FRDG Publication 17/96 An Assessment of the Use of Positive Pressure Ventilation in Domestic Properties

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An Assessment of the Use of Positive Pressure Ventilation In Domestic Properties

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ABSTRACT

This report describes a series of trials to assess the effects of a Positive Pressure Ventilation (PPV) fan upon the conditions in a single room fire in a typical domestic property. Trials were first undertaken in still air conditions, to assess outlet air velocities and cold smoke movement and these were followed by fire trials in real conditions.

It is concluded that the use of a PPV fan can improve conditions for firefighters by both rapidly improving visibility and reducing air temperatures between the inlet opening and the fire. The effect of the PPV fan upon the fire itself was seen not to be significant in this single room fire situation.

MANAGEMENT SUMMARY

INTRODUCTION

In February 1995 the Fire Experimental Unit (FEU) of the Home Office Fire Research and Development Group, based at Moreton-in-Marsh, was asked to conduct a research project into the likely effects of Positive Pressure Ventilation (PPV) when used in firefighting. Several different scenarios are to be investigated. This report covers the second of these - a simple one-room fire in a domestic building. FRDG Report 6/95 'An Assessment of the Effectiveness of Removable Pavement Lights when Fighting a Basement Fire' includes a brief look at the use of PPV in cellar fires. This work is seen as part of a broader package concerned with the ventilation of buildings in general.

This report describes a series of trials conducted in still air conditions and a series of fire trials conducted in a four bedroom detached house.

BACKGROUND

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.

In relatively recent years it has been suggested that fans could be used in some circumstances as an aggressive 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.

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.

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

2. 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.

3. 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.

4. 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.

5. 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.

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:

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

2. 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.)

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

TRIALS PLANNING

The basic underlying intention was to conduct trials in a fire building, while the fire was burning. The trials would be conducted in pairs: one using PPV and the other using natural ventilation only. Clearly, the choice of building which could be used for repeated hot fires would be severely limited.

The Fire Service College were approached and kindly agreed to make their 'domestic' building available to FEU for the trials, and to allow them to carry out some modifications to the building for the duration of the trials. This building, specially constructed to withstand repeated fires, represented a typical four bedroom detached house. FEU decided that the hot fire trials should be carried out in the main living room, on the ground floor. This room had a pair of French windows (double doors) at one end, two windows at the other and a single door into the hall. It was agreed that a dining area leading off the living room, where there would have been sliding doors to separate it, could be blanked off with steel plates for the duration of the trials.

STILL AIR TRIALS

The first step was to build a full size mock-up of the living room of the fire building in the FEU still-air facility at Little Rissington. This was an exact replica of the room, constructed of timber so that all windows and doors could be closed or removed.

The purpose of these trials, in which a 24" Tempest PPV fan was used, was to enable FEU to examine the effects of the fan upon the air in the room, in the absence of any natural air movement, when deployed with the various possible combinations of inlet and outlet openings. Specifically, it was intended to:-

a. Determine the optimum position for the fan in each possible inlet/outlet scenario (i.e. where the maximum average outlet velocity would be produced), and assess the sensitivity of this fan positioning.

b. Assess the effects of the ratio of the areas of the inlet and outlet.

c. Assess how the static pressure generated in the room varied with fan position, and with inlet/outlet area ratio.

d. Allow the experimenters to become familiar with the equipment and instrumentation, and enable them to become better able to predict the likely effects of the fan in subsequent fire trials.

This was done by measuring air velocities in the outlet opening/s and the static pressure in the room, over a wide range of fan positions (both distance from the opening and fan tilt angle were varied).

Also, some trials were undertaken using cold smoke in conjunction with video and smoke obscuration meters. The aim here was to ascertain whether it was possible to correlate outlet velocities with smoke clearance times, with and without the fan. It was accepted that, while the results of these cold smoke trials could be fairly compared one with another, they would not give any indication of the way in which hot smoke would behave, due to the lack of any buoyancy effects or continued smoke production.

Also, water sprays produced by firefighting nozzles were used in an attempt to clear cold smoke from the room, since this comparison would be of interest to brigades. Also several different fans were tried with cold smoke.

These trials showed that:

1. The room was cleared of smoke significantly faster when a PPV fan was used (some 2 minutes as opposed to some 30 minutes).

2. The optimum distance of the fan from the inlet opening was not particularly sensitive, and anyway, would depend upon what the primary objective was; maximum air throughput, maximum internal pressurisation, or ensuring no smoke or gases escaped via the 'inlet'. (This may be affected, in a real situation, by the natural wind.)

3. The differences in both outlet air velocity and static pressure caused by varying the inlet/outlet area ratio were found to be less significant than may have been supposed.

FIRE TRIALS

The fire trials were undertaken in the living room of the Fire Service College's 'domestic' building during October 1995 and March/April 1996. In all, 33 fire trials were completed; 18 using a PPV fan, and 15 not using a fan (of which, one used a hosereel spray).

A standard repeatable trial fire was developed and used in all trials except the first two. This was 7 litres of Heptane fuel in a 34B (1.2 metre diameter) tray, detonated electrically from outside the building.

Generally, the trials were undertaken in pairs, as far as possible, each pair comprising one trial in which a PPV fan was used and one using natural ventilation, only. The time elapsing between the trials in each pair was kept to the minimum practicable, so that the pair were conducted in broadly similar wind conditions, and results could therefore be fairly compared.

The procedure was the same for the majority of trials. In all trials the fire was allowed to burn for a period of 2 minutes before the room was opened. When the fan was used it was positioned and run up before the room was opened, so that it had developed full power when first deployed.

One pair of trials was designed to assess the effects of a PPV fan upon smoke in the hallway stairs, upstairs landing and furthest bedroom. This necessitated two fire officers, in full fire kit and BA giving a recorded commentary from within the building. Another pair of trials used a different fan which, in one trial, incorporated a fine, sparse, water spray and in yet another trial a hosereel spray, only, was used (this, at the suggestion of fire officers).

During the trials the room was instrumented to measure and record smoke obscuration at the 0.91 m. and 1.83m. levels, air temperatures at six levels at each of four positions in the room, air velocities in the outlet openings, and thermal radiation flux from the fire. Also, video was used, both internal and external to the room, to record all trials, and the natural wind speed and direction was recorded throughout each trial.

RESULTS AND CONCLUSIONS

The results obtained from each instrument in each trial were recorded by the data logger and, where practicable, were printed out in graphical form. All of the data and graphs from all trials have been retained by FEU. The sheer bulk of data obtained from the trials made it necessary to find a way of summarising the data so that comparisons between one trial and another could be readily made. (This summarised data is given in Tables 4 and 5 of this report.)

Guidance on ventilation is given in the supplement to the Manual of Firemanship: 'The Behaviour of Fire - Tactical Ventilation of Buildings and Structures'. Forced Ventilation, and specifically Positive Pressure Ventilation, is covered there only in general terms. However, the practical advice therein has been reinforced by these trials.

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.

It was not possible to use the measured effect of the fan in still air conditions and with no fire, to predict with any degree of certainty the difference that a PPV fan might make in a fire situation. Clearly, there are two things which can make a difference in the fire situation: the effect of the natural wind, and the buoyancy effect caused by the fire. It appears from the results obtained in the trials that the natural wind is the dominant factor, when only a single storey is involved.

The Manual of Firemanship supplement defines Offensive Ventilation thus: "ventilating close to the fire to have a direct effect on the fire itself, to limit fire spread, and to make conditions safer for the firefighters". The trials confirmed that, in general, the air temperature just inside the entry (fan) position reduced faster, at the 3 ' 0" level, with the PPV fan than without it. However, there were exceptions, in three pairs of trials, to this rule.

The Manual of Firemanship supplement defines Defensive Ventilation thus: "ventilating away from the fire, or after the fire is out, to have an effect on the hot gases and smoke, particularly to improve access and escape routes and to control smoke movement to areas of the building not involved in the fire". In the single pair of trials in which the first floor of the house was smoke logged, the fan had a marked beneficial effect. The path between the inlet and outlet openings (hall, stairs, landing and vented bedroom) was cooled and cleared of smoke very rapidly, and significantly faster than when the fan was not used.

When there is no wind blowing, or a negligible wind, use of a PPV fan can improve ventilation, reducing both smoke logging and air temperatures near the inlet opening. In this situation the inlet opening should be selected so that any slight breeze assists the fan if possible, but if this is not possible the fan should be able to reverse a slight breeze. In this latter case a large inlet/outlet area ratio should be used.

As a general rule, when there is an assisting wind component, use of the fan is beneficial. However, when a strong wind (in excess of 5.5 metres/second) is blowing directly, or almost directly, into the inlet opening, the use of a PPV fan to assist the wind does not cause any significant improvement, and may even hinder smoke clearance and temperature reduction.

When the natural wind is unavoidably opposing the fan (that is, if the decision is made to attempt to reverse the natural airflow through the building) it is possible for the fan to overcome the opposing component of the wind, provided that this is not too strong, and that the inlet/outlet area ratio is arranged to be in the fan's favour (large inlet, small outlet). However, in this situation the fan should only be tried with extreme caution since it is possible for the effect of the fan to cancel out the effect of the natural wind, and impede ventilation. The trials results suggested that, even if an inlet/outlet area ratio of 2/1 can be achieved (a single doorway to a single window), there would be no point in attempting to reverse the air flow caused by an opposing wind component of about 2.5 metres/second, or more.

When the component of the natural wind blowing across the fan is large compared to that either assisting or opposing the fan, the output of the fan appears to be somewhat disrupted. It is virtually impossible in these conditions to predict with certainty what the effect of a fan blowing directly at an inlet opening might be, or whether it will improve the natural ventilation. As the wind component either assisting or opposing the fan becomes greater relative to the 'across' component, it becomes in general rather more easy to predict what the effect of the fan might be.

Although, in the still air trials, an inlet/outlet area ratio of about 1/1 gave somewhat higher volumetric flowrates than a ratio of about 2/1, it is considered that an inlet/outlet ratio of about 2/1 would be a good one for brigades to aim for, and gives a PPV fan a good chance of improving the ventilation of a building. It would be advantageous to ensure, at least, that the inlet opening is larger than the outlet opening in order to try to ensure that the air flow set up in the building will be, and will remain, in the required direction, should the strength and/or direction of the wind change during the ventilation process.

Sealing of the inlet opening by the fan would be most important operationally where the intention is to ensure that no smoke (hot gases, products of combustion, etc) escape through the inlet opening, or where the direction of the airflow through the building needs to be kept under control. To this end, it is better to err on the side of being too far from the opening rather than being too close with the fan (although the volumetric flow-rate of air entering the building will be somewhat reduced). In the hot fire trials, the 24" Tempest fan was found to seal a single doorway at a distance of 2.75 metres, when set at the mid tilt position of the 5 available (+9°), in all of the conditions of the natural wind occurring in the trials..

If the object of using a PPV fan is solely to pressurise a room, or building, to the maximum extent possible, it is not necessary to seal the inlet opening with the fan. In this case, the results from the still air trials suggest that the optimum fan distance from the inlet opening is about 1.0 metre, for inlet/outlet area ratios of between, and including, 4/1 and 1/2. (Except when the fan was on the floor blowing upward at a window - inlet/outlet area ratio of about 1/2 when the optimum fan distance was not critical. This was the least effective way of using the fan).

If it is necessary to use a window opening as the inlet, no suitably placed doorway being available, better results are achieved, both in terms of average air flowrate and static pressure, if the fan can be raised to the level of the window and air projected horizontally into the building, than if it is standing on the ground projecting air upwards.

In the single trial in which a hosereel water spray was used instead of the PPV fan, the spray reduced the air temperatures in the room at least as rapidly as the fan could have done. Smoke logging was also reduced during the early stages of the attack so that daylight could just be seen in the opening at the far end of the room some 10 seconds after opening up the room and commencing the attack. However, some 450 litres of water were sprayed into the room.

In the single pair of trials in which both the inlet and outlet openings were at the same (downwind) end of the room, the use of the fan made little difference to the air temperatures just inside the inlet, but appeared to clear the smoke rather faster. However, it would appear that this would not be a very effective way of using PPV.

CONTENTS **PAGE NO.**

FIGURES

1. INTRODUCTION

In February 1995 the Fire Experimental Unit (FEU) of the Home Office Fire Research and Development Group, based at Moreton-in-Marsh, was asked to conduct a research project into the likely effects of Positive Pressure Ventilation (PPV) when used in firefighting. Several different scenarios are to be investigated. This report covers the second of these - a simple one-room fire in a domestic building. FRDG Report 6/95 'An Assessment of the Effectiveness of Removable Pavement Lights when Fighting a Basement Fire' includes a brief look at the use of PPV in cellar fires. This work is seen as part of a broader package concerned with the ventilation of buildings in general.

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) or to draw air out of the building (Negative pressure ventilation). In either case the fan, or fans, are 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 aggressive 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.

Over the last two or three 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.

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

2. 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.

3. 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.

4. 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.

5. 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 were 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. However, at present relatively few are equipping themselves with purpose-built fans, or 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:

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

2. 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.)

3. 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 twelve months, FEU have collated and studied a large number of articles, reports and papers. These are retained by FEU.

3. TRIALS PLANNING

3.1 General

It was agreed early on in the project that trials should be undertaken using a PPV fan and a building in which hot fires could be lit. It was further agreed that the work should be divided into two stages. In the first stage, trials would be carried out in still air conditions, without a fire, to measure air flows and static pressures due to a PPV fan, and to investigate the optimum positions for the fan, and how critical this positioning was. Cold, artificial, smoke would also be used to investigate speed of clearance with and without a fan.

In the second stage of the trials, hot fires would be used in realistic conditions, where the natural wind would have an effect, and convection currents due to the fire would also be experienced. Here, the difference between using PPV and not doing so, in broadly similar conditions, would be assessed both in terms of smoke clearance and changes in air temperatures. Also, it was considered that it might be possible to make some assessment of the importance of the natural wind and buoyancy effects, as well as the effects of varying the relative sizes of the inlet and outlet openings.

3.2 The Building

A building was needed in which hot fires could be repeatedly performed, while the interior remained the same, throughout a series of trials. These requirements greatly limited the range of buildings available.

After discussions with the Fire Service College (FSC), it was agreed that their 'domestic' fire house would be made available to FEU, to conduct the trials, provided that these could be fitted into the College's training programme. It was anticipated that a two week period would be needed for the hot fire trials.

This building, specially constructed to withstand repeated fires, represented a typical four bedroom detached house. FEU inspected the building and decided that the hot fire trials could be carried out in the main living room, on the ground floor. This room had a pair of French windows (double doors) at one end, two windows at the other and a single door into the hall (Figures 1, 2 and 3). It was agreed that a dining area leading off the living room, where there would have been sliding doors to separate it, could be blanked off with steel plates for the duration of the trials.

3.3 The Fire

Little detailed consideration was given to the fire at the initial planning stage, since it was thought that a suitable fire could be readily developed. It was accepted that some preliminary trials, in the selected room, would be necessary for this purpose. The fire was required to:

1. be easily repeatable, and reproducible;
2. produce sufficient quantities of visible smoke;
3. raise the 'air' temperatures in the room sufficiently; and
4. burn for long enough for the effects of the fan to be assessed.

3.4 Full Size Mock-up Room

It was clear that the first stage of the trials could not be performed in the FSC domestic building, both because of the unavoidable natural wind effects and because the building would not be available for the long periods required. It was therefore decided to construct an exact replica of the room in the FEU's still air facility at Little Rissington. This would mean accurately surveying the room, producing drawings and constructing a replica of timber and plywood, and would need to be one of the first parts of the work to be set in motion.

3.5 Instrumentation

It was agreed that instrumentation would need to be provided to measure and continuously log a number of variables. FEU already owned some of the equipment necessary but, since no such work had been undertaken previously, some would need to be purchased, if possible; or if not, designed, developed and manufactured. (See Section 4).

The measurements that would need to be made were:-

Air velocities in outlet openings, expected to range from zero to some 8.0 m/sec.

Static pressures inside the room, expected to range from zero to some 50 Pa.

Smoke obscuration, from zero to 100%.

Air temperatures experienced at a number of positions and levels.

Thermal radiation (from the fire, only).

Also continuous, synchronised, video recording would be required within and outside both ends of the room during both fire, and cold smoke trials, to record smoke movement and to record and time events.

4. PROCUREMENT AND DEVELOPMENT OF TRIALS 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

There were several PPV fans available on the UK market, all of which were considered for use in the trials. While these fans were all basically similar in design, they varied in size from 18 inch to 30 inch fan diameter, and in throughput from 6,000 to 16,000 ft.^{3}/min. (170 to 453 M^3/min.). Also, fans were available with petrol engine, electric motor or water drive.

After discussions with brigades personnel, FEU purchased a 24" Tempest petrol driven fan (1) The company also supplied a similar 21" fan free of charge. A third fan, a Ramfan GF-165 'Turboventilator' was borrowed by FEU(2). After some further discussion with brigades and initial trials, it was decided to use the 24" Tempest fan throughout the trials, largely on the grounds that: a. it did not 'walk' due to vibration when on a smooth concrete floor; and b. its noise level was found to be the most acceptable. Also, several brigades confirmed that this was the most likely kind and size of fan to be carried.

This fan (Figure 4) 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 9,130 ft.^{3}/min. (258 M^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 simple 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

4.3 Mock-up Room

A full size mock-up of the living room in the FSC domestic building was constructed in the FEU still air facility at Little Rissington. (This still air facility, a former aircraft hangar, measured 91.4m. long by 45.7m. wide, and was 9.1m. high, to the underside of the roof beams.) This was an accurate reconstruction of the fire room, including its somewhat complicated ceiling. The mock-up was constructed, close to the centre of the still air facility, principally from 4"x2" timbers, clad with 12mm. plywood and externally braced to prevent 'panting' under internal pressures. All door and window openings (and the hearth) could be blanked off with close fitting blanks so that any combination of openings could be selected. (Figures 3, 5 and 6.)

4.4 McCaffrey Probe Arrays, and Micro-manometers

A search was made for instrumentation which might be used to measure air velocities in the outlet openings of the room, in both ambient and hot conditions. It was found that the Fire Research Station (FRS)(3) had developed a method of using a bi-directional low velocity pitot tube, known as a McCaffrey probe, after its inventor (4) (Figure 7).

Discussions between FEU and FRS indicated that McCaffrey probes were the best known instruments for measuring velocities in the expected range, and could be expected to give reliable and adequate results. Also, being constructed of stainless steel they would be suitable for use in a hot, hostile environment. Essentially, these probes were a pair of short and relatively large diameter pitot tubes positioned back to back.

Since FRS had some experience of the manufacture and use of these probes, an order was placed with them for the manufacture and subsequent calibration of 24 probes. These were supplied to FEU, with a list of calibration factors, one for each probe, to be applied to the probe's readings in order to compute the true velocity. (It was also necessary to measure the air temperature adjacent to each probe as this too needed to be included in the calculation to compute the true velocity).

The probes thus obtained were built into two separate modules, each module containing nine probes. These modules were made so that each could be positioned in a window of the test room to measure the air velocities experienced at nine equally spaced positions in the window opening (Figure 8), the sampling tubes being bent away to a manifold block which would be outside the window, and out of the way of any direct radiation or flame.

Also, these modules were made so that they could readily be fixed one above the other to be positioned in a doorway, so that eighteen equally spaced positions in the opening could be monitored (Figures 8 and 9). The two modules needed to be different from each other only in the bending of the sampling tubes of the probes, so that the two manifold blocks were adjacent to each other, low down and to one side, at the outside of the opening.

A K-type thermocouple(5) was fixed to each of the probes with soft iron wire, its hot junction being some 10mm forward of the probe and a little to the side, so as not to impede the air flow.

Six micro-manometers (6) were purchased to measure the outputs of the McCaffrey probes. These were mounted external to the test room, in a small, heated, wooden shed to afford protection from the weather, and were connected to the McCaffrey probe manifold blocks by flexible silicon tubing (7) of 3mm bore and 5mm O.D., which was capable of withstanding high temperatures (relative to other flexible plastic or rubber tubing).

4.5 Static Pressure Measuring Device

Two static pressure tappings were built into the mock-up building. These were each simply a stainless steel tube, 4.8mm O.D. x 0.7mm wall, set into the wall, and ceiling, at right angles to the surface. The inner end of the tube was set flush with the wall surface and the outer end was connected, via a length of plastic tube to a micro-manometer. The positions of these tappings are shown in Figure 6. (In the event, only the wall tapping result was recorded in the trials since initial trials indicated that the readings were identical at the two positions.)

4.6 Smoke Obscuration Meters

Two smoke obscuration meters (8) were purchased for this work. 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 up facing each other, at any 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 hot fire trials (9). Two meter assemblies were constructed. In each, the emitter and receiver, mounted in their separate cooling jackets, were set up on a pair of Unistrut (10) 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 to support the meter assemblies one above the other, their effective heights being 1.83m. (6 ' 0"), and 0.915m (3 ' 0") from the floor, (Figure 10).

These meters were tried, prior to the hot fire trials, in a series of pavement light trials(11), 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 hot fire trials (in which the most likely fuel was thought 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 (12), via a purpose-made flow restrictor/deflector and robust, yet flexible, stainless steel tube assemblies (13, 14). 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.

4.7 Thermocouple Arrays

Four identical mild steel stands were constructed to support arrays of "K" type thermocouples(5), to measure air temperatures in the fire test room. These stands each consisted of a rectangular tube, 25mm. x 50mm. in overall cross section and 2.2m. long, which stood vertically with 25mm. square tubes welded at their lower end to form a stable base. Horizontal pins, 37mm. long and 5mm. in diameter were welded at intervals of 300mm. to the larger side of the vertical tube and immediately below each pin a 25mm hole was drilled through the wall of the tube.

A thermocouple was fixed to each of these pins with soft iron wire, its hot junction being just clear of the end of the pin, its cable being fed through the hole into the bore of the tube, and down inside the tube to within 50mm. of the floor, where it emerged through a slot at the same side of the tube as the hot junction. The cable terminated at its lower end in a connecting block at floor level, some 0.3m. from the vertical tube.

By this means, six thermocouples were mounted on each stand, so that the stand could be positioned with all of the hot junctions, and the 'cold' ends, facing away from the fire, thereby deriving some degree of protection from direct thermal radiation. The 'cold' ends, on the floor, could be readily insulated. The heights of the thermocouples were:- 0.61m. (2'0"), 0.91m. (3'0"), 1.22m. (4'0"), 1.52m. (5'0"), 1.83m.(6'0"), and 2.13m. (7'0").

4.8 Thermal Radiation Flux Meter

A single radiation flux meter (15) was mounted on one of the thermocouple stands at a height of 0.3m. (1' 0") from the floor. The meter was housed in a diecast aluminium alloy box with just its window protruding, to protect its electrical and water connections. This box was supported by a universal joint from a mild steel bracket fixed to the thermocouple stand.

Cooling water was recycled through the meter by a small electrically driven pump(12) via flexible plastic tubes, with a fine filter (some 0.25mm. mesh) immediately upstream of the meter. The flexible tubes were long so that the pump and its reservoir could be positioned well away from the hostile environment and the tubes, filter and meter box, within the room, were wrapped with thermal insulation. (See Section 4.14).

4.9 Wind Velocity Meter

A wind station (16), used in previous FEU trials, was set up on a vertical pole, at a height of 7.0m. from the ground, some 30m. from the building. This device monitored the wind speed and direction. The output from this instrument could be read and continually logged during trials.

A simple wind sock (17) was also mounted, on a separate pole, at about 4.0m. height, to give a quick visual indication of the wind behaviour to all of the researchers during, and between, trials.

4.10 Data Logger

During trials the outputs from the micro-manometers (static pressure and McCaffrey probes), and the smoke obscuration meters were continually recorded by the FEU's data logger (18). During the fire trials, the output from the wind station, thermocouples (42 in all) and radiation flux meter were also recorded.

The data logger was housed in a pod, used throughout as the trials control station. This control station was sited alongside the mock-up room during the still air trials, and at the south end of the 'domestic' building during the fire trials.

The data logger was connected to a computer which was programmed, using commercial software (19), to display essential monitoring data on monitor screens. The data from the trial was recorded on the computer's hard disk and also, as a back-up, summary information was recorded on the disc drive of the data logger. After a trial, the data recorded by the data logger was transferred into a spreadsheet software package (20) and processed to produce a graphical output.

4.11 Room Dividing Screens

Since it was intended to undertake the hot fire trials in a single room, the living room of the FSC's 'domestic ' building, it was necessary to blank off the dining room. These two adjoining rooms had a large opening connecting them (2.02m. high by 1.60m. wide), where there would originally have been a pair of sliding doors.

It was also intended to position a suitably protected CCD 'fisheye' video camera in the fire room, and this would require a good level of visible light (all surfaces within the room were matt black). Since the fire room would become too hot to contain the necessary lighting, it was decided that the lighting could be placed in the dining room, if strategically placed windows of heat resistant glass, could be provided in the room dividing screen.

A mild steel screen was therefore constructed, in two halves, from 40mm. x 40mm. x 3mm. tubes and 16SWG sheet, so that it could be secured in position, where sliding doors would be between the two rooms. This screen was made to fit the aperture as closely as possible so that the unavoidable small gaps could be effectively sealed with insulation material.

Each half of the screen had an 'ovenglass' window (21) fitted into it, each 380mm. x 330mm., one at a height of 1.51m. to its centre, the other at 0.80m. These windows enabled the room to be lit adequately both for the video, and to allow the researchers to move about safely while setting up and checking instrumentation, filling the tray, connecting detonators, etc.

4.12 Smoke Retaining Boxes

The intention in the hot fire trials was to allow the fire to burn in the closed room for a period sufficient to allow temperatures to rise to fairly realistic levels, and to ensure that the room would be severely smoke logged when a door or window was first opened. It would not be possible to close the 'outlet' opening in the normal way because the McCaffrey probe arrays would be positioned in these openings and their output tubes would emerge from them. Also, these 'outlet' doors or windows were to be removed completely because, opening outwards in both cases, they would complicate the airflows due to the natural wind if opened normally.

It was therefore necessary to construct large smoke retaining boxes to close these 'outlet' openings, as far as practicable, until the room was opened up, when the boxes would need to be rapidly removed.

Three such smoke retaining boxes were made, one for each of the two windows and one to cover the pair of French windows (See Figures 11 and 12). Although of different dimensions, these three boxes were essentially similar. All were constructed of 102mm. x 51mm. (4"x2") timber and 9mm. marine plywood. Each box consisted of a top, back and sides, and extended from just above the opening to some 0.3m. from the ground. The entire inner surface of each box was clad with 50mm. thick rigid slabs of rockwool with a hard flame-resistant coating(22).

The main frame of each box was hinged at its lower end so that the box could be pulled away from the face of the building at a given signal by means of a rope attached to its top. Where necessary, local slots were cut in the side of a box to clear instruments or other obstructions. The boxes were designed to topple, when pulled, into a horizontal position well clear of the room opening.

4.13 Video Cameras

Two video cameras were set up outside the fire building to record the progress of each fire trial. They were positioned just clear of the south end of the building, one looking along the front of the building to show the front door and living room windows, the other looking along the back of the building to show the French windows. Both cameras were set far enough back to show the PPV fan when in its furthest 'out' position.

Also, a small CCD video camera (23) fitted with a fisheye lens, giving a field of view of 110°(24) was mounted low down inside the fire room. It was positioned in a corner of the room at the 'fan end', where applicable. This camera was protected by a stainless steel, air cooled, jacket with an 'oven glass' window(25).

During each fire trial, cool air was circulated through this protective jacket by an electrically driven air blower(12) outside the room, via suitably insulated plastic tubes which entered the room by the nearest available low level opening (See Section 7.2.2). This camera was used to record all hot fire trials, from the initial fuelling of the fire tray to the conclusion of the trial. It was also used in the same way, but without air cooling, during the still air trials in the mock-up room when artificial smoke was used. (In this latter case, an external camera was also used to record the smoke exiting the room.)

4.14 Thermal Insulation Materials

It was perceived that difficulty might be experienced during the fire trials in protecting the instrumentation in the room, and its cabling, from damage. It was agreed that, as a general rule, all electrical cabling and plastic tubing should be kept as low as practicable, on the floor if possible.

However, it was unavoidable that all materials in the fire room would be subjected to high temperatures, and might come into contact with flame. For this reason, three different materials were purchased to protect the more vulnerable parts of the instrumentation, and the cabling in particular. These were:-

(a) Flexible, helically wound, stainless steel tubing, of some 20mm. diameter, braided on the outside(26). This, with suitable end fittings from the same manufacturer, was used to protect the cabling of the smoke obscuration meters between the instrument housings (at 1.83m. and 0.91m. from the floor) and their steel connection boxes at floor level. This was further protected by (c) below.

(b) A ceramic felt blanket material(27) which exhibited very low thermal conductivity. 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 was used to wrap, or cover, cabling laid along the floor of the room, and also pressed into any gaps around doors, windows, screens etc., to minimise leaks. It was loosely tied in place with soft iron florist's wire where necessary.

(c) Aluminium baking foil, which exhibits extremely low surface emissivity, was used either singly or over (b) above, to protect cabling and plastic 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.

4.15 Standard Trial Fire

The intention was to develop a repeatable fire which would raise the 'air' temperatures to fairly realistic levels and produce sufficient smoke (a smoke obscuration meter reading of 100% was the aim).

It was considered that a 2 minute pre-burn would be sufficient to allow temperatures and smoke logging to rise to the required initial levels. It was therefore proposed to let the fire burn in the 'closed' room for a period of 2 minutes, then the room would be opened and the PPV fan immediately deployed (or not), after which the fire should continue to burn for a further one minute at least, in order to allow time to assess whatever differences the fan may make.

However, the duration of the test fire had to be limited so as not to increase the residual heat in the fabric of the building unduly. Since it might be necessary to attempt to complete several trials in a day, it was important that the room could cool sufficiently between trials.

In order to determine what the standard test fire should be, a series of preliminary trials were conducted in the fire room. During the first few of these, a representative of the FSC was present to advise and ensure that the FEU's proposed test fire would not be so severe as to risk damage to the building. The effects of fires of increasing sizes, using standard circular test fire trays, were examined, until it was agreed that a 34B tray (1.20m. in diameter) gave the largest surface area that could reasonably be used in the room.

The duration of the test fire would be determined by the depth of fuel, and the burn rate of the given fuel. However, while it was possible to establish a burn rate for a given fuel in a given tray, outdoors, which would be fairly repeatable, it was found to be impossible to achieve good repeatability in the fire room when its doors and windows were shut for part of the time. (The time taken to burn a given volume of fuel could vary by up to some 70%). This was due to oxygen depletion, which varied with the strength and direction of the prevailing wind.

When all doors and windows were closed, the only openings through which gasses could escape, and/or oxygen be drawn in, were the chimney and three 150mm. diameter vents some 380mm., from the floor, two at the west (windows) end of the room and one at the opposite end, as well as numerous small leaks around doors and windows.

Further preliminary trials were carried out to determine the quantity of Heptane fuel to burn, whether fuel additives 'improved' the smoke production, etc. These trials were also useful in developing, and proving, the fuelling and detonating equipment and techniques. In all of these trials the fire tray was positioned on the longitudinal centreline of the room, and 200mm. from the front of the fireplace at its nearest point.

The detonator used to start the fire in these, and all subsequent, trials was an electrically detonated 'firework' (28). This small firework, 75mm. long and 25mm. in diameter, was fixed inside the lip of the tray by a steel clip. It was triggered by an FEU-made detonating switch box incorporating a removable safety key, powered by a car battery.

On the basis of the results of these preliminary trials, it was decided that the standard trial fire would be a 34B tray containing 5.0 litres of Heptane fuel(29) on a 15mm. deep water base, which would be detonated electrically from outside the building. (The quantity of fuel was again altered, to 6.0 litres and then 7.0 litres, during the first three trials because, in the interim period, the hearth cheeks and fireback had been removed from the fireplace, unknown to FEU until the trials were about to commence. This gave a significantly larger opening, and resulted in a faster, shorter duration burn.)

5. TRIALS IN STILL AIR

5.1 General

A series of trials using the 24" Tempest fan(1) was undertaken in the mock-up room (an exact replica of the 'domestic' building's living room) built in the FEU still air facility at Little Rissington. This still air facility is an ex-aircraft hangar, of internal dimensions 91.4m. (300'0") by 45.7m. (150'0") by 9.1m.(30'0") high, to the underside of the lowest roof beams. These trials were completed before any fire trials were started.

The purpose of the trials was to enable FEU to examine the effects of the fan upon the air in the room, in the absence of any natural air movement, when deployed with the various possible combinations of inlet and outlet openings. Specifically, it was intended to:-

a. Determine the optimum position for the fan in each possible inlet/outlet scenario (i.e. where the maximum average outlet velocity would be produced), and assess the sensitivity of this fan positioning.

b. Assess the effects of the ratio of the areas of the inlet and outlet.

c. Assess how the static pressure generated in the room varied with fan position, and with inlet/outlet area ratio.

d. Allow the experimenters to become familiar with the equipment and instrumentation, and enable them to become better able to predict the likely effects of the fan in subsequent fire trials.

This was done by measuring air velocities in the outlet opening/s and the static pressure in the room, over a wide range of fan positions (both distance from the opening and fan tilt angle were varied).

Also, some trials were undertaken using cold smoke in conjunction with video and smoke obscuration meters. The aim here was to ascertain whether it was possible to correlate outlet velocities with smoke clearance times, with and without the fan. It was accepted that, while the results of these cold smoke trials could be fairly compared one with another, they would not give any indication of the way in which hot smoke would behave, due to the lack of any buoyancy effects or continued smoke production.

Also, water sprays produced by firefighting nozzles were used in an attempt to clear cold smoke from the room, since this comparison would be of interest to brigades. Also several different fans were tried with cold smoke.

5.2 Description of Trials Set-up

The trials control room was set up alongside the mock-up room, some 5.0m. away, as shown in Figure 13. This Figure also shows the convention used throughout the trials (including the subsequent fire trials) for identifying the room openings. Doorway 'A' which, in the firehouse, led from the hall into the room, was 2.06m. high and 0.76m. wide. The French window openings, 'B' and 'C', were each 2.06m. high and 0.72m. wide, and the window openings 'D' and 'E', at the opposite end of the room were each 1.02m. high and 0.66m. wide, their lower edges being 0.91m. from the floor. The only other opening in the room was the hearth where the fire surround opening was 0.56m. high and 0.41m. wide. This could be either open or blanked off.

The dimensions of the mock-up room (and the fire test room, upon which they were based), in plan, are given in Figure 3. The ceiling was rather complicated, having three different, local, levels. These are given in Figure 6. This figure also shows the positions of the two static pressure tappings.

The only equipment sited outside of the mock-up room and the trial control room, apart from the fan, was a movable waterproofed shed which was fitted out to house the micromanometers used to measure the output pressures of the McCaffrey probes and static pressure tappings. This shed needed to be positioned adjacent to the 'downstream' or outlet, end of the room, the opening/s of which would house the McCaffrey probes. Hence, when the fan was positioned to blow from, say, window 'E' to door 'C' ('E'→C') it was positioned as shown in Figure 13, and when blowing from door 'C' to window 'E' ('C→ 'E') it was positioned diagonally opposite (shown dotted in Figure 13).

The only movable instruments installed in the room were the McCaffrey probe arrays, smoke obscuration meters and the fisheye video camera. During cold smoke clearance trials, the McCaffrey probes were removed from the room. When air velocities were being measured, only the outputs from the McCaffrey probes, and the static pressures, were recorded, but the other equipment was retained in its selected positions in the room, to keep all conditions the same in all cases. The smoke obscuration meters were always at the downstream end of the room. The video camera was always at the upstream end, 20mm. from the floor and angled to show almost the entire room, in the corner of the room adjacent to either opening 'B' or 'D'. These positions are as shown in Figure 14 when blowing 'C'→'E', and in Figure 15 when blowing 'E'→'C'.

All cabling from the instrumentation was brought out of the mock-up room through small holes in the end walls, which could be sealed with heavy duty adhesive tape, up the outside of the room and across to the trials control station, laid in metal trunking at roof level. Inside the control station, all trials data could be fed directly into the datalogger, as well as being monitored in real time. All video used inside the room during smoke trials was recorded.

Outside the mock-up room, at each of its ends, the floor was marked out to assist in positioning the fan, and to check that it had not moved of its own volition during a trial. (The floor was very smooth, level concrete.) A centre line was drawn from each opening, and for the pair of French windows when both were open. Lines were then drawn at right angles, across these, at 0.25m. intervals, and labelled according to their distance from the opening.

A substantial wooden box was constructed upon which the fan could be placed, to raise its axis to the level of the centre of the window openings.

5.3 Trials Procedures

5.3.1 General

There were necessarily two different procedures adopted during the trials, one for trials where air velocities in the outlet opening were being measured, and another for cold smoke clearance trials. These are described below.

5.3.2 Air Velocity Trials

The first task to be undertaken in the newly constructed mock-up room was to check the initial results obtained from the McCaffrey probe arrays against the results obtained from two different types of hand-held anemometer. These latter instruments were both relatively simple, quick and easy to use, but neither could be used in the hostile environment which the McCaffrey probes were designed to subsequently endure. The anemometers used were:-

a. A self-contained 100mm. (4") diameter fan(30), which gave an electrical readout.

b. A hot wire instrument(31), in which the rate of cooling was related to the air movement around the wire, also giving an electrical readout.

Strings were stretched horizontally and vertically across a doorway and window opening, in turn, so that their intersections defined the positions taken by the McCaffrey probes (See Figure 8). The fan was started outside of the far end of the room and each anemometer was, in turn, held in each probe position in the outlet opening. Readings were taken with all three instruments, and compared. The differences in the results obtained were negligible, and this gave confidence in the McCaffrey probes, which would be used throughout all subsequent trials.

Initial experiments with the fan showed that the two static pressure tappings, one in the long wall and one in the ceiling gave identical readings. Therefore, the readings from only one tapping, that in the wall, were recorded in all subsequent trials.

The trials were divided into a number of scenarios, each using a particular opening as the inlet, where the fan would be positioned, and the outlet (or outlets), where the McCaffrey probes would be set up. For each scenario, a number of fan positions were tried. The procedure adopted for each scenario was identical each time. The McCaffrey probe arrays were always set up with the probe axes at right angles to the wall surface and with their inner, leading, end 25mm. inside the inner surface of the room.

The smoke obscuration meters and fisheye video camera were inside the room during all trials, but were not used. Their positions were as shown in Figures 14 and 15 generally, the smoke obscuration meters at the downstream end of the room, and the video camera at the upstream end.

In each trial, the fan was set at one of the pre-determined position marks, and its tilt angle set and noted. In all cases the stated position of the fan was the distance from the inner surface of the wall of the room to the foremost part of the cylindrical fan casing (usually, at the bottom).

The fan was aligned by eye with the opening. The fan was started and run up, and when running steadily, usually after about one minute, data taking was commenced.

The data taking was done in the trial control room, each McCaffrey probe output being selected and displayed in turn. These outputs, displayed in metres/second, were found to vary with time over a relatively small range, and so each was logged manually over a period of some 1-1½ minutes, after which the average velocity, for each probe, was calculated. These average velocity values were recorded, and an overall average velocity for the opening was calculated by adding the individual average values and diving the result by the number of probes. These overall average values were plotted against fan position immediately after the conclusion of each trial. This assisted the researchers in deciding the next fan position to be tried.

Also, Lametta (Christmas tree decoration, consisting of long narrow strips of very thin aluminised Melinex) was used before each trial, with the fan running, to assess the airflows in and around the room. This material was taped to a cardboard tube which could be held close to the room openings, while the experimenter kept his body out of the airflow, as far as possible. This crude tool (see Figure 16) gave a useful visual indication of even the smallest air movement. It was used to assess the swirl patterns within the room and, also, the air movements between the McCaffrey probes and at the extreme top and bottom of both upstream and downstream openings. The experimenter's notes were appended to the results sheets where considered necessary.

During the scenarios where the fan was blowing into the room through a window, two different methods were tried. The first was to position the fan on the floor and, at each distance, to tilt the fan axis to whichever setting appeared to give the best attainable angle, ideally with the fan axis pointing towards the centre of the opening. The second method was to stand the fan on a large, substantial wooden box, which brought the fan axis up to the level of the centre of the window opening. (While it was accepted that this latter method would, almost certainly, not be operationally practicable for brigades, FEU wished to establish what differences this might make.)

The scenarios examined in this way covered inlet/outlet area ratios of approximately:-

4/1 (Both French windows→single window)
2/1 (Single French window→single window)
1/1 (Single French window→both windows)
1/2 (Single window→single French window)
1/4 (Single window→both French windows)

Trials using each scenario were continued until all useful positions of the fan had been tried, that is until its effect had reduced markedly due to being either too close or too far away from the room opening. After each trial the fan was moved closer to, or further from, the opening in 1.0m., 0.5, or 0.25m. increments, depending upon the developing shape of the corresponding graph relating fan position to the overall average outlet velocity. The static pressure in the room, which remained virtually constant during each trial, was noted during every trial.

In the later stages of this work, a limited number of other trial scenarios were tried which, although somewhat different in detail could be expected to give similar results to those of previous trials where the inlet/outlet area ratio was the same. These were undertaken simply in order to ascertain whether any significantly different results might be obtained, possibly due to different swirl patterns in the room, etc. Also, a single trial was performed to assess the effect of opening the hearth outlet, since the trials were performed with the hearth opening blanked off. (It was thought that this blanking of the hearth may be possible in the fire test room, thereby eliminating one unknown effect.)

Results are given in Section 5.4.

5.3.3 Cold Smoke Clearance Trials

Cold smoke canisters(32) were purchased for this work. These were in effect smoky, non-flaming, fireworks, detonated electrically from a 3v. battery. The canisters produced smoke for a period of 4 minutes (plus or minus some 15 seconds), and it was found that a single canister was adequate to completely smokelog the mock-up room, from floor to ceiling, giving smoke obscuration meter readings of 100% at both 1.83m. (6 ' 0") and 0.91m. (3 ' 0") levels.

