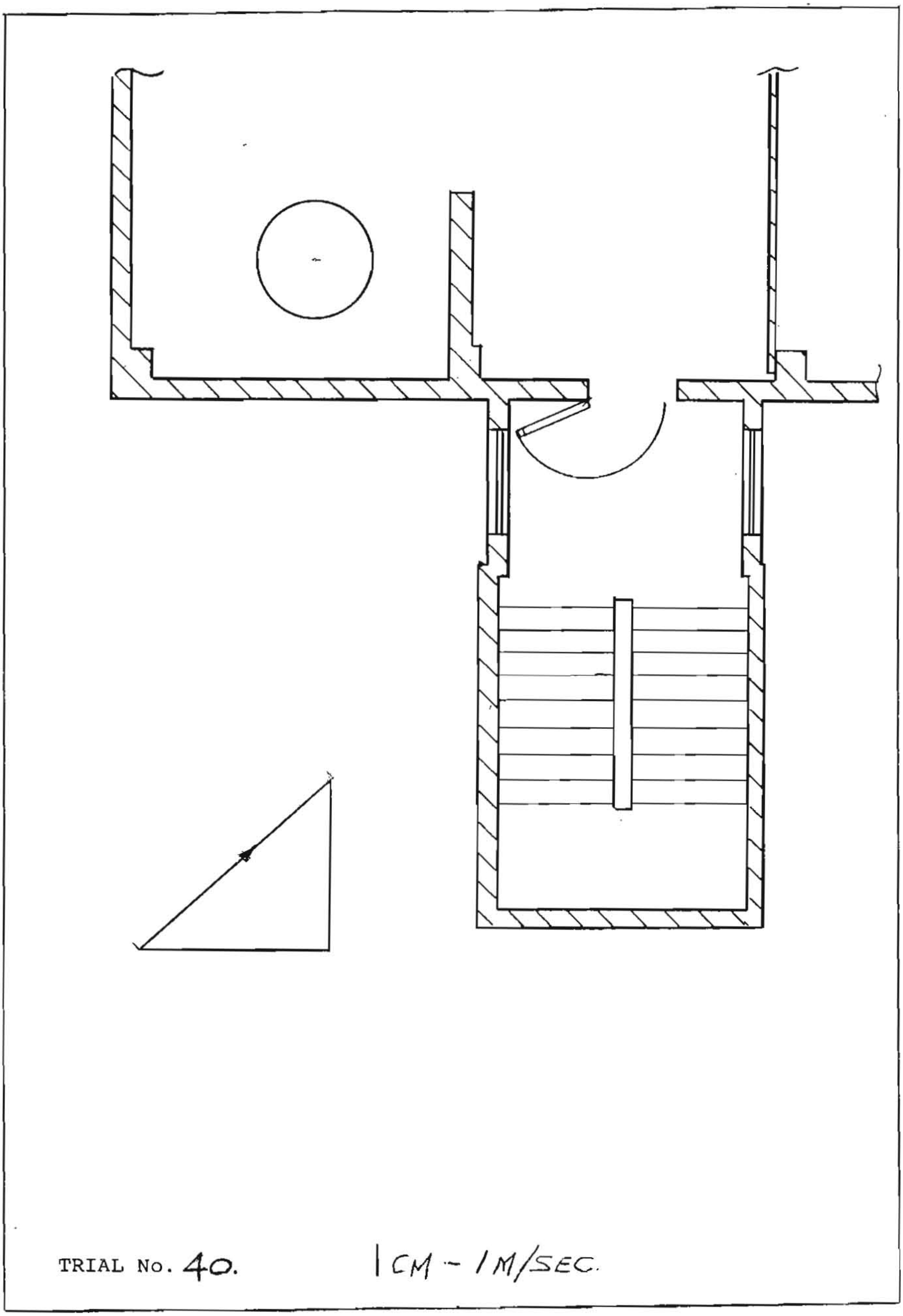


Figure 20 Example of Average Wind Velocity Vector Diagram (Trial Number 40)

APPENDIX A

ABBREVIATED RESULTS FOR EACH TRIAL USED FOR COMPARISONS

This appendix gives the results of the eleven trials used for direct comparisons in Sections 7, 8 and 9, in summarised form. Each of the following pages refers to a single trial, and the format of each is identical to allow comparisons to be readily made. In all graphs and tables 'time=0' is when the fire was lit.

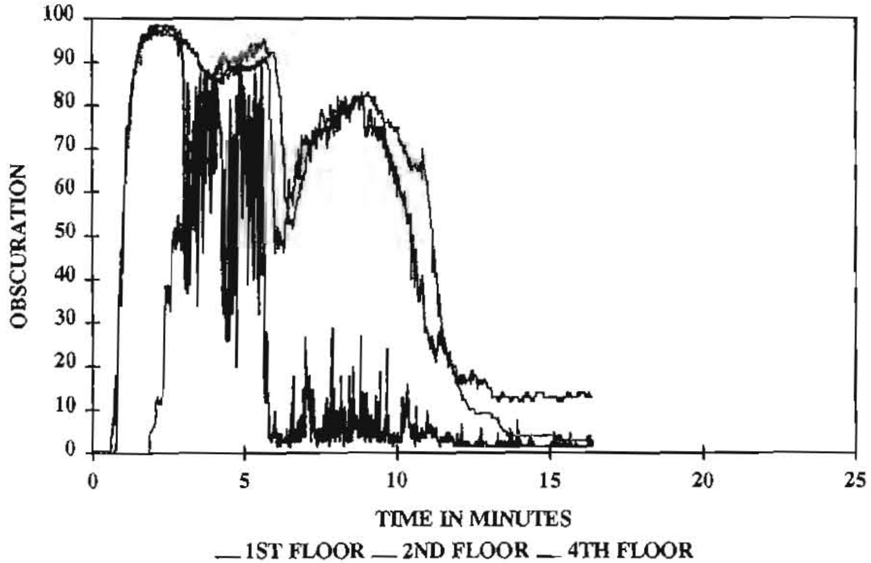
On each page, the percentage smoke obscuration measured at 1m. above the floor on the 1st, 2nd and 4th floors is plotted against time, over the duration of the trial, at the top left hand side.

The table at the lower right hand side gives the times, in minutes and seconds, at which the stairwell torches, on each landing, became visible to the video camera on the 1st half landing. Where two different times are stated in this table, the first indicates when the torch first became visible, to subsequently disappear again, while the second time given is that after which the torch remained visible.