In all, 12 trials were undertaken using cold smoke, mostly using the Tempest 24" fan used throughout the air velocity trials (and subsequent fire trials). However, 4 different fans were also tried,(2, 33, 34, 35) to determine whether any significant differences could be achieved. One trial was undertaken where no fan was used, and the time taken for the room to clear naturally was recorded. Also, 2 trials were undertaken using water sprays instead of a fan.

The final trial was a repeat of an earlier one using the selected trials fan blowing from opening 'C' to opening 'E' ('C'→'E'), (see Figure 3). On this occasion one of FEU's seconded fire officers, in self-contained breathing apparatus (BA), sat in the room alongside the fisheye video camera (at the extreme inlet end of the room) his eyes about 0.91m. (3 ' 0") from the floor. The fire officer gave a commentary on what he could see as the trial progressed, and this was recorded. During this trial the room was lit in the same way as for all other trials where the video camera was used: a single 1KW wide angle lamp, shining diagonally across the room, positioned directly above the video camera. The internal walls were natural plywood colour, and brightly coloured adhesive tapes, 50mm. wide, were stuck into the far corners of the room. The purpose of this trial was to obtain a correlation between the smoke obscuration meter readings, the video recordings, and the human eye (through a BA facemask).

The procedure adopted was the same for each trial until the room was opened and, in all trials where a fan was used, was identical throughout. A single smoke canister was positioned on the floor at the geometrical centre of the room, the hearth opening being blanked off for all trials. All door and window openings were closed and, at a given signal, the canister was detonated from outside the room. After 5 minutes had elapsed the inlet and outlet were opened simultaneously and, where applicable, the fan started immediately after this. The fan had been positioned and warmed up previously so that it developed full power almost immediately in all cases.

In the 2 trials where water sprays were used, the jet/spray branch(36), and hosereel gun(37) were operated from outside the room immediately after the room was opened. In each case, the branch was held at 0.3m.~0.4m. outside the doorway at a height of some 1.0m. In each case, the branch had been pre-set to deliver water in a cone of 40°~45° included angle (see list, below), and the fire appliance(38) supplying the water run up so that the full flowrate was delivered immediately the branch was opened. The axis of the branch was aimed towards the outlet opening at the far end of the room, and spraying continued until the room was cleared of smoke.

When the direction of the attack was reversed (the fan at the opposite end of the room) the positions of the smoke obscuration meter and video camera were altered so that the smoke obscuration meters were always in the downstream end of the room, and the video camera was always upstream. Figures 14 and 15 show these positions.

All trials were continued until the smoke obscuration meter's readings returned to zero, or levelled out just above zero due to a film deposited on their windows by the cold smoke. Also, all trials were recorded by the fisheye video camera over the period from just before the detonation of the canister until the smoke obscuration meter readings levelled out.

Although the cold smoke was claimed to be harmless, it was unpleasant to breathe and so the experimenters exposed to the smoke wore self-contained, battery powered respirators(39) throughout each trial and until the still air facility was virtually cleared of smoke. (All external doors and vents were closed during, and opened fully after the completion of, each trial).

The trials completed are listed below:-

Trial No.	Description
1.P.	'C'→'E': fan at 2.25m., +9° tilt.
2.P.	'C' and 'E': no fan, natural clearance, only.
3.P.	'C'→'E': water spray from jet/spray branch(36). 40° inc. cone angle, 7 bar branch pressure, flowrate = 368 l/min.
4.P.	'C'→'E': water spray from hosereel gun(37) 45° inc. cone angle, 7 bar branch pressure, flowrate = 148 1/min.
5.P.	'C'→'E': Ramfan 'Turbo-Hurricane'(2) at 2.25m.
6.P.	'C'→'E': Doman prototype fan(34) at 2.25m.
79.	'C'→'E': Helysphere fan(33) at 2.25m.
80.	'C'→'E': Doman 'Airdriver' fan(35), at 2.25m.
85.	'E'→'C': fan on floor at 2.25m. +21° tilt.
86.	'E'→'C': fan on base at 2.25m., -3° tilt.

96. 'E'→'C': fan on floor at 1.5m., +21° tilt.

109. As for 1.P. with fire-fighter's commentary.

In the above list the fan used is that selected for the air velocity trials, the Tempest 24", unless otherwise stated. The trial numbers do not run in a continuous sequence because the later ones were interspersed with the air velocity trials. Trials were numbered in the chronological order in which they were undertaken, and the 'P' added to the first 7 trial numbers indicates that these were preliminary trials.

Results are given in Section 5.4, below, and Figures 17-44 inc.

5.4 Results of Still Air Trials

5.4.1 Air Velocity Trials

During each trial the reading of each McCaffrey probe, averaged over some 1~1½ minutes, was recorded on a pro forma results sheet. These values were then averaged, to give the average outlet velocity for the opening.

In trials where there were two outlet openings, probes 1~9 in one opening and 10~18 in the other, the average value for each opening was calculated and then an overall average, of these two values, was calculated. (It was this overall average value that was tabulated, see below.) Figure 17 shows a typical result sheet for this case, which gives an indication of the variations in velocity from one part of an opening to another.

In the relatively small number of trials in which both French windows were opened together, to form an outlet opening, the procedure was necessarily different. Since only 18 McCaffrey probes could be used in a trial, these trials needed repeating to obtain velocity readings across the whole (double) doorway. The McCaffrey probes were set up in one half of the doorway opening and a trial undertaken. The probe array was then moved to the other side of the doorway and a separate trial undertaken. These two trials were given separate numbers, and for each trial an overall average velocity was calculated. Also, an overall average outlet velocity for the scenario was calculated from these two average values.

All of the average outlet velocities, along with all other information relating to each particular trial are given in Table 1.

For each scenario (i.e. inlet/outlet area ratio) a graph was produced, of average outlet velocity against fan position. These graphs also indicate the static pressure recorded at each fan position. The graphs are reproduced in Figures 18 to 29 inclusive.

Graphs were also plotted to show how both average outlet velocities and static pressures varied with the inlet/outlet ratio, each over a range of fan positions, (Figures 30 and 31), and how static pressure varied with fan position, for a range of inlet/outlet area ratios. (Figure 32).

5.4.2 Cold Smoke Trials

The results of all trials were recorded and plotted. The resulting graphs, plotting smoke obscuration (as a percentage) against time, are reproduced in Figures 33 to 44 inclusive.

These graphs show the degree of smoke obscuration at both the 1.83m. (6'0") and 0.91m. (3'0") levels throughout each trial. It can be seen that obscuration rose at both levels to 100% well before the smoke canister was exhausted, at about 4 minutes. The smoke clearance rate at each level can be judged from these graphs for each trial, and direct comparisons made between trials.

The result of the last trial, no. 109, was studied in conjunction with the video recording and the recorded commentary of the firefighter in the room. Key events from this commentary have been superimposed on to the obscuration v. time graph to set the smoke obscuration values, from all trials, into a human context. (See Figure 44).

This figure shows that the firefighter could first see the smoke canister, on the floor some 3.1m. from his eyes, when the recorded smoke obscuration was 58% at the 0.91m. level, and could tell where the windows were, some 6.0m. distant, when the obscuration was 40% at the 0.91m. level and 57% at the 1.83m. level.

6. DISCUSSION ON STILL AIR TRIALS

6.1 Air Velocity Trials

The outlet air velocity readings in any trial varied with time, and from probe to probe. In each trial, each of the McCaffrey probes showed an essentially cyclic variation with time. These cyclic variations were, in general, relatively small, but were the reason for each probe being monitored for 1~1½ minutes, which usually covered several cycles. The average values thus obtained from the probes also varied from probe to probe in a single outlet opening. In a window opening, the maximum variation (highest/lowest average readings) was typically some 20%, with a maximum of about 34%. In a single doorway, the typical maximum variation was again some 20%, with a maximum of about 40%. The relative positions of the probes indicating the highest and lowest velocities in an opening did not remain constant but changed virtually with each scenario, and often with fan position within a single scenario.

The Lametta stick proved useful in checking the existence, and location, of these areas of relatively high and low velocity within a single opening. This crude tool proved to be a very sensitive indicator of air movement and, with a little practice, it was possible to detect quite small differences in air velocity by noting the 'angle of dangle' of the Lametta. Also, the degree of agitation of the Lametta gave some idea of the steadiness, or otherwise, of the air velocity in any location. This Lametta stick, along with periodic cross checking of the probes and micromanometers, showed that there was no reason to disbelieve the results obtained from the McCaffrey probes throughout the trials.

When Lametta was used to assess the seal at the inlet opening, it was invariably very disturbed across the whole opening, indicating that the airflow from the fan was far from streamlined and stable, containing many swirls. However, overall there was clearly a large nett flow of air into the opening over virtually all of its area.

The optimum fan position to attain the maximum average outlet velocity while at the same time affecting a seal at the inlet opening was found to be difficult to determine. (The fan manufacturer suggested "About 6 feet (1.83m.) should make a seal.") According to the Lametta stick, some small proportion of air leaked outwards at the top of a single doorway when the fan was as much as 3.0 metres away from the opening, with an inlet/outlet area ratio of about 1/1. With an inlet/outlet area ratio of about 2/1, and a single doorway inlet, there was evidence of some, very small, outward airflow in the top 100mm of the doorway, with the fan at a distance of 4.0 metres, according to the Lametta. The behaviour of the Lametta, in these trials, showed that the air movement in the extreme top of the doorway was always very unstable, and that any outward flow was probably transient. As the fan was moved closer to the inlet opening, a correspondingly larger area of the opening showed signs of some outward airflow according to the Lametta stick, irrespective of the size of the opening, or the inlet/outlet area ratio.

However, the cold smoke trials (Section 5.3.3) did not show any smoke, other than a very occasional tiny puff, coming out of the inlet opening, when the fan was positioned 2.25 metres from the single door inlet, with an inlet/outlet area ratio of about 2/1. Also, no smoke was seen to emerge from an inlet window when the fan was set up level with the window and 1.0 metre away, with an inlet/outlet area ratio of about 1/2.

From an operational point of view, if it is essential for the fan to effect a seal at the inlet opening, it would be better to set the fan 'too far back' than 'too far forward'. For the range of inlet/outlet area ratios considered, it can be seen (Figures 18 - 29 inc.) that the average outlet air velocity is not particularly critical over the range of fan distances which are of interest. It would therefore probably be considered by brigades that it would be worth sacrificing some of the attainable air flowrate to ensure that the inlet opening is effectively sealed.

For this reason, FEU decided to use a fan distance, when blowing into a single doorways, of 2.50 metres in the subsequent hot fire trials. (However, in the event a fan distance of 2.75 metres was used in some trials, where the seal did not 'feel right' at the 2.50 metre setting. Very little smoke was seen to escape from the inlet openings in these, trials, except when opposing the natural wind).

The method of checking this sealing at the inlet opening of running an un-gloved hand around the outside of the opening appears to be a reasonably reliable guide. If this 'feels right' it is considered unlikely that smoke will emerge from the inlet opening, unless a change in the natural wind overcomes the effect of the fan.

In all cases the Lametta showed that there were complicated swirl patterns set up inside the room due to the geometry of the room and the turbulence of the fan air flow whatever combination of inlet/s and outlet/s were used.

The graphs of average outlet velocity versus fan position (Figures 18-29 inc.), taken overall, show that the average outlet velocities usually tended to increase as the distance of the fan from the inlet opening decreased, until some limiting position was reached. This is seen to be due to the fact that as the fan gets closer to the opening more of its output enters the room. However, once the fan gets so close to the opening that it no longer seals the inlet some of the air will exit through the inlet opening, due to the increased internal pressure. When the fan is so close (1.0m. or less, in a single doorway) that a significantly large area of the inlet opening is not sealed the overall average velocity measured in the outlet opening/s may reduce (See Figure 25).

This sealing of the inlet opening by the fan would be most important operationally in those cases where the intention was to ensure that no smoke escaped through the inlet opening, and the direction of the air flow through the building needed to be known, and under control.

However, if the object of using the fan was solely to pressurise the room to the maximum possible extent, this 'sealing' of the inlet is seen to be unimportant. The static pressures experienced in the room during the air velocity trials are summarised graphically in Figure 32. This Figure shows that for all inlet/outlet scenarios,except those where the inlet/outlet area ratio was only 0.23 and where the fan was on the floor blowing up at a window, the static pressure increased with decreasing fan distance until a distance of about 1 metre was reached. This suggests that a fan distance of about 1 metre from the opening is the best for pressurising the room, for inlet/outlet area ratios between 4/1 and 1/2. (At this distance a PPV fan will not seal a doorway unless steps are taken to make a seal around the fan, using salvage sheets etc., in which case the fan may be better placed right in the doorway.)

In the trials where the fan blew in through a window opening, two different methods of mounting the fan were used: standing it on the floor tilted upwards, and standing it on a box to raise its axis to the level of the centre of the window opening. The graphs of average outlet velocity versus fan position (Figures 18 and 29) show that:

a. Higher average outlet velocities were produced with the fan on the box than with the fan on the floor at the same horizontal distances, once within 3.0m.

b. With the fan on the box, the average outlet velocities increase with decreasing fan distance, whereas with the fan on the floor they remain essentially the same or decrease slightly with decreasing distance.

c. Significantly higher static pressures within the room were achieved with the fan on the box, increasingly so at the shorter distances.

This shows that better results were achieved, overall, when the fan was brought up to the level of the window. While this approach may not be practicable for brigades using a fan operationally, these results do indicate the sort of improvements in performance that might be possible.

The graphs also show that the static pressure in the room generally increased as the distance between the fan and the opening decreased. The highest static pressure for each scenario was usually achieved when the fan was at its closest to the opening, as stated previously. The only two exceptions to this rule were: with the fan on the floor blowing into a single window with a single doorway outlet (Figures 19 and 20), and at the extreme short fan distances when blowing into a single doorway with a single window outlet (Figure 25). In the first case the static pressures were relatively low for all of the measured fan distances, peaking at a distance around 2.0~3.0m. while the average outlet velocity also decreased slightly at fan distances of less than 3.0m. This suggests that 3.0m. may be about the optimum fan distance for a fan used in this way. In the second case, the static pressure, as well as the average outlet velocity, increased, for both fan tilt angles of +9° and +21°, as the fan distance decreased to 1.0m. Then, with still further decreasing fan distances, to 0.75m. and 0.50m., in the +9° tilt case the average outlet velocity increased slightly at 0.75m., then decreased at 0.5m. while the corresponding static pressures reduced slightly, and then reduced further. In the +21° tilt case the overall outlet velocity reduced and then increased to be virtually identical to the 1.0m. value, while the static pressure also reduced slightly and then increased to its 1.0m. value. In the former (exception) case, the window opening becomes more foreshortened relative to the fan axis as the distance decreases, thus presenting a smaller effective inlet area, while in the latter case it appears probable that the fan was so close to the doorway that an unstable regime was set up in the room.

The ratio of the inlet opening area to the outlet opening/s area, or 'inlet/outlet area ratio', varied in the trials as follows:-

One window→two French windows: inlet/outlet area ratio		= 0.23
One window→one French window:	–"–	= 0.45
One French window→two windows:	–"–	= 1.11
Two French windows→two windows:	–"–	= 2.21

Two French windows→one window: inlet/outlet area ratio = 4.42

The relative effects of these differences in inlet/outlet area ratio were not found to be as significant as may have been supposed. Where average outlet velocities are concerned, the graph of average outlet velocity vs. inlet/outlet area ratio (Figure 30) shows, for each area ratio, the range of average outlet velocities achieved with the fan at 2.0m., 3.0m. and 4.0m. from the inlet opening. It is seen that the average outlet velocities recorded are in similar broad, overlapping bands for each area ratio, with a general trend towards higher average outlet velocities at the higher inlet/outlet area ratios. However, it is clear that, for example, doubling the inlet/outlet area ratio does not double the average outlet velocity, and hence the volumetric flowrate through the outlet, and may have only a relatively small effect.

Similarly, the static pressures in the room are not affected as markedly by changes in the inlet/outlet area ratio as may have been expected. The graph of static pressure vs. inlet/outlet area ratio (Figure 31), again shows broad, overlapping bands with a tendency for the static pressure to increase with increasing inlet/outlet area ratios. However, the highest static pressures recorded in the trials occurred with the inlet/outlet area ratio of 2.21.

The fact that the average outlet velocity is not linked more strongly to the inlet/outlet area ratio appears difficult to explain adequately. However, there are several effects which, taken together, go some way towards explaining this.

a. As the inlet/outlet area ratio increases the static pressure caused in the room increases. This will have the effect of limiting how much of the fan output actually enters the room, effectively against a higher back pressure.

b. When the inlet opening is larger, the fan needs to be placed further back from the opening to effect a seal. Thus a larger cross sectional area of the cone of the fan output is used, and the dynamic pressure, and hence volumetric flowrate, would be expected to be higher closer to the axis of the fan. (Doubling the inlet area does not double the volume of air entering the room.)

c. Air will escape from the room in any way it can, due to the increased internal static pressure. When the inlet/outlet area ratio is high the static pressure also tends to be relatively high, and the total leakage (air escaping, but not through the monitored outlet opening) will be correspondingly higher. This leakage is due to a combination of the hearth and many small holes and cracks in the fabric of the building(45).

There is no doubt that, when there is no natural wind (a fairly rare occurrence during daylight hours in the UK), a PPV fan can create a local wind which may be used to assist in searching or firefighting, and for smoke clearance. The effect of the fan in the still air trials can be very briefly summarised as follows.

(1) When blowing from a single door (French window) to a single window (approximate inlet/outlet area ratio of 2/1), with the fan 2.5 metres from the opening, and tilted upwards 9° above horizontal, the measured average outlet velocity was about 3.3 metres/second, giving a volumetric flowrate in the outlet of 2.2 cubic metres/second (4,662 cubic feet/minute).

(2) When the fan was set up in the same way, to blow from a single door to two windows (approximately inlet/outlet area ratio of 1/1) the measured average outlet velocity was about 3.0 metres/second. This implies that significantly more air is leaving the room via the windows than in (1) above. It would therefore appear that more air must be entering the door. This gives a volumetric flowrate of 3.9 cubic metres/second (8,264 cubic feet/minute). This may be explained by the slightly lower static pressure in the room in this latter case, offering less resistance, and hence allowing more of the fan's output to enter the room.

(3) When blowing from a single window to a single door (approximate inlet/outlet area ratio of 1/2) with the fan on the floor, 2.25 metres from the opening and tilted 21° above horizontal, the average outlet velocity was about 1.4 metres/second, giving a volumetric flowrate of 2.0 cubic metres/second (4,238 cubic feet/minute).

It would appear from the above summary that, in the absence of any natural wind or buoyancy effect due to the air being heated, an inlet/outlet area ratio of about 1/1 would be the most effective of those tried in attaining the greatest volumetric flowrate at the outlet. It would also appear that there would be little difference, in this respect, between an inlet/outlet area ratio of 2/1 and 1/2, 2/1 being marginally the better.

6.2 Cold Smoke Trials

6.2.1 General

All of the trials using cold smoke were conducted in FEU's still air facility at Little Rissington, where there were no natural wind effects. The graphs of smoke obscuration vs. time (Figures 33-44 inc.) can therefore be fairly compared one with another.

The results of trial no. 2.P. (Figure 34) show that the room took some half hour to clear when no fan was used. Timing events from when the room was first opened (This applies to all timings throughout this section): it took 8 mins. to move from 100% obscuration at the 3' 0" level, and 10 mins. at the 6' 0" level. 50% obscuration was reached after 18 mins. at 3' 0" and 24 mins. at 6' 0"; 30% after 21 mins. at 3' 0" and 28 mins. at 6' 0"; and 15% after 30 mins. at 3' 0" and 38 mins. at 6' 0". After 53 minutes, when metering was discontinued, the obscuration had levelled out to 8% at the 3' 0" level, and 10% at the 6' 0" level. The results of all other cold smoke trials, where either a fan or a water spray was used, can be compared with this 'natural ventilation' result.

However, the repeatability of these trial results has to be questioned. Each trial was performed once, only, with one exception. It is interesting to compare the results of trial 1.P. (Figure 33) and trial 109 (Figure 44), which was a repeat of trial 1.P., except with a firefighter seated in the room. It is seen that in trial 109 the room was cleared faster, taking only 55% of the time to clear, to 10% obscuration at the 3' 0" level, taken in trial 1.P.

In any event, it can be seen that a PPV fan cleared the room of cold smoke quickly, to 10% obscuration at the 3' 0" level within 2.5 minutes in the worst case, and within 1.5 minutes in the best.

6.2.2 Comparison of Obscuration with Visibility

The results of trial no. 109 (Figure 44) give some perception of what the smoke obscuration figures mean in human terms. The firefighter, sitting in the upstream end of the room with his eyes at the 0.91m. (3 ' 0") level, gave a recorded commentary on the smoke clearance based solely upon what the he could see. The following key points have been extracted from this commentary and are compared with the smoke obscuration meter readings at the 3 ' 0") level, at the same times:

58% obscuration - "Can see the smoke canister" (on the floor at the centre of the room, some 3.1m. from him.)

40% " - "Can see the shape of the windows at the far end of the room." (some 6.0m. distant)

28% " - "To all intents and purposes, it is clear."

18% " - "Can see all of the room.".

In interpreting the above comments, it should be borne in mind that the room was well lit (for the video), whereas in a real situation a smoke logged room would not be as well lit, and would probably be, at least partially, matt black. However, the daylight visible in the window openings, at about 40% obscuration, would give a firefighter a good idea of the size of the room.

6.2.3 Effect of Various Fan Designs

In trial nos. 1.P., 5.P., 6.P., 79 and 80 (Figures 33, 37, 38, 39 and 40) different fans, available to FEU, were used in a similar way each time to determine whether there were any significant differences in performance from one fan to another. In all cases the entry opening was a single French window and the outlet opening a single window. The performances of the fans did differ from one to another, by up to 100% in terms of time to clear the 3 ' 0" level to 10% obscuration. The results of these trials are summarised in Table 2, following.

TRIAL NO.	FAN	OBSCURATION					
		LEFT 100% AT		50%		10%	
		3'	6'	3'	6'	3'	6'
		SEC.	SEC.	SEC.	SEC.	SEC.	SEC.
1.P.	Tempest 24"	40	40	85	100	145	265
5.P.	Ramfan'Turbo-hurricane'	40	40	85	84	135	140
6.P.	Doman prototype	25	30	50	55	80	95
79	Helysphere	15	15	40	40	80	125
80	Doman 'Airdriver'	30	30	75	90	120	135
109	Tempest 24"	20	20	55	75	95	145

Table 2 Summary of Results of Selected Cold Smoke Trials

The differences in performance shown above may be considered significant when comparing fans, but overall they have no great significance when comparing the technique with natural ventilation in still air, or the effects achieved by water sprays applied from outside the room (See below).

6.2.4 Effect of Fan Siting with Window as Inlet

Trial nos. 85, 86 and 96 (Figures 41, 42 and 43) were undertaken to ascertain what might be achieved when the fan was used to blow in through a window, with a single French window outlet. The same fan was used in each of these trials: on the floor 2.25m. from the opening and tilted 21° above horizontal (no.85), on the floor 1.5m. from the opening and tilted 21° above horizontal (no.96), and on a box - level with the window - at 2.25m. and tilted 3° below horizontal (no.86).

Comparing the results of trials 85 and 86 shows that there was little difference between the two. In trial 86 the obscuration readings took some 15 sec. longer to reduce below 100% obscuration but then reduced faster to reach 10% obscuration in 120 secs., some 15 secs. faster than in trial no.85. This suggests that the performance with the fan raised to the level of the window was marginally better than with the fan on the floor at the same distance from the opening.

Comparing the results of trials 85 and 96, in which the fan was on the floor at 2.25m. and 1.50m. respectively, shows that the obscuration was reduced faster with the fan in the closer position. The fan, tilted 21° above horizontal in each case, formed an effective seal at the window in both settings. In trial 96, 10% obscuration was achieved at both the 3'0" and 6'0" levels in some 60 secs., whereas in trial 85 this took 140 secs.

6.2.5 Use of Water Sprays

The two trials carried out using water sprays, trials no. 3.P. and 4.P. (Figures 35 and 36) were undertaken at the suggestion of fire officers. The intention was to ascertain whether a similar smoke clearing performance could be obtained from a jet/spray branch or hosereel gun to that of a PPV fan. The resulting graphs show that both a jet/spray branch and a hosereel gun, producing a spray cone of some 40°~45° included cone angle, did produce some limited smoke clearance, the larger jet/spray branch being rather the better of the two, but neither approached the performance of the fans.

With the jet spray branch, it is seen that the obscuration decreased from 100% to 60% at both levels in about 80 secs., after which the obscuration at the 6 ' 0" level started to increase again. At the 3 ' 0" level, 50% obscuration was reached in about 140 secs., after which it levelled out. The trial was discontinued after 225 secs., to limit water damage, some 1,380 litres of water having been used. With the hosereel gun, the obscuration started to reduce at both levels after about 40 secs., At the 6 ' 0" level, obscuration reduced to 80% in 105 secs., and then levelled out. At 3 ' 0", obscuration reduced to 67% in 100 secs., and then levelled out. The trial was discontinued after 140 seconds, when it was evident that no further progress was being made, to limit water damage, some 345 litres of water having been used.

It should be noted that, in these two trials, no attempt was made to seal the inlet opening. The branch was held at a height of about 1.0m. some 0.3m.~0.4m. outside the opening so that the whole of the cone of spray entered the room. The spray was directed towards the outlet opening at the far end of the room. However, very little smoke was seen to escape from the inlet opening when the spray attack commenced, but a large plume of smoke was seen to escape from the outlet opening during the fairly early stages of the attack.

6.3 Comparison between Outlet Air Velocity and Rate of Smoke Clearance

Overall, it would be expected that, for a given scenario, the fan setting which gave the highest average outlet velocity would also clear the cold smoke fastest. However, from a study of the very small number of trials results where direct comparisons can be made, it appears that this may not necessarily be so, in all cases. The only trials where such direct comparisons could be made were; nos. 82, 85, 81, 86, and 92 and 96. In each of these pairs of trials the scenario and fan setting was identical. One trial in each pair measured the average outlet velocity and the other measured the smoke clearance.

Comparing the results of trials no. 85 and 86 shows that the cold smoke was cleared rather faster in trial no. 86 when the fan was raised to the window level. Comparing the average outlet velocities attained in trial nos. 82 (identical to trial no. 85), and 81 (identical to trial no. 86) shows that in trial no. 81 the average outlet velocity was 67% greater than in trial no.82. Thus the fan setting which produced the higher average outlet velocity also cleared the cold smoke rather faster.

Comparing the results of the cold smoke trial nos. 85 and 96 shows that the smoke was cleared appreciably faster in trial no. 96, with the fan in the closer position. Comparing the equivalent average outlet velocity trial nos. 82 (identical to trial no.85) and 92 (identical to trial no. 96) shows that the average outlet velocity in trial no. 92 was some 3 times that of trial no. 82. This, again, shows that the setting which achieved the greater average outlet velocity also cleared the cold smoke faster, at the 3 ' level.

6.4 Conclusions of Still Air Trials

The trials confirmed that, in still air, the room was cleared of cold smoke much faster using a PPV fan than when a fan was not used (some 2 minutes as opposed to 30 minutes).

The minimum distance of the fan from the inlet opening to effect a seal around the opening was virtually impossible to establish. Using a single personal access doorway, the Lametta suggested that there may be some small, outward air movement with the fan up to 3.0m. away (even 4.0m. with a 2/1 inlet/outlet area ratio), but no cold smoke was seen to emerge through the inlet when the fan was only 2.25 m. away. (The manufacturer had suggested that "About 6 feet should make a seal".)

The relative effect of varying inlet/outlet area ratios was found not to be as significant as may have been supposed. There was a general trend for average outlet velocities to increase with increasing inlet/outlet area ratios. However, it is clear that, for example, doubling the inlet/outlet are ratio does not double the average outlet velocity, and may have only a relatively small effect.

Similarly, the static pressure in the room was not affected by differences in inlet/outlet area ratio as markedly as may have been expected. There was a broad trend for the static pressure to increase with increasing inlet/outlet area ratios.

The effect of the fan in the still air trials can be briefly summarised as follows:-

1. When blowing from a single door to a single window (fan 2.5 metres from the opening) an average outlet velocity of some 3.3 metres/second was achieved, giving a volumetric flowrate of some 2.2 cubic metres/second.

2. When blowing from a single door to two windows, with the same fan setting, an average outlet velocity of some 3.0 metres/second was achieved, giving a volumetric flowrate of some 3.7 cubic metres/second.

3. When blowing from a single window to a single door (fan on the floor 2.25 metres from the wall and tilted to 21° above horizontal) an average outlet velocity of some 1.4 metres/second was achieved, giving a volumetric flowrate of some 2.0 cubic metres/second.

From the above it would appear that an inlet/outlet ratio of about 1/1 is best if the objective is a large volumetric flow, but if internal pressurisation is the prime objective 2/1 would be better.

From a brigade's viewpoint: if effecting a seal at the inlet opening is essential, it is better to position the fan 'too far back' rather than 'too far forward', sacrificing a little airflow into the opening in order to ensure a seal is achieved and maintained. (In a real situation, this sealing could be affected by a cross wind.)

If the aim is to pressurise the room to the maximum extent and achieving a seal is unimportant, the best fan distance from a doorway opening is about 1.0m.

If it is necessary to use a window as the inlet, no suitably placed doorway being available, better results are achieved, both in terms of average air flowrate and static pressure if the fan is raised to the level of the window and projects air horizontally into the building than if the fan stands on the ground projecting air upwards at the window.

Spraying water into the room through a single doorway produced only limited cold smoke clearance, by some 30%-40% during the first 2 minutes of application, and virtually none thereafter.

7. FIRE TRIALS

7.1 General

A series of trials was undertaken in the living room of the domestic building on the fireground of the Fire Service College, at Moreton-in-Marsh, during October 1995. FEU were allocated a 2 week period in which the conduct the trials.

A further series of trials was undertaken in March/April 1996 to augment the results of the first series. This was considered necessary because during the first 2 week period, there had been no opportunity to carry out trials either with a very light wind or with a wind assisting the fan and roughly aligned with it.

During the trials, decisions had to be made on a day to day basis concerning what trial to undertake next, based upon the predicted natural wind. FEU placed a contract with the meteorological office at RAF Brize Norton, some 20 miles south of Moreton-in-Marsh, for them to supply both a daily local weather forecast, received early each morning, and a 'long range', 2~3 day, forecast. These forecasts paid particular attention to wind speed and direction.

This was necessary because FEU intended to carry out trials using both ends of the room, in turn, as the inlet end, and to undertake trials both with the PPV fan assisting the natural wind and opposing it. It took the team of 4 experimenters almost a whole working day to reverse the equipment and instrumentation and check everything, when preparing to reverse the direction of the attack, and so the decision on when to do this was important. The local weather forecasts proved invaluable in making these decisions.

In the event, 26 trials were completed, during the first series, of which 23 proved to be valid, in that their results could be directly compared one with another. Of these 23 trials, 12 used the fan, 10 used natural ventilation, only, and 1 used a water spray. (Of the remaining non-valid trials, in the first 2 trials to be undertaken the trial fire was being developed, the quantity of fuel being increased each time to obtain a satisfactory duration of burn, and in the 6th trial the fire went out prematurely, leaving a significant quantity of Heptane fuel unburnt). In the second series, a further 7 trials were completed, in 4 of which the fan was used. All of these latter trials produced valid results.

7.2 Description of Trials Set-up

7.2.1 External to the Building

The domestic building was, in fact, a specially constructed building in which quite fierce fires could be repeatedly undertaken. Its layout was that of a fairly typical modern detached 4 bedroom house (See Figure 45). The living room, in which the trials were undertaken, was situated to the right hand side of the front door and extended from the front of the house to the back. The room had a pair of windows at one end, at the front of the house, and a pair of French windows (in effect, rather narrow double doors) at the other end, at the back of the house, all opening outwards (See Figure 3). The fireplace, with a hearth suitable for a solid fuel fire, was situated as shown with the chimney breast built into the outer end wall of the house. At the time the trials were carried out, the side cheeks and fireback had been removed, resulting in a larger opening into the flue than had been expected (and modelled in the mock-up room).

The building was situated to one side of one of the main roads (an ex-aircraft runway) of the Fire Service College's fireground. Its long axis ran at an angle (to grid north) of 210°, that is from 30° E of N to 30°W of S, so that the long axis of the living room, at right angles to this, was on the 120° line. The building was surrounded by tarmac, giving good vehicular access all round and there was a step up, or kerb, all round the building 1.0m. wide and some 180mm. high.

The trials control room, a de-mountable vehicle pod, was sited outside the end of the building closest to the living room. It was positioned some 6m. from this end wall so that it did not project beyond the front or back of the building, and remained in this position throughout the trials. The cabling from all of the instrumentation was laid to this control room, along the ground as far as possible. The trials control room housed the data logger, computer and video monitors and recorder.

Electrical power supplies were taken from the building's 240V. supply sockets, one in the dining room and another on the upstairs landing. This was transformed down to 110V, and powered the equipment inside and immediately outside the fire room. A petrol driven generator(40), sited outside the far end of the building, was also used to augment the building supply to prevent the possibility of overloading. This was used to power the air blower of the smoke obscuration meters, the water recirculating pump of the radiometer and the lights for the video camera.

The wind station was set up at a height of 7m. from the ground, in a position some 30m. to the south of the south east corner of the building. This instrument fed wind speed and direction information to the control room, throughout each day, both during and between trials. (Its output data was logged during trials.) A simple windsock was also mounted, to give a quick visual indication of wind behaviour. This was set up at a height of 4m. in a position some 25m. to the south east of the south east corner of the building.

The FEU's fire appliance, registration no. ALT 469H, was positioned alongside the far end of the front of the building, some 5m. distant from the building, its rear (pump) end some 8m.~9m. from the front door. This was necessary to provide safety fire cover during fuel handling and trials. At the start of each day, a hosereel was laid out along the front of the building and the hosereel gun laid adjacent to the front door. Also, foam extinguishers were positioned close to the front door and the appliance. A steel tray, 0.7m. square, was placed on the ground close to the front end of the appliance. Its purpose was to contain any drips or spillage during fuel decanting and measuring, immediately before each trial.

The smoke retaining boxes, 3 in all (one for each window and one for the French windows), were laid on the ground, each several metres from the particular opening which they had been made to fit, where they would not cause any serious obstruction when not in use. A 'catcher' device, to avoid damage to the smoke retaining boxes when they were pulled over, was generally placed where it would next be needed, just outside of the kerb. This catcher consisted of a large wooden pallet, on top of which were laid 2 or 4 car tyres and a length of rubber matting.

The wooden shed which housed the micromanometers of the McCaffrey probes was positioned on the kerb immediately outside the closest end of the building, between the building and the control room. This shed was made as weatherproof as possible and contained a small oil-filled electric radiator to protect the instruments overnight. It was positioned either towards the front or the back of the building, depending upon which end of the room was next to be the 'outlet end' which would house the McCaffrey probes. In all cases the shed was positioned so that it did not protrude outside of the line of the front, or back, of the building.

During each day's trials, video cameras were set up at the south west end of the building, one viewing along the front of the house, the other along the back. These were used to record all trials.

The trials area was coned off from the main roadway for safety, and large 'no smoking' signs were prominently displayed at these temporary barriers.

7.2.2 The Trials Room

The living room in which the trials were undertaken is shown in Figure 3 which gives the dimensions of the room in the plan view. Figure 6 gives details of the ceiling heights, and Figures 14 and 15 and indicate the positions of the various pieces of equipment in the room, approximately to scale.

Before the commencement of trials, FEU removed the panes of wired glass from the windows and French windows of the room and replaced them with sheet steel for the duration of the trials. This was necessary for safety reasons since the trials fire was fiercer than the fires usually lit in the room. Also, the existing glass windows were badly cracked and would have leaked badly. In normal use, by the Fire Service College, built-in sparge pipes would direct water sprays on to the tops of the window panes to protect them, but FEU could not do this in these trials. Two other windows, in upstairs rooms, were found to be broken immediately before the trials period, and FEU replaced these also with sheet steel for the duration of the trials.

The swinging part of both windows and both French windows in the trials room were made to be readily removable, by FEU, since this would be necessary for the trials. This was done by punching out the hinge pins, in each case, and replacing them with bolts and self-locking nuts for the duration of the trials. It was only necessary to remove a window, or French window, when that particular opening was to be the 'outlet' opening during the next trial to be performed. This removal was necessary to allow the smoke retaining boxes to fit flush against the outer surface of the wall around the opening, since all windows and French windows opened outwards.

As well as the windows and French windows, there were 3 circular holes in the end walls of the trials room, 2 at the front (windows) end, 1 at the opposite end. These were each 150mm. in diameter and their centres were some 380mm. from the floor. Those at the front of the house were directly below the windows, and the one at the opposite end was near the corner of the room furthest from the hearth. Each of these holes could be partly sealed by means of a sliding concrete slab on the inside, but could not be closed during the trials because cables and tubes were passed through them into the room. Each of these holes was approximately half open during the trials.

The living room had a large opening, opposite the hearth, into the adjoining dining room, where a pair of sliding or folding, doors would have been. This opening was 2.02m. high and 1.6m. wide. FEU made and installed a pair of steel screens to blank off this opening so that the inner surface of the screens would be flush with the living room wall. These screens each had an oven glass window, one at high level the other low, so that a pair of bright lamps(41) positioned in the dining room could provide sufficient light in the living room for the internal video camera, and to allow the experimenters to move about safely in the room to check the instrumentation, fuel the firetray, etc. The lamps, on tripods, were carefully positioned and fixed close to the screens to give the best attainable lighting in the room. The screens were securely fixed in position and sealed around their edges with small pieces of insulation blanket material(27). They remained in place for the duration of the trials.

The firetray, 1.20m. diameter and 250mm. deep, was positioned on the longitudinal centreline of the room, 200mm. from the fireplace at its nearest point. A water base 15mm. deep was added to the tray, and this level was maintained throughout the trials. The Heptane fuel was floated on top of this, for each trial.

7.2.3 Instrumentation

The instrumentation itself has been described in Section 4, and so is not described again here.

The instrumentation was positioned in the trials room in one of two different ways, depending upon which end of the room was to be designated the ‘inlet end’ in the next trial to be undertaken. When the inlet was to be one, or both, of the French windows the instruments were positioned as shown in Figure 14. When the inlet was to be one of the windows, or door ‘A’ via the front door, the instruments were positioned as shown in Figure 15. These figures also show the identification letters allocated to each opening. These letters were used throughout the trials, for convenience, and the openings are referred to by these letters throughout this report. The figures also show the numbers allocated to the thermocouple arrays. These numbers were used to identify the arrays so that it could be readily seen which of the arrays would be the closest to a fire-fighter's entry position into the room.

In all cases, except for the McCaffrey probe arrays, any power, air or water supplies and all output cabling were run from the instruments along the floor as far as possible and out of the room through the nearest low level hole. These were all protected by thermal insulation as thoroughly as practicable.

The McCaffrey probe arrays were set up in the appropriate outlet openings prior to each trial, with their inner (‘inlet’) ends flush with the inner surface of the wall. The individual McCaffrey probes were numbered for calibration purposes, and were arranged in the arrays as shown in Figure 8. These probe numbers were used to indicate which parts of the opening were being monitored, since it proved impossible to monitor all of the probes during the trials. (This was because conditions changed so fast during the trials that there was insufficient time to switch around them all (see Section 7.3.1).

7.3 Trials Procedure

7.3.1 General Procedure For Most Trials

Two 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, on the side of the vehicle remote from the trials building.

A team of four experimenters performed the trials, augmented for two trials, nos. 7 and 8, by FEU's two seconded fire officers. The duties allotted to each member of the team were, very broadly, as follows.

1. Project Officer - fuel and detonator handling - outlet opening - observer.
2. Safety cover - inlet opening - fan - observer.
3. Data recording and processing, from all instruments.
4. Video recording - photography - observer.

All four took part in equipment handling and testing the instrumentation, when preparing for each trial.

The trials were, in general, conducted in pairs, one using the PPV fan and the other not using the fan in, hopefully, similar weather conditions, to enable the effects of the fan to be ascertained. The procedure adopted was essentially the same for all trials, although there were differences in trials no. 7, 8, 14, 15, 27, 28 and 29. (See Section 7.3.2). Therefore, the following description of the procedure followed before and during a typical trial will cover the majority of the trials completed.

Consider trial no. 9 as a typical example. Here the inlet opening was French Window 'C' and the outlet openings were both windows 'D' and 'E'. The instrumentation was therefore set up in the positions shown in Figure 14.

The building was unlocked and all the movable equipment, stored inside the building overnight, was moved outside, approximately into its working position. The PPV fan and petrol driven generator were filled and checked over. The lamps in the dining room were switched on to illuminate the trials room, and door 'A' between the hall and the trials room was wedged open.

The fan was placed in its selected position for the forthcoming trial, this position having been decided by studying the results of the still air trials. The fan was mounted on a wooden plinth, 180mm. high, to nullify the effect of the kerb making the geometry of the fan and inlet opening similar to that of the still air trial. The fan position was again checked by hand, to ensure that the air from the fan made an effective seal around the inlet opening. The distance from the fan to the openings was either 2.50 metres or 2.75 metres in all trials.

The smoke retaining boxes were positioned on their catchers so that they would 'seal' their respective openings when erected. The level of the water base in the firetray was checked and topped up if necessary. The position of all of the instruments in the room was checked against marks on the floor, to ensure that nothing had been inadvertently moved.

The McCaffrey probe arrays were each positioned in their respective window openings, with the central vertical row of probes on the vertical centreline of the opening and the inner ends of the probes flush with the inner surface of the wall. The sampling tubes from the probes to be used in the forthcoming trial were connected to their respective micromanometers, housed in the wooden shed at the end of the building.

In the event, it was found that only six McCaffrey probes could be monitored in any fire trial, because of the relatively slow response of the micromanometers. In a trial where the outlet was a single window (see Figure 8), the probes monitored were nos. 2, 3, 4, 5, 6 and 8, or alternatively nos. 11, 12, 13, 14, 15 and 17. In a trial where the outlet was two windows, the probes monitored were those on the vertical centreline of each opening, nos. 2, 5 and 8 in one window and 11, 14 17 in the other. In a trial where the outlet was a single French window (a doorway in effect) the probes monitored were those on the vertical centreline of the opening, nos. 2, 5, 8, 11, 14 and 17. In trials where the outlet was both French windows (in effect, a double door) the probes monitored were the same ones monitored in a single French window, and the vertical centreline of the array was positioned 430mm. from the left hand side of the opening (viewed from inside). This was the closest it could be placed to the centreline of the opening while adequately protecting the silicon plastic connecting tubes from the fire.

All of the instrumentation was now checked. These checks were undertaken to ensure that all instruments were functioning correctly, and were correctly connected to the data logger. They were undertaken by a member of the team in the trials room and another in the control room. These two were in two way communication, using the Diktron system(42). In all cases the member in the trials room did something to each instrument in turn, while the other noted the response in the control room.

The McCaffrey probes, micromanometers and their connections were checked by an experimenter blowing gently into each probe in turn, while their associated thermocouples were checked by warming each in turn slightly with a small gas cylinder powered hair curling tong (43), to ensure that they were functioning and correctly connected. All of the other thermocouples, on the thermocouple arrays (24 in all) were checked in the same way.

The thermal flux meter, or radiometer, was checked by means of a test lamp, made by FEU specifically for this purpose. This lamp was a 600 W. Ianebeam with an attachment, made in house, that readily fixed it at a known distance from, and position relative to, the window of the radiometer. It provided both a check that the instrument was functioning and a check on the calibration of the instrument.

The windows of the smoke obscuration meters were cleaned and the level of the water in their cooling jackets checked, and topped up if necessary, and a check was made to ensure that the window protecting airflows were functioning. (The effect of this very small airflow on the smoke from a lighted match or taper was just visible inside its tube). The calibration of each smoke obscuration meter was checked with a set of optical filters, supplied by the manufacturer of the instruments. The wrapping of all cables and pipes within the room was checked and made good where necessary, using thermal insulation blanket and aluminium foil.

The internal fisheye video camera and its cooling air supply were switched on, and the output displayed on a monitor screen in the control room.

The smoke retaining boxes were next set up vertically to cover the outlet openings. Care was taken to ensure that they fitted as closely to the wall as possible and that they would fall, when pulled, on to their catchers without fouling the McCaffrey outlet tubes, etc. They were designed to rest against the wall of the building, but were also secured by removable wooden props, for safety, and their hauling lines were run out along the ground away from the building.

A length (some 8m.) of soft iron wire was fixed to the outer handle of the French window 'C', the inlet opening, so that it could be pulled open safely at the correct time during the trial. The French window was then held in the closed position by means of a concrete block and wedges, positioned so that they would topple out of the way and allow the door to open when the wire was pulled sharply. The fan was switched on and run for a few minutes to warm up, then switched off. This was done to ensure that the fan would start when required, and quickly develop full power.

The members of the team conferred, at this point, to confirm that all was set for the trial. If all was ready the fire appliance was started, the pump engaged and the hosereel charged (water was recirculated to prevent damage to the pump).

The fuel handler, having ensured that he had the detonator safety key in his pocket, proceeded to measure Heptane fuel into measuring/pouring cylinders and transfer it to the fire tray, entering the room via the front door and door 'A'. Throughout this procedure a second member of the team, carrying a dry powder extinguisher, stayed close to the fuel handler to provide safety cover. Both of these experimenters wore Nomex boiler suits, Nomex fire tunics and fire helmets with polycarbonate visors.

When the fuel handling was completed the fuel handler, and safety cover man, re-entered the room to connect the detonating 'firework'(28). This was supported horizontally by a steel clip inside the lip of the tray, some 50mm. above the fuel surface. The detonator was wired to its lead, which entered the room through one of the low level holes, and its safety shorting wire was cut. The experimenters then left the building, shutting door 'A' and the front door.

Data recording, from all instruments and all 3 video cameras, was started. The safety key was inserted into the detonator box, making detonation possible, and after a final check that all was ready, the countdown commenced.

On the call "Zero":-

a. the detonator switch was pressed, starting the fire;

b. an audible signal was given, to enable video tapes etc. to be subsequently synchronised;

c. a 'marker' was put on to all recorded data, to signify 'time=0'.

d. two stopwatches were started, for the experimenters who would control the room openings.

Two experimenters collected running stopwatches from the control room and took up their positions, one at the front of the house the other at the back. The fan was started and run up to full power. Shortly before the 2 minute period of the pre-burn had expired, the props of the smoke retaining boxes were removed, and 2 minutes after detonation, (t=2-00), both smoke retaining boxes were pulled down, clear of the window openings. Three seconds later, (t=2-03), the inlet French window was opened as wide as possible by means of the wire attached to its handle. This French window opened through some 150° and was held in this wide open position for the duration of the trial.

All instrument readings were recorded at least until the smoke obscuration reduced to, or near, zero. Typically, the fire burned for a total of 3~3½ minutes, after which the trial was continued for several further minutes. After the trial was finished, all recording ceased, and instruments were switched off. All doors and windows were opened fully to assist in cooling the room, to allow the next trial to proceed as soon as possible.

The above description covers the majority of the trials performed, whether or not the fan was used.

7.3.2. Procedure For Other Trials

(i) General

There were certain trials performed in which the procedure was necessarily different from that outlined above. The preparations for these trials were generally the same as outlined above up until just before the fire was started. The differences in procedure from then on are detailed below.

(ii) Trials no. 7 and 8

In trials 7 and 8, FEU's two seconded fire officers took up positions upstairs in the building before the fire was lit. They wore full fire kit and BA. One was in 2-way communication with the experimenters, using the Diktron system. Their brief was to open the bedroom window furthest from the fire room, (bedroom 1 in Figure 45), at a given signal, and to give a commentary on the progress of smoke clearance and thermal effects throughout the upper parts of the house. (The fan was used at the front door in trial no. 8, and no fan was used in trial no. 7).

After fuelling the tray and placing the detonator, the fuel handler left the building, leaving door 'A' fully open and closing the front door. The fire was started in the usual way. One of the firefighters descended the stairs and, at a given signal 2 minutes after detonation, (t = 2-00), opened the front door, and then 5 seconds later closed door 'A'. He then returned through the heavily smokelogged house, up the stairs on to the landing. The single window in the bedroom furthest from the fire was opened fully at t=4-12 in trial no. 7, and at t =2-47 in trial no. 8. The firefighter described the conditions in this bedroom, on the stairs and landing and in the other bedrooms, the commentary being recorded on video tape. The trials continued for some 14 minutes in trial no. 7, and 9 minutes in trial no. 8, after which all windows and external doors were opened in order to clear and cool the building.

(iii) Trials no. 14 and 15

In trials no. 14 and 15 the front door, door `A' and window `E' were opened. The fan was used in trial no. 14, set up outside the front door. Trial no. 15 was identical except that no fan was used. Before the tray was fuelled, a length of soft iron wire was securely fixed to the inner handle of door `A'. This wire was then fed through a small hole in the lower lip of the window frame, `E', to the outside of the building. This hole in the window frame acted as a fairlead, allowing the door to be pulled fully open from outside the building by means of the soft iron wire, without interfering with the McCaffrey probe array set up in window 'E'.

The fuel handler, having fuelled the tray and placed the detonator came out of the building, shutting, but not latching, door 'A' (it stayed shut until the wire was pulled hard), and shutting the front door. The fire was started and, in trial no. 14, the fan started. At t = 2-00, the smoke retaining box at window 'E' was pulled away, at t = 2-03 the front door was opened, and at t = 2-06 door 'A' was fully opened from outside the building. All data was recorded in the usual way.

(iv) Trial no. 26

In trial no. 26 the procedure was the same as for the majority of trials except that no McCaffrey probes were set up in the outlet opening 'C' and, when the room was opened up, a water spray was projected into the room through the inlet opening 'E'. The fire was lit and at t = 2-00 the outlet was opened. The inlet was opened at t = 2.03, and the first water applied at 2-07. The hosereel gun was held in the inlet opening, its front end approximately flush with the outside of the wall, and the attack was continued until the smoke obscuration was reduced to below 20%.

The hosereel gun used was the Akron 'Marauder', set at its narrowest 'V' setting and operated at 20 bar gun pressure. This gave a flow rate of 140 litres per minute and an included cone angle of approximately 45°.

7.4 The Second Series of Trials

The first series of trials no. 1 to no. 26 inclusive, was carried out during October 1995 and a second series, nos. 27 to 33, was carried out during March and April 1996. This was because, when the results of the first series of trials were being analysed and the report being prepared, it became obvious that during the two weeks allotted for the trials, FEU had been unable to complete pairs of trials - with and without the fan - during which:

a. there was no wind, or a light wind, only.

b. the wind was blowing more or less directly towards the inlet opening.

In all cases, except one, where direct comparisons could be made, the wind was more than 45° away from this ideal line, blowing more across the opening than into it. (The exception was trials no. 22 and 23 which were themselves complicated by needing to use the front door and door 'A' as the entry opening.

Further, it was perceived that the scenario of most interest to brigades was that where a doorway was used as the inlet opening (and, from their point of view, entry point) which, in this fire room, meant that the outlet opening would have to be a window, or windows. During the first series of trials, twelve such trials (six pairs) were undertaken but none of these were performed in the hoped-for conditions outlined above.

Since it was agreed that the wind conditions, outlined above, were those that could be expected to yield the most useful information on the performance of the fan, it was decided to approach the Fire Service College with a view to conducting further trials in the 'domestic' building, during a different time of the year.

During the second series of trials, which took place in late March and early April 1996, seven further trials were completed, all using, or simulating, the doorway inlet and single window outlet scenario. From these, three pairs of trials (each with and without the fan) could be compared. In one pair of trials, nos. 28 and 29, the wind was blowing directly or nearly directly at the inlet. In another pair, nos. 30 and 32, the wind once again blew essentially across the inlet opening. In the third pair of trials, nos. 32 and 33, the wind was very light (averaging about 0.5m/sec. during the trial where the fan was used, and about 1.5m/sec. during the other, when it was not). Thus, this series of trials produced results data from two pairs of trials undertaken in conditions which were of prime interest, but had not been experienced during the first series of trials.

During the first three trials of this second series the wind was westerly. For this reason, the front door had to be used as the inlet opening with door 'A', as described in Section 7.3.2.(ii), and all other doors and windows, except the outlet opening firmly closed. A window-sized outlet opening was created by blanking off the lower part of the opposite French window, 'C', with sheet steel. A steel stand was made and installed to replicate the window sill upon which the McCaffrey probes were supported, and these were located in the outlet opening as previously. In this simulated set-up, the inlet/outlet area ratio was kept the same as that obtaining in the previous trials, when blowing from a French window to a window.

Following this, the wind became easterly and so, for the last four trials, the equipment was reversed to make the French window, 'C', the inlet opening and window 'E' the outlet, as in the previous series of trials.

The equipment inside the fire room was all positioned as for the previous trials (Figures 14 and 15), except that in the second series of trials, no thermal flux meter was installed, the time to fire extinction being taken solely from the fisheye video camera.

The results of this second series of trials were processed identically to those of the previous trials, and are given along with all others in this report.

7.5 List of Trials Completed

Table 3 gives a complete list of trials undertaken in the domestic building during the two periods available, irrespective of whether or not the results were valid for direct comparison. The trials are numbered in chronological order. The `configuration' column shows which openings were designated `inlet' and `outlet' openings (see Figure 3). For example, where opening 'C' was the designated inlet and 'E' the designated outlet the convention is 'C→E'. The arrow between the letters indicates the NOMINAL direction of air flow through the room (where the direction of air flow was, in fact, reversed in some trials the 'outlet velocity' values in the trials results are preceded by a minus sign, e.g.: '-1.9'). In pairs of trials where the fan was used in one trial but not in the other, the openings designated 'inlet' and 'outlet' remained the same for both trials. The fan used was the Tempest 24", unless otherwise stated in the list.

Also, in Table 3, the 'fan position' column gives the distance from the front of the fan to the outer surface of the building wall, and a positive (+) tilt angle means above horizontal.

7.6 Results of Fire Trials

7.6.1 General

The results obtained from each instrument in each trial were recorded by the data logger and, where practicable, were printed out in graphical form. All of the data and graphs from all trials have been retained by FEU. As a typical example of each of these printouts, all of the graphs relating to trial no. 9 are reproduced as figures 46 to 48 inclusive and 53. These graphs and tables and the ways in which they were processed, or interpreted, are explained below.

7.6.2 The Natural Wind

The natural wind velocity during each trial was printed out as two separate graphs. The first (Figure 46) plotted wind speed, in metres per second, against time, in minutes. The second (Figure 47) plotted the wind direction, or, more precisely, the sense relative to magnetic north, over the same period.

These values of wind speed and wind sense were then each averaged over three different periods (Figure 48):

a. from when the room was opened (t = 2-00) until the end of the trial

b. from when the fire started (t= 0-00) until the room was opened (t = 2-00)

c. from when the room was opened (t = 2-00) until (t = 4-00).

The average values obtained from 'a', above, were subsequently used in comparing the effects of the fan. These average values were used to obtain an average velocity, (wind speed and sense combined) and this average velocity was resolved vectorically into components normal to, and parallel with, the end walls of the trials room. The resulting component normal to the wall, and its openings was designated as the wind component (apparently) assisting, or opposing the fan. Sketches of these vector diagrams relating to the trials room were produced, to make the apparent wind effects easier to visualise.

These velocity diagrams, drawn to the scale: 1cm = 1 metre/second, are given for all of the fire trials (except no. 6) in Figures 49 - 63, inclusive, because they make the natural wind effects much easier to visualise. The diagrams are arranged, as far as possible, in pairs in each Figure, the pairs being those pairs of trials to be compared with each other, e.g. with and without the fan.

7.6.3 Smoke Obscuration

The results from the smoke obscuration meters, placed one above the other at the 1.83m (6'0") and 0.91m (3'0") levels, were plotted on a single sheet (Figure 64). The percentage obscuration, at each meter, was plotted against time over a period from just before the fire started until the end of the trial. The trial was discontinued when the recorded smoke obscuration levelled out, generally at about 5%.

7.6.4 Thermal Radiation Flux

The result from the thermal radiation flux meters was plotted (Figure 65). Flux, in kilowatts per square metre was plotted against time over the duration of each trial. These graphs were used, along with the video tapes from the internal video camera, to assess when the fire was extinguished). They also gave an indication of how the fire behaved both before the room was opened and after.

7.6.5 Air Velocities in Outlet Openings

The air velocities (strictly air/gas speeds) in the outlet openings were measured and recorded over the entire duration of each trial. In trial no.9, probes 2, 5 and 8 were in window opening `E' and probes 11, 14 and 17 were in window opening `D'. A graph was plotted of outlet air velocity, in metres per second, against time for each outlet opening, each showing the results from each of the three probes (figures 66 and 67).

In these graphs, air flowing out of the room is positive, and air flowing into the room is negative. (It was common for the velocities to be negative until the room was opened, after 2 minutes, particularly at the lower levels). These graphs proved difficult to read due to their `spike-iness', and they were therefore processed to smooth them out (in effect, made less sensitive by a factor of 9). The resulting plots are shown in figure 68 and 69.

The average value from the three probes in each window was next plotted, over the period from when the room was first opened, at t = 2-00, until the end of the trial (figures 70 and 71). Finally, the average outlet velocity for each opening, over the period from opening the room until the end of the trial was calculated, (figure 72) and then the overall outlet velocity was calculated from these two values.

7.6.6 Temperatures in The Room

All thermocouple readings were recorded throughout the whole of each trial, and these were subsequently plotted. Four graphs were produced for each trial, one for each thermocouple array. Each graph shows the air temperatures recorded at each of the 6 levels monitored. (Figures no. 73 - 76 inclusive).

7.6.7 Video Evidence

Every trial was recorded on video tape by cameras in three different positions: low down inside the trials room, outside the front (windows end) of the house and outside the back of the house. These tapes, which are all retained by FEU, were subsequently used to ascertain when the fire was extinguished, to check procedures and timing, and to record the smoke movements from the room openings.

7.7 Further Data Processing

The sheer bulk of data obtained from the trials made it necessary to find a way of summarising the data so that comparisons between one trial and another could be readily made. For this reason Table 4. was prepared.

This table, on 4 sheets, contains information relating to each trial as well as results data which has been processed in some way, or has been selected from the available data as the particular part likely to be of most interest to firefighters. The table is explained below.

Column 1	Identifies the trials by number. These numbers give the chronological order in which the trials were performed.
Column 2	Gives the configuration, i.e.: inlet and outlet openings. (These should be read in conjunction with figures 13 and 14). The arrow, where shown, indicates the NOMINAL direction of air flow, hence `C→(D + E)' means 'C' is the inlet and `D' and `E' the combined outlet.
Column 3	Gives the 'inlet/outlet area ratio'. This is simply the cross sectional area of the inlet opening, divided by the cross sectional area of the outlet opening/s. The hearth opening and low level holes through the walls were ignored.
Column 4	States whether or not a PPV fan was used.
Column 5	Gives the average values of the natural wind, over the period from when the room was first opened until the end of the trial. The column is divided into three sub-columns. The left hand sub-column gives the average natural wind speed, in metres per second. The central sub-column gives the average angle (from magnetic north to where the wind blows FROM, measuring clockwise). The right-hand sub-column gives the calculated component of the wind which, apparently, assists or

opposes the PPV fan, i.e. at 90° to the plane of the inlet opening. If this natural wind component is opposing the fan, the figure is preceded by a negative, or minus, sign.

Column 6 Gives the overall average outlet air velocity, over the period from when the room was first opened until the end of the trial. Where a negative, or minus, sign precedes a figure in this column, it indicates that the average airflow was INWARD. through this 'outlet' opening (i.e. The fan, if used, is 'being beaten' by the natural wind). It should be noted that the number of McCaffrey probes in each outlet opening was severely limited (See Section 7.3.1).

Column 7 This gives the time taken, in seconds, for the air temperatures at the 0.91m (3'0") level in the room to reduce to 3 different values. The times are measured from when the room was first opened. The selected temperatures, 160°C, 120°C and 100°C are temperatures of interest to firefighters and relate to earlier FEU work assessing the firefighters' environment (44). Also, the 0.9m (3') level is of interest to firefighters because it is about the level of a kneeling man's head and firefighters are trained, and accustomed to needing, to work while keeping at or below this level.

The column is sub-divided into 3 sub-columns; '160°C' at the left hand side, '120°C' in the centre, and '100°C' at the right hand side. Each of these sub-columns is further sub-divided into 4 'position' sub-columns. These positions are those of the thermocouple arrays (see Figures .14 and 15).

Asterisks (*) were subsequently added to one of the 'position' sub-columns, for each trial, to indicate which thermocouple array was the closest to the inlet opening, and hence, what could possibly be the firefighter's entry point. (However, it is accepted that a firefighter would be unlikely to enter a fire building via a window opening).

It should be noted that these times cannot be fairly used to compare one trial with another because the fire can be rather different in each case, particularly in terms of extinction time. However, they can be fairly used to compare the conditions in different parts of the room during any particular trial.

Column 8 Gives the average temperature reduction at the 0.91m (3') level. The data is based upon that given in Column 7. The column is, again divided into 3 sub-columns; '160°C', '120°C' and '100°C'. The values given are the average times, in seconds, measured from when the room was first opened, for the air temperature at that level to reduce to the stated temperatures.

Column 9	This column is identical to column 7, except that it applies to the 1.83m (6'0") level. This level is of interest to firefighters because it represents approximately a standing man's head.
Column 10	This column is identical to column 8, except that it applies to the 1.83m (6'0") level.
Column 11	Gives the time, in seconds, from the room being first opened until the fire went out. The figures in this column were determined predominately from the in-room video data, but the thermal radiation flux meter graphs were also studied. (This was because there was often a fairly long period of time between the large flames dying down and the last very small flames becoming extinct).
Column 12	Gives the times taken for the smoke obscuration to reduce to 20% at both the 0.91m (3'0") and 1.83m (6'0") levels. These times were measured from when the room was first opened. The 20% obscuration level was chosen because firefighters were certain that they could see across this, and any similar sized, room at this measured level of obscuration.
Column 13	This column gives some indication of how the air temperatures at the 0.91m (3'0") level increased or decreased, overall, during the first minute after the room was opened. The two sub-columns each give a unit-less number calculated from the data from the thermocouples closest to, and furthest from, the 'entry' or inlet, position. The figures in this column were calculated in the following way:- At each of the 2 positions: add the 61 temperature values recorded at 1.0 second intervals from t=2-00, until t=3-00 inclusive. Divide this total by the temperature recorded at t=2-00. The resulting figures are therefore normalised to the 2 minute value, whatever this was. The period from t=2-00 to t=3-00 was used because the fires were fairly constant, from trial to trial, over this period and, in the majority of trials, were still burning at t=3-00. The resulting figure would be 61 if the temperature had not changed overall, during this one minute period: a higher figure shows that the temperature had increased overall, while a lower figure shows that they had reduced overall. The extent of the change, in either direction, is indicated by the magnitude of the resulting figure (ie. its difference from 61).

7.8 Analysis of Results

7.8.1 General

Of the 33 trials completed, 28 could be used for direct comparisons of the effects of a fan being used, and not being used, in similar circumstances, and broadly similar wind conditions. These pairs of similar trials (each pair comprising one with and one without a fan) were trials no: 3 and 11, 4 and 5, 7 and 8, 9 and 10, 12 and 13, 14 and 15, 16 and 17, 18 and 19, 20 and 21, and 22 and 23, 24 and 25, 28 and 29, 30 and 31, and 32 and 33.

In trials 7 and 8, unlike all other trials, the upper storey of the house was smoke logged while firefighters inside the house gave a commentary on the conditions throughout the trials. In trials 24 and 25 a different PPV fan, capable of supplying a fine water spray was used, with the water spray in trial 24 and without it in trial 25. In trial 26, the water spray from a firefighting hosereel gun was tried instead of a fan.

Of the remaining four trials, three (numbers 1, 2 and 6) did not produce results which could be fairly compared with others because, in the first two cases a non-standard fire was used (a satisfactory standard trial fire was still being developed), and in trial no. 6 because the fire went out prematurely due, presumably, to oxygen starvation. The results of trial no. 27 were not used for comparison with those of no.28, the results of trial no. 29 being preferred because the wind conditions were more similar, and also during trial no. 27, the smoke retaining box was seen to leak (this leak was eliminated for the subsequent trials).

7.8.2 Comparison of Trials No. 7 and 8

The results of trials no. 7 and 8, in which the upper storey of the house was smoke logged, show that the fan had a marked beneficial effect in improving visibility in the path between the inlet and outlet openings and also had a rapid cooling effect, much appreciated by the firefighters. In both of these trials a firefighter opened the front door from the inside 2 minutes after the fire was lit, closed door 'A' between the fire room and the hall, stairs and landing, some 5 seconds later, and then made his way back up to the head of the stairs. During this time, the other fire officer remained at the far end of the landing from the stairwell. All doors opening on to the landing were open, and all windows were closed. The window of the bedroom furthest from the head of the stairs (bedroom 1 in Figure 45) was opened after the firefighter had regained the landing.

In trial no. 7, without the fan, the firefighters reported some air flowing in through the bedroom window, while smoke was seen to be escaping from the front door. 53 seconds after the window was opened (all subsequent times are given from when the bedroom window was opened) one firefighter could first see the light from the other's torch, over the entire length of the landing. At 2 minutes 33 seconds, vision was "good" in bedroom 1 and "reasonable for firefighting" in the other bedrooms, but "not good enough for visual searching". At 6 minutes, one firefighter could "just make out" the other at the far end of the landing, by the reflective strips on his tunic. The other bedrooms were still smoke logged at this time, although it was reported at 7 minutes 48 seconds that it would be easy to work in bedroom 2 as the firefighters could see across this room with a torch.

In trial no. 8, the PPV fan was running when the front door was opened. 12 seconds after the window was opened in bedroom 1 the firefighter reported "smoke clearing rapidly in this bedroom" and at 22 seconds "very cool". At 28 seconds, "...can see Gary very clearly at the far end of the landing". At 1 minute 23 seconds; "... can see the bottom of the stairs easily". At 1 minute 55 seconds, it was reported "... very cool, stairs and landing are all clear".

It is clear from the above summaries of the commentaries that the hall, stairs, landing and vented bedroom were cleared of smoke and cooled, much faster with the fan than without it. There appears, in general, to have been little difference in the other, unvented, bedrooms, between the trials, due to the draught across their doorways due to the fan, although they may have cleared marginally faster than when no fan was used.

If, when using the fan, it was necessary to search the other bedrooms, a sequential clearing of the other rooms would be necessary, in which each room's window would be opened, in turn, while all other windows were shut.

7.8.3 Comparisons of Other Pairs of Trials

A study of Table 4 shows that there are no simple hard and fast conclusions to be drawn from the unprocessed data, and that further simplified analysis was required. The underlying aim of this analysis was to assess the difference made to the overall room environment by the use of the PPV fan. The trials were therefore arranged in pairs, each pair with and without the fan, where all other variables were kept as constant as possible. (Obviously, the one variable over which there could be no control was the natural wind, and it can be seen that this significantly affected the trials results).

A check list (Table 5) was produced, relating the results of the pairs of trials to four different criteria to determine, within each pair, whether the use of the fan improved the room conditions according to each of the criteria. Checking along the rows of this check list shows that all four criteria agreed upon which of a pair (fan, or no fan) was best in five cases, out of the twelve. (Trials no. 4/5, 16/17, 20/21, 22/23 and 30/31). Of these five pairs of trials, four showed that the trial in which the fan was used gave the better result. One pair, however, (trials no.16/17) showed that the better result was obtained without the fan.

Of the other seven pairs of trials, five pairs had only a single criterion disagreeing with the others. Of these five pairs, four showed that the results when the fan was used were better than when it was not used, except for a single criterion, while one pair (trials no. 28/29) showed that the results when the fan was used were worse than when it was not used. The 'odd' criterion in each of these pairs of trials was:

average outlet flowrate	in nos. 3/11
smoke clearance at 3' level	in nos. 12/13
$\frac{\Sigma T_{(t=2)-(t=3)}}{T_{(t=2)}}$	in nos. 18/19

average outlet flowrate in nos. 28/29

smoke clearance at 3' level in nos. 32/33.

Both of the remaining two pairs of trials had three criteria showing that the results were better when the fan was used (than when it was not used) and three criteria showing that they were worse. In trial nos. 9/10, the fan gave the better results according to the three criteria concerned with the room air temperatures, but worse results in terms of smoke clearance and average outlet flowrate. In trial nos. 14/15, use of the fan gave the better result according to the smoke clearance at 6', temperature reduction time at 6' and average outlet flowrate criteria, but worse in terms of $\frac{\Sigma T.(t=2)-(t=3)}{T.(t=2).}$ and both smoke clearance and temperature reduction at the 3' level.

It was considered that the most important single criterion of those tabulated (Table 4) was the $\frac{\Sigma T\ (t=2)-(t=3)}{T.(t=2)}$ value (see Section 7.7), which gives an idea of how the temperature near the inlet position, at the 3' level changed during the first minute after the room was opened. This was because it was considered that it would be the temperature in the room, rather than the level of smoke logging, which would determine whether a firefighter would enter, if there were strong reasons for doing so. Most conclusions are therefore based upon this criterion.

8. DISCUSSION ON FIRE TRIALS

8.1 Choice of Criteria for Comparisons

Table 4 was constructed in order to summarise the data obtained from the trials, and to assist in deciding which pairs of trials results could be fairly compared one with the other, and which of the criteria could be fairly used for these comparisons.

The two important factors in improving conditions for firefighters in the fire room were perceived to be:

(a) the reduction of temperatures between the inlet opening and the fire, and

(b) improved visibility, or rate and direction of smoke clearance.

For this reason, four criteria were selected for comparisons between trials. These were:

(a) $\frac{\Sigma T(t=2)-(t=3)}{T(t=2)}$, at 3 ' 0" near the 'inlet'.

(b) Smoke clearance - time to clear to 20% at the 3 ' 0" level.

(c) Smoke clearance - time to clear to 20% at the 6 ' 0" level.

(d) Average volumetric flowrate in the outlet opening.

It was decided that the times taken for the temperatures to reduce to the three pre-determined levels could not be fairly used as a basis for comparisons between trials because the behaviour of the fire could be rather different from trial to trial, particularly in terms of extinction time. (Although, in fact, they agree with the $\frac{\Sigma T}{T}$ conclusion in all but one pair of trials at the 3 ' 0" level, and all but two at the 6 ' 0" level.) However, they can be used to compare the conditions in different parts of the room during any single trial.

Subsequently, Table 5 was constructed, listing twelve pairs of trials - each pair comprising one with and one without the PPV fan - whose results could be fairly compared one with the other, each pair of trials having been conducted in broadly similar wind conditions. In this table, a tick simply means that the result indicated was the better of the two, within that pair, according to that particular criterion. The extreme right hand column of this Table gives the overall conclusion drawn from each pair of trials.

8.2 Overall Performance of PPV

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. Firefighters would always enter a fire building on the upwind side when this is possible.

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.

However, it is possible that on occasion, firefighters may find it impossible to enter a fire building from upwind. For this reason some trials were undertaken where the PPV fan was used to oppose the natural wind, simply to find out whether it would have any effect and whether, if the opposing component of the natural wind were light enough, it could reverse the airflow through the building.

It is evident from the fire trials results that the effect that a PPV fan may have upon the airflow in a room fire is not simple to predict. Nor is it possible to use the measured effect of the fan in still air conditions and with no fire, to predict with any degree of certainty the difference that a PPV fan might make in a fire situation. Clearly, there are two things which can make a difference in the fire situation: the effect of the natural wind, and the buoyancy effect caused by the fire. It appears from the results obtained in the trials that the natural wind is the dominant factor.

The following observations can be made, from a study of Table 5.

When there is no wind, or a negligible wind blowing, use of a PPV fan can improve the ventilation performance (trials 32 and 33). In this situation the inlet opening should be selected so that any slight breeze assists the fan if possible, but if this is not possible the fan should be able to reverse a slight breeze. In this latter case a large inlet/outlet area ratio should be used.

When a strong wind is blowing directly, or almost directly, into the inlet opening, the use of a PPV fan to assist the wind does not cause any significant improvement and may even hinder smoke clearance and temperature reduction. (Trials 28 and 29, where the assisting wind was in excess of 5.5metres/second.)

In the vast majority of cases where use of a PPV fan may be considered, the natural wind will not be blowing either directly at the proposed inlet opening or directly away from it. Generally, the wind will be arriving at some angle to the surface of the wall containing the proposed inlet opening, so that there will be a component of the wind along the surface of the building (normal to the proposed fan direction), and a component either assisting or opposing the fan.

When the wind component blowing across the fan is large compared to that either assisting or opposing the fan, the output of the fan appears to be somewhat disrupted. It is virtually impossible in these conditions to predict with certainty what the effect of a fan blowing directly at an inlet opening might be, or whether it will improve the natural ventilation. As the wind component either assisting or opposing the fan becomes greater relative to the 'across' component, it becomes in general rather more easy to predict what the effect of the fan might be.

A look at Table 5 shows how, within each pair of trials, the components of the natural wind compared to each other, and the conclusion drawn from that pair of trials.

In the pairs of trials where there was a wind component assisting the fan, the 'assisting'/'across' relationships were approximately:

Trials no. 9 and 10;	0.2	(no fan better)
" " 12 " 13;	2.5	(fan better)
" " 18 " 19;	0.4	(fan better)
" " 20 " 21;	1.0	(fan better)
" " 22 " 23;	3.6	(fan better)
" " 30 " 31;	0.3	(fan better)

In the pairs of trials where there was a wind component opposing the fan, the 'opposing'/'across' relationships were approximately:

Trials no. 3 and 11;	0.1	(fan better)
" " 4 " 5 ;	1.7	(fan better)
" " 14 " 15;	1.0	(little difference)
" " 16 " 17;	0.5	(no fan better)

This suggests that, as a general rule: when there is an assisting wind component the use of the fan is beneficial (in the only such trial where this was clearly not so, the across component was 5 times as strong as the assisting component), and even when there is a small opposing wind component, use of the fan may have a beneficial effect, provided that the inlet/outlet area ratio is suitable. (See Section 8.4).

When the natural wind is unavoidably opposing the fan (that is, when the decision is made to attempt to reverse the natural airflow through the building) it is possible for the fan to overcome the opposing component of the wind, provided that this is not too strong, and that the inlet/outlet area ratio is arranged to be in the fan's favour (large inlet, small outlet).

In trial no.4, a 2.5metres/second opposing component was overcome using 2/1 inlet/outlet area ratio, with better results than in trial 5. (In the broadly comparable still air trials an average outlet velocity of only some 3.0metres/second was recorded). However, in 16 and 17, the fan made things worse when opposing a 2.2metres/second component, with a 1/2 inlet/outlet area ratio (in the broadly comparable still air trial the average outlet velocity was 1.36 metres/second), and in trials no. 14 and 15, opposing a wind component of 2.0metres/second with an inlet/outlet area ratio of 2/1 made little difference.

These results would suggest that, even if an inlet/outlet area ratio of 2/1 can be achieved, there would be no point in attempting to reverse the air flow caused by an opposing wind component of about 2.5metres/second, or more.

8.3 The Effect of the Natural Wind

The effects of local wind conditions in the immediate vicinity of the room inlet and outlet are complicated. These effects will be different from building to building, depending upon surrounding walls, buildings, trees, etc. Also, for a given building the effects will depend upon the direction of the prevailing wind. Furthermore, they will be affected by the geometry of the windows or doors, how they open and how far they open. A window or door which opens outwards may act as a deflector, preventing the natural wind from entering, or as a scoop, drawing air in. In the trials, neither of these effects was present because the windows and French windows, when at the 'downstream' end of the room, were completely removed. However, the local wind effects experienced, according to the Lametta stick, were often not what would have been expected from the data obtained from the wind station, which was set up at a height of 7 metres in the open, some 30 metres away from the trials building.

Where the fan was used to assist, or augment, the natural wind, and was roughly aligned with it, it did increase the average velocity in the outlet. Where the natural wind was roughly at right angles to the fan axis things were very much more complicated. When the natural wind had a component which opposed the fan, the beneficial effects of the fan were limited, but the effects of the natural wind are seen to be complicated and virtually impossible to predict.

For example, in trial no. 4, with an inlet/outlet area ratio of about 2/1, there was an average natural wind component of 2.4 metres/second opposing the fan. Yet the fan overcame this opposing wind component to produce an average outlet velocity of 3.41 metres/second. On the other hand, the most surprising result as far as air velocities are concerned is that of trial no.3 (identical to trial no.4, except for the natural wind). Here the fan had no effect whatever when opposed by a wind component of only 0.5 metres/second, while the wind was blowing at some 4.0 metres/second at an angle of 84° to the fan axis. When the room was opened, the average 'outlet' velocity was - (minus) 0.95metres/second, i.e. inwards.

This can only be explained in terms of differences in the local wind conditions between the fan and the 'inlet' opening. In trial no. 3, the wind was blowing across the fan output, undisturbed (apparently) by the building, over most of the distance between the inlet opening and the fan. (Also allied to this, there may be a Venturi, or ejector pump, effect where the wind blows across the 'inlet' doorway.)

Trial no. 16 was a case which fell somewhere between the two extreme cases compared above. In this trial, with an inlet/outlet area ratio of about ½ (a window to a doorway), there was an opposing wind component of 2.2 metres/second, with an 'across' component of about double this. The fan could not overcome this wind component, reducing it to about 0.9 metres/second in the 'outlet' opening.

This would suggest that, with an inlet/outlet area ratio of about ½ (a window to a doorway), there would be no point in deploying a PPV fan to oppose a natural wind component of more than about 1 metre/second, since the effect would probably be to impede the natural ventilation.

It is evident from the foregoing that the effect that a fan will have in any situation where the natural wind is blowing against, or mainly across, the fan is impossible to predict. Also, in these situations the effect of the fan cannot be predicted from the results of trials conducted in still air, in otherwise identical conditions.

8.4 Effect of Inlet/Outlet Area Ratio

The Tempest 'Positive Pressure Training Manual'(46) states "Positive Pressure is most efficient when the exhaust opening (window, door, etc.) is between three fourths to one and three fourths the size of the entrance opening." However, in practice brigades would have to make use of whatever openings were available: invariably, in a domestic building, doorways and windows. The ratio of the areas of a doorway to a window in the trials room was approximately 2/1, and this is believed to be true for the majority of domestic properties. The inlet/outlet area ratios tried in the trials were approximately 4/1 (one pair of trials), 2/1 (six pairs of trials), 1/1 (two pairs of trials) and 1/2 (two pairs of trials).

The single pair of trials which used a 4/1 inlet/outlet area ratio had an assisting wind, though blowing more across than along the fan's axis. The conclusion drawn from this pair of trials was that the fan improved things somewhat.

In the six pairs of trials using a 2/1 inlet/outlet area ratio, three pairs had an assisting wind and three pairs an opposing wind. However, in none of these pairs of trials did the use of the fan make matters worse overall, according to the Table 5 criteria. In the three pairs which had an assisting wind, the conclusions (from Table 5) were: 'fan better', 'fan probably better' and 'little difference' (this latter result where the wind was strong and blowing along the fan's axis). In the three pairs of trials which had an opposing wind, the conclusions drawn were: 'fan better' (where the 'across' wind component was some 60% of the opposing component), 'fan probably better' (where the 'across' wind component was 8 times greater than the opposing component), and 'little difference' (where the wind was at about 45° to the fan's axis).

In the two pairs of trials using a 1/1 inlet/outlet area ratio, both had a wind with an assisting component. The conclusion drawn from one pair was 'fan better' (where the 'across' component was relatively small), and that from the other was 'no fan better' (where the 'across' component was 5 times the assisting component).

In the two pairs of trials using 1/2 inlet/outlet area ratio, one pair had an assisting wind component (and an 'across' component twice as great), and the conclusion drawn from this pair was 'fan probably better'. The other pair had an opposing wind component (and an across component twice as great), and the conclusion drawn from this pair was 'no fan better'.

A fairly wide range of inlet/outlet area ratios can be effective when no wind, or little natural wind is present, or when the natural wind is blowing in roughly the same direction as the fan. However, natural wind conditions can change fairly quickly, particularly wind direction when the wind is light. It is possible for a wind which was assisting the fan to some extent to swing round and oppose the fan, during the ventilation process, and this would impede the flow through the compartment due to the fan, and could produce a 'stall' effect (halt the flow), or even reverse it. This possible reversal of flow through the compartment would be more likely to occur if the 'outlet' area was large relative to the inlet area. This would appear to be a valid reason for making the inlet area larger than the outlet area.

It would appear from the above than an inlet/outlet ratio of about 2/1 would be a good one for brigades to aim for, and gives a PPV fan a good chance of improving the ventilation of a building. It would be advantageous to ensure, at least, that the inlet opening is larger than the outlet opening in order to try to ensure that the air flow set up in the building will be, and will remain, in the required direction.

For example, consider this. Suppose a natural wind was blowing directly into a building which had identical inlet and outlet openings, in its upstream and downstream ends respectively. The wind would produce an airflow through the inlet opening of, say, x cubic metres per minute. Since what goes in must come out, and assuming no leaks, this same volumetric flowrate would also flow out through the outlet opening. If a PPV fan was now set up to blow directly at the natural outlet opening, opposing the natural wind, in such a way that it would, if acting in still air conditions, produce an airflow of x cubic metres per minute in the opening the result would be stalemate. There would be no airflow through the building, the natural wind and the fan cancelling each other out. If, now, while everything else remains constant, the opening at the fan end of the building could be made larger it would admit more air from the fan, allowing more than x cubic metres per minute to enter, and hence set up a nett airflow through the building.

In other words, if the inlet opening area is significantly larger than the outlet opening, the airflow set up by a PPV fan will be less likely to be disrupted, or even reversed, by changes of strength or direction, or both, of the natural wind.

However, it was seen from the still air trials that what may be gained by loading the inlet/outlet area ratio in favour of the fan is limited. For example, halving the cross sectional area of the outlet opening, while all else remains constant, does not double the average outlet velocity, and may have only a relatively small effect. (See Section 6.1 and Figure 30).

8.5 The Effect of PPV upon the Fire

It had been predicted that the use of a PPV fan would cause the rate of burning to accelerate faster than it would otherwise have done, once the room was opening up. However, this was seen to be not necessarily the case, in so small a room.

The internal video camera showed that the fire was subdued, in all cases, prior to the room being opened up, due to oxygen depletion. (The extent of this depended upon the wind conditions while the room was 'closed', when the only openings were the services holes low down in the end walls, the bases of the smoke retaining boxes and the chimney. The fire was seen to die down more when there was little natural wind.) When the room was opened up, the burning rate increased rapidly in all cases, irrespective of whether a PPV fan was being used or not.