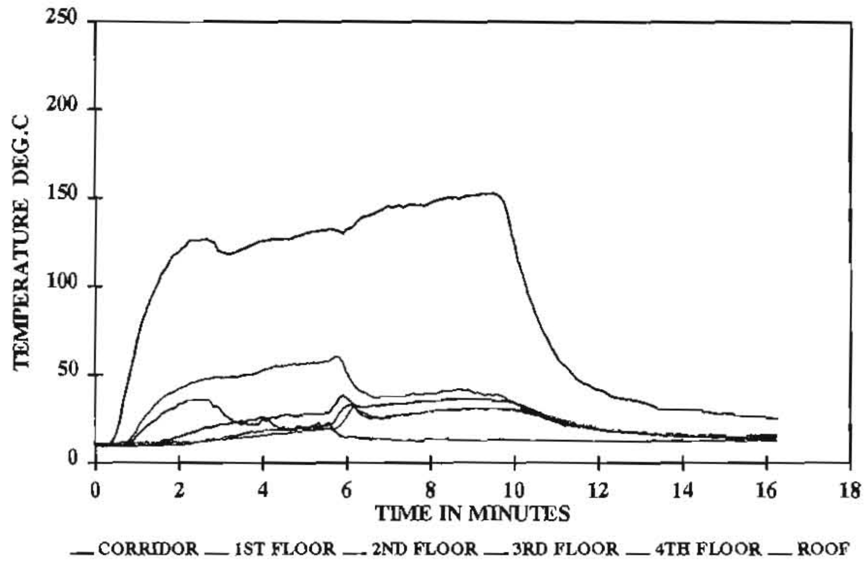
The temperatures measured at 3 feet above the floor in the corridor, on the 1st, 2nd, 3rd and 4th floor landings, and at the roof level are plotted against time over the duration of the trials, at the top right hand side.

The average wind velocity, averaged over the duration of the trial, is given at the lower left hand side. Here, the average wind speed is stated in metres per second, while the average wind direction relative to the building is indicated by an arrow. (Note that the arrow is not a vector, its length is immaterial.)

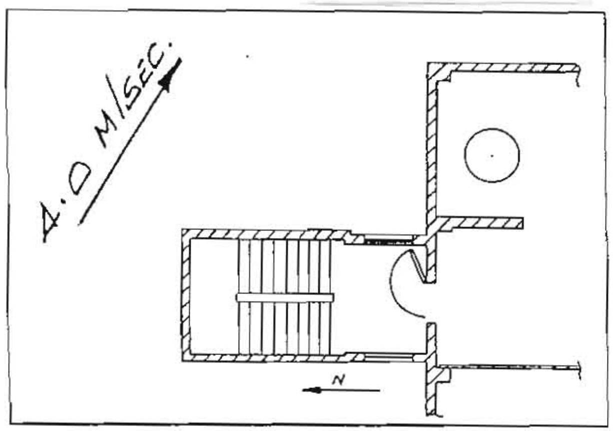
TEST 25 The entry door was opened at 2 mins. 30 secs. and the roof door was opened at 5 mins. 36 secs. The PPV fan was started immediately the roof door was opened.



Smoke obscuration



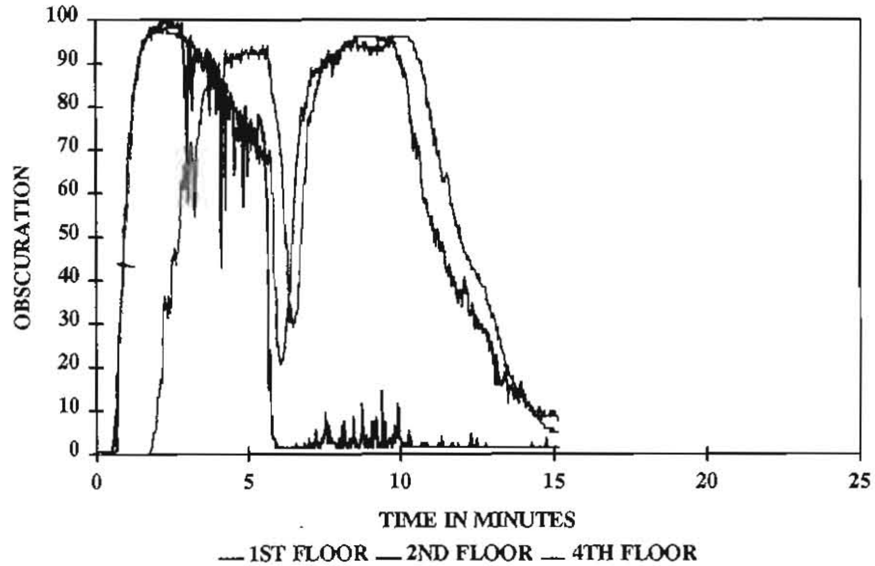
Temperature at 3 foot level



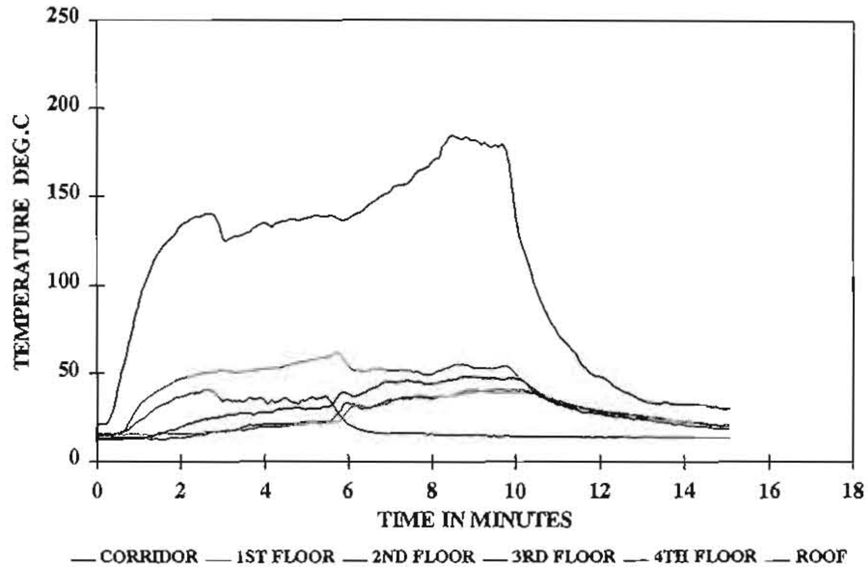
Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
Never Lost	10:05	10:35	10:57	11:08

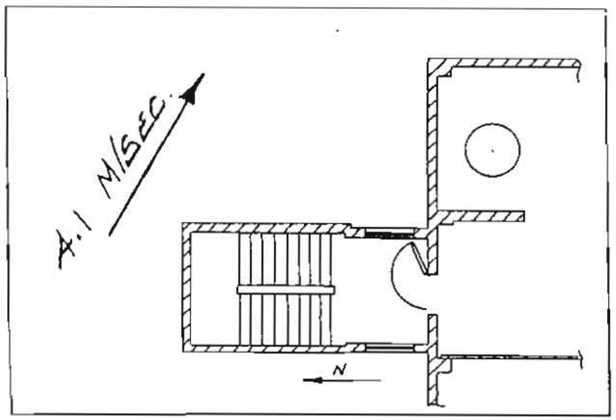
TEST 27 The entry door was opened at 2 mins. 30 secs. and the roof door was opened at 5 mins. 36 secs. PPV was not used.