When the results from the thermal flux meter were compared, for pairs of trials with and without the fan, no clear trend was evident. These flux meter plots were only available for trials up to, and including, no.23, and so only 9 pairs could be fairly compared. These pairs were trials no. 3 and 11, 4 and 5, 9 and 10, 12 and 13, 14 and 15, 16 and 17, 18 and 19, 20 and 21, and 22 and 23. Of these 9 pairs of trials:-

the use of the fan gave the greater acceleration to the fire in 3 cases, (trials no. 3 and 11, 4 and 5, and 12 and 13;

the fire accelerated faster without the fan in 3 cases, (trials no.16 and 17, 20 and 21, and 22 and 23;

the acceleration was similar - with and without the fan - in 3 cases (trials no. 9 and 10, 14 and 15, and 18 and 19).

Studying the flux meter plots from these trials showed that the peak fluxes did vary quite widely (from some 5.0kw/m.^{2} to 15.0kw/m.^{2}, overall), but that these peaks lasted for only a few seconds. There was no evidence to suggest that, during these pairs of trials, radiation flux was in any way related to the average air velocity in the outlet opening, and hence to the volumetric airflow through the room. It is likely that the differences in the recorded transient flux levels were due more to the movement of the flames and their closeness to the meter. (The meter was some 2.5m. from the edge of the fire tray.)

8.6 Trials Variations

8.6.1 Both Vents at Same End of Building

A single pair of trials (nos. 14 and 15) was conducted in which the inlet and outlet openings were essentially at the same end of the room, the inlet being the front door and door 'A', and the outlet the adjacent window 'E'. During both of these trials an opposing wind was blowing, towards the closed end of the room.

The results of both of these trials were among the worst, overall, in terms of the $\frac{\Sigma T}{T}$ criterion, no fan being marginally better than with the fan, but in both cases, there was an overall increase in temperature during the first minute after the room was opened, near the inlet opening.

In terms of smoke clearance, the times taken to clear to 20% obscuration were about average overall, the fan giving the better result at the 6'0" level, and no fan giving the better result at the 3'0" level. It should be remembered that the smoke obscuration meters were positioned towards the closed end of the room, remote from the inlet and outlet openings. It seems clear that there must have been large swirl effects causing air movement throughout the whole of the room.

It would appear that this would not be a very effective way of using PPV, although the smoke clearance may have been speeded up somewhat.

8.6.2 Smoke Clearance Upstairs

It is clear from the results of trials 7 and 8, in which the first floor of the house was smoke logged, that the PPV fan had a marked beneficial effect both in terms of rapid smoke clearance and reduced air temperature (See Section 7.8.2). In the trial where the fan was used, the path between the inlet and outlet openings - hall, stairs, landing and vented bedroom - was cooled and cleared of smoke very rapidly, and significantly faster than when the fan was not used.

It was noted that there was very little difference in the degree of smoke logging in the other, unvented, upstairs rooms either with or without the fan. If, in a real fire situation, it was necessary for firefighters to search the other bedrooms, the rooms could be vented sequentially. That is, each bedroom in turn could be vented singly, its window being opened while all others remain closed. It would be possible to do this in a relatively short time using a PPV fan.

8.6.3 Water Sprays

(i) Hosereel spray

In the single trial (no.26) in which a hosereel gun was used to direct a water spray into the room, instead of any PPV fan, no outlet velocity measurements were taken because it was believed that water droplets would render the McCaffrey probes inoperable, and may have caused them permanent damage. Also, no results were obtained from the smoke obscuration metres, due, apparently, to water droplets on their windows.

It can be seen from Table 4 that the fire took significantly longer to extinguish in this trial than in any other, with or without a fan (151 seconds from the room being opened, as opposed to an average of 79 seconds with the fan, and 69 seconds without). This was because the water spray, which was applied as soon as the room was opened, suppressed the fire, reducing the rate of burning and thus extending the burning time.

The air temperature in the room descended rapidly when the water was applied. The times taken for the air temperatures to be reduced to the three selected values, at the 3 ' 0" level, were significantly shorter than the times taken in most of the other trials. The time taken to reach 160°C at the 3 ' 0" level was 19 seconds at the nearest (to the inlet) thermocouple position and 16 seconds at the furthest, compared with averages of 36 seconds and 57 seconds when the fan was used, and 64 seconds and 54 seconds with no fan.

The times to reach 120°C at the 3 ' 0" level were 23 seconds at the nearest position and 20 seconds at the furthest, compared with averages of 57 seconds and 66 seconds when the fan was used and 67 seconds and 64 seconds with no fan.

The times to reach 100°C at the 3 ' 0" level were 27 seconds at the nearest position and 21 seconds at the furthest, compared with averages of 66 seconds and 72 seconds when the fan was used, and 73 seconds and 71 seconds with no fan.

In this trial, the times taken for the air temperature to reduce to the selected values at the 3 ' 0" level were, in all cases, shorter at the furthest (outlet) end of the room than at the inlet end.

The $\frac{\Sigma T_{(t=2)-(t=3)}}{T_{(t=2)}}$ values for trial no. 26 were the lowest recorded in any trial, (except for the inlet position in trial no.27, in which the fire went out relatively early, and trial no.1, which had a smaller non-standard fire). That for the furthest (outlet) end of the room was lower than that for the inlet end.

The rate of smoke clearance in this trial could only be judged by studying the video tape from the camera inside the room. From this, the daylight in the doorway at the far end of the room was first discernible 10 seconds after the room was opened. In similar trials using the PPV fan, in broadly similar wind conditions, the corresponding times were 33 seconds (trial no.22), and 15 seconds (trial no.12).

This suggests that in this particular scenario, the water spray performed at least as well as the PPV fan, both in reducing the air temperatures in the room, and in the early stages of smoke clearance. However, during trial no.26, some 450 litres of water were sprayed into the room over a period of 3 minutes 20 seconds. If water application had been stopped when the fire went out, only about 350 litres would have been used, and at this time, the 3 ' 0" level temperatures at the inlet and outlet thermocouple positions were about 80°C and 60° C respectively. Spraying was continued until the room appeared to be clear of smoke.

(ii) Fan Incorporating a Water Spray

Trials no.24 and 25 used a different fan from that used in the other trials. This fan, the Doman Airdriver shown in Figure 77, had a pair of water spray nozzles incorporated into it as an 'optional extra'. These nozzles could be used to create a fairly fine water spray which would be carried along by the airstream from the fan. The fan was used with the water spray in trial no. 24, and without the spray in trial no. 25.

In both trials, the fan was set up in a position very similar to that used in the corresponding trials using the Tempest fan. In trial no. 24, water was fed to the fan from the low pressure side of the fire appliance pump and the spray nozzles were operated at 2.0 bar gauge pressure, as recommended by the manufacturer. This gave a total flowrate 8.2 litres per minute. The nozzles each produced a fine, sparse looking fan shaped spray of some 120° included angle, with its major axis vertical, which wet the ground for a distance of about 3 metres forward of the fan when the fan was not operating. When the fan was operated, with the water spray, the droplets were carried along in the airflow for some 15 metres.

It was estimated during trial no. 24 that about 75% of the water used entered the fire room. Trial no. 25 was performed in the same way as no. 24, except without the water spray, in similar natural wind conditions.

The smoke clearance times in these two trials (to 20% obscuration) were similar, as were the overall average outlet air velocities. Also, the results according to the $\frac{\Sigma T_{(t=2)-(t=3)}}{T_{(t=2)}}$ criterion were similar, but rather worse in the case where the spray was used, and there were no significant differences in the average times for the air temperature to reduce to the three selected levels between the trials.

It would appear that this particular water spray was too sparse to have any discernible effect upon either the behaviour of the fire or the cooling of the air within the room. However, this is not to say that the ability to induce a fine water spray into the output from a PPV fan might not be a potentially useful option in brigade operations.

9. CONCLUSIONS

9.1 General

Guidance on ventilation is given in the supplement to the Manual of Firemanship: 'The Behaviour of Fire - Tactical Ventilation of Buildings and Structures'. Forced Ventilation, and specifically Positive Pressure Ventilation, is covered there only in general terms. However, the practical advice therein has been reinforced by these trials.

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. 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 the fire compartment or adjacent parts of the building, 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 the 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.

It was not possible to use the measured effect of the fan in still air conditions and with no fire, to predict with any degree of certainty the difference that a PPV fan might make in a fire situation. Clearly, there are two things which can make a difference in the fire situation: the effect of the natural wind, and the buoyancy effect caused by the fire. It appears from the results obtained in the trials that the natural wind is the dominant factor, when only a single storey is involved.

9.2 The Use of PPV in Offensive Ventilation

The Manual of Firemanship supplement defines Offensive Ventilation thus: "ventilating close to the fire to have a direct effect on the fire itself, to limit fire spread, and to make conditions safer for the firefighters".

The trials confirmed that, in general, the air temperature just inside the entry (fan) position reduced faster, at the 3 ' 0" level, with the PPV fan than without it. However, there were exceptions, in three pairs of trials, to this rule.

9.3 The Use of PPV in Defensive Ventilation

The Manual of Firemanship supplement defines Defensive Ventilation thus: "ventilating away from the fire, or after the fire is out, to have an effect on the hot gases and smoke, particularly to improve access and escape routes and to control smoke movement to areas of the building not involved in the fire".

In the single pair of trials in which the first floor of the house was smoke logged, the fan had a marked beneficial effect. The path between the inlet and outlet openings (hall, stairs, landing and vented bedroom) was cooled and cleared of smoke very rapidly, and significantly faster than when the fan was not used.

9.4 The Effect of Wind on the Use of PPV

When there is no wind blowing, or a negligible wind, use of a PPV fan can improve ventilation, reducing both smoke logging and air temperatures near the inlet opening. In this situation the inlet opening should be selected so that any slight breeze assists the fan if possible, but if this is not possible the fan should be able to reverse a slight breeze. In this latter case a large inlet/outlet area ratio should be used.

As a general rule, when there is an assisting wind component, use of the fan is beneficial. However, when a strong wind (in excess of 5.5 metres/second) is blowing directly, or almost directly, into the inlet opening, the use of a PPV fan to assist the wind does not cause any significant improvement, and may even hinder smoke clearance and temperature reduction.

When the natural wind is unavoidably opposing the fan (that is, if the decision is made to attempt to reverse the natural airflow through the building) it is possible for the fan to overcome the opposing component of the wind, provided that this is not too strong, and that the inlet/outlet area ratio is arranged to be in the fan's favour (large inlet, small outlet). However, in this situation the fan should only be tried with extreme caution since it is possible for the effect of the fan to cancel out the effect of the natural wind, and impede ventilation. The trials results suggested that, even if an inlet/outlet area ratio of 2/1 can be achieved (a single doorway to a single window), there would be no point in attempting to reverse the air flow caused by an opposing wind component of about 2.5 metres/second, or more.

When the component of the natural wind blowing across the fan is large compared to that either assisting or opposing the fan, the output of the fan appears to be somewhat disrupted. It is virtually impossible in these conditions to predict with certainty what the effect of a fan blowing directly at an inlet opening might be, or whether it will improve the natural ventilation. As the wind component either assisting or opposing the fan becomes greater relative to the 'across' component, it becomes in general rather more easy to predict what the effect of the fan might be.

9.5 The Effect of the Inlet/Outlet Vent Area Ratio

Although, in the still air trials, an inlet/outlet area ratio of about 1/1 gave somewhat higher volumetric flowrates than a ratio of about 2/1, it is considered that an inlet/outlet ratio of about 2/1 would be a good one for brigades to aim for, and gives a PPV fan a good chance of improving the ventilation of a building. It would be advantageous to ensure, at least, that the inlet opening is larger than the outlet opening in order to try to ensure that the air flow set up in the building will be, and will remain, in the required direction, should the strength and/or direction of the wind change during the ventilation process.

9.6 Tactical Variation Using PPV

Sealing of the inlet opening by the fan would be most important operationally where the intention is to ensure that no smoke (hot gases, products of combustion, etc) escape through the inlet opening, or where the direction of the airflow through the building needs to be kept under control. To this end, it is better to err on the side of being too far from the opening rather than being too close with the fan (although the volumetric flow-rate of air entering the building will be somewhat reduced). In the hot fire trials, the 24" Tempest fan was found to seal a single doorway at a distance of 2.75 metres, when set at the mid tilt position of the 5 available (+9°), in all of the conditions of the natural wind occurring in the trials..

If the object of using a PPV fan is solely to pressurise a room, or building, to the maximum extent possible, it is not necessary to seal the inlet opening with the fan. In this case, the results from the still air trials suggest that the optimum fan distance from the inlet opening is about 1.0 metre, for inlet/outlet area ratios of between, and including, 4/1 and 1/2. (Except when the fan was on the floor blowing upward at a window - inlet/outlet area ratio of about 1/2 when the optimum fan distance was not critical. This was the least effective way of using the fan).

If it is necessary to use a window opening as the inlet, no suitably placed doorway being available, better results are achieved, both in terms of average air flowrate and static pressure, if the fan can be raised to the level of the window and air projected horizontally into the building, than if it is standing on the ground projecting air upwards.

In the single trial in which a hosereel water spray was used instead of the PPV fan, the spray reduced the air temperatures in the room at least as rapidly as the fan could have done. Smoke logging was also reduced during the early stages of the attack so that daylight could just be seen in the opening at the far end of the room some 10 seconds after opening up the room and commencing the attack. However, some 450 litres of water were sprayed into the room.

In the single pair of trials in which both the inlet and outlet openings were at the same (downwind) end of the room, the use of the fan made little difference to the air temperatures just inside the inlet, but appeared to clear the smoke rather faster. However, it would appear that this would not be a very effective way of using PPV.

9.7 Effect of PPV on Fire Size

It is clear that when a fire room which has been virtually closed to the outside environment is opened up, the fire will begin to burn more fiercely, due to the increased oxygen supply. There was no evidence from these trials (in this relatively small room) that using a PPV fan necessarily caused this acceleration of the fire to be any more marked that it would have been without the fan.

9.8 Training Implications

Brigades deciding to introduce and promote the use of PPV as an aggressive firefighting tactic will need to consider how this can best be done. Clearly, training for all fireground personnel will be essential. It is considered essential that all personnel should have a thorough understanding of natural ventilation techniques before being introduced to PPV training. It appears most unlikely that it will be possible to reduce the necessary training to a list of simple, hard and fast, rules.

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Also, thanks are due to the FEU members of staff who were involved in the preparation for, and performance of, the trials. This involved much hard labour in far from pleasant conditions.

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TABLES

RESULTS (STILL AIR) SPREADSHEET

H97 Trial No.	Room Inlet → outlet	Inlet area/ Outlet area Ratio	Average outlet Velocity m/s	Outlet area m^2	Average outlet volumetric flowrate m^3/s	Fan to inlet m	Fan tilt angle Degrees	Static pressure Pascals	Comments
1	C→(D+E)		3.16			1.50	+9°		
2	C→(D+E)					2.00	+9°		Test abandoned, manometer fault
3	B→D		4.64			1.50	+9°		
4	B→D	2.21	3.93	0.667	2.621	2.00	+9°		
5	B→D	2.21	3.26	0.667	2.174	2.50	+9°		
6	B→D	2.21	2.88	0.667	1.921	3.00	+9°		
7	B→D	2.21	2.22	0.667	1.481	4.00	+9°	6.5	
8	B→D	2.21	4.33	0.667	2.888	1.25	+9°	23.0	
9	B→D	2.21	3.59	0.667	2.395	1.75	+9°	15.0	
10	B→D	2.21	4.37	0.667	2.915	1.00	+9°	25.0	
11	B→D	2.21	3.89	0.667	2.595	1.63	+9°	18.0	
12	B→D	2.21	3.97	0.667	2.648	1.50	+9°	20.0	
13	B→D	2.21	4.17	0.667	2.781	0.50	+9°	20.0	
14	B→D	2.21	2.10	0.667	1.401	4.00	+21°	5.0	
15	B→D	2.21	2.77	0.667	1.848	3.00	+21°	10.0	
16	B→D	2.21	3.12	0.667	2.081	2.50	+21°	12.0	
17	B→D	2.21	3.54	0.667	2.361	2.00	+21°	14.0	
18	B→D	2.21	3.64	0.667	2.428	1.75	+21°	15.0	
19	B→D	2.21	3.74	0.667	2.495	1.50	+21°	17.0	
20	B→D	2.21	4.06	0.667	2.708	1.25	+21°	18.0	
21	B→D	2.21	4.88	0.667	3.255	1.00	+21°	27.0	
22	B→D	2.21	4.50	0.667	3.002	0.75	+21°	23.0	
23	B→D	2.21	4.81	0.667	3.208	0.50	+21°	27.0	
24	B→D	2.21	4.50	0.667	3.002	0.75	+9°	24.0	
25	(B+C)→D	4.42	2.33	0.667	1.554	5.50	+9°	7.0	
26	(B+C)→D	4.42	2.80	0.667	1.868	5.00	+9°	9.0	
27	(B+C)→D	4.42	2.83	0.667	1.888	4.50	+9°	9.0	
28	(B+C)→D	4.42	3.12	0.667	2.081	4.00	+9°	11.0	
29	(B+C)→D	4.42	3.09	0.667	2.061	3.50	+9°	12.0	

Table 1 (Sheet 1) **Results of still air trials (air velocity trials)**

30	(B+C)→D	4.42	3.54	0.667	2.361	3.00	+9°	15.0	
31	(B+C)→D	4.42	3.38	0.667	2.254	2.50	+9°	13.0	
32	(B+C)→D	4.42	3.44	0.667	2.294	2.00	+9°	15.0	
33	(B+C)→D	4.42	4.30	0.667	2.868	1.50	+9°	20.0	
34	C→D	2.21	2.62	0.667	1.748	4.00	+9°	8.0	
35	C→D	2.21	2.80	0.667	1.868	3.00	+9°	9.0	
36	C→D	2.21	3.71	0.667	2.475	2.00	+9°	16.0	
37	C→D	2.21	3.62	0.667	2.415	1.50	+9°	15.0	
38	C→D	2.21	3.88	0.667	2.588	1.00	+9°	18.0	
39	C→(D+E)	1.11	2.14	1.334	2.855	4.00	+9°	5.0	
40	C→(D+E)	1.11	2.26	1.334	3.015	3.00	+9°	6.0	
41	C→(D+E)	1.11	2.96	1.334	3.949	2.50	+9°	10.0	
42	C→(D+E)	1.11	2.90	1.334	3.869	2.00	+9°	9.0	
43	C→(D+E)	1.11	2.96	1.334	3.949	1.50	+9°	11.0	
44	C→(D+E)	1.11	3.16	1.334	4.215	1.00	+9°	13.0	
45	C→(D+E)	1.11	2.50	1.334	3.335	2.75	+9°	7.0	
46	C→(D+E)	1.11	2.81	1.334	3.749	2.25	+9°	9.0	
47	B→(D+E)	1.11	1.97	1.334	2.628	4.00	+9°	5.0	
48	B→(D+E)	1.11	2.36	1.334	3.148	3.00	+9°	7.0	
49	B→(D+E)	1.11	2.77	1.334	3.695	2.00	+9°	9.0	
50	B→(D+E)	1.11	2.61	1.334	3.482	2.50	+9°	8.0	
51	B→(D+E)	1.11	2.67	1.334	3.562	2.25	+9°	8.0	
52	B→(D+E)	1.11	3.08	1.334	4.109	1.50	+9°	12.0	
53	B→(D+E)	1.11	3.01	1.334	4.015	1.00	+9°	12.0	
54	B→(D+E)	1.11	3.21	1.334	4.282	1.00	+21°	13.0	
55	B→(D+E)	1.11	2.93	1.334	3.909	2.00	+21°	12.0	
56	B→(D+E)	1.11	2.38	1.334	3.175	3.00	+21°	6.0	
57	B→(D+E)	1.11	1.90	1.334	2.535	4.00	+21°	4.0	
58	B→(D+E)	1.11	1.44	1.334	1.921	4.00	-3°	3.0	

Table 1 (Sheet 2) **Results of still air trials (air velocity trials)**

59	B→(D+E)	1.11	1.90	1.334	2.535	3.00	-3°	4.0	
60	B→(D+E)	1.11	2.44	1.334	3.255	2.00	-3°	5.0	
61	B→(D+E)	1.11	3.09	1.334	4.122	1.00	-3°	5.0	
62	(B+C)→(D+E	2.21	1.89	1.334	2.521	5.50	+21°	4.0	
63	(B+C)→(D+E	2.21	2.22	1.334	2.961	5.50	+9°	6.0	
64	(B+C)→(D+E	2.21	2.81	1.334	3.749	4.00	+9°	9.0	
65	(B+C)→(D+E	2.21	2.49	1.334	3.322	4.00	+21°	7.0	
66	(B+C)→(D+E	2.21	2.69	1.334	3.588	3.00	+21°	8.0	
67	(B+C)→(D+E	2.21	2.83	1.334	3.775	3.00	+9°	10.0	
68	(B+C)→(D+E	2.21	2.79	1.334	3.722	2.00	+9°	9.0	
69	(B+C)→(D+E	2.21	3.00	1.334	4.002	2.00	+21°	10.0	
70	(B+C)→(D+E	2.21	3.12	1.334	4.162	1.00	+21°	12.0	
71	(B+C)→(D+E	2.21	3.14	1.334	4.189	1.00	+9°	9.0	
72	(B+C)→E	4.42	2.21	0.667	1.474	5.00	+9°	8.0	
73	(B+C)→E	4.42	2.67	0.667	1.781	4.00	+9°	10.0	
74	(B+C)→E	4.42	3.04	0.667	2.028	3.00	+9°	14.0	
75	(B+C)→E	4.42	2.96	0.667	1.974	2.00	+9°	15.0	
76	(B+C)→E	4.42	3.34	0.667	2.228	1.00	+9°	15.0	
77	C→E	2.21	2.90	0.667	1.934	2.00	+21°	11.0	Hearth blanked off (as all others)
78	C→E	2.21	2.74	0.667	1.828	2.00	+21°	10.0	Hearth OPEN (0.56m high x 0.405m wide)
79	C→E	COLD SMOKE - HELESPHERE FAN				2.75		35	
80	C→E	COLD SMOKE - DOMAN FAN				2.25		7	
81	E→C	0.45	2.27	1.474	3.346	2.25	-3°	4	Fan on box
82	E→C	0.45	1.36	1.474	2.005	2.25	+21°	2	Fan on floor
83	E→C	0.45	1.30	1.474	1.916	1.50	+21°	1	Fan on floor
84	E→C	0.45	1.54	1.474	2.270	3.00	+21°	2	Fan on floor
85	E→C	COLD SMOKE		1.474		2.25	+21°		Fan on floor Assess box Vs floor

Table 1 (Sheet 3) **Results of still air trials (air velocity trials)**

86	E→C	COLD SMOKE		1.474		2.25	-3°		Fan on box
87	E→C	0.45	1.36	1.474	2.005	4.00	+15°	1	Fan on floor
88	E→C	0.45	3.32	1.474	4.894	1.50	-3°	7	Fan on box
89	E→C	0.45	1.44	1.474	2.123	3.00	-3°	3	Fan on box
90	E→C	0.45	1.28	1.474	1.887	4.00	-3°	2	Fan on box
91	E→C	0.45	4.16	1.474	6.132	1.00	-3°	15	Fan on box
92	D→B	0.45	4.03	1.474	5.940	1.00	-3°	11	Fan on box
93	D→B	0.45	1.52	1.474	2.240	4.00	-3°	2	Fan on box
94	D→B	0.45	1.28	1.474	1.887	4.00	+15°	1	Fan on floor
95	D→B	0.45	1.30	1.474	1.916	1.50	+21°	2	Fan on floor
96	D→B	COLD SMOKE		1.474		1.00	-3°	10	Re-run of test 92
97	D→(B+C)	0.23	1.51	2.948	4.451	1.50	-3°	0	Fan on box : probes in B See 102
98	D→(B+C)	0.23	1.05	2.948	3.095	2.00	-3°	0	As above See 101
99	D→(B+C)	0.23	0.90	2.948	2.653	2.50	-3°	0	As above See 100
100	D→(B+C)	0.23	1.43	2.948	4.216	2.50	-3°	<0.5	Fan on box : probes in C See 99
101	D→(B+C)	0.23	1.77	2.948	5.218	2.00	-3°	0	As above
102	D→(B+C)	0.23	2.38	2.948	7.016	1.50	-3°	0	As above
103	A→(B/2)	2.068	3.90	0.737	2.874	2.00	+21°	10	Compare with 17. Better
104	(A/2)→(B+C)	0.258	2.07	2.948	6.102	1.50	-3°	3	Compare with 97
105	(A/2)→(B+C)	0.258	1.62	2.948	4.776	1.50	-3°	4	
106	A→B	1.034	2.96	1.474	4.363	2.00	+21°	6	Compare with 55. Same
107	A→(B+C)	0.516	1.82	2.948	5.365	2.00	+21°	0	Probes in B
108	A→(B+C)	0.516	2.39	2.948	7.046	2.00	+21°	0	Probes in C
109	C→E	COLD SMOKE		Firefighter in room (eyes at 3 foot) Vs. SOM printout (& fisheye video)					
110	E→(B+C)	0.23	2.44	2.948	7.193	1.00	-3°	♎0.5	Fan on box See 111
111	E→(B+C)	0.23	2.22	2.948	6.545	1.00	-3°	♎0.5	Fan on box See 110
112	E→(B+C)	0.23	2.45	2.948	7.223	0.75	-3°	4	Fan on box See 113
113	E→(B+C)	0.23	2.47	2.948	7.282	0.75	-3°	4	Fan on box See 112

Table 1 (Sheet 4) **Results of still air trials (air velocity trials)**

					COMBINED RESULTS				
97 +102	D→(B+C)		1.95		5.734				
98 +101	D→(B+C)		1.41		4.157				
99 +100	D→(B+C)		1.17		3.434				
104 +105	(A/2)→(B+C)		1.85		5.439				
107 +108	A→(B+C)		2.11		6.206				
110 + 11	E→(B+C)		2.33		6.869				
112 + 11	E→(B+C)		2.46		7.252				

Table 1 (Sheet 5) **Results of still air trials (air velocity trials)**

Table 2

SUMMARY OF RESULTS OF SELECTED COLD SMOKE TRIALS

TRIAL NO.	FAN	OBSCURATION					
		LEFT 100% AT		50%		10%	
		3'	6'	3'	6'	3'	6'
		SEC.	SEC.	SEC.	SEC.	SEC.	SEC.
1.P.	Tempest 24"	40	40	85	100	145	265
5.P.	Ramfan'Turbo-hurricane'	40	40	85	84	135	140
6.P.	Doman prototype	25	30	50	55	80	95
79	Helysphere	15	15	40	40	80	125
80	Doman 'Airdriver'	30	30	75	90	120	135
109	Tempest 24"	20	20	55	75	95	145

Trial No.	Configuration	Fan used	Fan position
1	C→E: Non-standard fire	Yes	2.5m and + 9° tilt
2	C→E: Non -standard fire	No	
3	C→E:	Yes	2.5m and + 9° tilt
4	C→E	Yes	2.75m and +9° tilt
5	C→E	No	
6	D→E Trial invalid, fire went out prematurely	Yes	2.5m and + 21° tilt
7	Firefighters inside (Smokelog whole house, open front door, close door `A')	No	
8	As no. 7	Yes	2.5
9	C→(D + E)	Yes	2.75m and + 9° tilt
10	C→(D + E)	No	
11	C→E	No	
12	(B + C) →E	Yes	4.0m and + 9 ° tilt
13	(B + C)→E	No	
14	Front door, via `A'→E	Yes	2.75m and + 9 ° tilt
15	As no. 14	No	
16	E→C	Yes	2.5m and + 21 ° tilt
17	E→C	No	
18	E→C	Yes	2.5m and + 21° tilt
19	E→C	No	
20	E→(B + C)	Yes	2.5m and + 21° tilt
21	E→(B + C)	No	
22	Front door via A→C	Yes	2.75m and + 9° tilt
23	As no. 22	No	
24	E→C	Yes (prototype fan with water spray)	

Table 3 (sheet 1) List of Fire Trials Undertaken

25	E→C	Yes (Same prototype as trial no. 24, without water spray).	
26	E→C	No. (Hosereel spray, only	
27	A→C/2	Yes	2.75m. +9° tilt
28	A→C/2	No	
29	A→C/2	Yes	2.75m. +9° tilt
30	C→E	Yes	2.75m. +9° tilt
31	C→E	No	
32	C→E	Yes	2.75m. +9° tilt
33	C→E	No	

Table 3 (sheet 2)

1	2	3	4	5			6
TEST NO	BUILDING CONFIGURATION INLET→OUTLET	INLET/OUTLET AREA RATIO	FAN	NATURAL WIND			O/A AV. OUTLET AIR VELOCITY (MEASURED FROM 1ST VENT OPENING TO END) (+IVE= OUTWARD)
				SPEED	SENSE	COMPONENT ASSISTING FAN	
				(AVERAGE FROM t=2 000 TO END)			
				M/S	° TRUE	M/S	M/S
1	NON STD. FIRE C→E	2.21	YES	5.59	182	2.60	2.69
2	NON STD.FIRE C-E	2 21	NO	5 84	222	(-1 2)	-4 60
3	C→E	2.21	YES	3 99	216	-0.50	-0 95
4	C→E	2 21	YES	2.76	269	-2.40	3.41
5	C&E	2.21	NO	3.37	266	(-2.7)	-2.51
6	D→E	1	YES	1 92	262		2 11
7	SMOKE LOG UPSTAIRS - OPEN FRONT DOOR CLOSE "A" (FIREFIGHTERS IN)		NO	5 02	153	(-4 1)	NOT INSTRUMENTED
8	AS TEST 7		YES	4.80	142	-4.40	NOT INSTRUMENTED
9	C→(D+E)	1.105	YES	3.29	200	0.60	1.84
10	C,D&E	-	NO	3 65	182	-1.70	1.48
11	C&E	-	NO	3.66	204	-0.40	-1.00
12	(B+C)→E	4.42	YES	2.76	187	1.10	3.19
13	B,C&E	-	NO	2.62	204	-0.30	-0.39
14	FRONT DOOR VIA "A→-E	approx. 2.2	YES	2 76	167	-1 90	1 28
15	FRONT DOOR A &E	approx. 2.2	NO	2.64	166	(-1.8)	0.58
16	E→C	0 452	YES	4.92	183	-2.20	-0.89
17	E&C	-	NO	5.31	188	(-1.9)	-1.70
18	E→C	0 452	YES	6.87	229	2.40	2 69
19	E&C	-	NO	5.15	229	-1.80	1.77
20	E→(B+C)	0.226	YES	2.37	255	1.60	1.23
21	E,B&C	-	NO	2.84	252	-1.90	0.73
22	FRONT DOOR VIA "A"→C	1	YES	2 64	286	2 50	2 83
23	FRONT DOOR A&C	-	NO	3.26	288	-3 1	1.54
24	E→C	0 452	YES PROTO WITH WATER SPRAY	4 09	252	2.75	2.5
25	E→C	0 452	YES PROTO W/O WATER SPRAY	4 45	245	2 5	2.67
26	E-C	0 452	NO (HOSEREEL SPRAY)	4 35	247	2 60	NOT INSTRUMENTED
27	A→C/2	2.21	YES	5 14	284	4 85	4.27
28	A&C/2	2.21	NO	7.02	300	6 94	4.88
29	A→C/2	2.21	YES	6.3	278	5.69	4.94
30	C→E	2.21	YES	3.3	49	1.04	2.85
31	C&E	2.21	NO	5.93	38	0 81	1 24
32	C→E	2.21	YES	0.52	198	0.12	2.97
33	C&E	2.21	NO	1.67	329	-1 42	-0.73

Table 4 (Sheet 1) **Summary of Results**

TEST NO.	7												8		
	TEMPERATURE REDUCTION AT 091m. (3'0")LEVEL TIME (FROM FIRST ROOM OPENING) TO REDUCE TO:- *Entry Position												AVERAGE TEMPERATURE REDUCTION AT 091m. (3'0") LEVEL TIME TO REDUCE TO AVERAGE OF:-		
	160°C				120°C				100°C				160°C	120°C	100°C
	POSITION				POSITION				POSITION						
	1	2	3	4	1	2	3	4	1	2	3	4			
	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC.	SEC.	SEC.
1	20	14*	15	17	26	21*	24	25	31	27*	28	29	16.5	24.0	28.8
2	63	64*	68	67	70	71*	78	75	75	76*	86	79	65.5	73.5	79.0
3	68	73*	81	79	84	85*	90	85	92	92*	97	91	75.3	86.0	93.0
4	84	71*	71	74	94	84*	82	82	101	93*	89	88	75.0	85.5	92.8
5	77	76*	77	80	85	85*	87	89	90	91*	93	97	77.5	86.5	92.8
6	29	26	10*	23	42	37	28*	30	50	44	35*	36	22.0	34.3	41.3
7	32	31	26	31*	45	45	39	44*	55	56	48	54*	30.0	43.3	53.3
8	31	30	24	29*	48	45	39	44*	64	60	55	59*	28.5	44.0	59.5
9	64	57*	52	61	72	69*	64	70	78	73*	70	75	58.5	68.8	74.0
10	58	61*	13	17	67	71*	50	37	73	77*	55	49	37.3	53.3	63.5
11	81	81*	75	79	90	92*	86	89	97	99*	93	95	79.0	89.3	96.0
12	57	19*	33	52	66	53*	53	60	73	60*	60	65	40.3	58.0	64.5
13	72	69*	14	17	80	78*	22	22	85	84*	29	26	43.0	50.5	56.0
14	62	72	55	63*	74	83	64	74*	82	90	71	81*	63.0	73.8	81.0
15	71	67	57	61*	81	76	66	71*	88	85	73	77*	64.0	73.5	80.8
16	54	62	49	47*	64	74	56	54*	68	82	64	60*	53.0	62.0	68.5
17	47	54	32	21*	53	63	48	42*	57	71	55	49*	38.5	51.5	58.0
18	50	51	58	52*	59	59	68	55*	64	64	72	60*	52.8	60.3	65.0
19	63	54	68	11*	70	66	78	63*	77	72	85	67*	49.0	69 3	75.3
20	45	45	16	15*	57	55	34	41*	64	61	49	52*	30.3	46.8	56.5
21	39	39	46	44*	48	50	54	47*	54	55	60	50*	42.0	49.8	54.8
22	51	48	20	26*	59	54	31	39*	65	59	37	48*	36.3	45.8	52.3
23	56	55	41	44*	66	62	49	54*	72	67	53	62*	49.0	57.8	63.5
24	56	52	23	17*	67	65	62	59*	72	73	74	69*	37.0	63.3	72.0
25	60	55	51	16*	67	67	65	35*	72	72	75	60*	45.5	58.5	69.8
26	20	16	19	19*	22	20	25	23*	23	21	29	27*	18.5	22.5	25.0
27	22	24	18	25*	28	29	23	33*	32	33	25	39*	22	28	32
28	54	54	20	18*	62	60	35	41*	67	65	42	49*	37	50	56
29	59	60	16	14*	66	66	48	49*	72	71	52	57*	37	57	63
30	74	21*	64	60	86	64*	71	72	95	69*	77	81	55	73	81
31	88	77*	79	81	100	84*	88	90	107	89*	94	97	81	91	97
32	69	21*	63	63	81	68*	73	73	87	75*	79	79	54	74	80
33	69	68*	56	56	80	75*	65	67	89	81*	69	78	62	72	79

Table 4 (Sheet 2) **Summary of Results**

TEST NO.	9												10		
	AVERAGE TEMPERATURE REDUCTION AT 1.83m (6' O") LEVEL TIME TO REDUCE TO AVERAGE OF:- *Entry Posiition												AVERAGE TEMPERATURE REDUCTION AT 1.83m (6' O") LEVEL TIME TO REDUCE TO AVERAGE OF;-		
	160°C				120°C				100°C				160°C	120°C	100°C
	POSITION				POSITION				POSITION						
	1	2	3	4	1	2	3	4	1	2	3	4			
	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC	SEC.	SEC.	SEC.
1	29	18*	26	27	37	24*	34	35	42	32*	42	40	25.0	32.5	39.0
2	68	70*	82	41	77	79*	97	46	86	87*	110	58	65.3	74.8	85.3
3	96	97*	94	86	104	106*	107	93	116	117*	116	98	93.3	102.5	111.8
4	93	83*	87	90	104	92*	99	99	112	97*	106	105	88.3	98.5	105.0
5	101	105*	100	99	110	116*	115	112	116	122*	127	121	101.3	113.3	121.5
6	41	38	13*	27	53	48	18*	35	62	56	21*	40	29.8	38.5	44.8
7	57	57	56	54*	94	97	91	84*	129	137	133	118*	56.0	91.5	129.3
8	60	60	59	56*	108	114	114	96*	175	184	178	150*	58.8	108.0	171.8
9	75	69*	73	74	86	74*	82	81	92	77*	93	87	72.8	80.8	87.8
10	78	76*	73	63	89	89*	87	70	101	103*	100	75	72.5	83.8	94.8
11	94	96*	92	90	105	110*	105	101	112	120*	117	110	93.0	105.3	114.8
12	73	72*	72	71	83	85*	85	81	90	89*	90	87	72.0	73.3	89.0
13	82	85*	78	76	90	96*	88	84	96	106*	97	91	80.3	89.5	97.5
14	86	87	85	87*	102	105	99	102*	116	120	115	112*	86.3	102.0	115.8
15	90	91	88	62*	112	112	103	104*	130	129	121	119*	82.8	107.8	124.8
16	73	74	67	64*	84	88	78	70*	97	100	84	76*	69.5	80.0	89.3
17	67	69	65	62*	75	82	74	68*	81	94	79	72*	65.8	74.8	81.5
18	61	59	68	48*	67	67	73	50*	72	72	78	55*	59.0	64.3	69.3
19	78	74	83	60*	88	84	93	65*	96	93	105	68*	73.8	82.5	90.5
20	63	63	63	13*	73	71	70	21*	80	75	75	38*	50.5	58.8	67.0
21	63	68	67	69*	72	78	80	81*	78	85	89	90*	66.8	77.8	85.5
22	58	52	49	49*	68	61	56	56*	76	67	60	61*	52.0	60.3	66.0
23	70	67	68	68*	80	75	77	75*	89	82	84	81*	68.3	76.8	84.0
24	70	64	74	11*	76	74	82	14*	80	80	87	17*	54.8	61.5	66.0
25	70	74	73	11*	77	72	81	14*	81	80	87	20*	54.5	61.0	67.0
26	23	21	27	24*	25	23	63	28*	27	25	89	50*	23.8	34.8	47.8
27	33	29	31	33*	40	35	37	40*	44	38	43	45*	32.0	38.0	43.0
28	65	59	59	60*	73	64	64	67*	79	68	68	72*	61.0	67.0	72.0
29	71	65	63	66*	79	72	72	76*	84	77	77	80*	96.0	75.0	80.0
30	88	84*	83	80	99	93*	92	91	107	99*	98	99	84.0	94.0	101.0
31	105	105*	99	102	121	116*	114	119	131	120*	120	125	103.0	118.0	124.0
32	81	73*	73	75	93	80*	85	83	99	84*	93	89	76.0	85.0	91.0
33	92	90*	86	88	106	104*	101	102	115	114*	118	118	89.0	103.0	116.0

Table 4 (Sheet 3) **Summary of Results**

TEST NO.	11	12		13	
	TIME TO FIRE EXTINCTION (MEASURED FROM FIRST ROOM OPENING)	SMOKE CLEARANCE TIME TO CLEAR TO 20% (MEASURED FROM FIRST VENT OPENING) AT:-		$\frac{\Sigma T(t=2 \rightarrow t=3)}{T.at\ t=2}$ AT 0.91m (3' 0") LEVEL	
		0.91m (3' 0") LEVEL	1.83m. (6' 0") LEVEL		
	SEC	SEC	SEC	ENTRY ARRAY	FURTHEST ARRAY
1	0.22 FROM RADIOMETER ONLY	40	51	30.49	33.90
2	57	72	95	52.13	56.73
3	90	99	106	50.16	58.20
4	111	83	90	55.72	66.90
5	72	112	152	61.09	60.18
6	FIRE WENT OUT AT t=2.35. REIGNITED BY LANCE AT 6.00 INVALID	69	69	43.54	51.44
7	26 SMOKE LOG UPSTAIRS	128	DIDN'T COME DOWN TO 20%	35.48	38.63
8	10 SMOKE LOG UPSTAIRS	183		35.89	38.30
9	84	75	83	51.26	61.10
10	50	65	75	63.85	37.15
11	80	101	117	63.72	56.72
12	88	57	76	43.08	55.83
13	79	39	90	72.09	31.04
14	69	82	118	69.69	87.49
15	74	76	131	67.99	78.66
16	57	82	101	46.75	63.63
17	44	67	97	34.33	56.11
18	71	54	59	45.09	47.14
19	60	79	98	36.14	46.39
20	80	52	59	33.83	50.51
21	60	57	66	41.85	42.75
22	59	66	77	39.58	68.39
23	77	107	127	48.64	65.44
24	82	60	68	37.85	48.86
25	75	65	64	33.6	47.28
26	151	163	DIDN'T COME DOWN (WATER DROPS ON WINDOWS)	33.3	27.40
27	44	42	52	(FIRE OUT 29.76	BY T=3) 35.13
28	75	76	79	37.59	58.68
29	81	78	88	44.51	76.59
30	89	87	99	48.03	54.45
31	88	92	109	61.21	65.28
32	106	86	95	46.89	63.34
33	65	82	125	61.51	53.84