Smoke obscuration



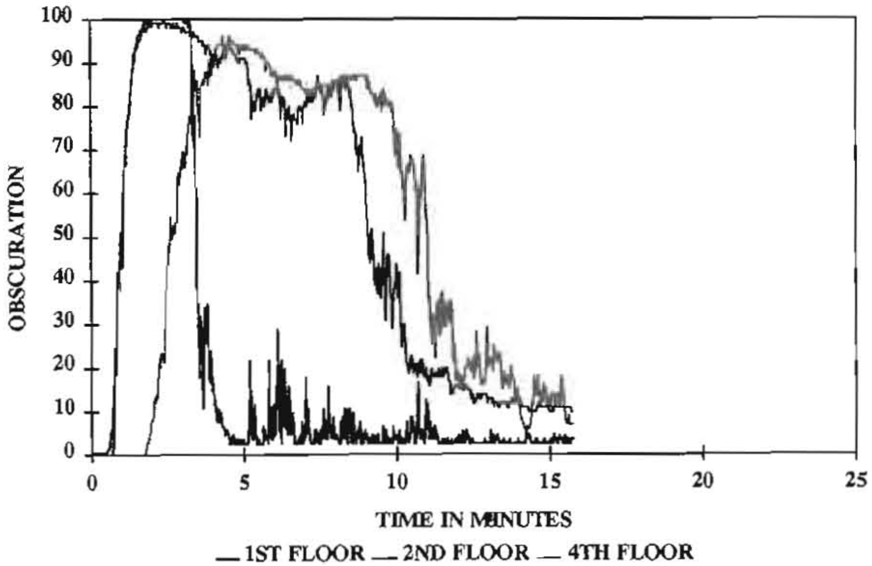
Temperature at 3 foot level



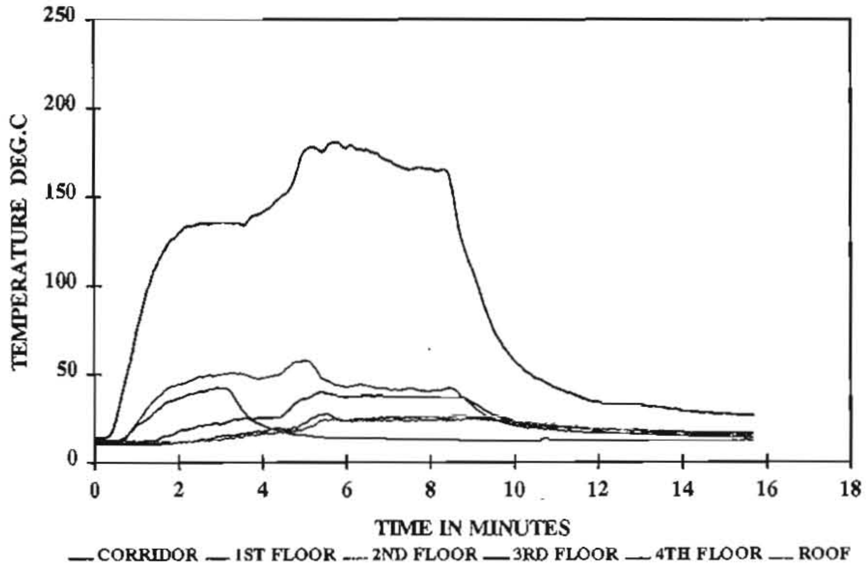
Average Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
02:44	(5:40) 10:32	(5:35) 11:26	N/A	12:23

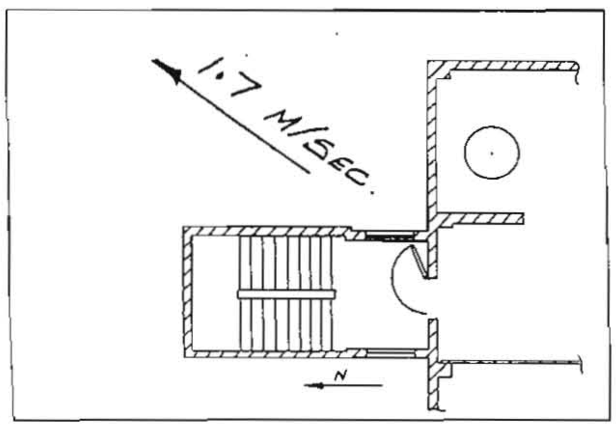
TEST 28 The firefighters entered at 2 mins. 30 secs. The downwind window on the 1st floor landing was opened at 3 mins. 9 secs. and the downwind window on the 4th floor landing was opened at 4 mins. 26 secs. The PPV fan was started immediately the 4th floor window was open.



Smoke obscuration



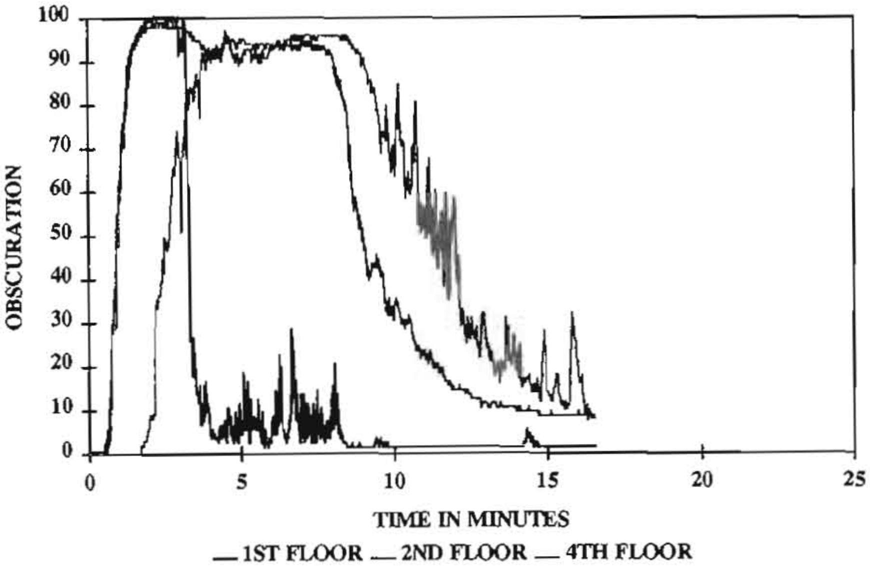
Temperature at 3 foot level



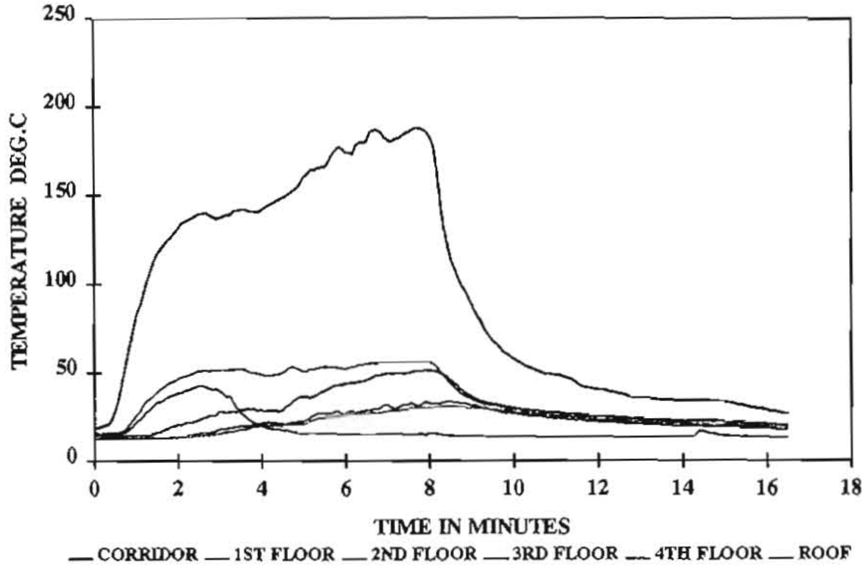
Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
02:55	08:36	09:26	10:58	11:58

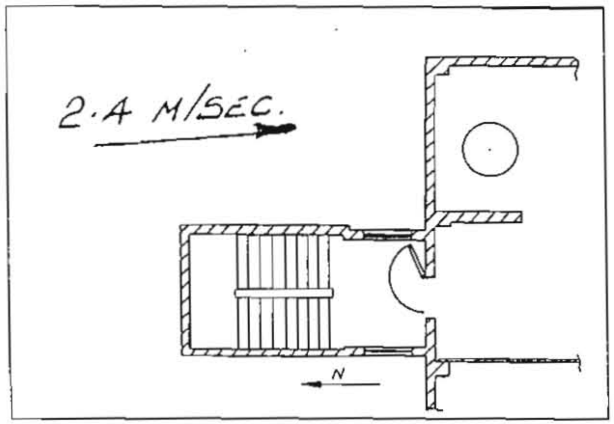
TEST 30 The firefighters entered at 2 mins. 30 secs. The downwind window on the 1st floor landing was opened at 3 mins. 9 secs. and the downwind window on the 4th floor landing was opened at 4 mins. 26 secs. The PPV fan was started immediately the 4th floor window was open.



Smoke obscuration



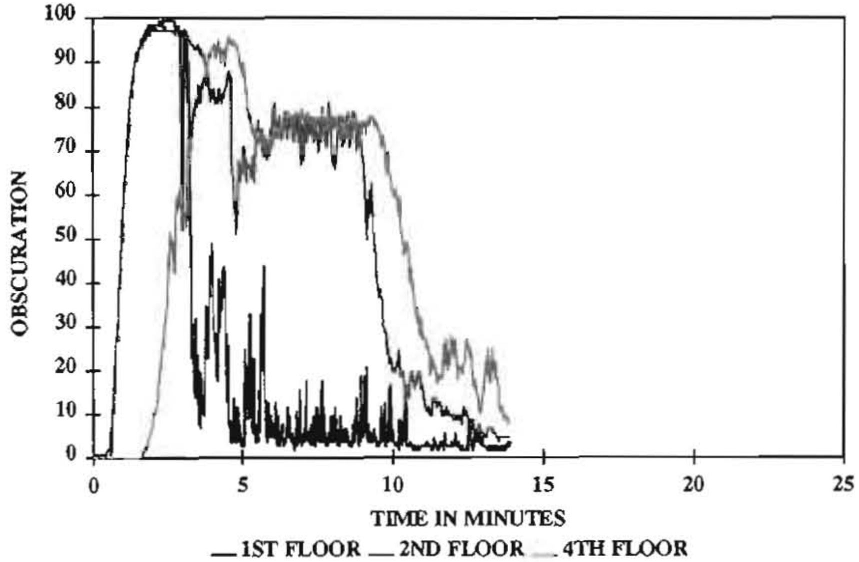
Temperature at 3 foot level



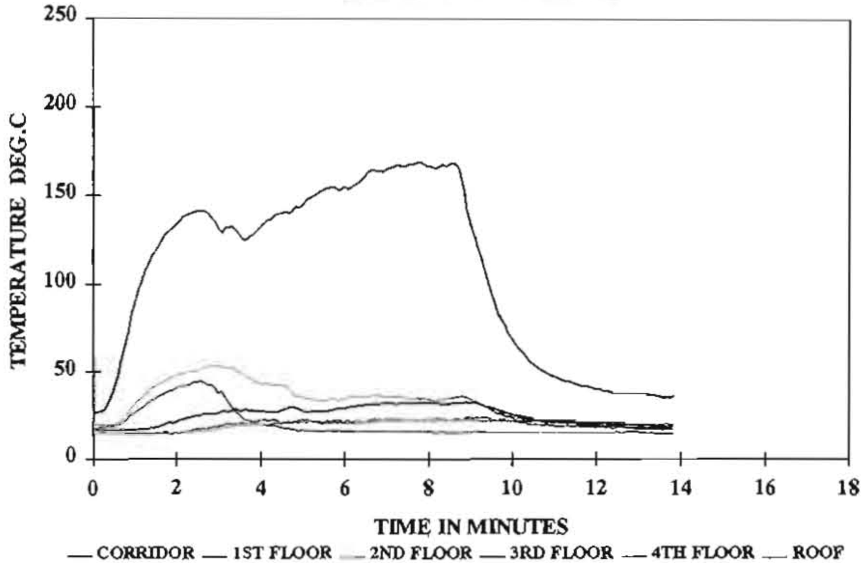
Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
Never Lost	08:20	09:08	(10:05) 11:29	12:25

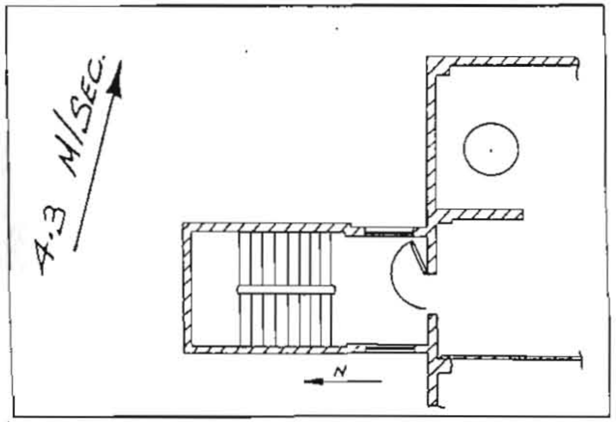
TEST 31 The firefighters entered at 2 mins. 30 secs. The downwind window on the 1st floor landing was opened at 3 mins. 9 secs. PPV fan was started at 3 mins. 17 secs. The downwind window on the 4th floor landing was opened at 4 mins. 26 secs.