Table 4 (Sheet 4) **Summary of Results**

TRIAL NO	APPROX. WIND COMPONENTS M/Sec.	APPROX. INLET/OUTLET AREA RATIO	FAN USED	$\frac{\Sigma T_{\tau=2 \sim \tau=3}}{T_{\tau=2}}$	SMOKE CLEARANCE TIME TO CLEAR TO 20%		AVERAGE OUTLET VOLUMETRIC FLOWRATE	OVERALL CONCLUSION
					3'0"	6'0"		
3	0.5 opposing fan,	2/1	YES	✓	✓ slight	✓		
11	4.0 across fan		NO				✓ slight	fan probably better
4	2.5 opposing fan,	2/1	YES	✓ slight	✓	✓	✓	
5	1.5 across fan		NO					fan better
9	0.6 assisting fan,	1/1	YES	✓				
10	3.0 across fan		NO		✓	✓	✓ slight	no fan probably better
12	1.0 opposing fan,	4/1	YES	✓		✓	✓	
13	2.5 across fan		NO		✓			fan probably better
14	2.0 opposing fan,	2/1	YES			✓	✓ slight	
15	2.0 across fan		NO	✓ slight	✓ slight			little difference
16	2.2 opposing fan,	1/2	YES					
17	4.4 across fan		NO	✓	✓	✓ slight	✓ slight	no fan better
18	2.5 assisting fan,	1/2	YES		✓	✓	✓	
19	6.5 across fan		NO	✓				fan probably better
20	1.6 assisting fan,	1/4	YES	✓	✓	✓	✓	
21	1.6 across fan		NO					fan better
22	2.5 assisting fan,	1/1	YES	✓	✓	✓	✓	
23	0.7 across fan		NO					fan better
28	7.0 assisting fan,	2/1	NO	✓	✓ slight	✓ slight		
29	zero across fan		YES				✓ slight	no fan probably better
30	1.0 assisting fan,	2/1	YES	✓	✓ slight	✓	✓	
31	3.2 across fan		NO					fan better
32	0.2 opposing fan,	2/1	YES	✓		✓	✓	
33	0.5 across fan		NO		✓			fan probably better

Table 5 Comparisons of pairs of trial results according to the different criteria
(A tick indicates the better of the two)

Figures

Figure 1 The Fire Service College's 'Domestic Building' - Front

Figure 2 The Fire Service College's 'Domestic Building' - Back

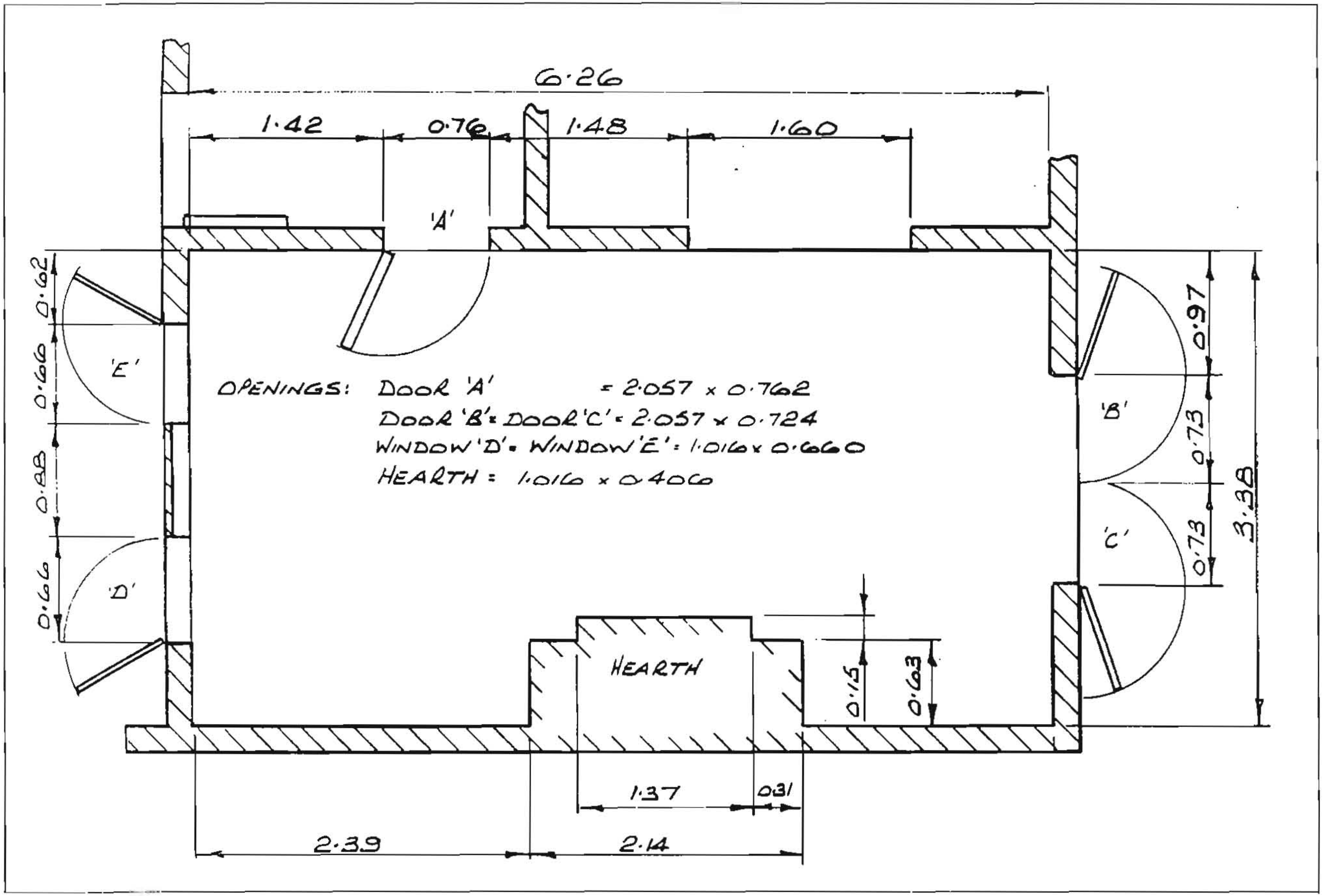


Figure 3 Plan View of Domestic Living Room Basic Dimensions

Figure 4 The Tempest 24" Fan used throughout the Trials

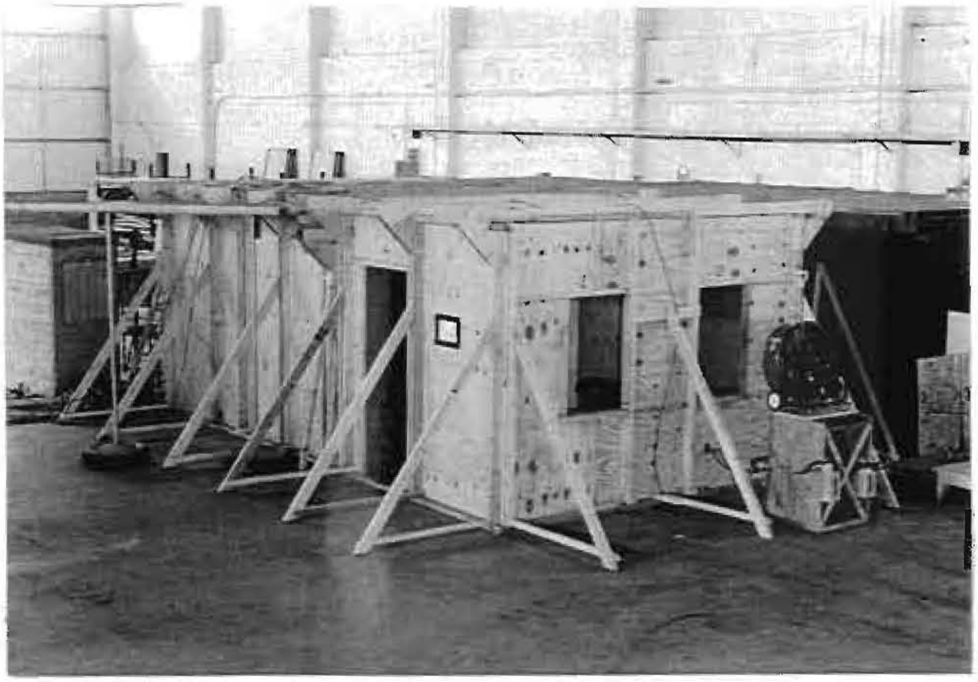


Figure 5 Full Size Mock-up of Living Room for Still Air Trials - General View

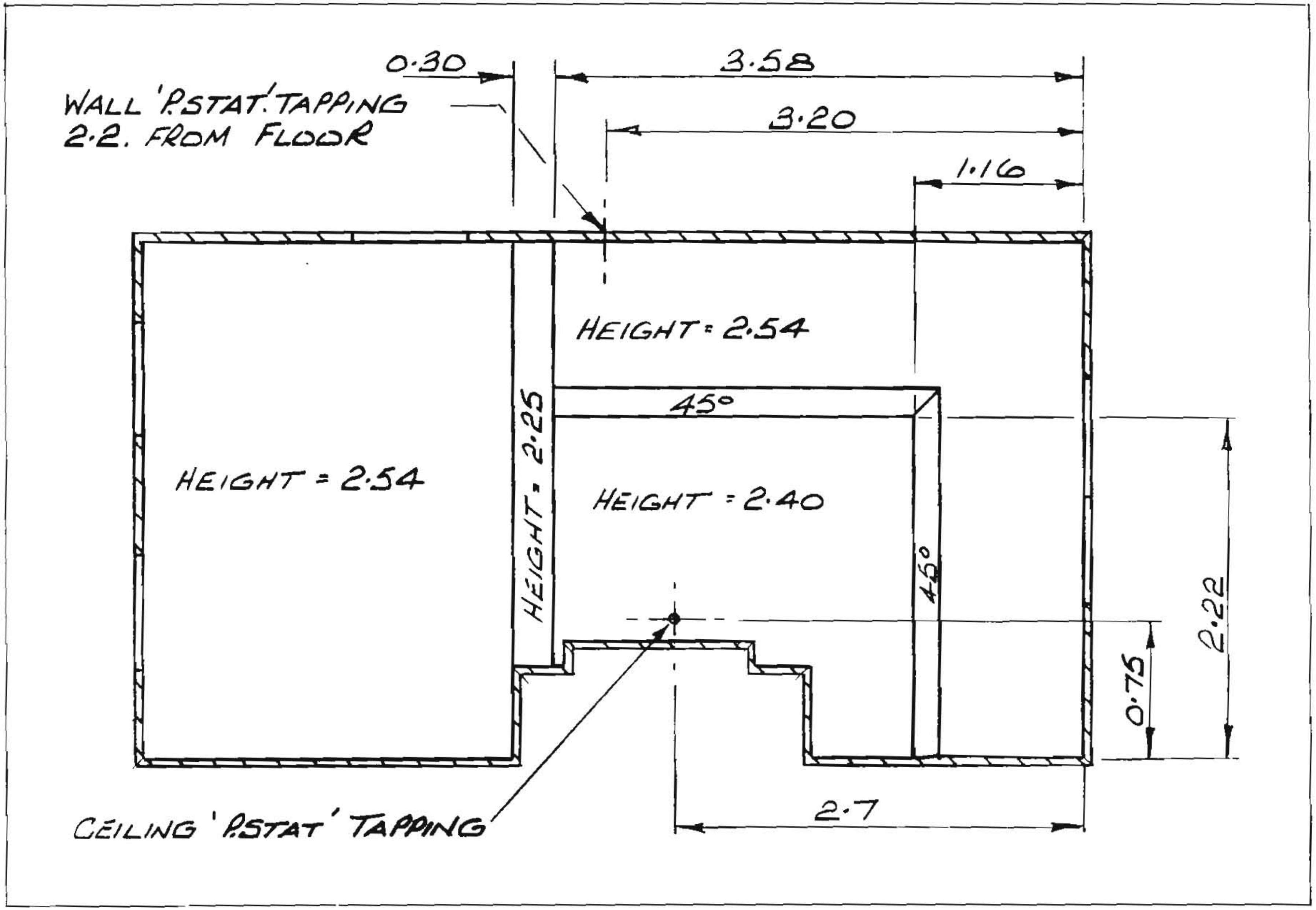


Figure 6 Details of Room Ceiling and Positions of Static Pressure Probes in Mock-up Room

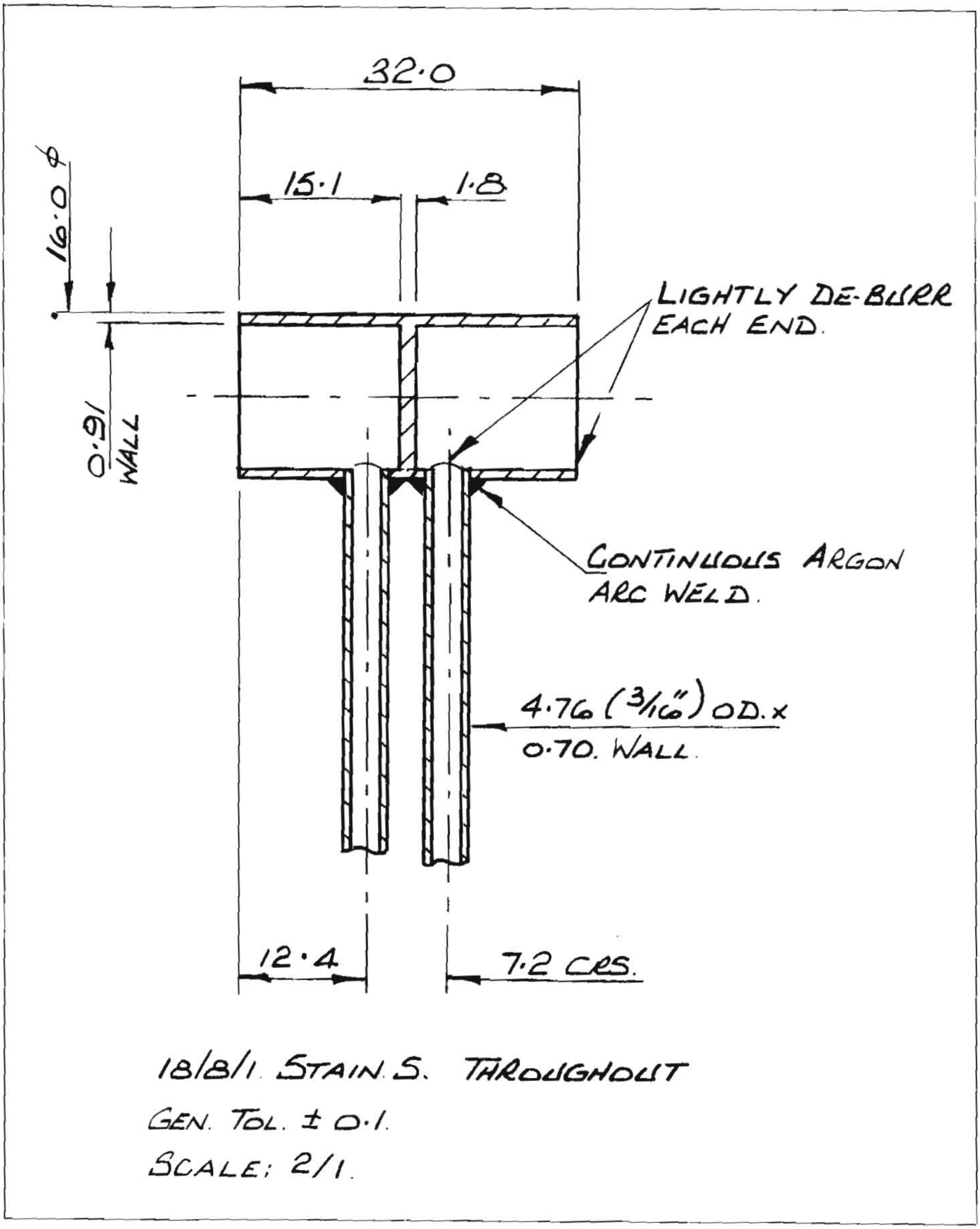
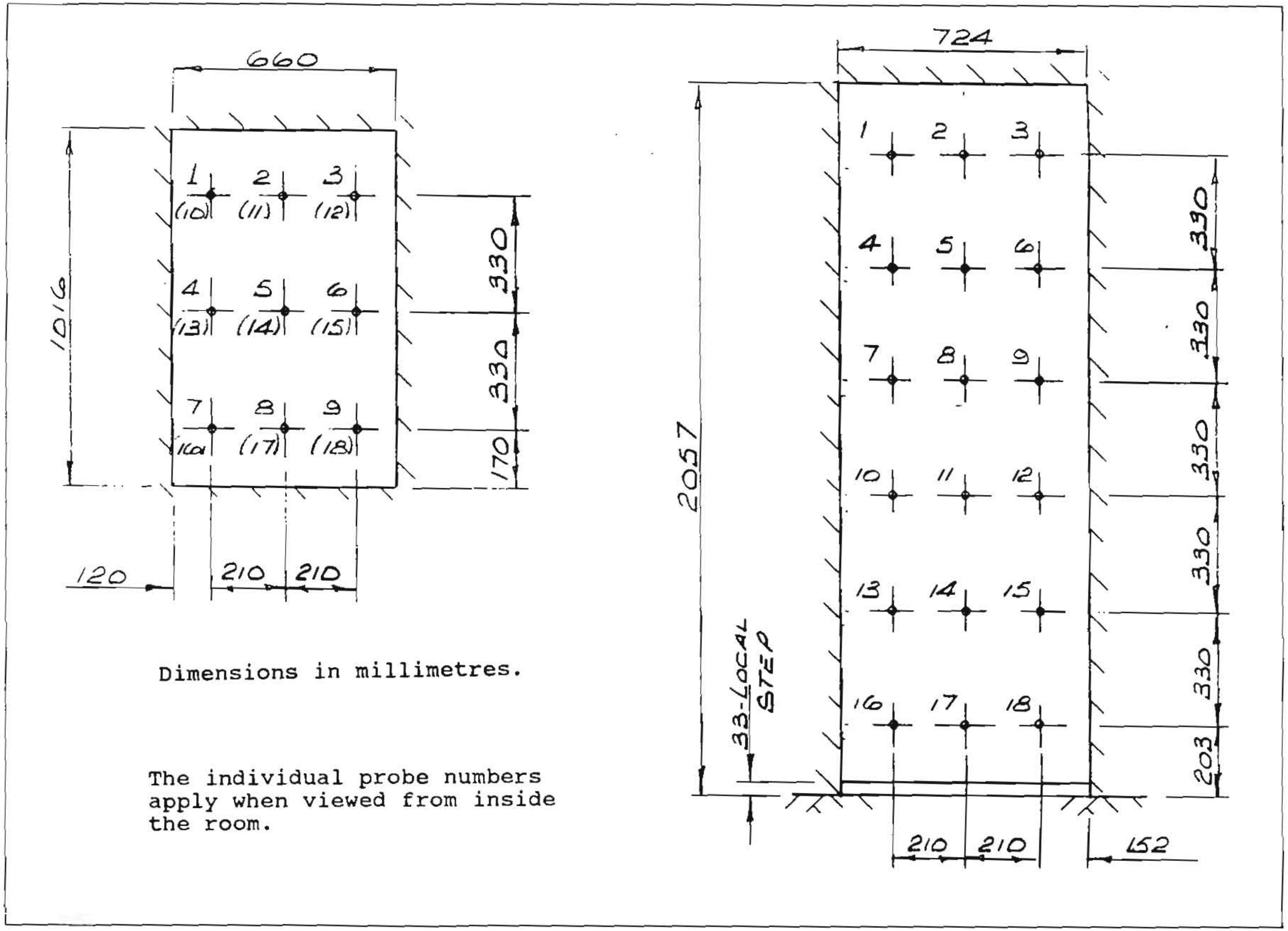


Figure 7 The Mccaffery Probe - Longitudinal Cross Section



Dimensions in millimetres.

The individual probe numbers apply when viewed from inside the room.

Figure 8 The Positions of the McCaffrey Probes in Window(s) or Doorway

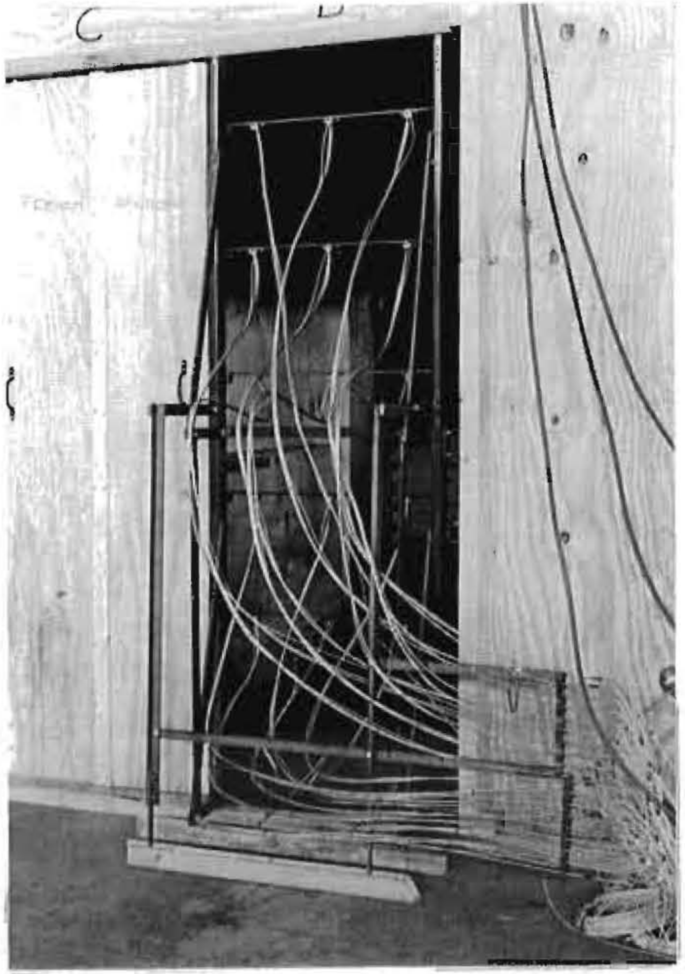


Figure 9 The McCaffrey Probe Arrays in a Doorway in the Mock-up Room

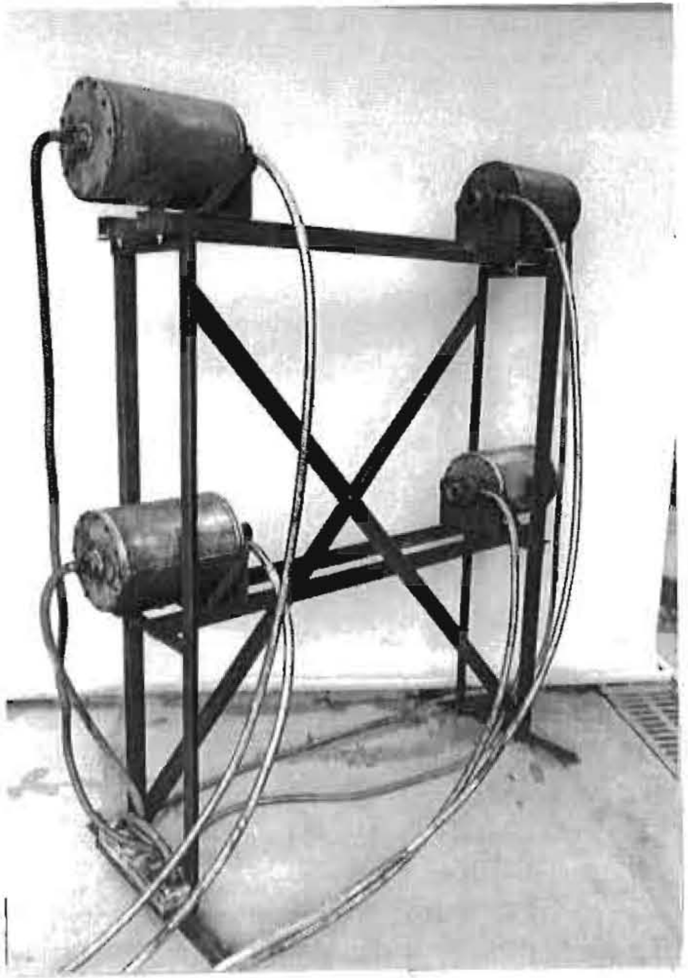


Figure 10 The Smoke Obscuration Meter Assembly

Figure 11 The Smoke Retaining Boxes in Position at Window Openings

Figure 12 A Smoke Retaining Box being removed from a French Window Opening during a Trial

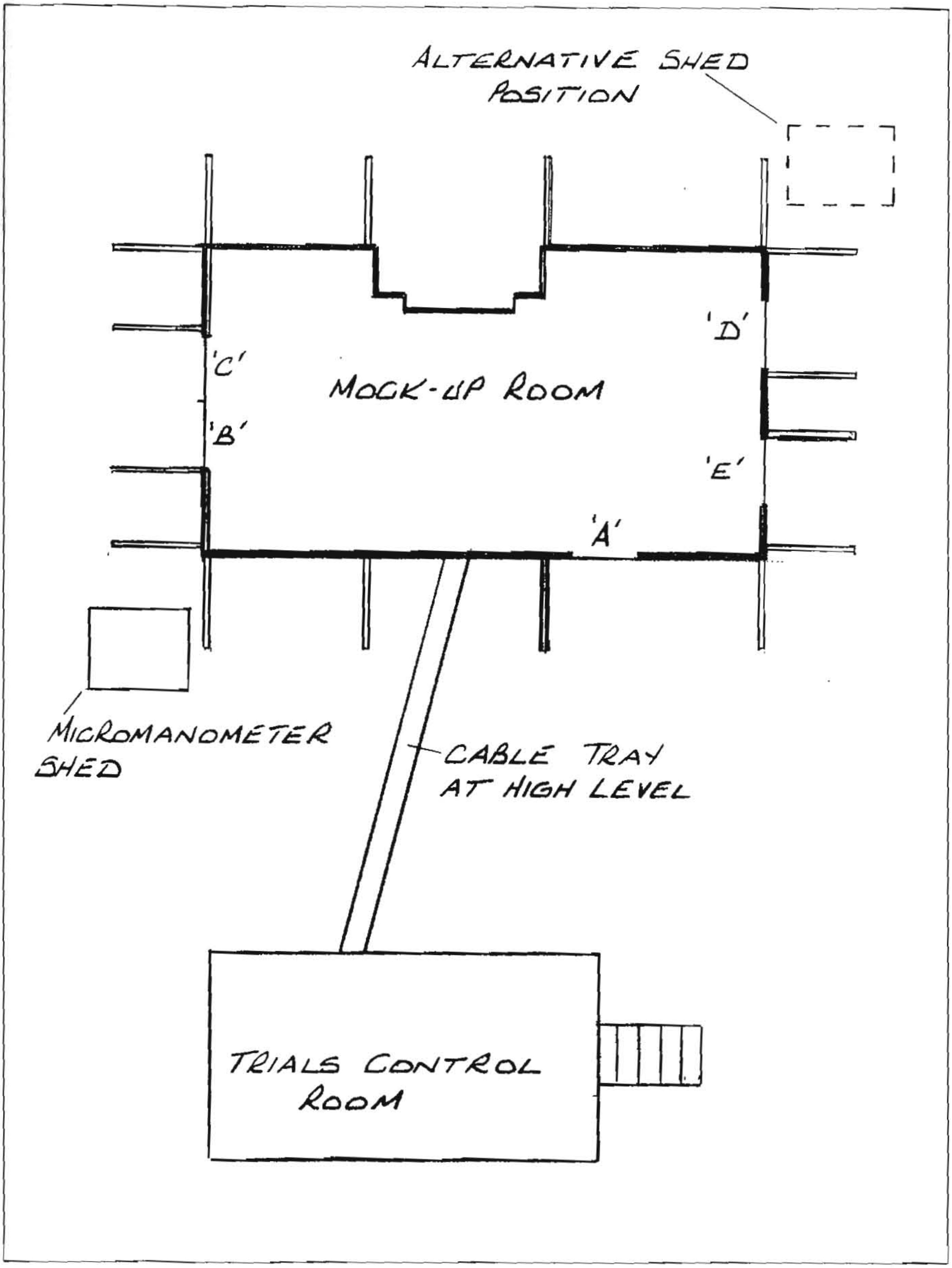


Figure 13 General Layout for Still Air Trials

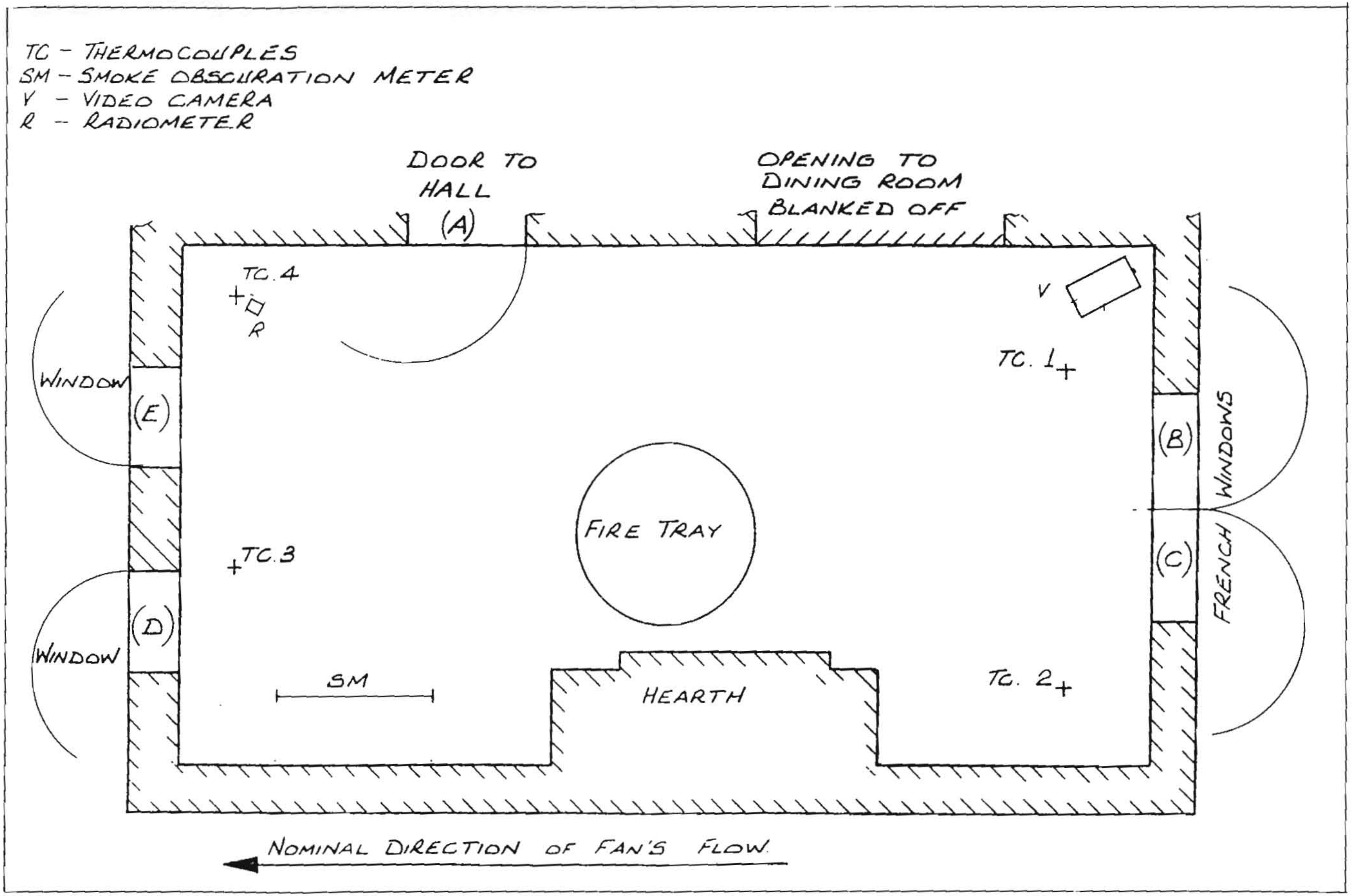


Figure 14 Layout of Fire Room Showing Positions of Instruments for Trials Numbered 1 to 13 and 30 to 33 Inclusive

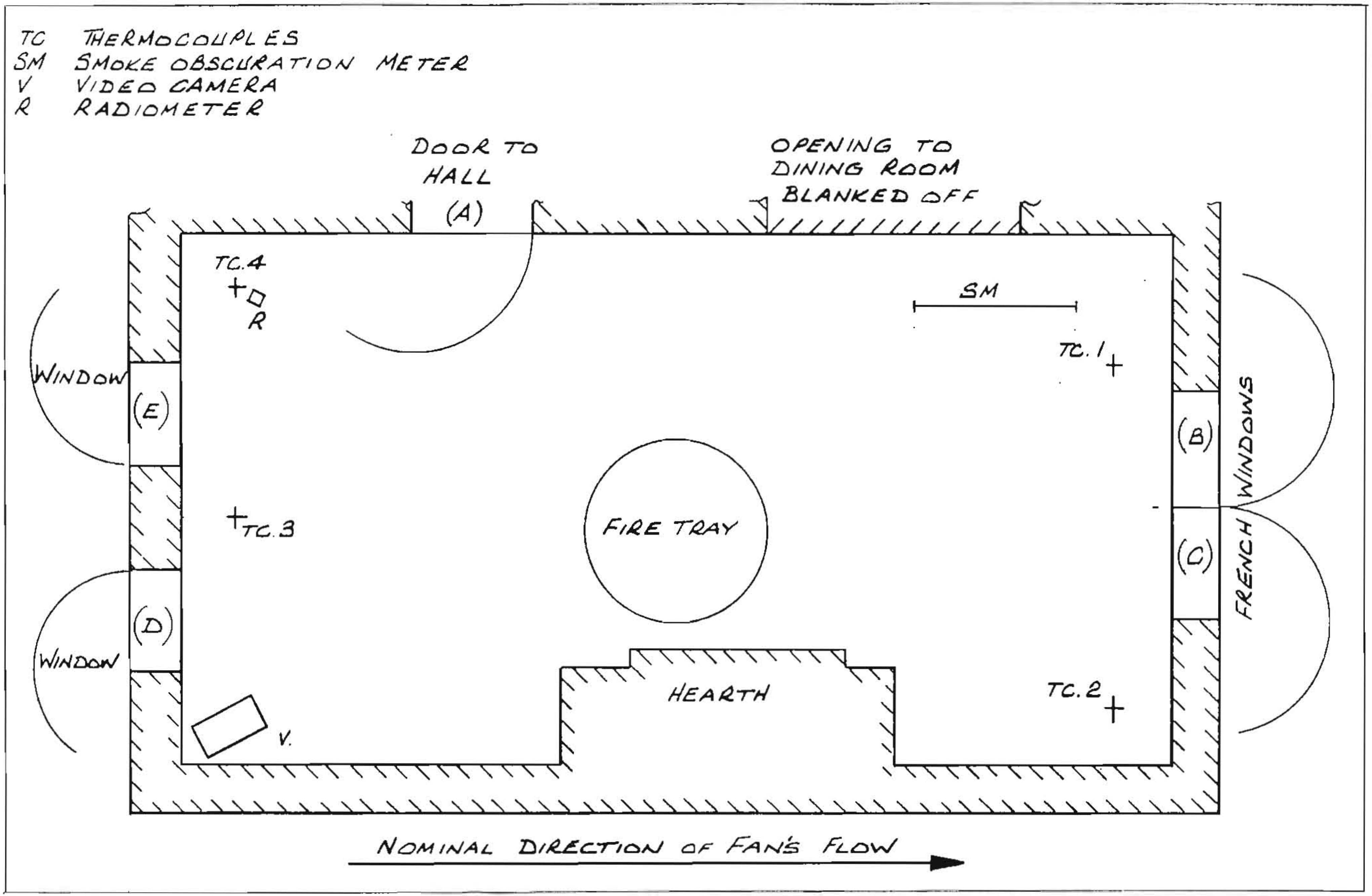


Figure 15 Layout of Fire Room Showing Positions of Instruments for Trials Numbered 14 to 29 Inclusive

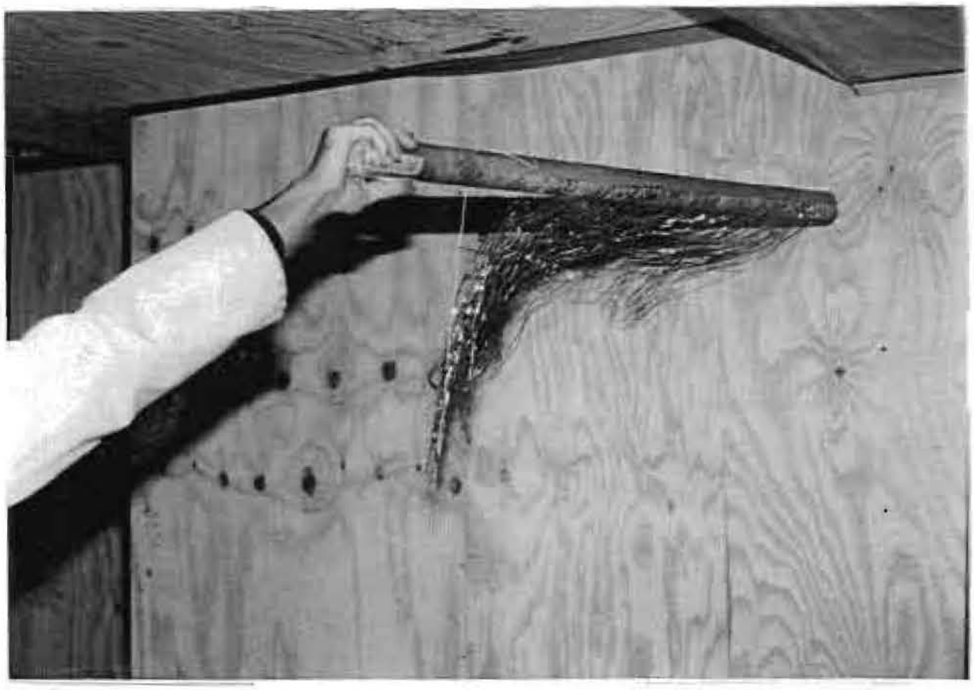


Figure 16 Lametta (Christmas Tree Decoration) being used to Assess Air movement in the Mock-up Room

TEST No..... 70 ....DATE..... 4/5/95 ....TIME.... 10:00

FAN	DISTANCE m	HOLE POSITION	INLET(S)	OUTLET(S)	TIME CONSTANT
24"	1	1	BC	DE	· FULL

PROBE No.	READING m/s	PROBE No.	READING m/s
1	2.52	**10**	3.22
2	2.51	**11**	2.84
3	2.31	**12**	3.20
4	3.02	**13**	3.32
5	3.12	**14**	3.20
6	3.15	**15**	3.19
7	3.37	**16**	3.69
8	3.33	**17**	3.50
9	3.23	**18**	3.57
AVERAGE	2.95	**AVERAGE**	3.30

OVERALL AVERAGE.... 3.12 ....m/s

ROOM STATIC PRESSURE... 12 Pa.

Figure 17 Typical Results Sheet from Still Air (Air Velocity) Trials

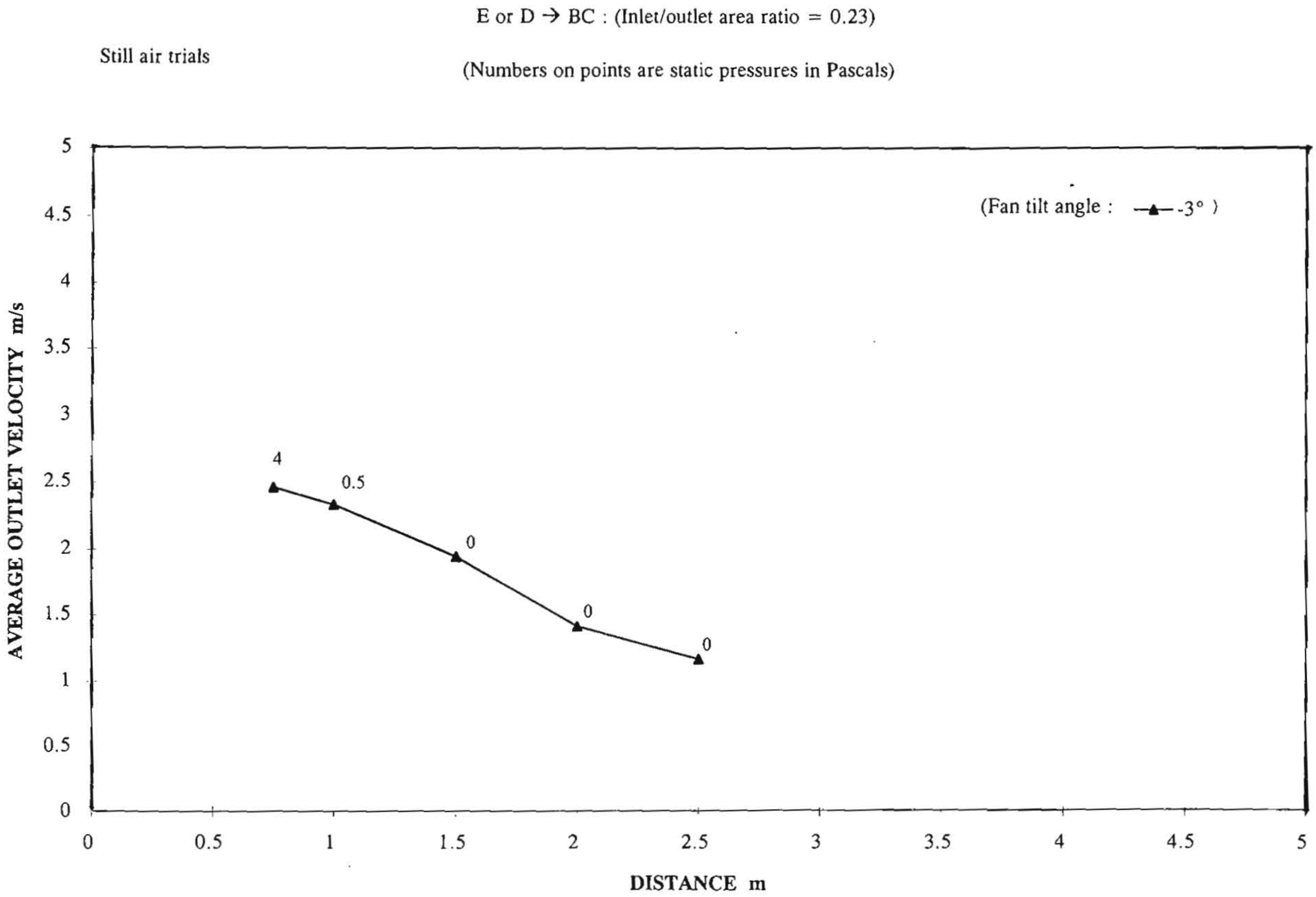


Figure 18. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening - (opening D or E → (B+C)) - fan on box, tilt angle = -3°.