Smoke obscuration



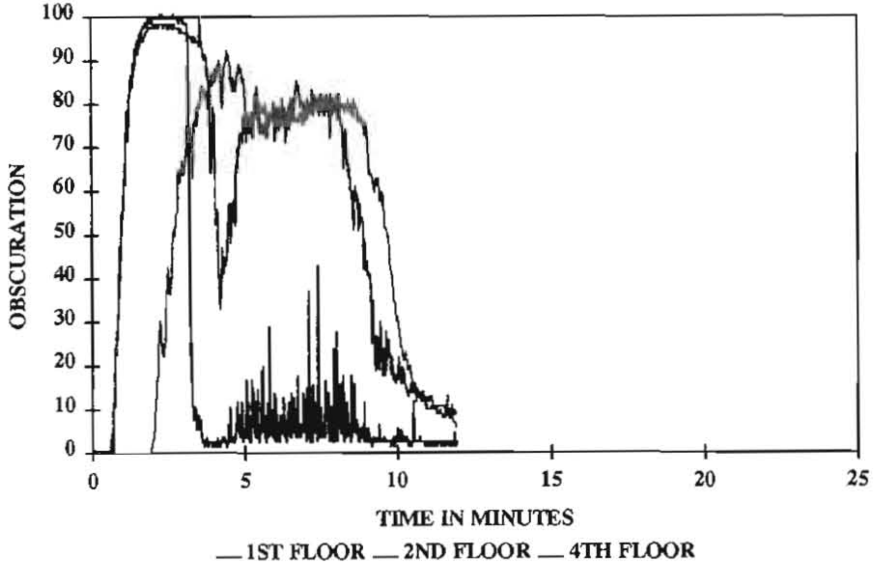
Temperature at 3 foot level



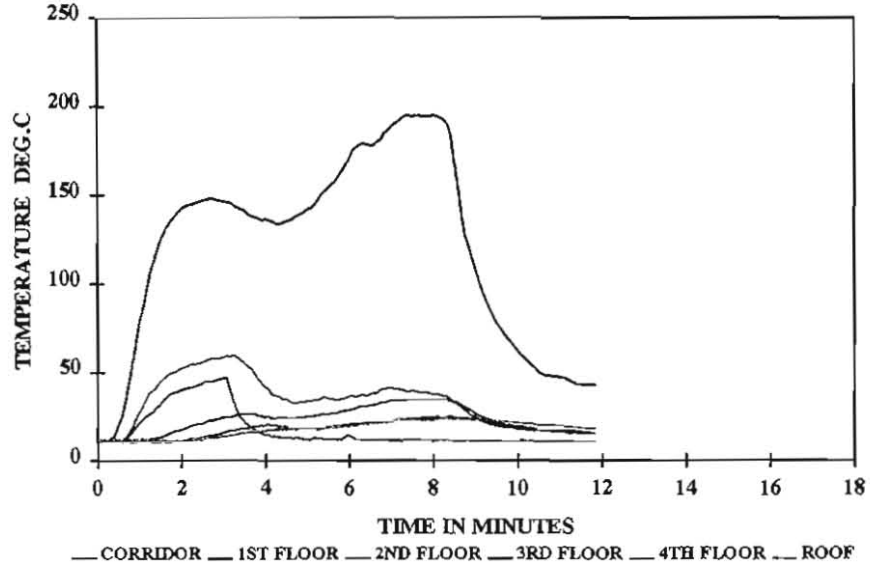
Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
02:40	(4:39) 8:50	09:32	10:01	N/A

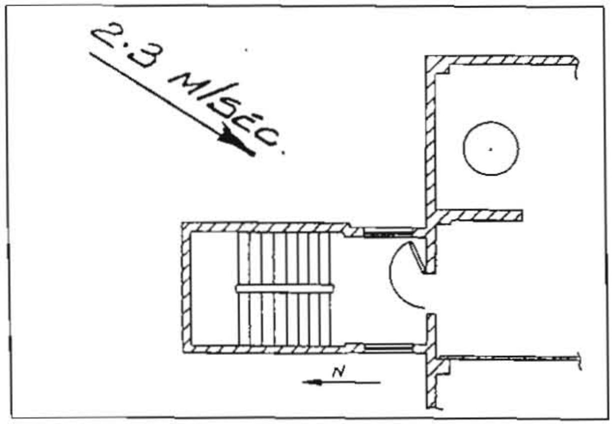
TEST 34 The firefighters entered the stairwell at 2 mins. 30 secs. They opened the window on the downwind side of the stairwell at each floor level as they came to it. The 1st floor landing window was opened at 3 mins. 02 sec., and the PPV fan was started at 3 mins. 06 sec. The 2nd floor window was opened at 3 mins. 33 secs., the 3rd at 4 mins. 11 secs. and the 4th at 4 mins. 50 secs.