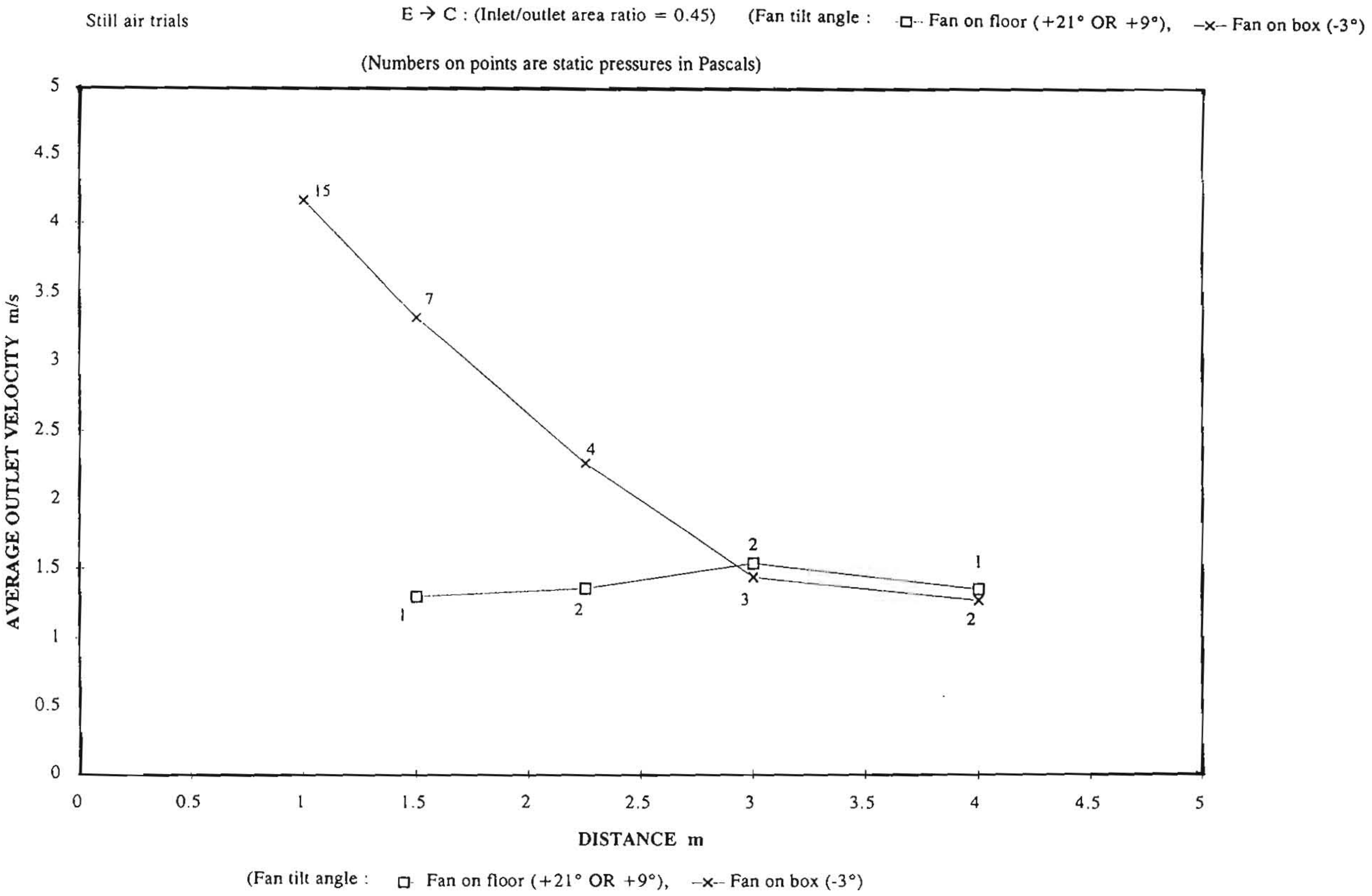


Figure 19. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening (openings E → C) - fan on floor, and on box.

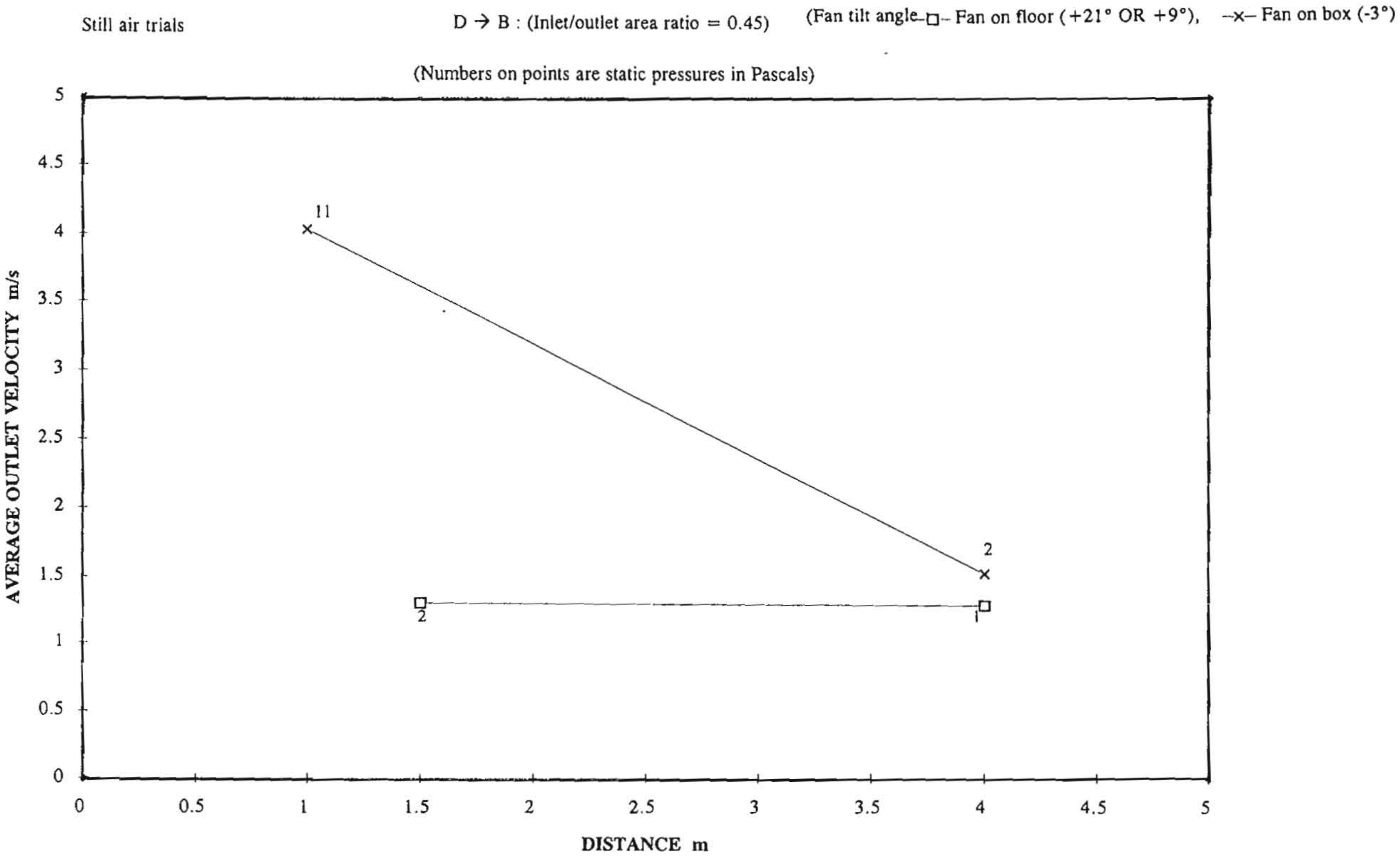


Figure 20. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening (openings D → B) - fan on floor, and on box.

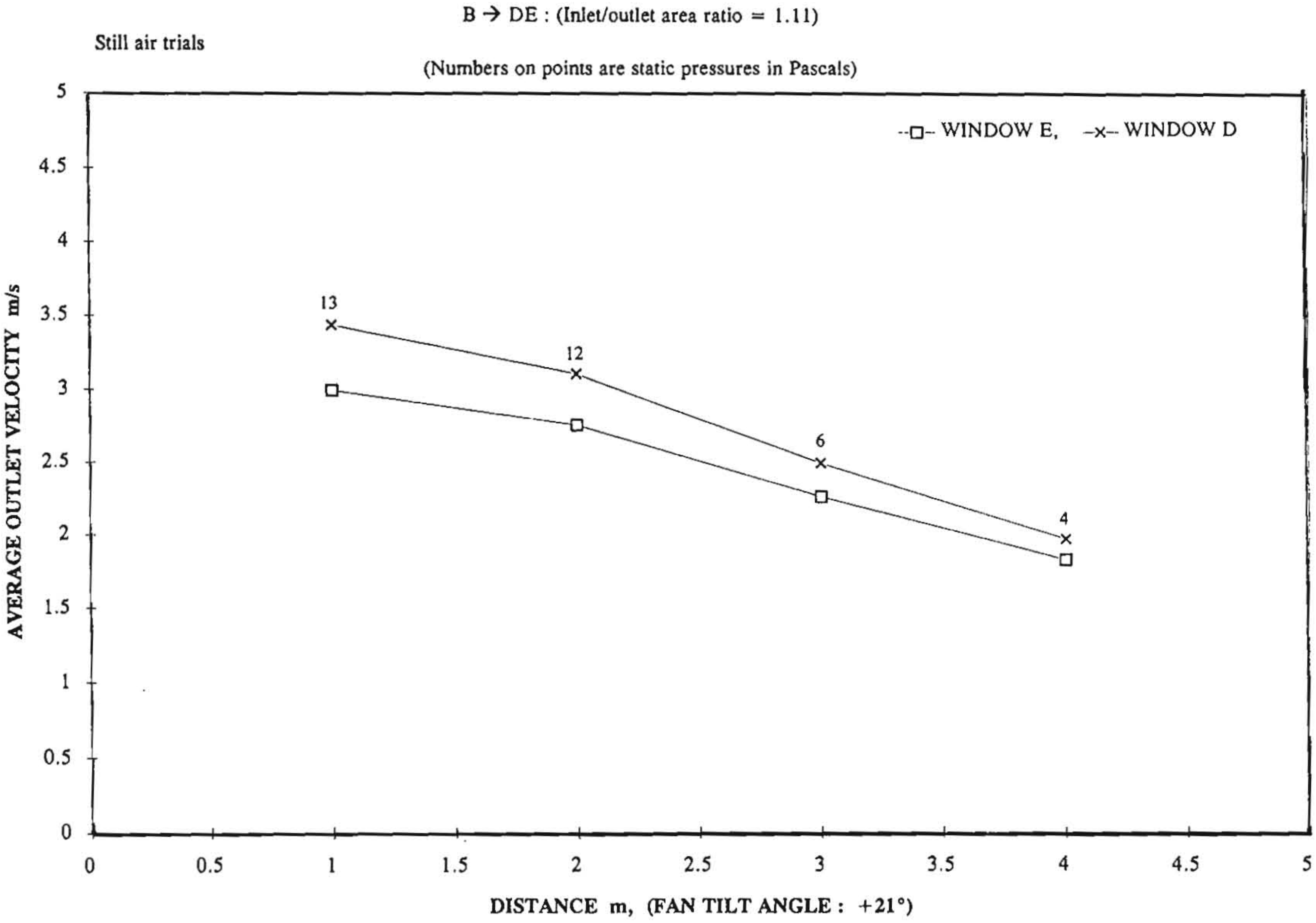


Figure 21. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening (openings B → (D+E)) - fan tilt angle = $+21^{o}$.

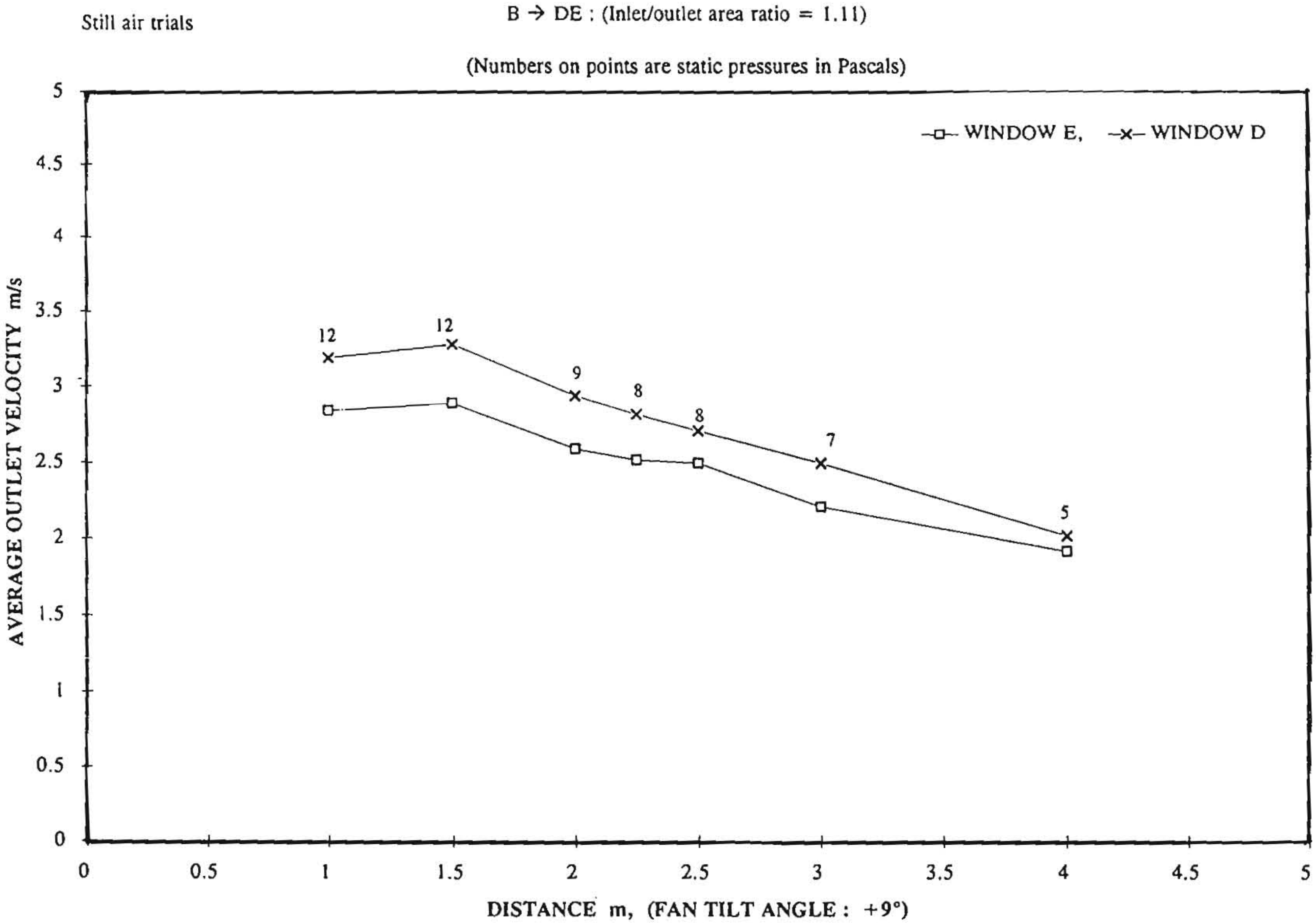


Figure 22. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening - (openings B →(D+E)) - fan tilt angle +9 .

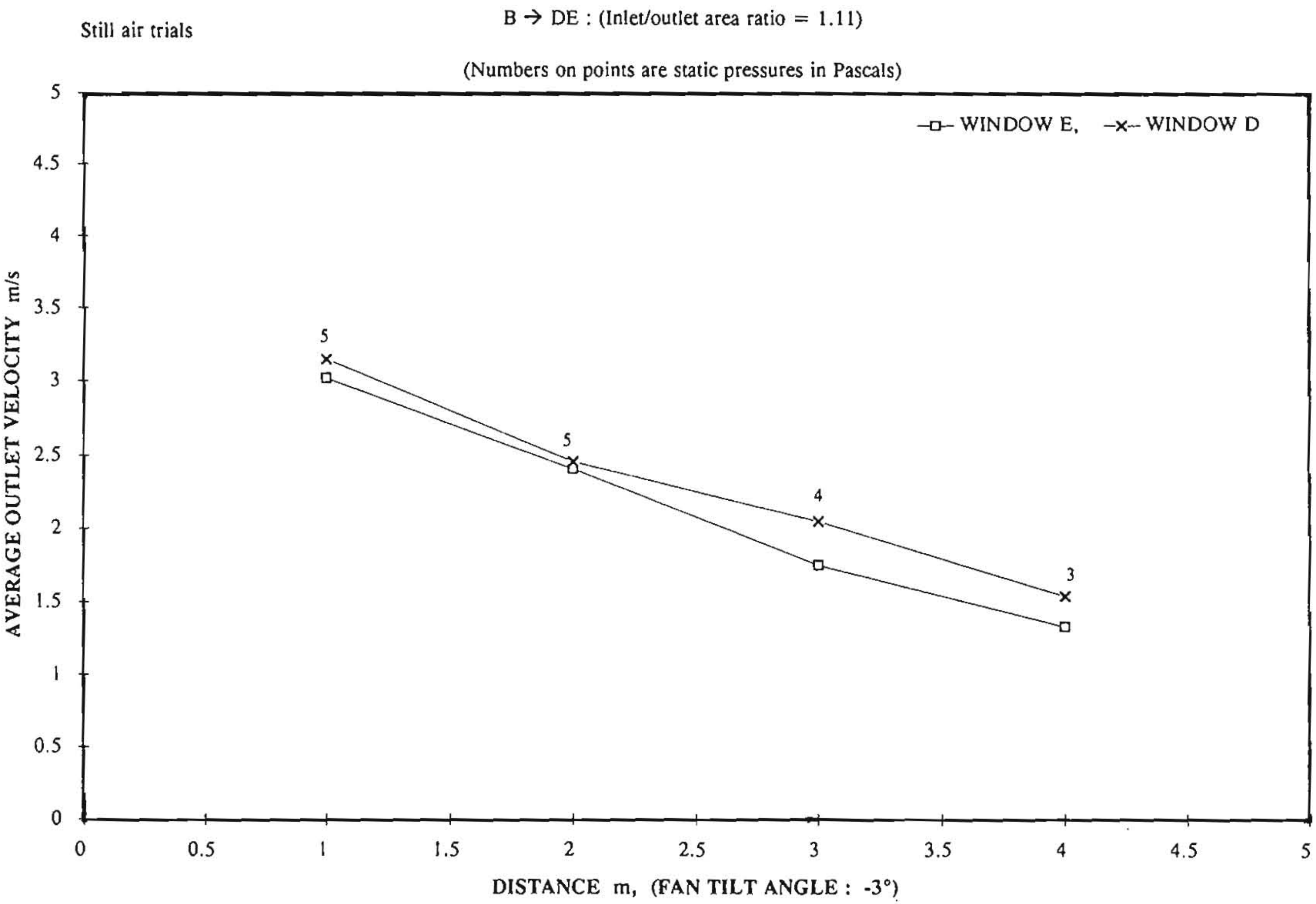


Figure 23. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening - (openings B ➛ (D+E)) - fan tilt angle = -3^{o}.

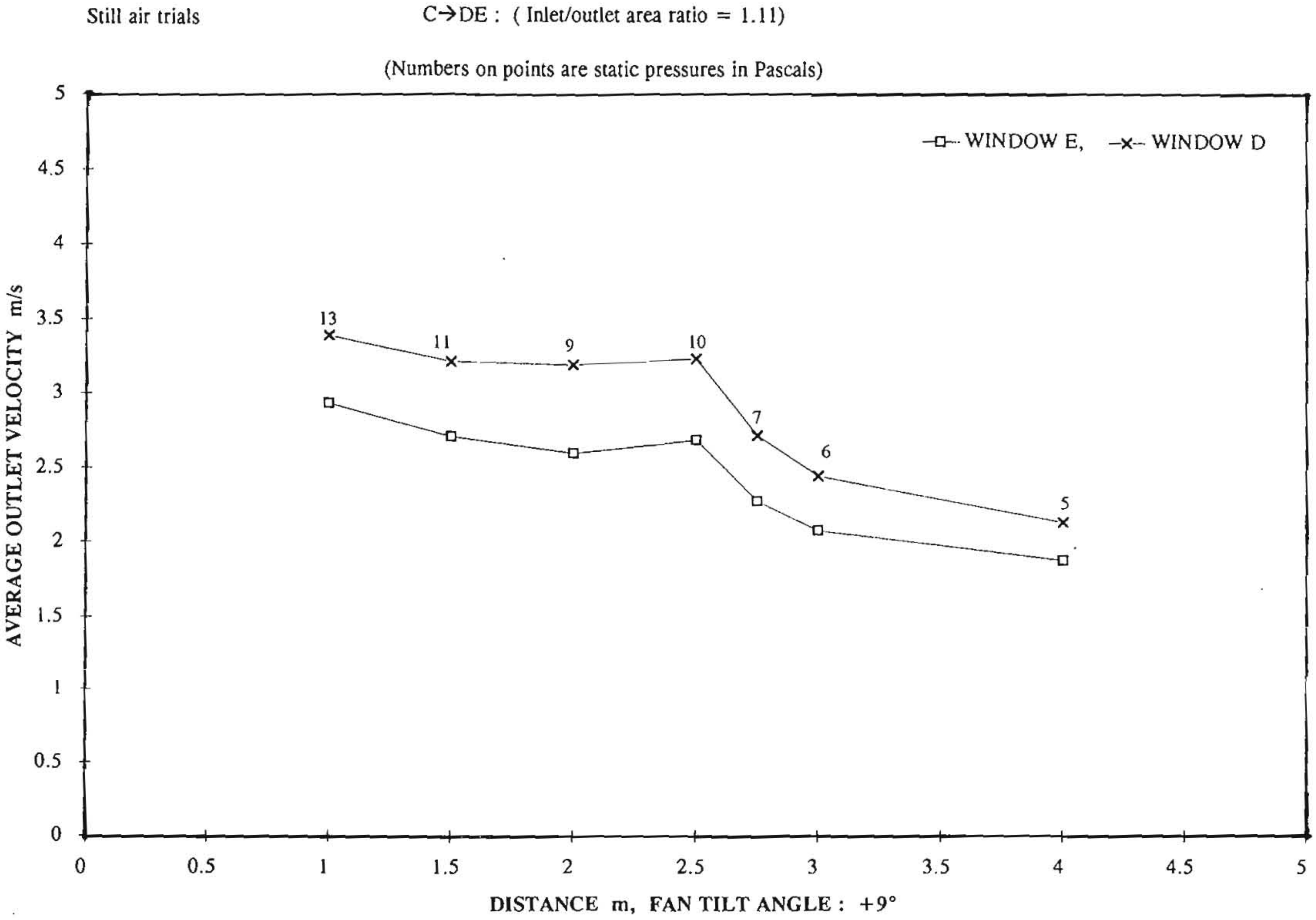


Figure 24. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening - (openings C →(D+E)) - fan tilt angle = +9°.

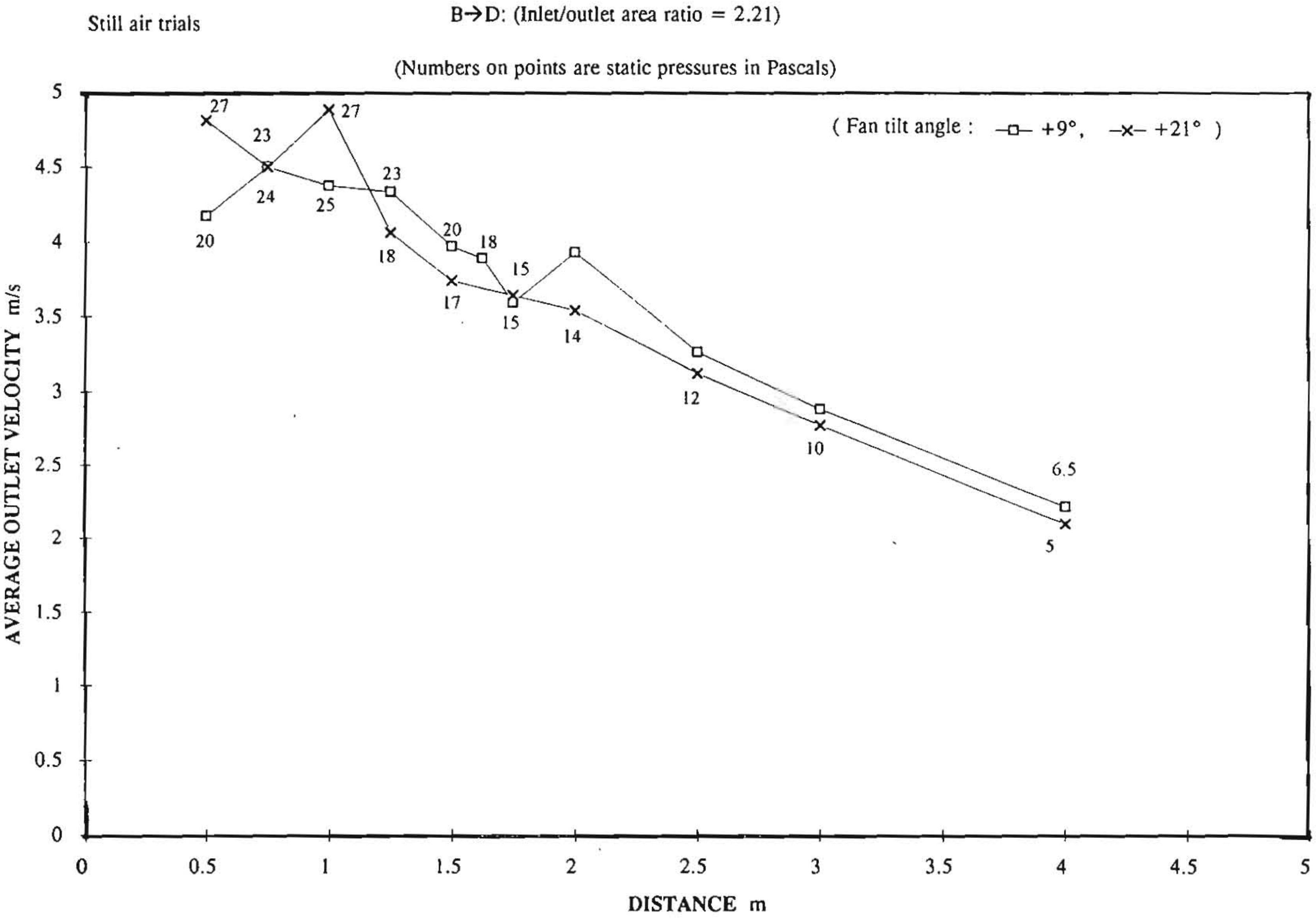


Figure 25. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening - (openings B → D) - fan tilt angles = +9°, and + 21°.

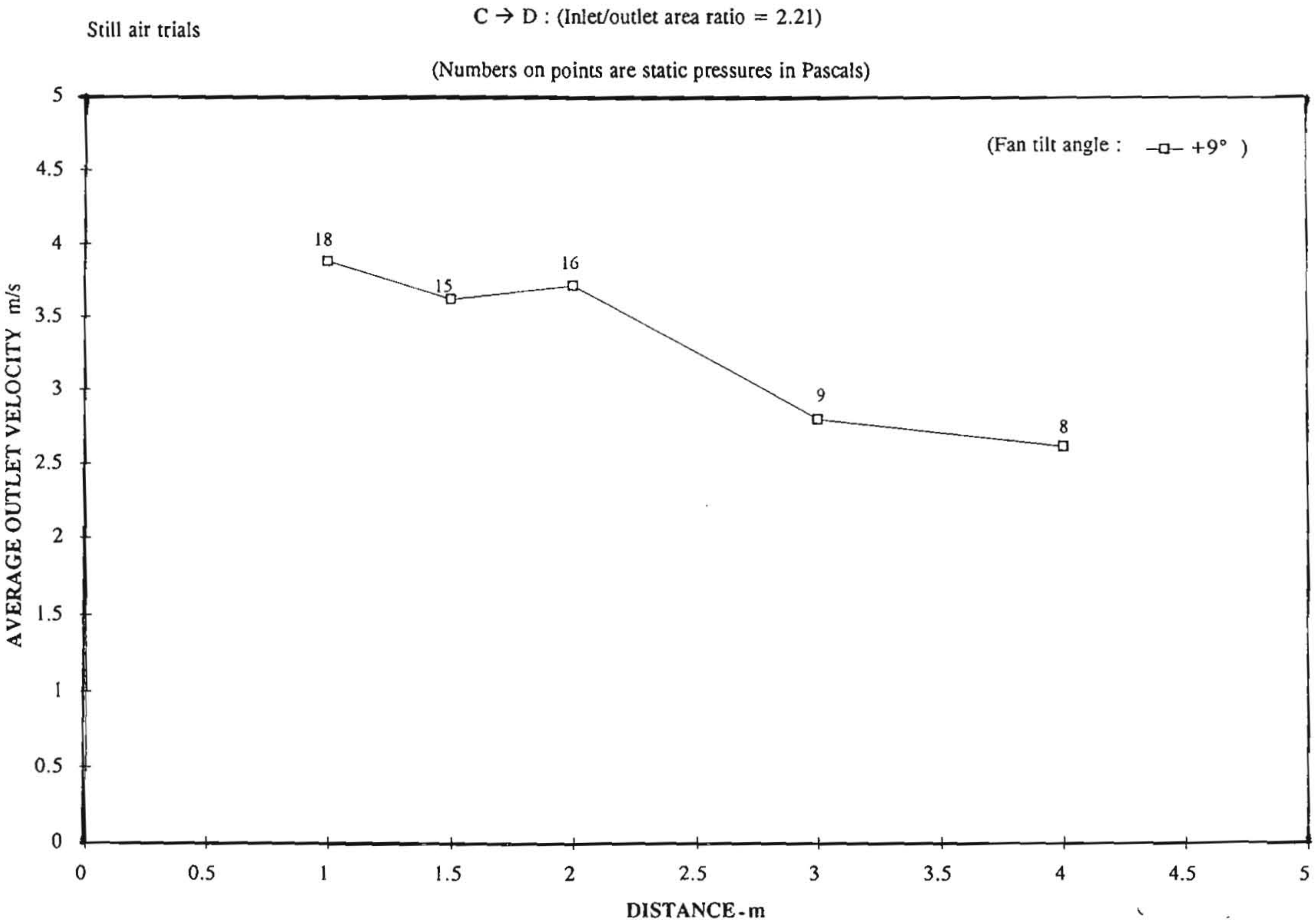


Figure 26. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening - (openings C → D) - fan tilt angle = +9°.

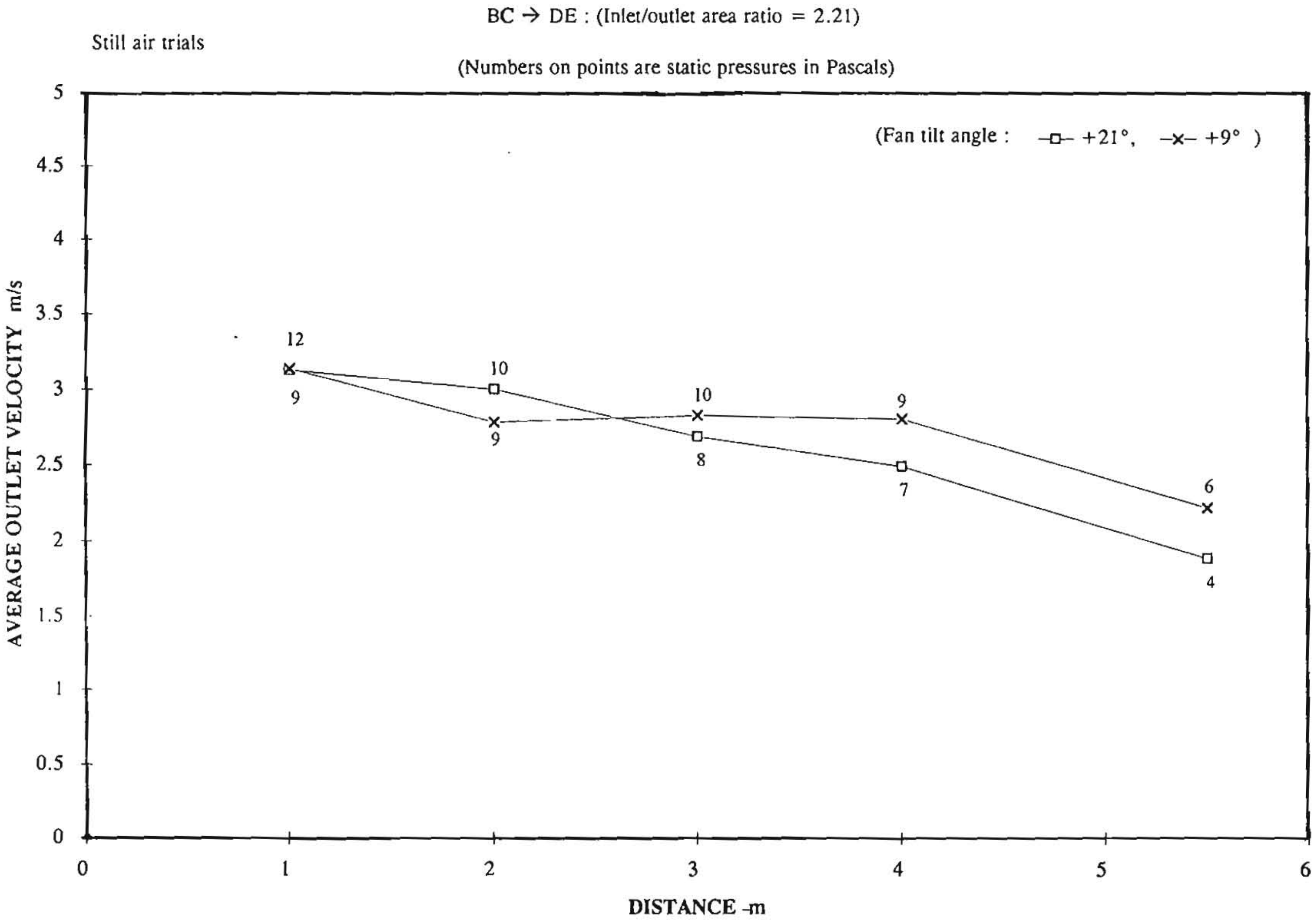


Figure 27. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening - (openings (B+C) → (D+E)) - fan tilt angles = +21°, and +9°.

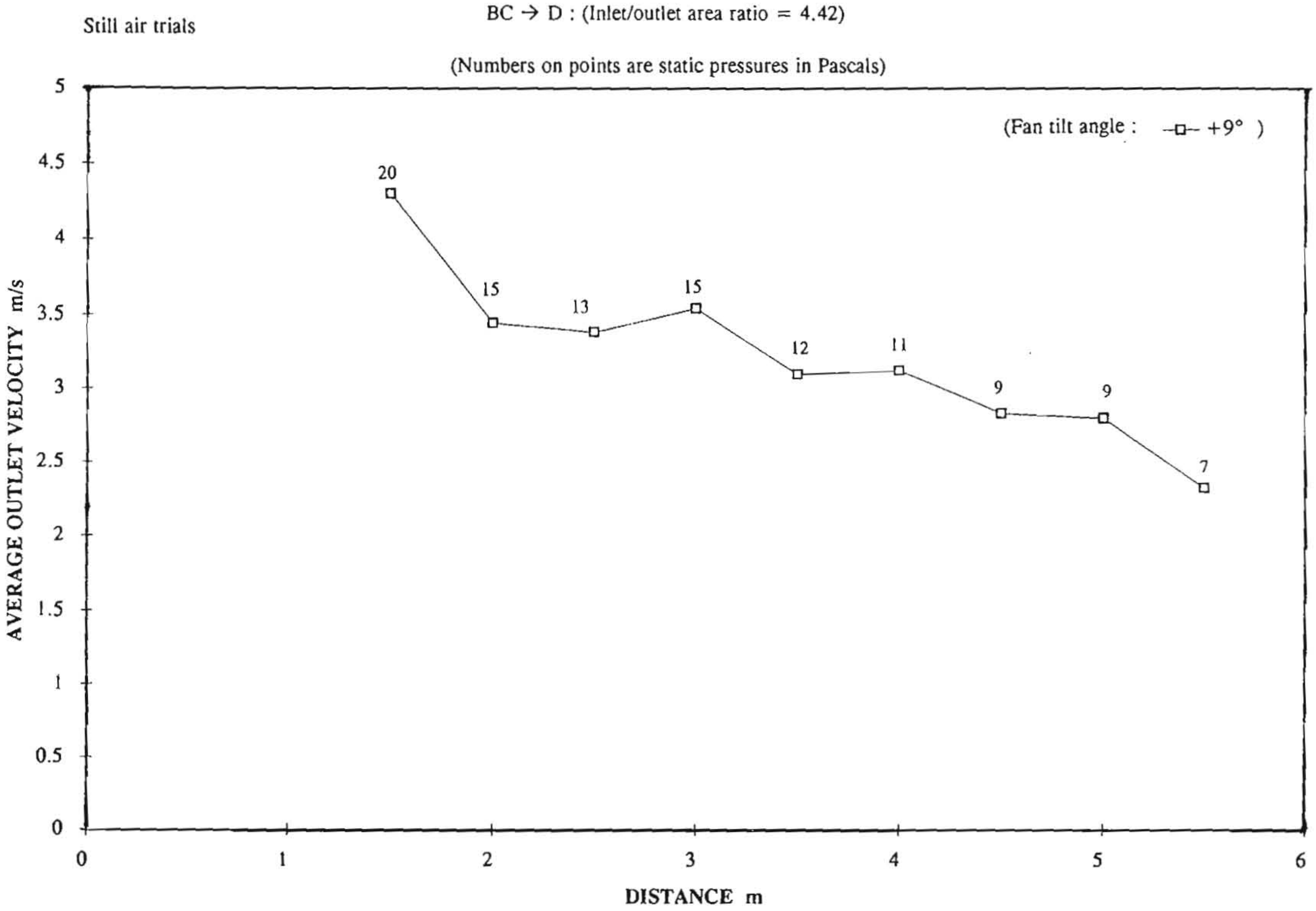


Figure 28. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening - (openings (B+C) → D)) - fan tilt angle = +9°.

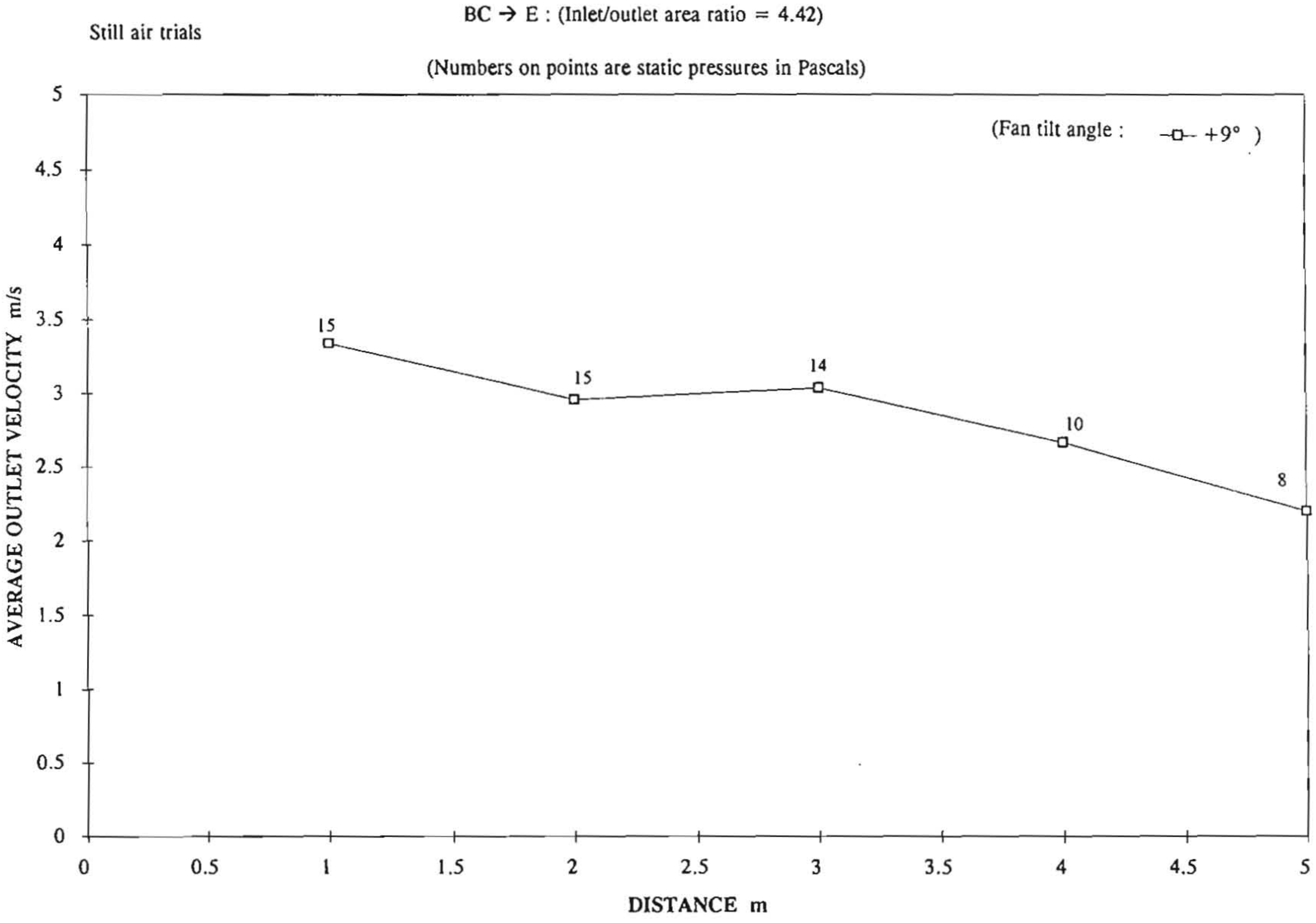


Figure 29. Still air trials results - graph of average outlet velocity Vs. distance of fan from opening - (openings (B+C) → E) - fan tilt angle = +9°.