Smoke obscuration



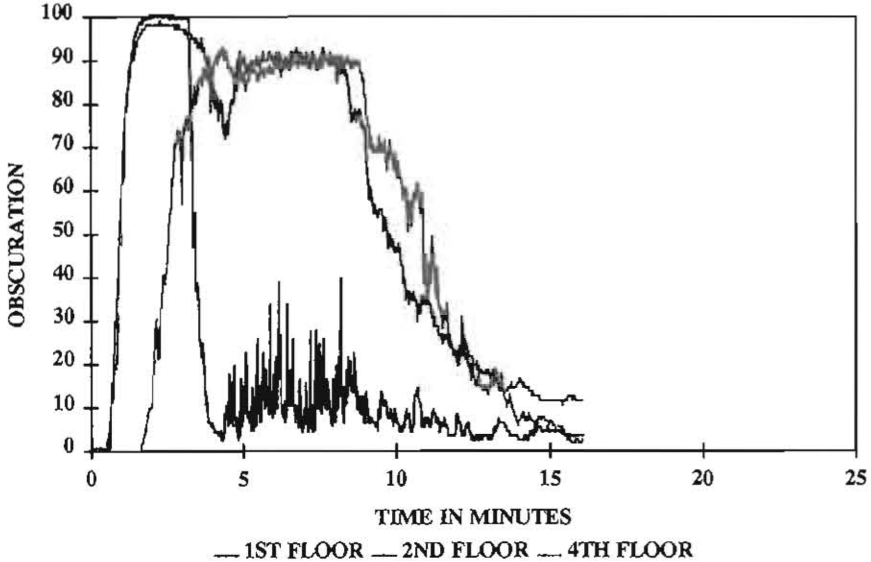
Temperature at 3 foot level



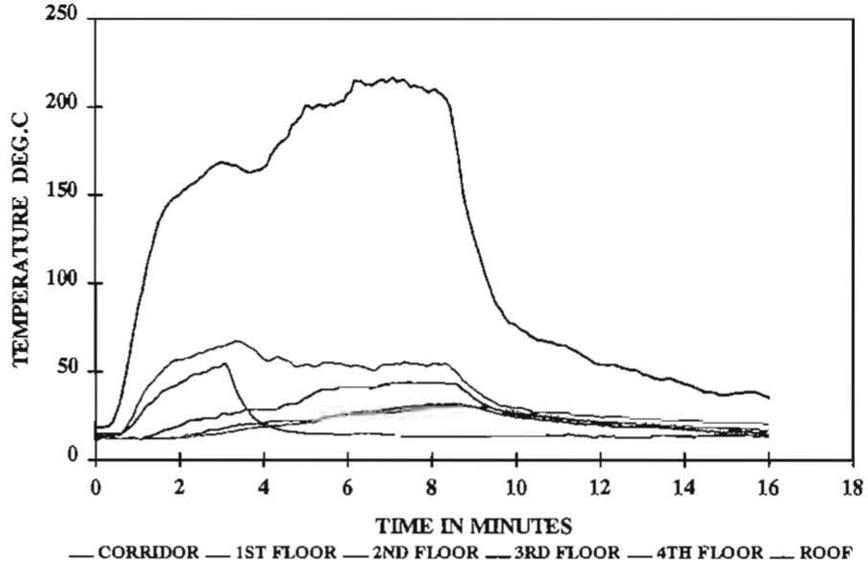
Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
03:05	(3:35) 8:07	09:08	09:45	10:50

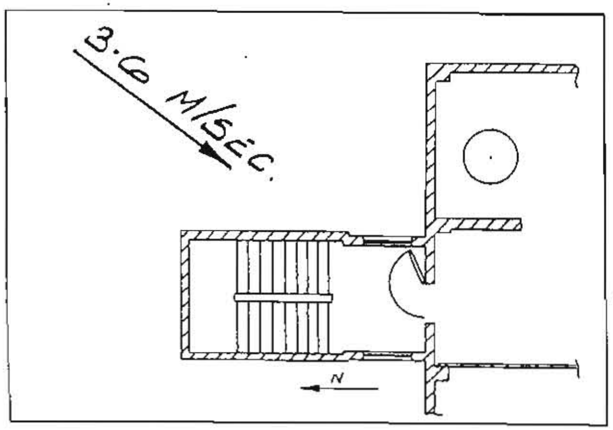
TEST 35 The firefighters entered the stairwell at 2 mins. 30 secs. They opened the window on the downwind side of the stairwell at each floor level as they came to it. The 1st floor landing windflow was opened at 3 mins. 02 sec. The 2nd floor window was opened at 3 mins. 33 secs., the 3rd at 4 mins. 11 secs. and the 4th at 4 mins. 50 secs. PPV was not used.



Smoke obscuration



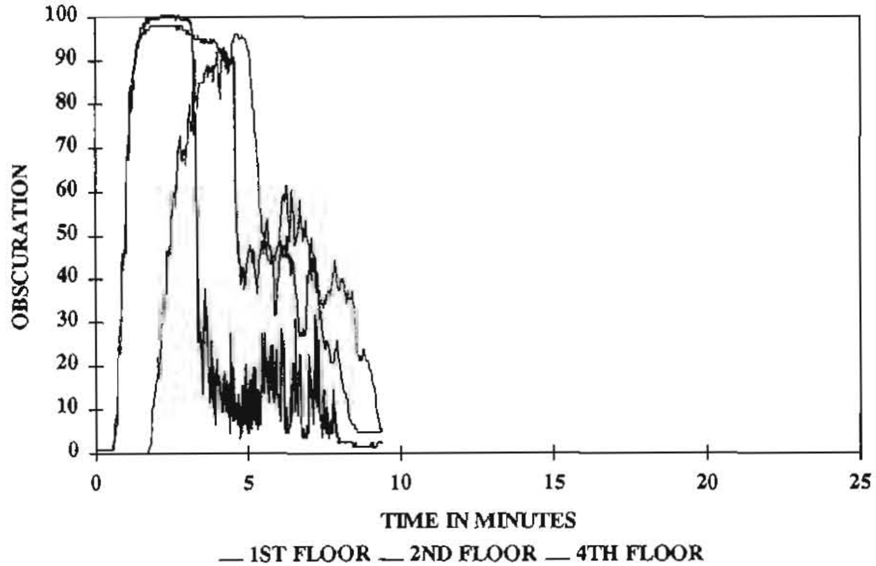
Temperature at 3 foot level



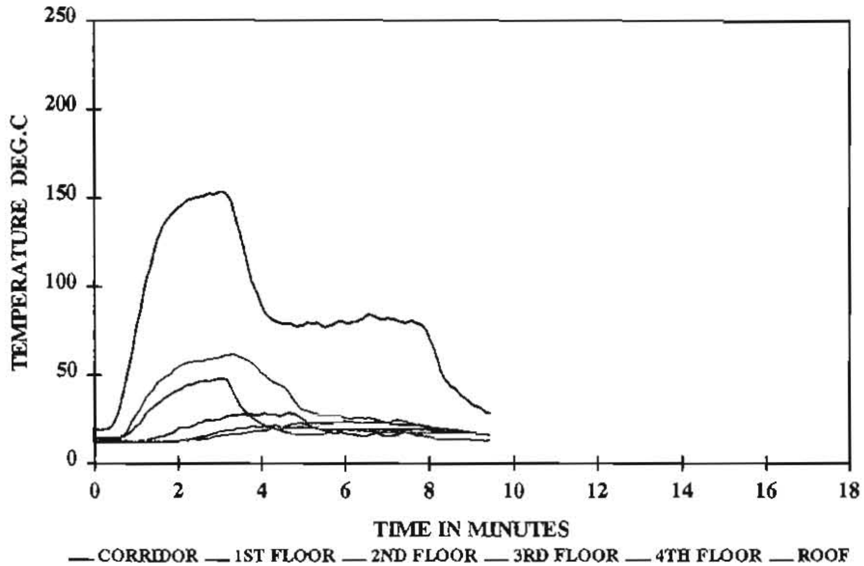
Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
03:12	09:00	10:57	11:03	13:24

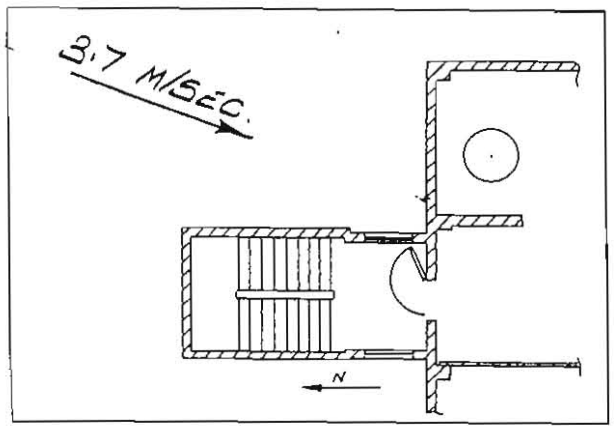
TEST 36 The firefighters entered at 2 mins. 30 secs. The 1st floor 'window' - at the southern end of the corridor - was opened at 3 mins. 06 secs. The PPV fan was started at 3 mins. 26 secs., and the downwind 4th floor landing window was opened at 4 mins. 23 secs.,



Smoke obscuration



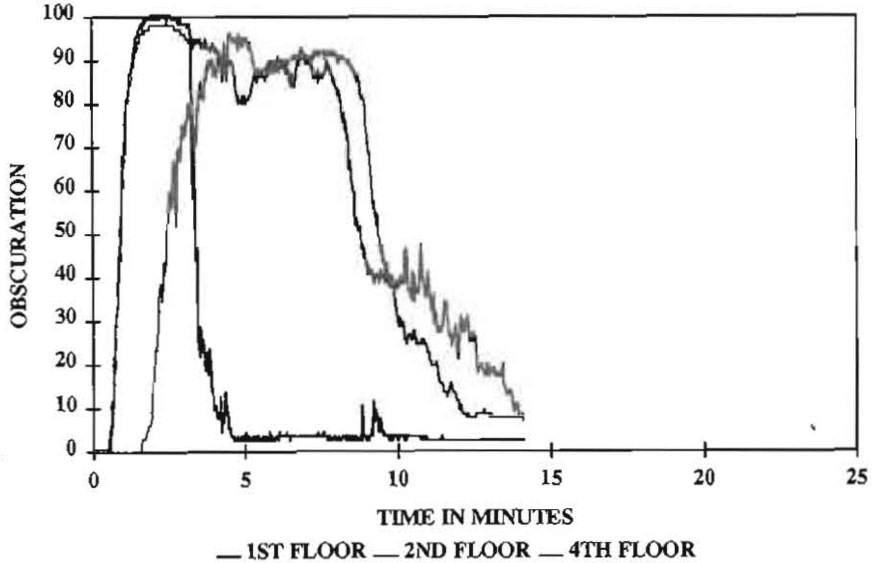
Temperature at 3 foot level



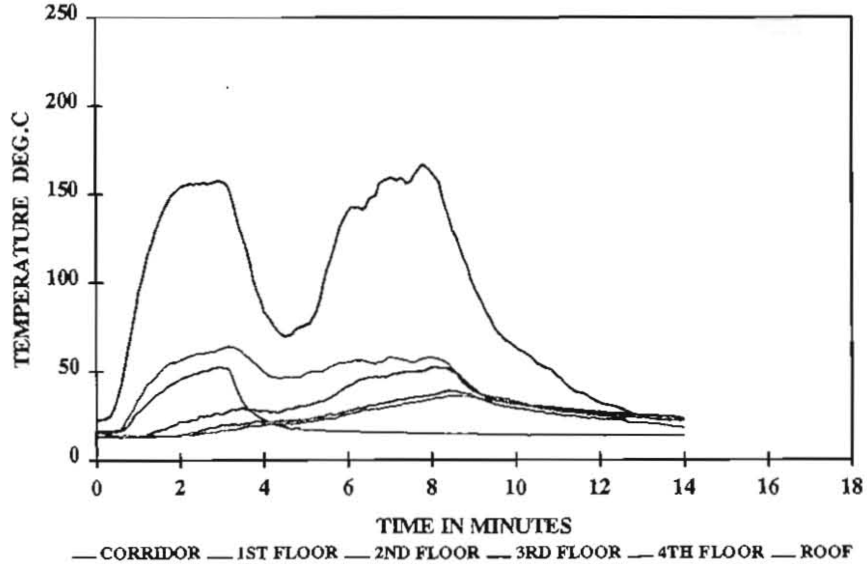
Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
03:04	09:08	N/A	07:40	08:40

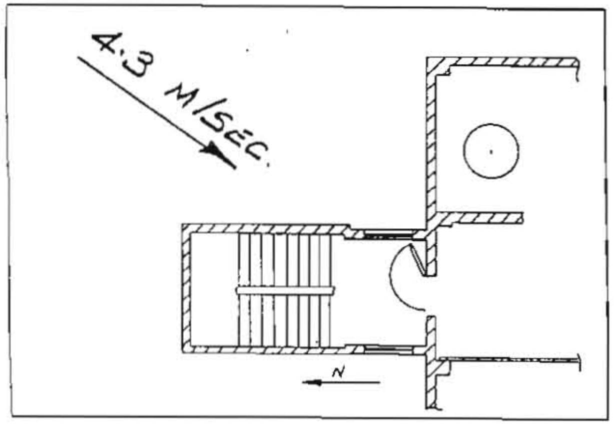
TEST 37 The firefighters entered at 2 mins. 30 secs. The 1st floor 'window' - at the southern end of the corridor - was opened at 3 mins. 06 secs. The the downwind 4th floor landing window was opened at 4 mins. 23 secs. PPV was not used.