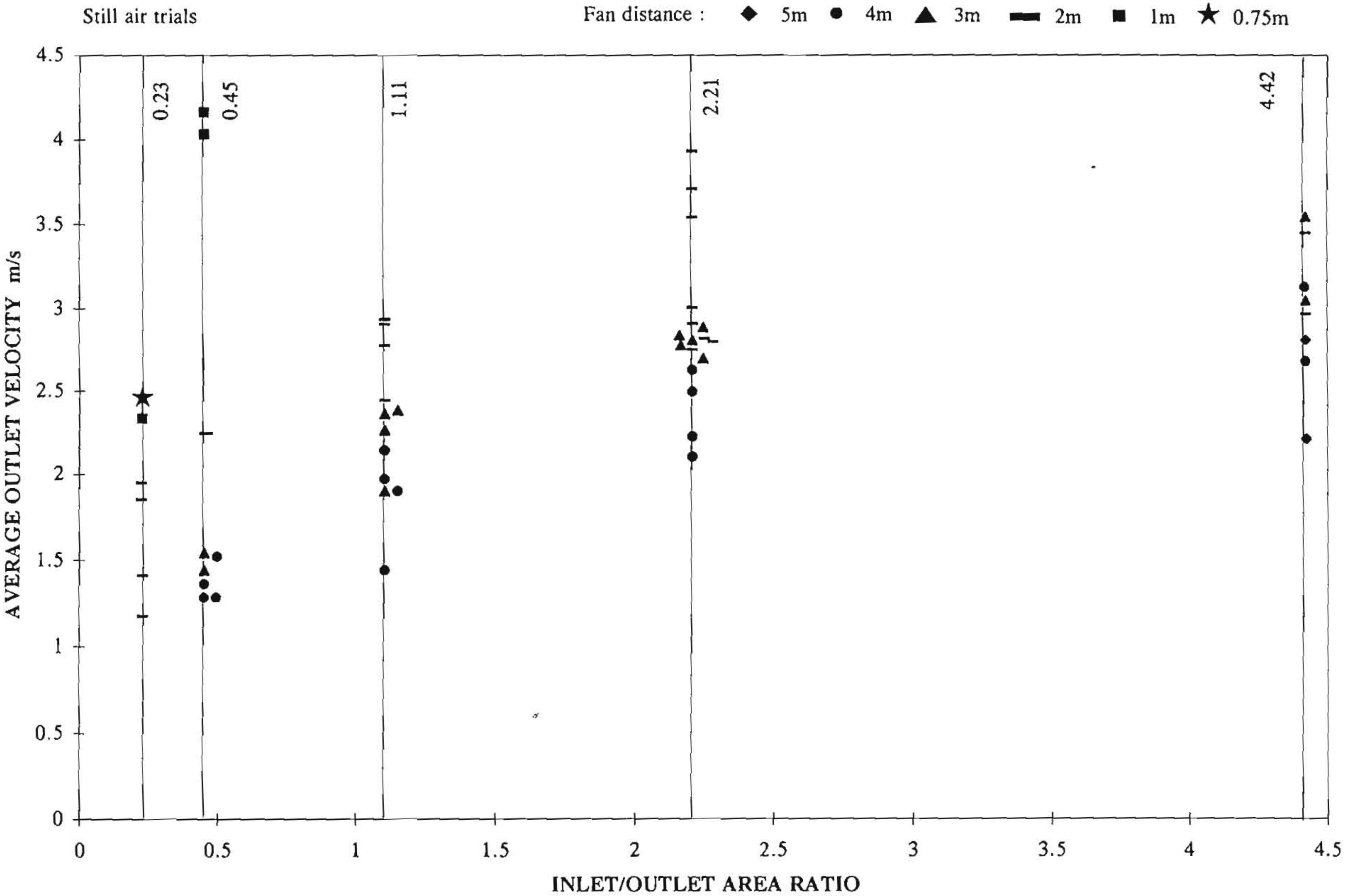


Figure 30 Graph of Inlet/Outlet Area Ratio Vs. Average Outlet Velocity

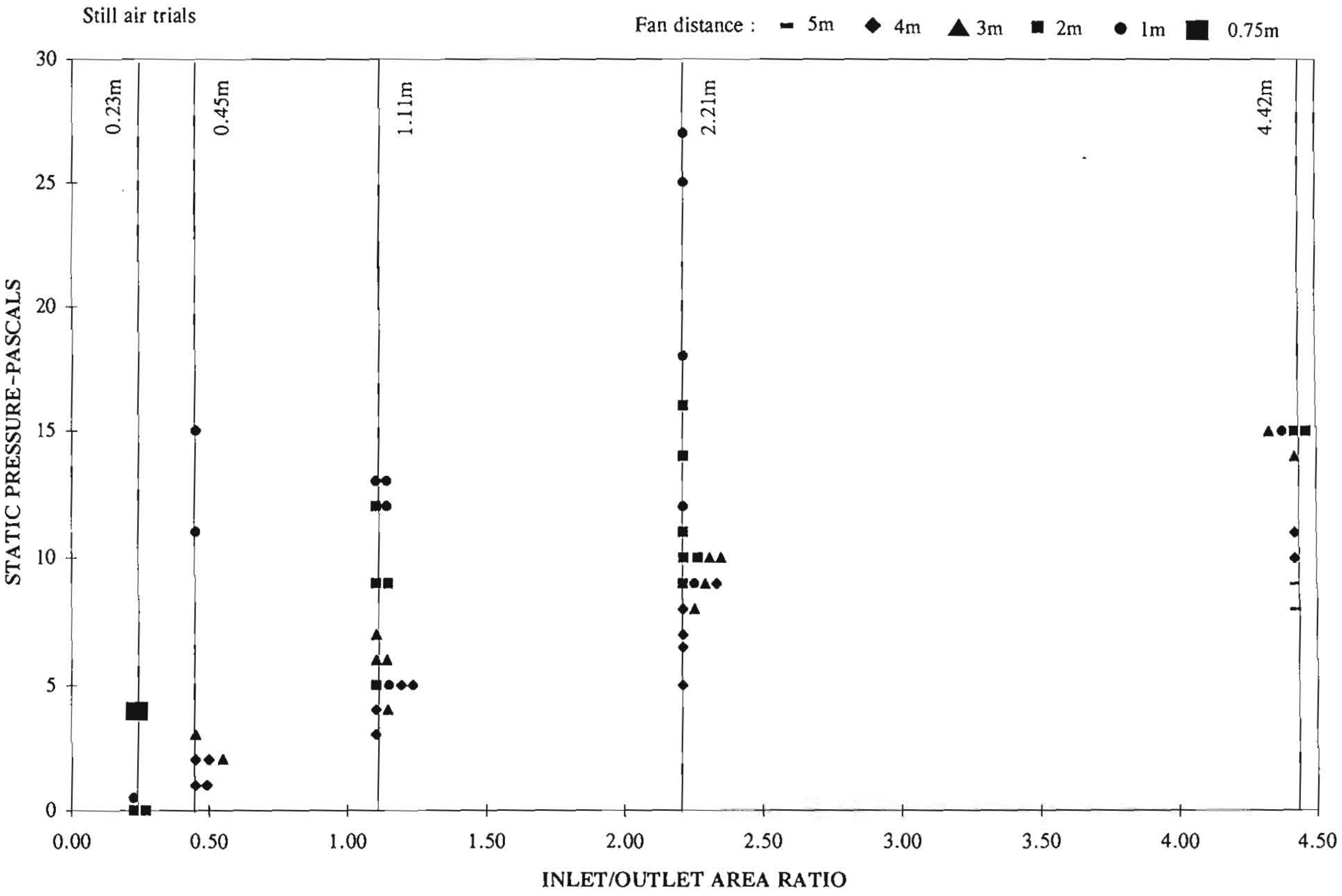


Figure 31. Graph of inlet /outlet area ratio Vs. static pressure.

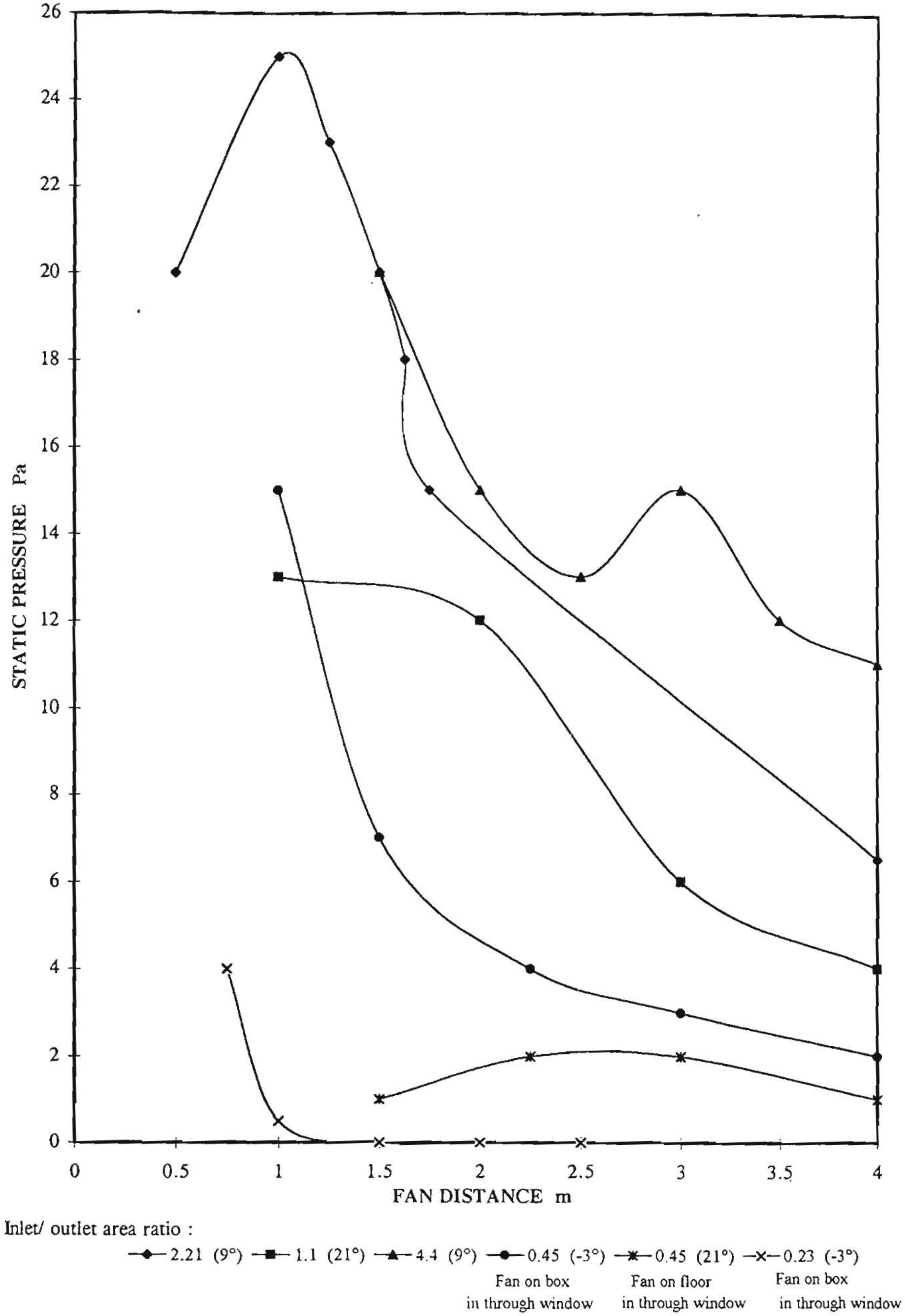


Figure 32 Still Air Trials Results - Graph of Static Pressure Vs Fan Distance

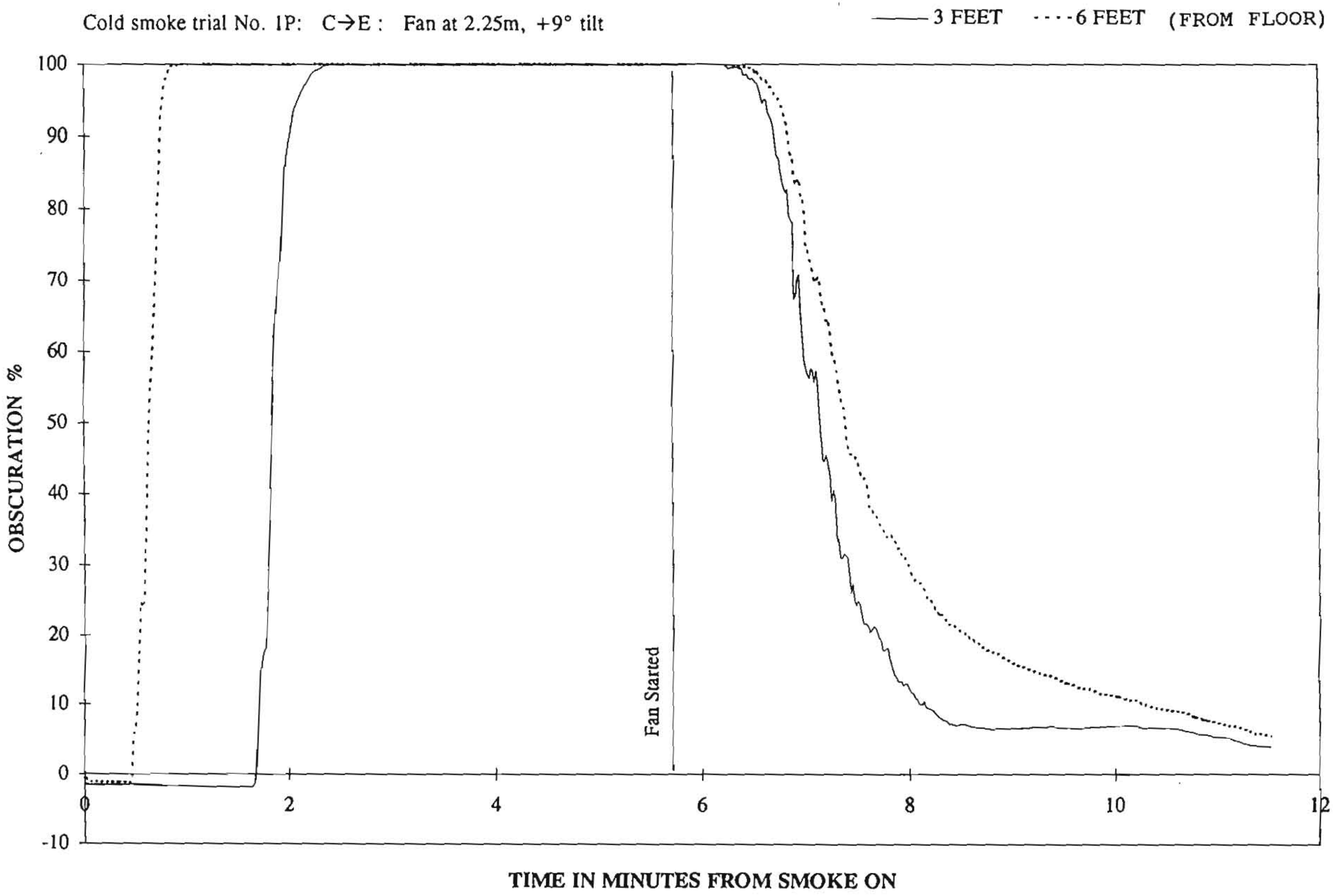


Figure 33. Cold smoke trial, no.1P. - graph of obscuration Vs. time.

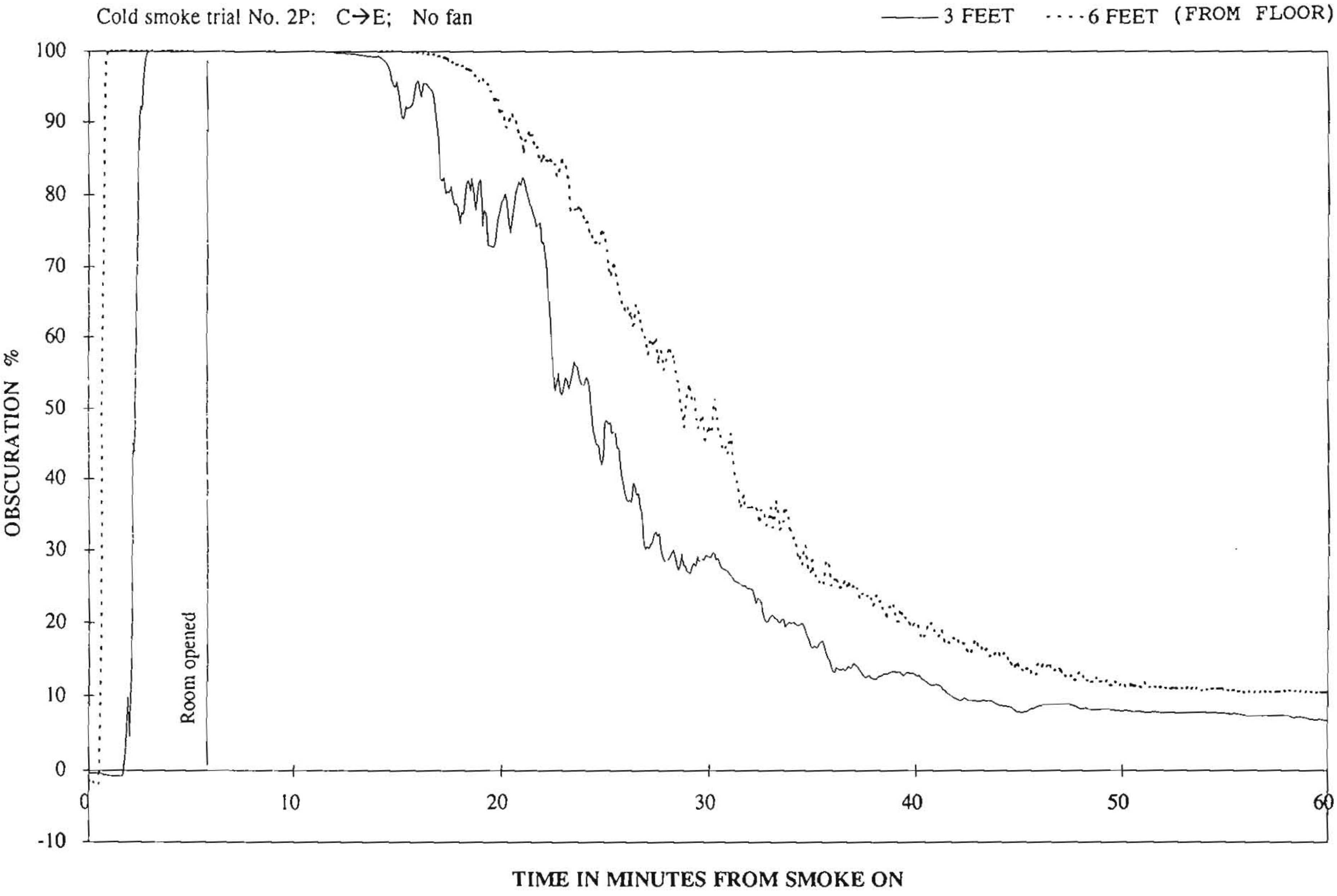


Figure 34. Cold smoke trial, no.2P. - graph of obscuration Vs. time.

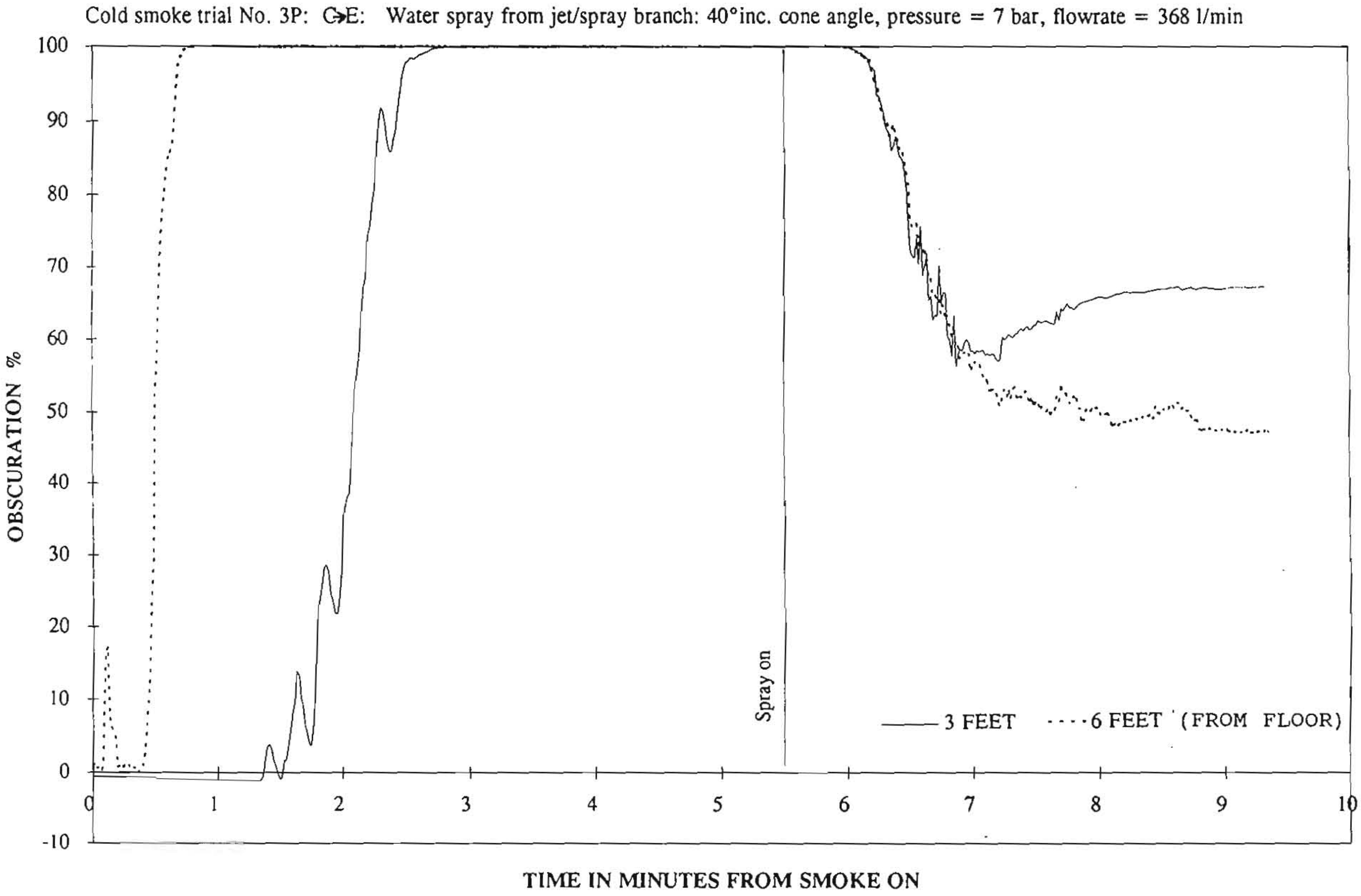


Figure 35. Cold smoke trial, no.3P. - graph of obscuration Vs. time.

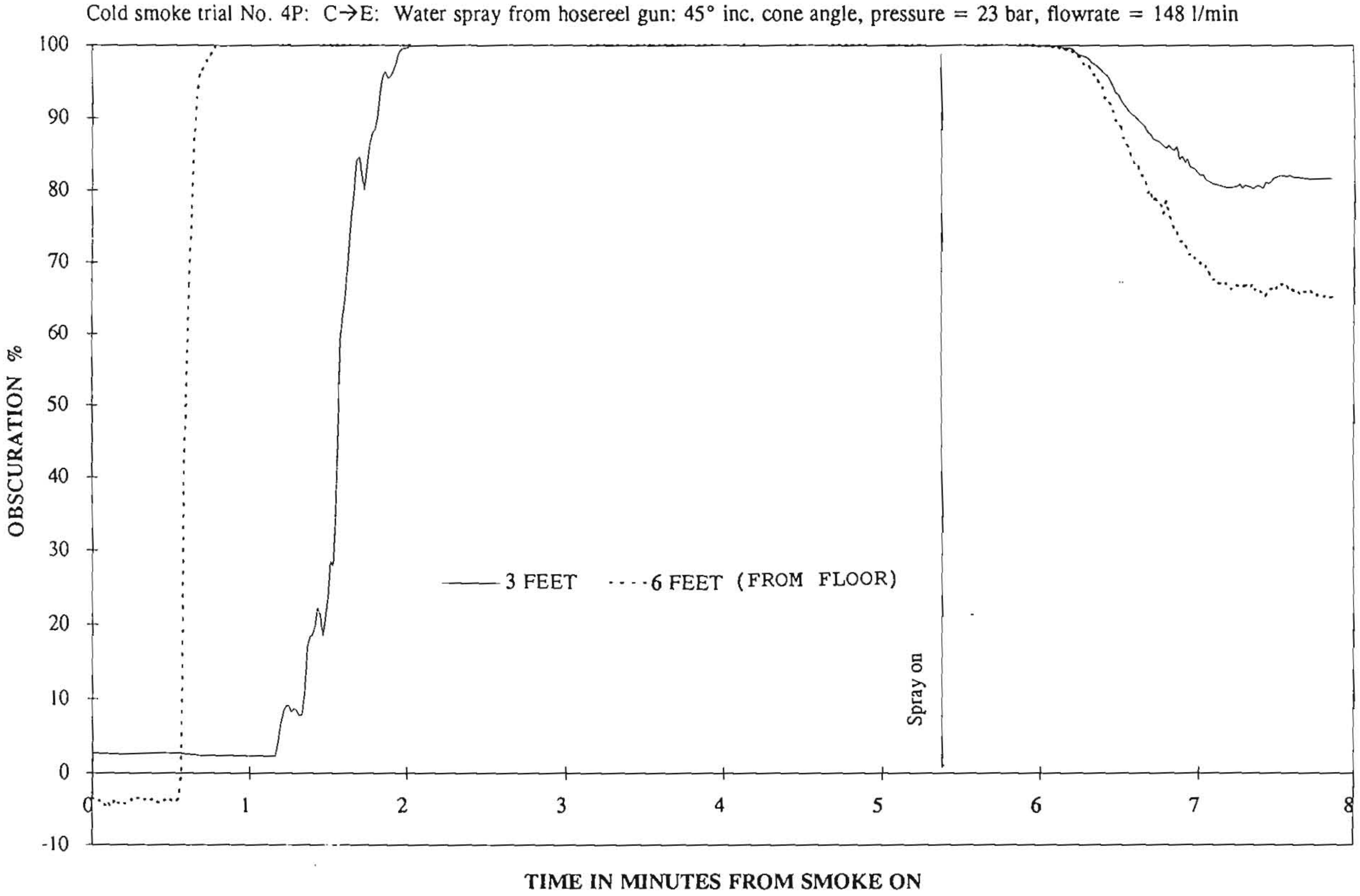


Figure 36. Cold smoke trial, no.4P. - graph of obscuration Vs. time.

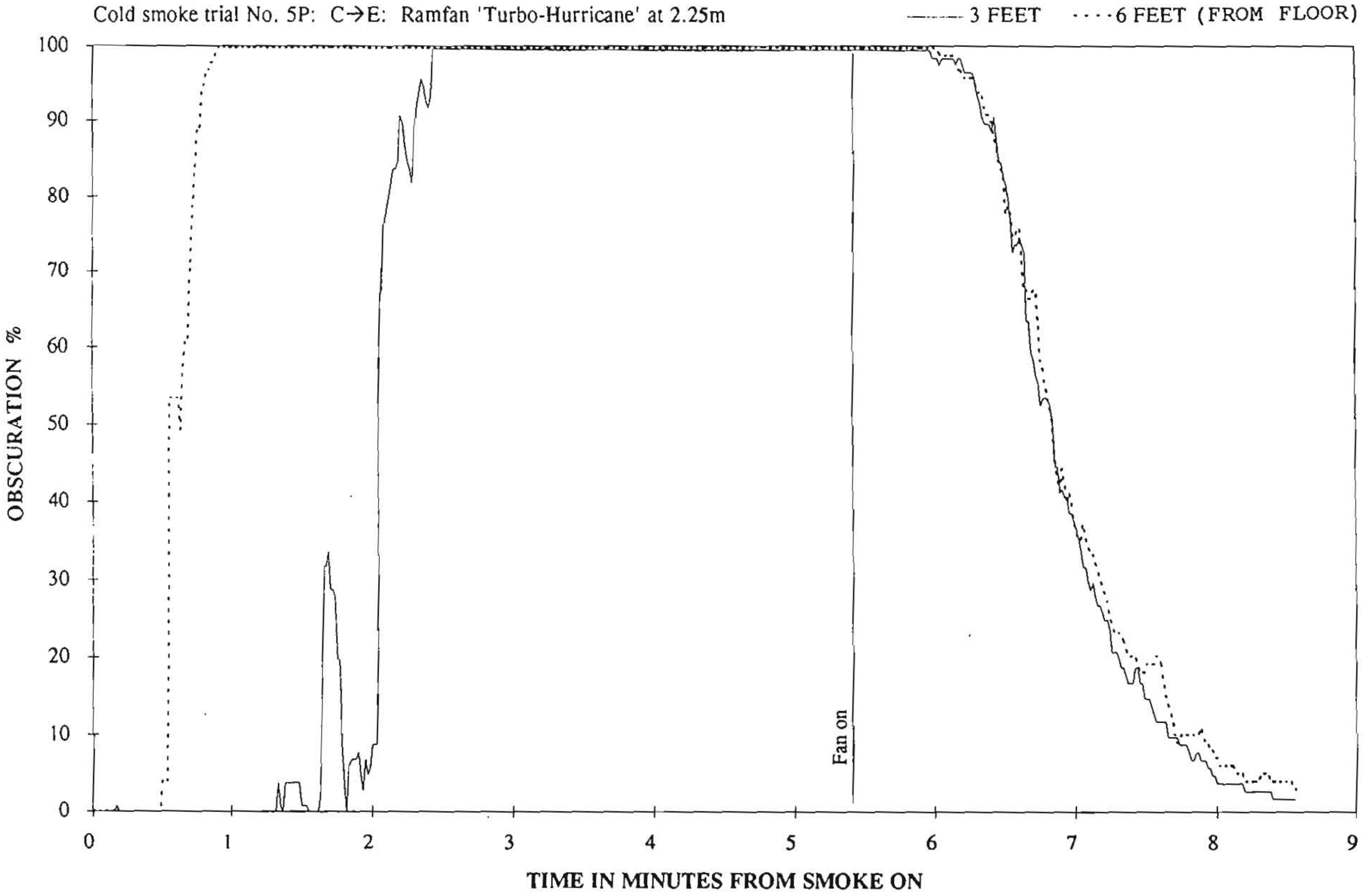


Figure 37. Cold smoke trial, no.5P. - graph of obscuration Vs. time.

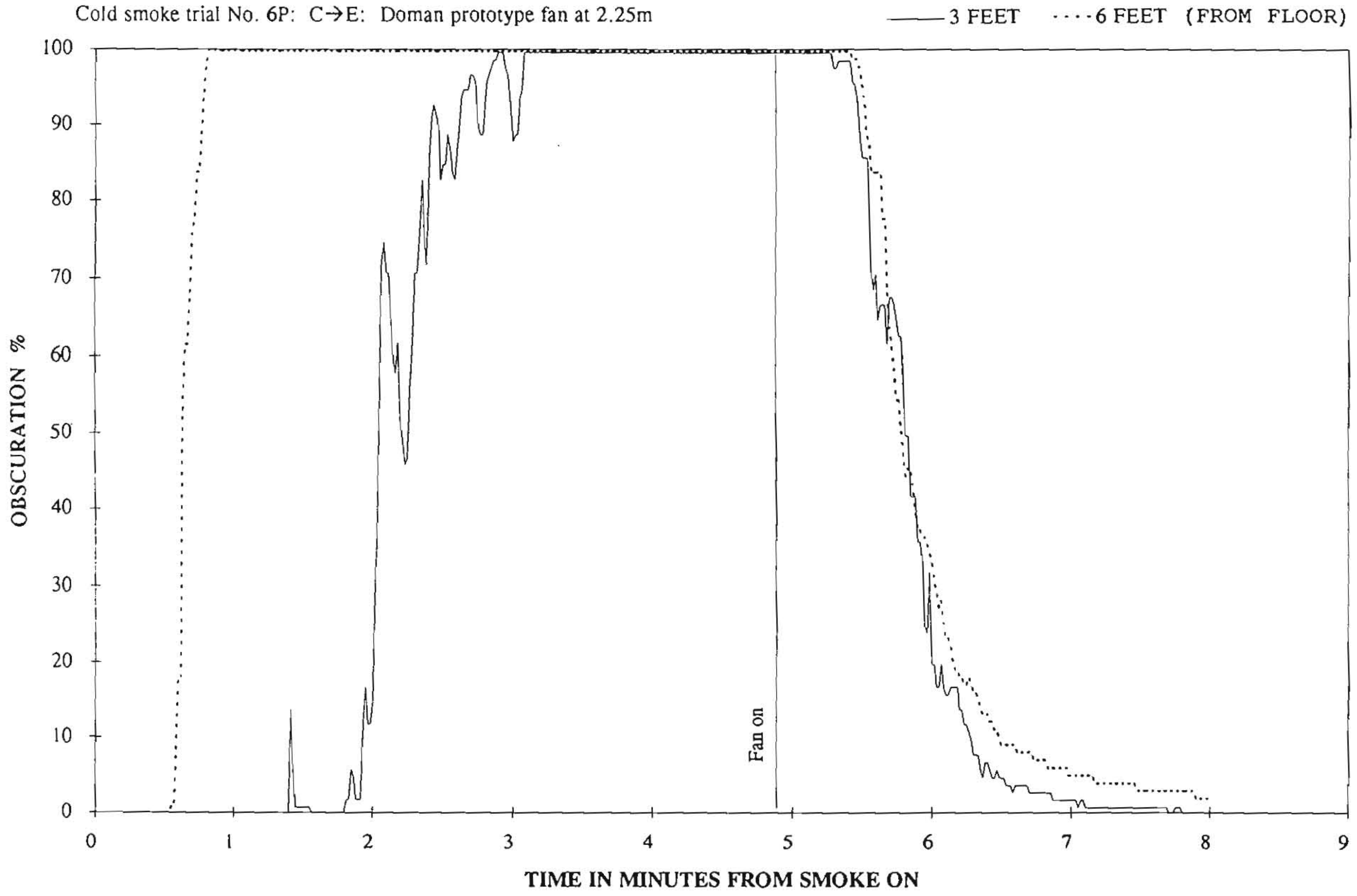


Figure 38. Cold smoke trial, no.6P. - graph of obscuration Vs. time.

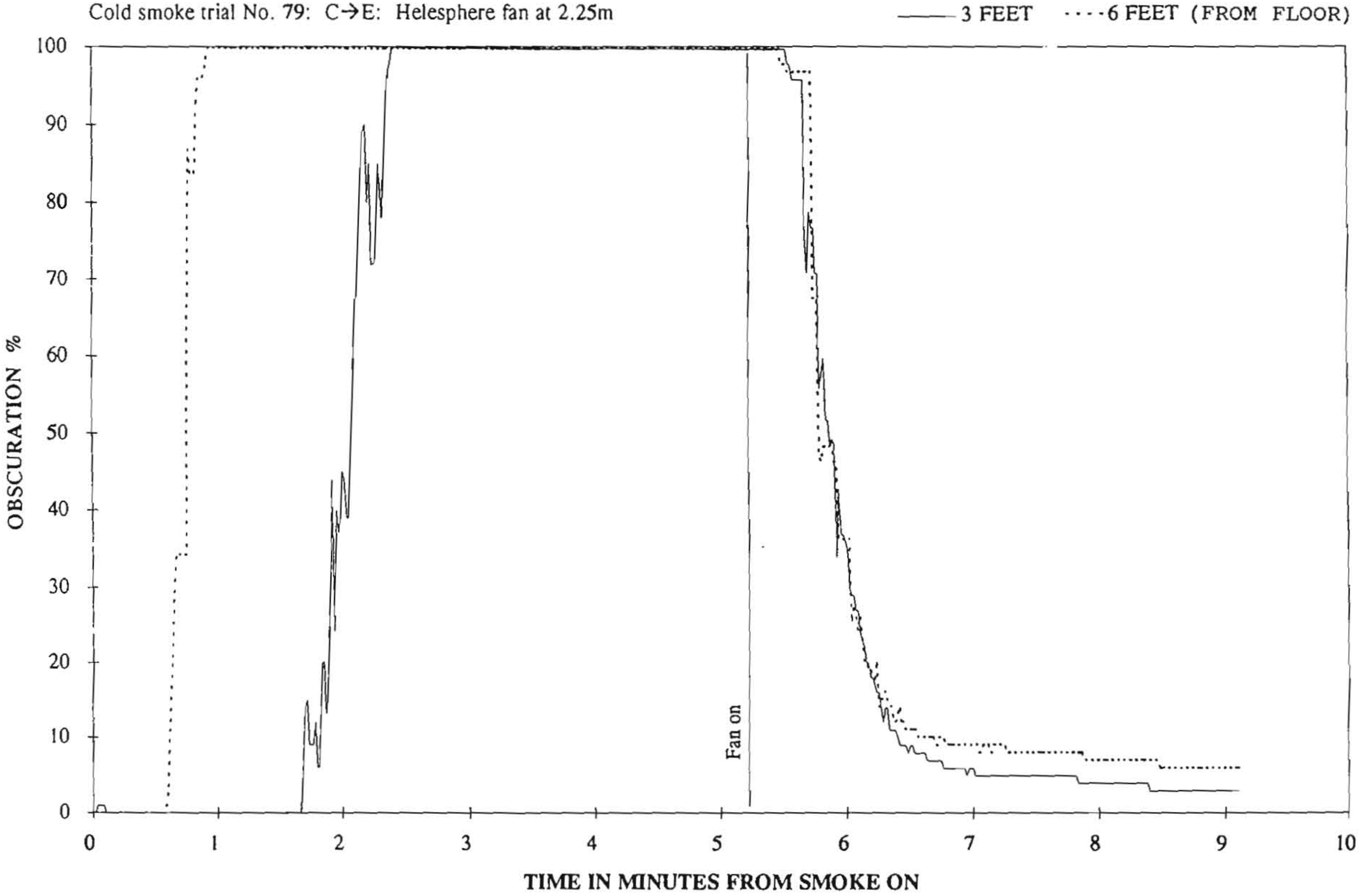


Figure 39. Cold smoke trial, no.79. - graph of obscuration Vs. time.

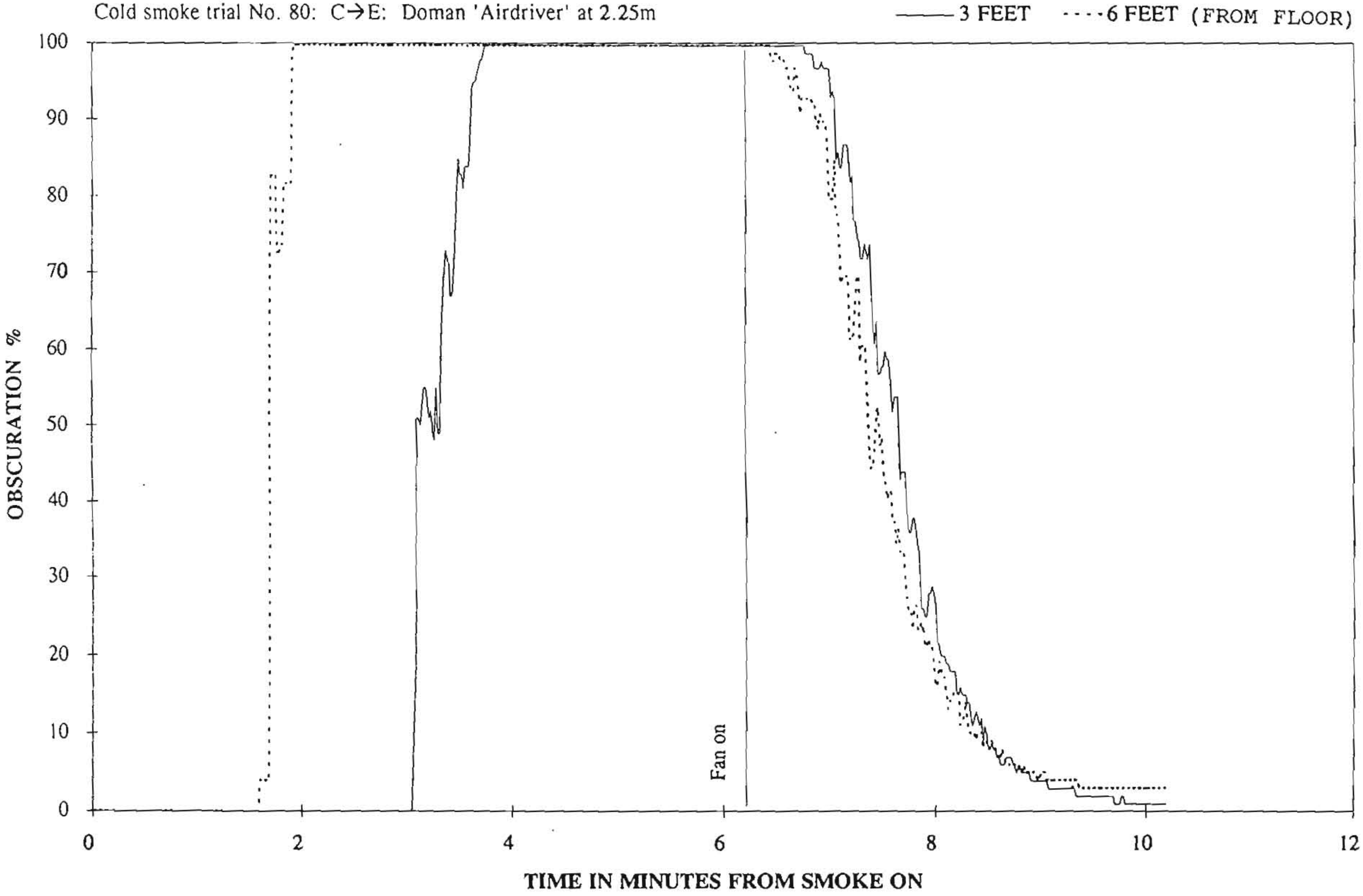


Figure 40. Cold smoke trial, no.80. - graph of obscuration Vs. time.