Smoke obscuration



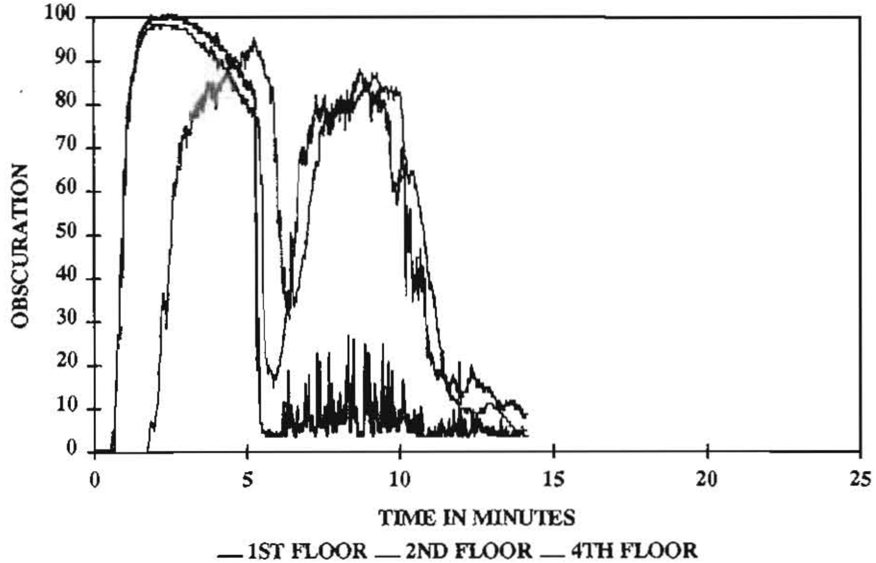
Temperature at 3 foot level



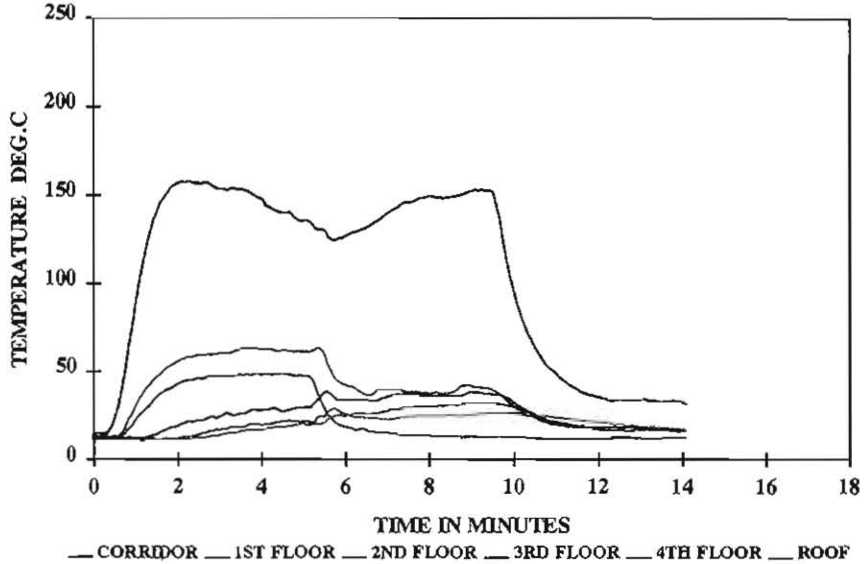
Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
03:14	08:43	08:43	N/A	12:44

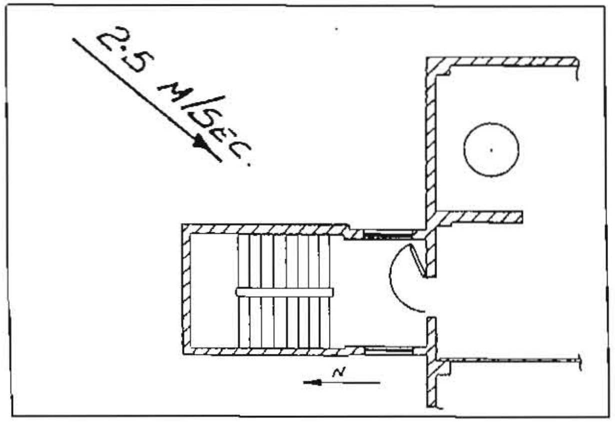
TEST 38 The entry door was opened at 2 mins. 30 secs. and both 4th floor windows (one each side of the stairwell) where opened at 5 mins. 21 secs. The PPV fan was started immediately the windows were open.



Smoke obscuration



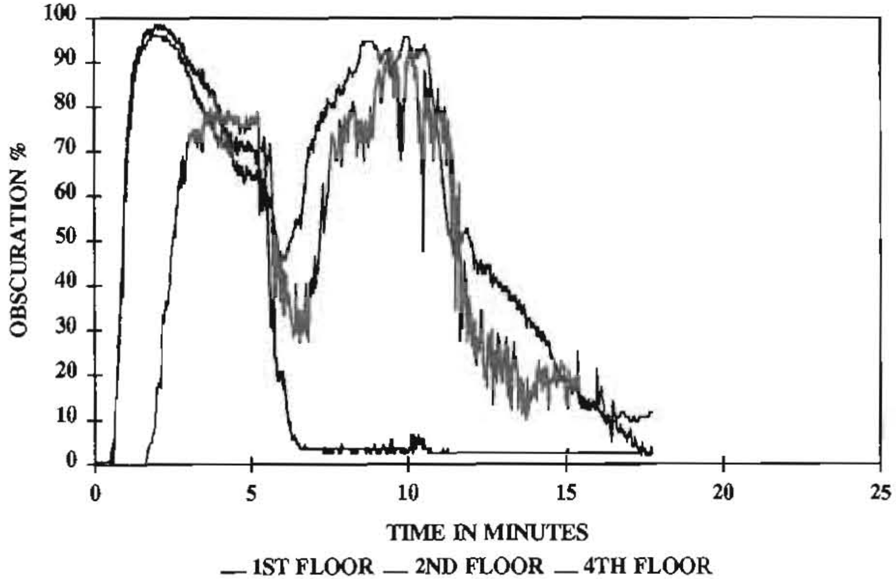
Temperature at 3 foot level



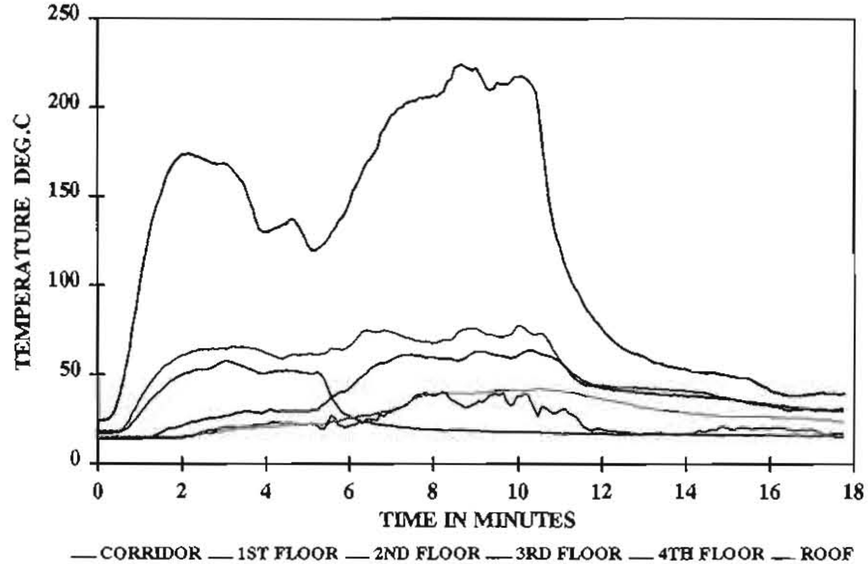
Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
03:32	(5:24) 9:26	(5:33) 10:16	(5:46) 10:48	11:15

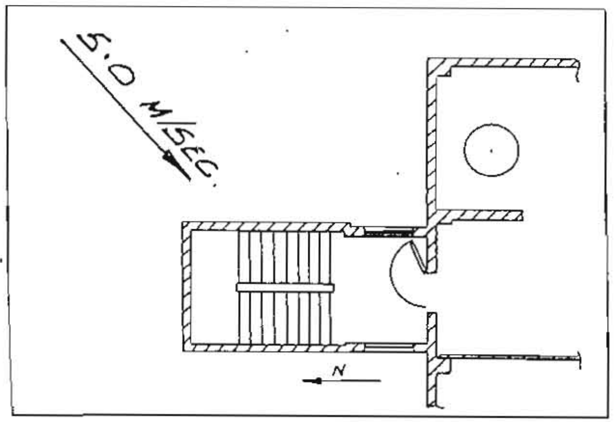
TEST 40 The entry door was opened at 2 mins. 30 secs. and both 4th floor windows (one each side of the stairwell) were opened at 5 mins. 21 secs. PPV was not used.



Smoke obscuration



Temperature at 3 foot level



Average
Wind velocity

Times that torches became visible				
1st	2nd	3rd	4th	Roof
03:40	10:52	11:21	14:35	15:00