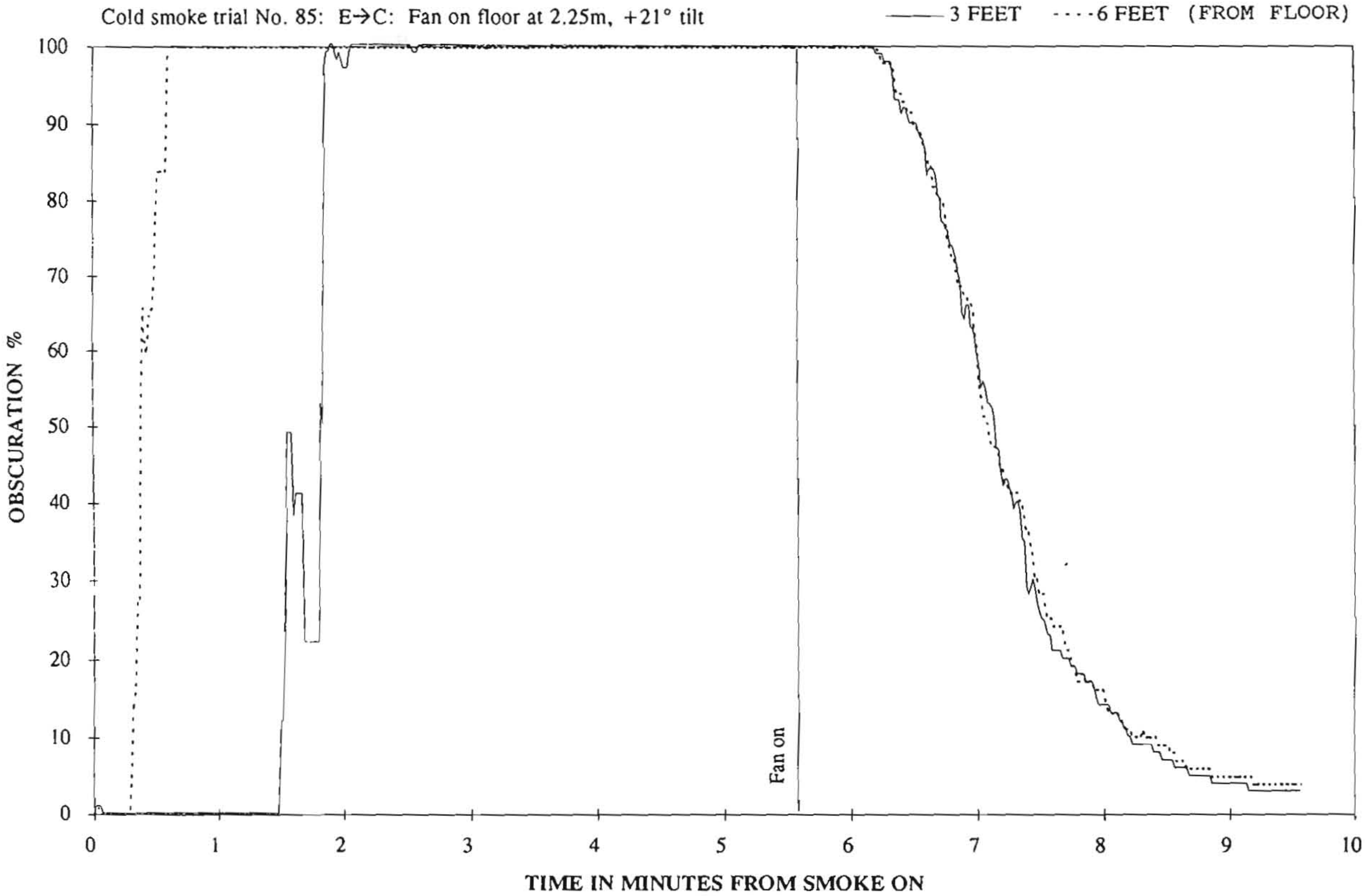


Figure 41. Cold smoke trial, no.85. - graph of obscuration Vs. time.

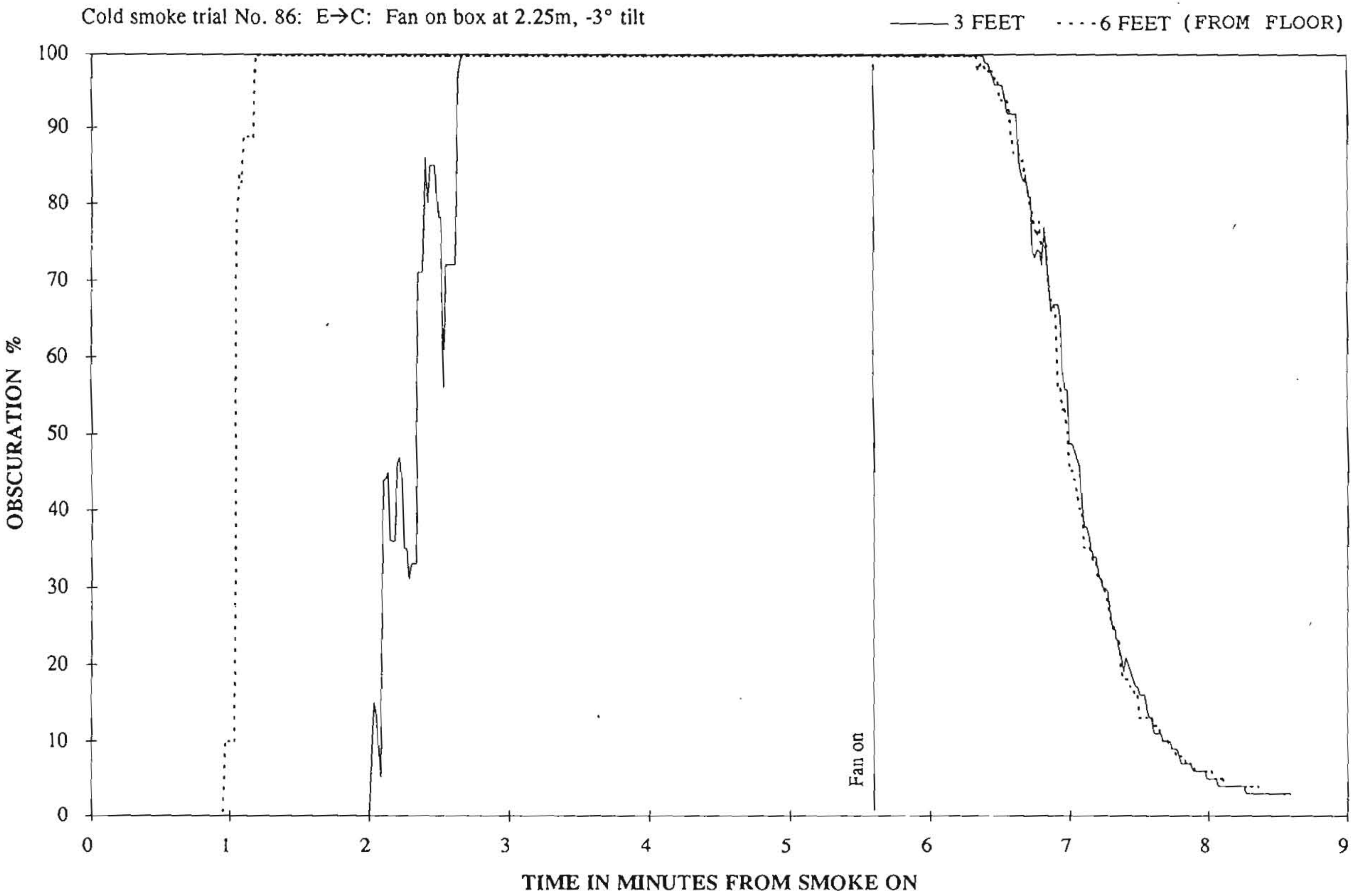


Figure 42. Cold smoke trial, no.86. - graph of obscuration Vs. time.

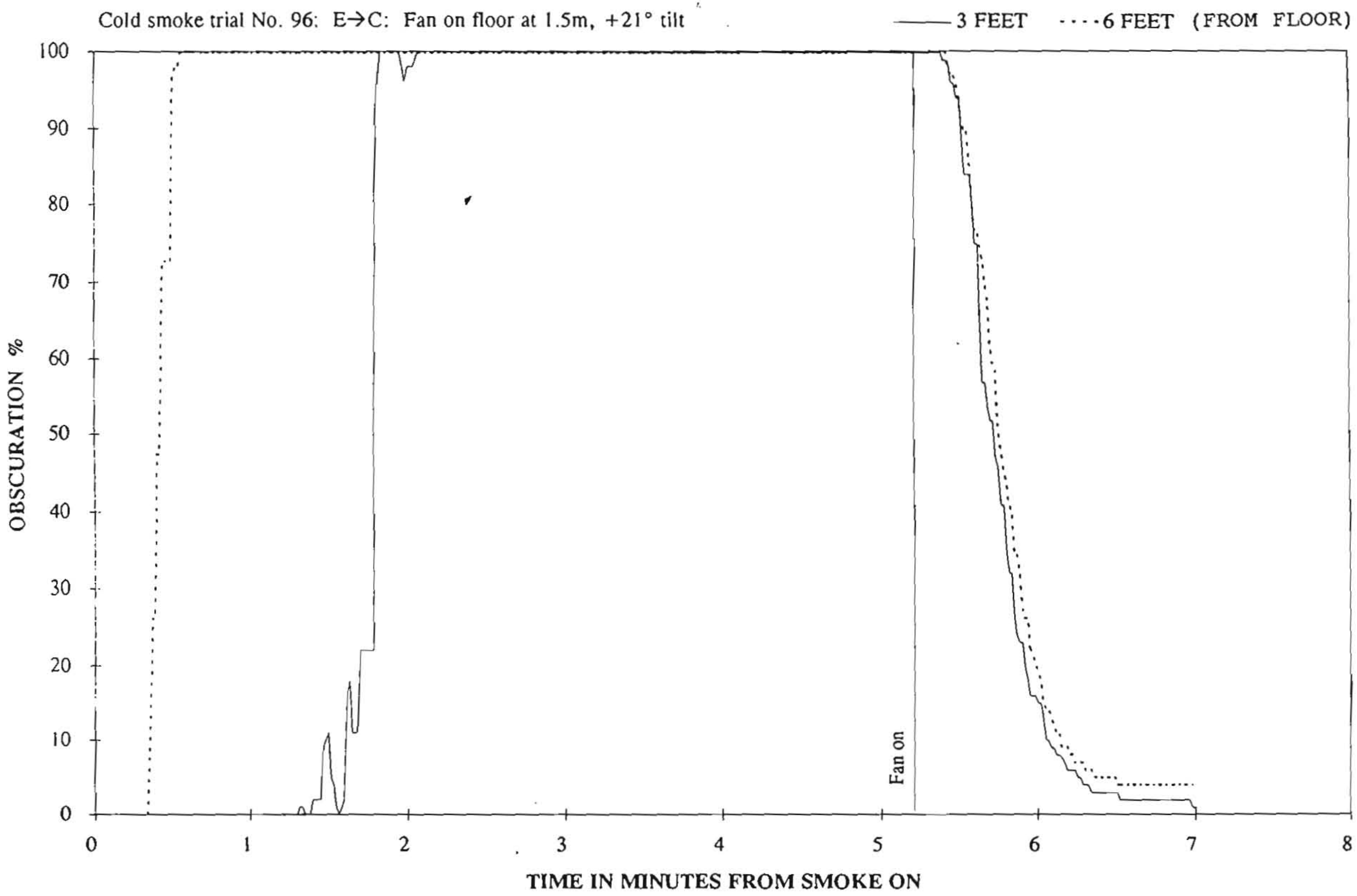


Figure 43. Cold smoke trial, no.96. - graph of obscuration Vs. time.

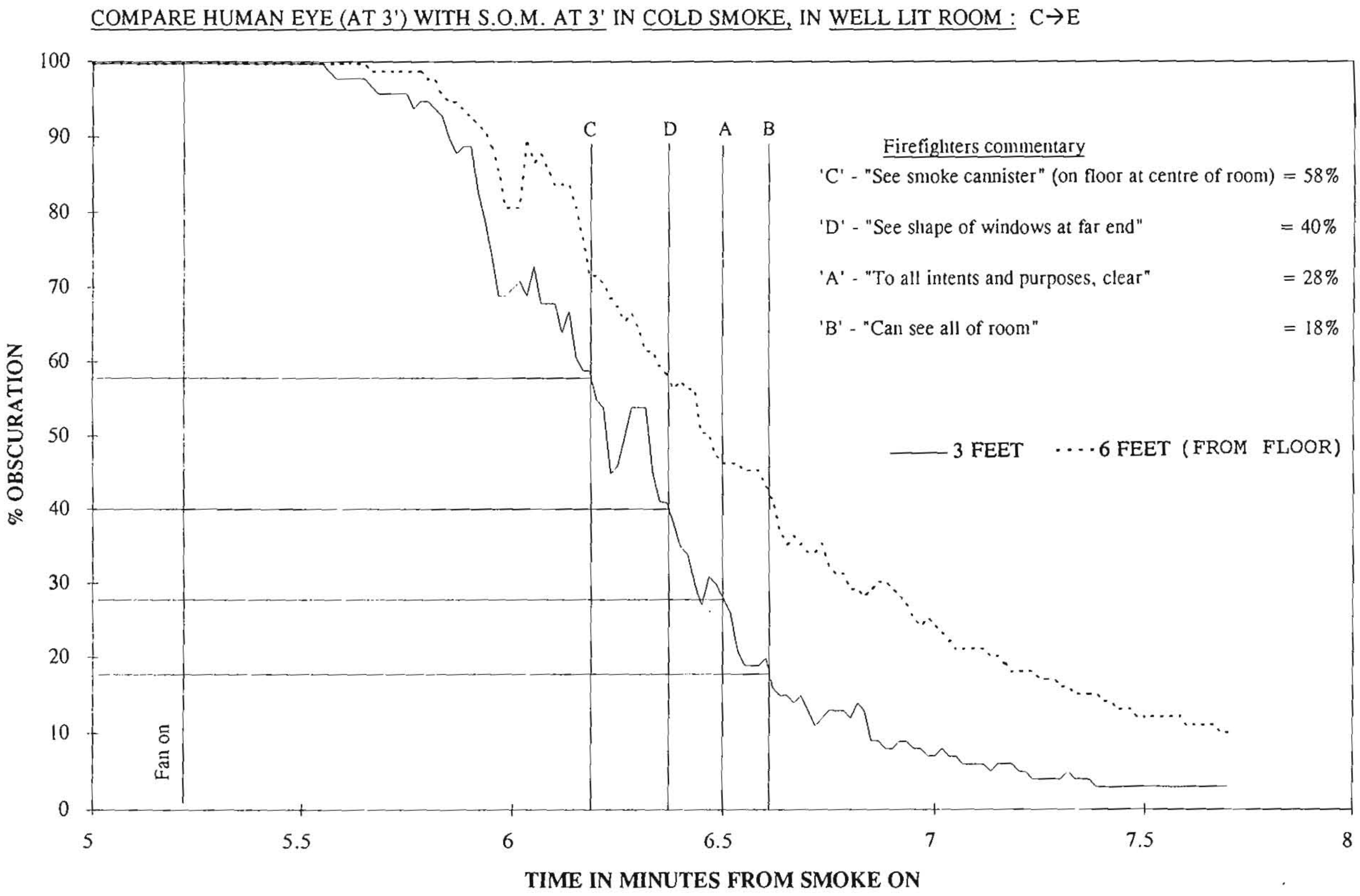


Figure 44. Cold smoke trial, no.109. - graph of obscuration Vs. time (with firefighter's comments).

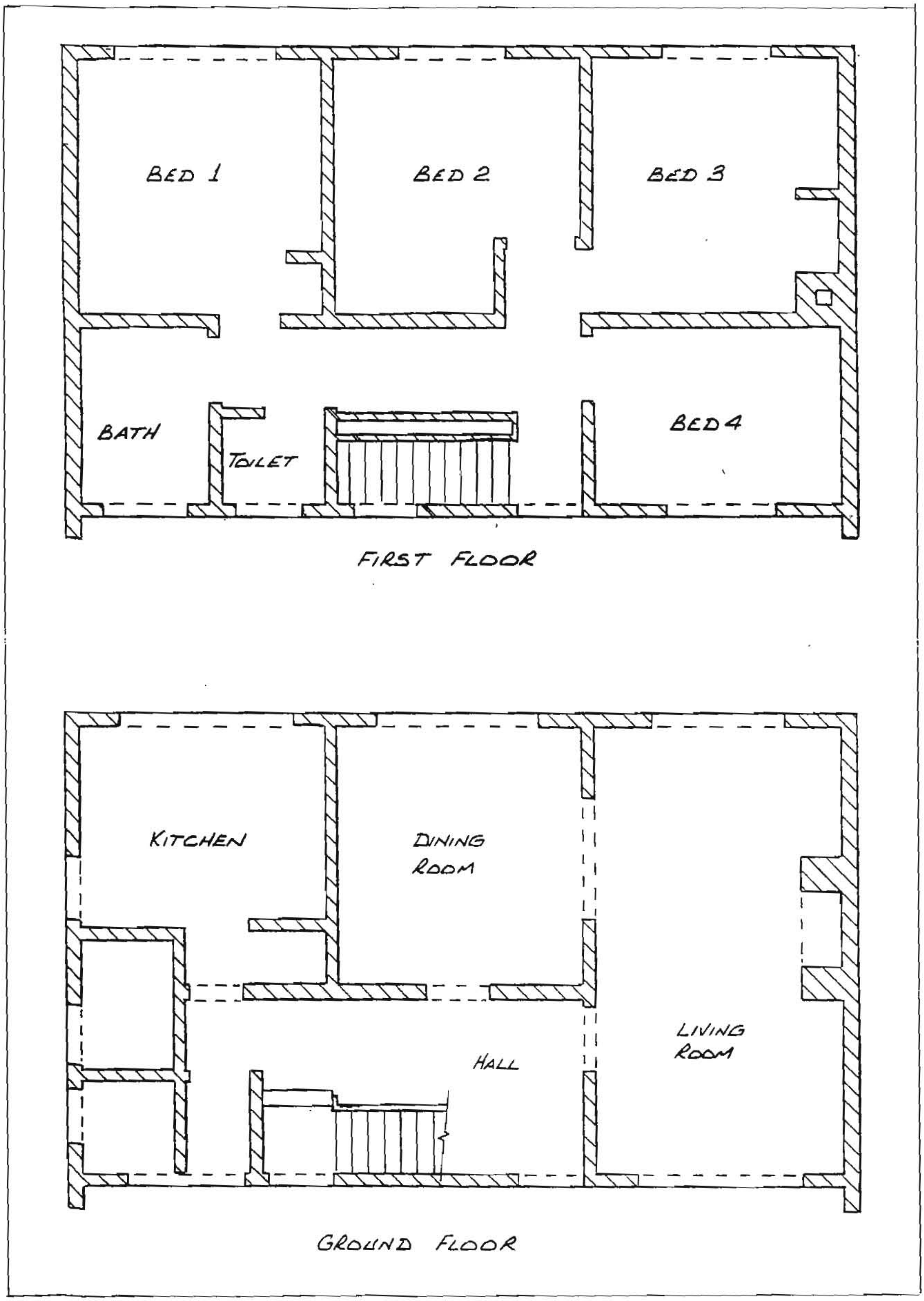


Figure 45 Layout of the 'Domestic Building'

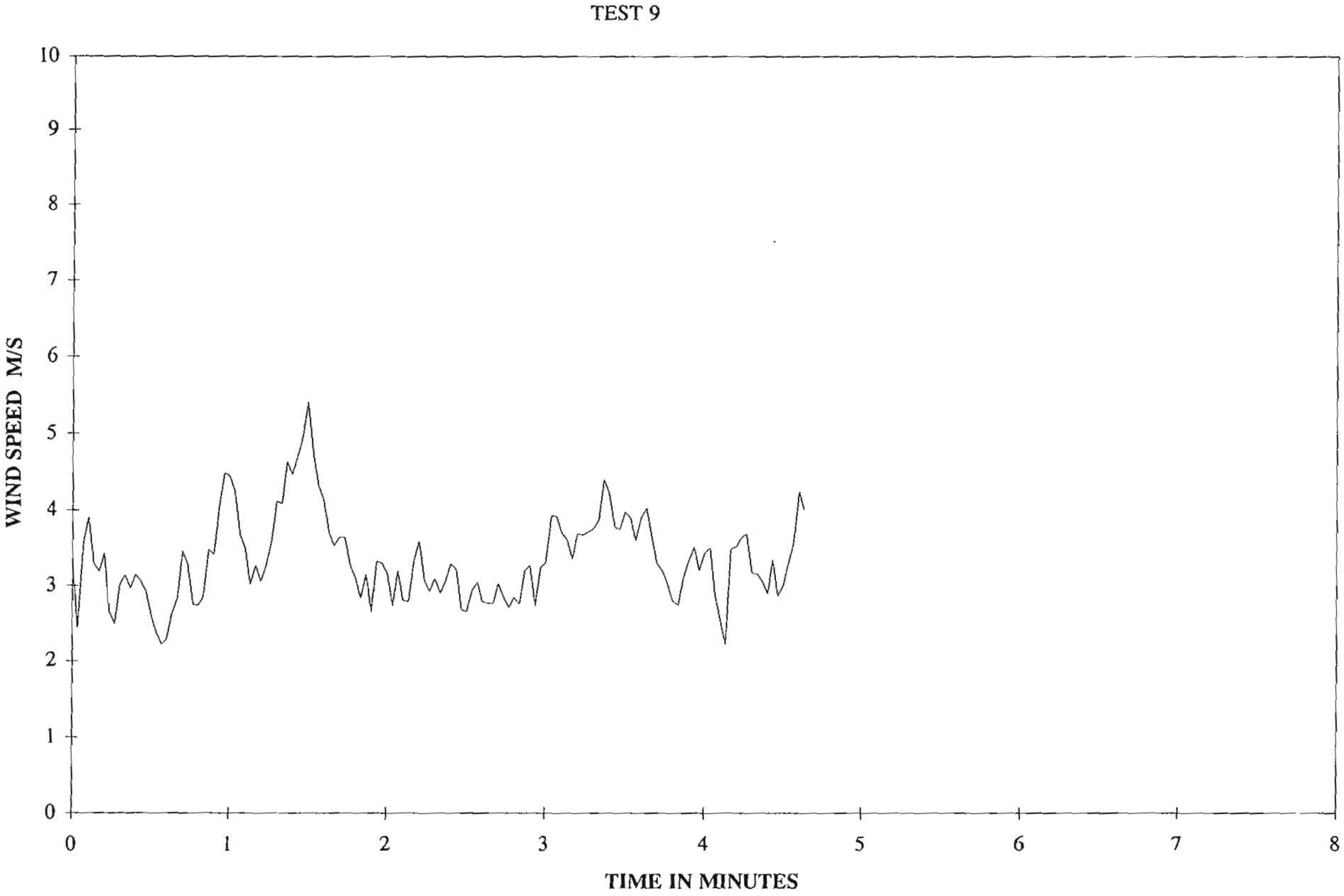


Figure 46. Typical plot of natural wind speed Vs. time, over the duration of a trial.

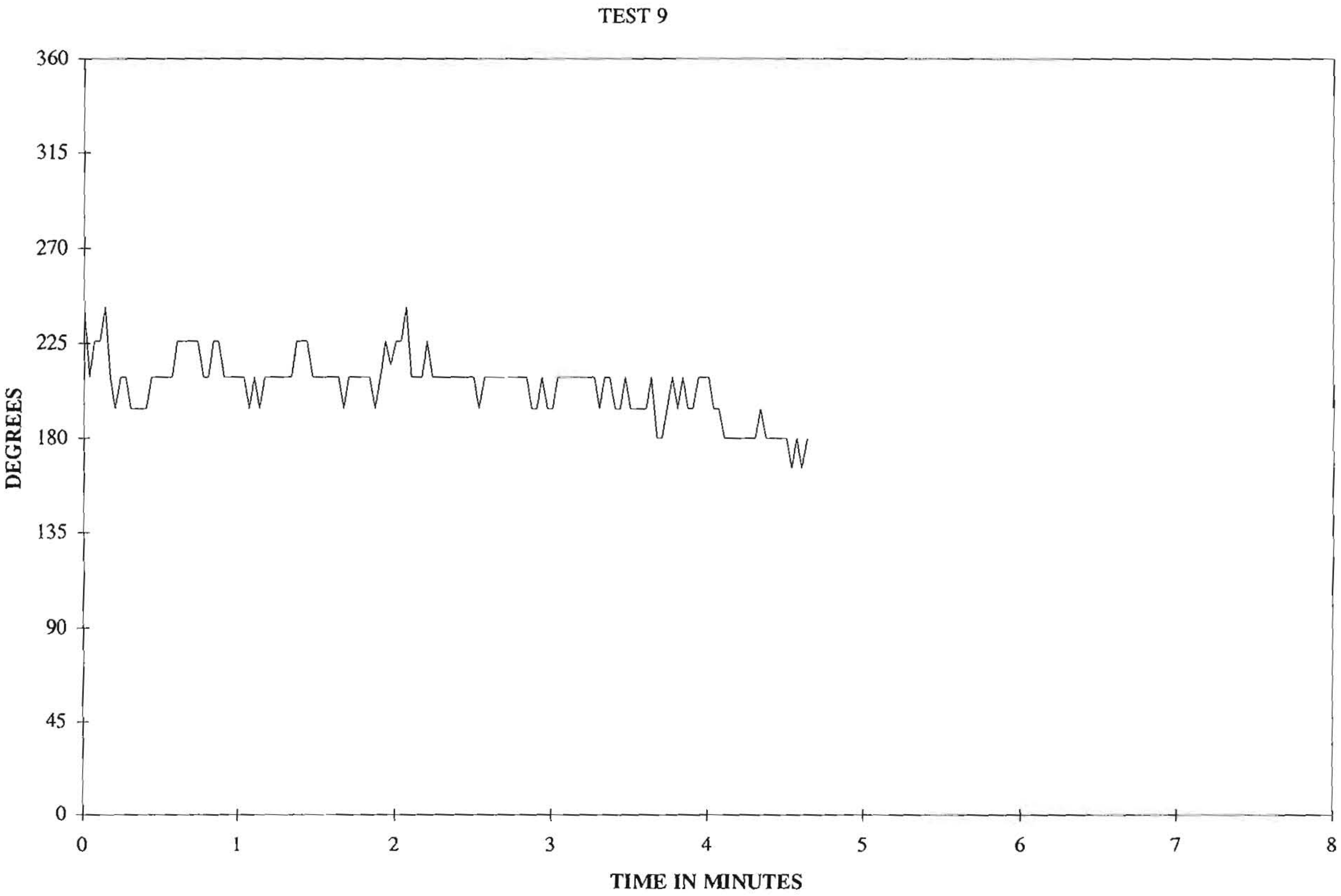
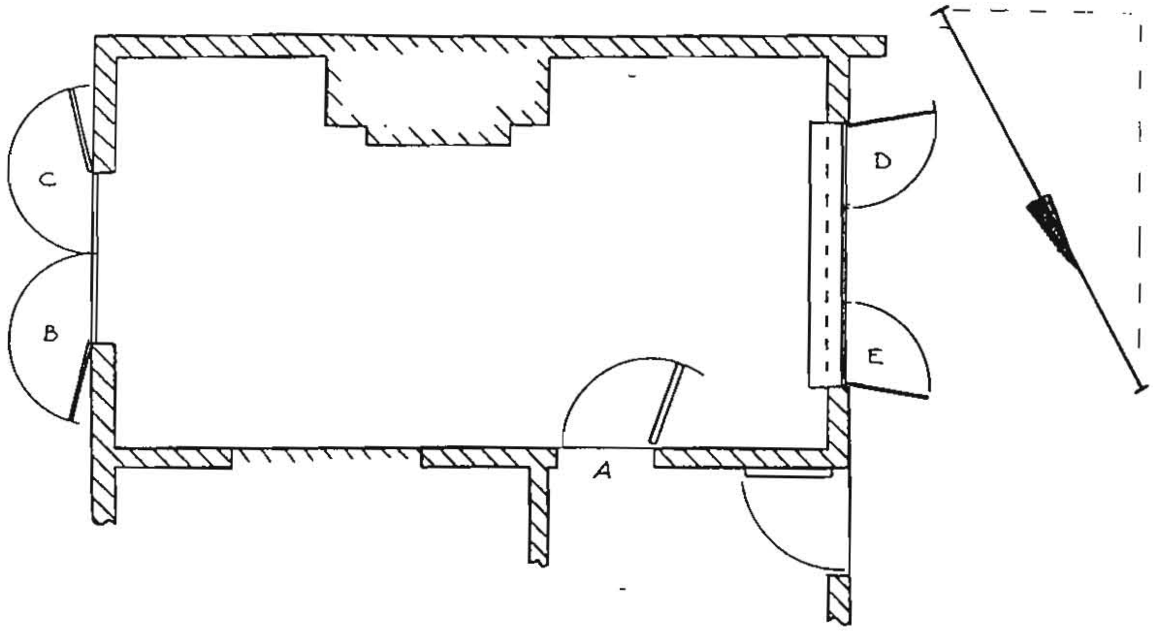


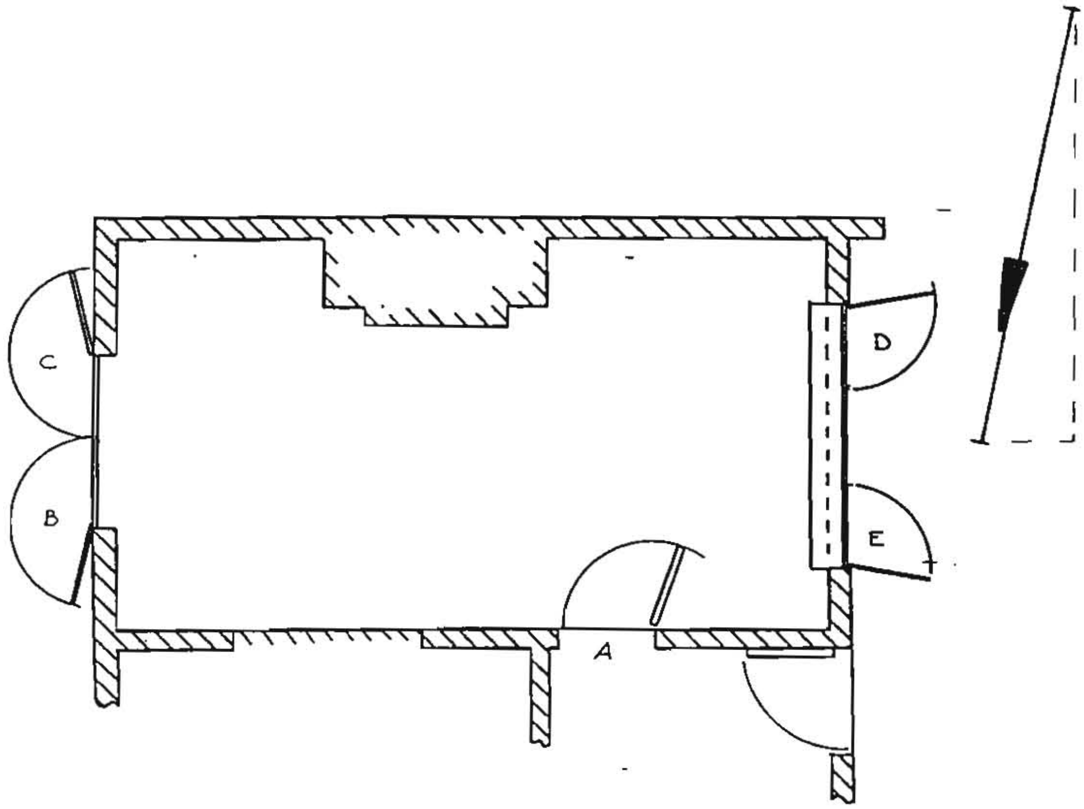
Figure 47. Typical plot of natural wind sense (direction) Vs. time, over the duration of a trial.

	TEST 9	WIND	
		SPEED	SENSE
2 - END	AVG	3.28868625	199.8021708
2 - END	STD	0.45449435	14.49825424
	TEST 9	WIND	
		SPEED	SENSE
0 - 2 MIN	AVG	3.42689836	212.1224262
0 - 2 MIN	STD	0.70633082	11.3828697
	TEST 9	WIND	
		SPEED	SENSE
2 - 4 MIN	AVG	3.29438361	205.7392745
2 - 4 MIN	STD	0.44766204	10.46560921

Figure 48 Typical Print Outof Average Natural Wind and Sense (direction). [see section 7.6.2]

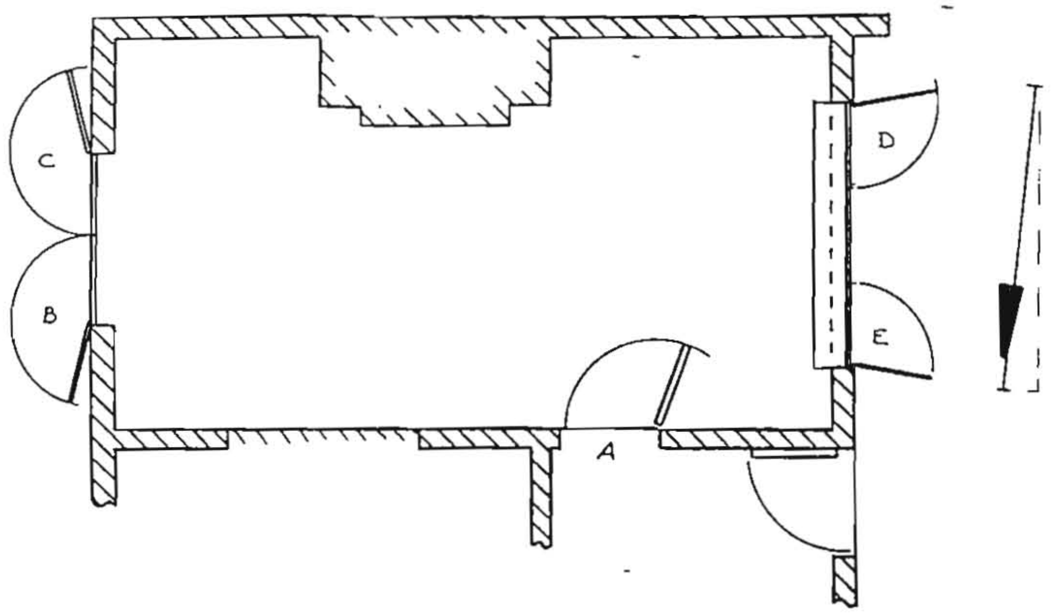


TEST No. 1. FAN. 'C'→'E'.

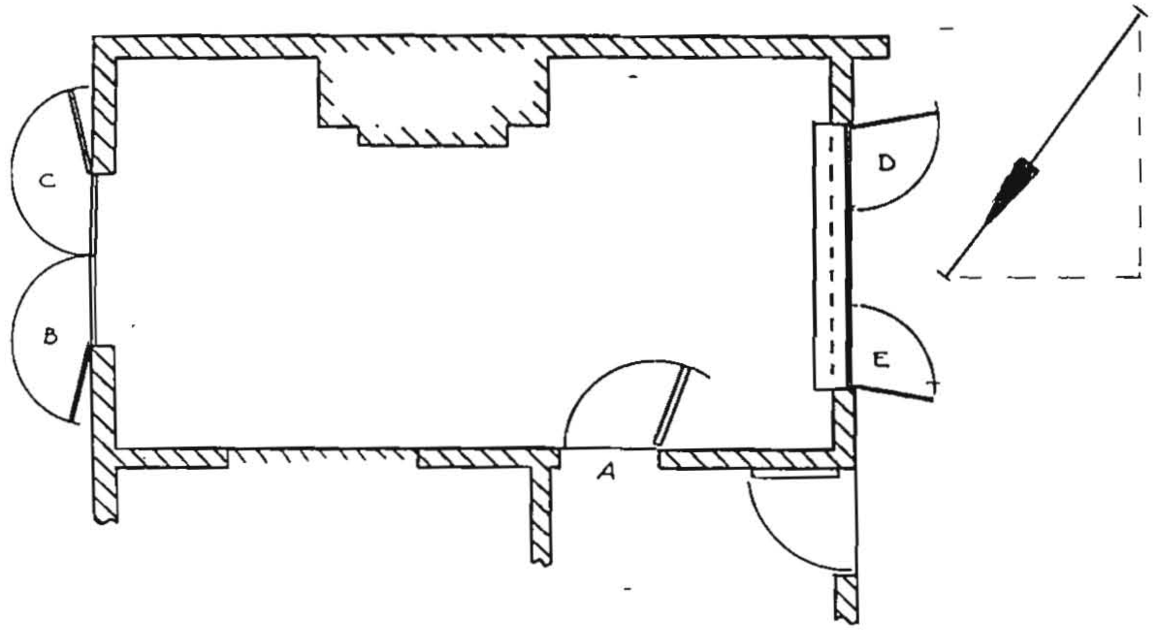


TEST No. 2. NO FAN. 'C' AND 'E' OPEN

Figure 49 Average Natural Wind Velocity Diagrams
Trials No. 1 and 2 (scale: 1cm = 1 M/sec)

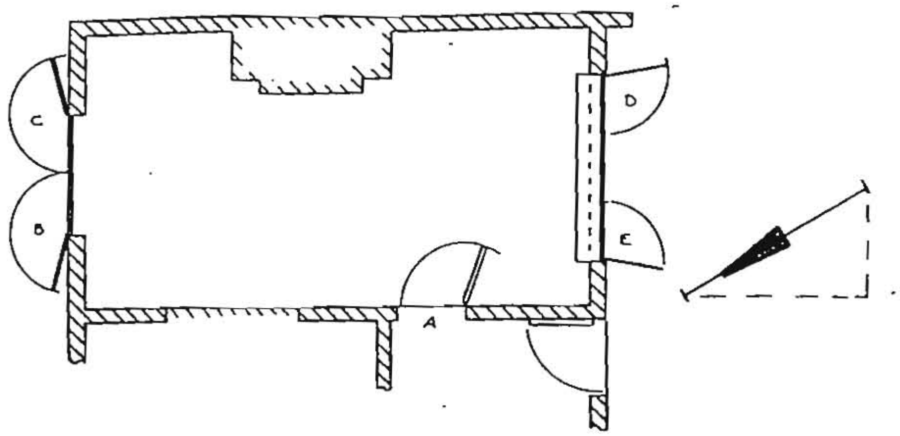


TEST No. 3. FAN. 'C' → 'E'

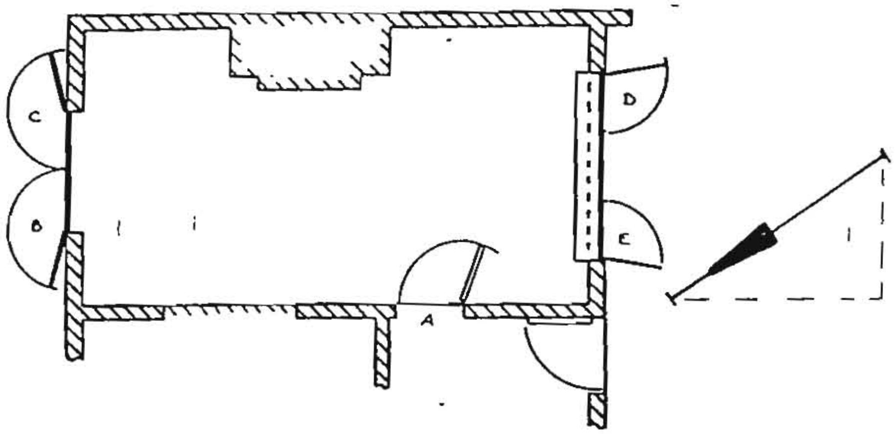


TEST No. 26. HOSEREEL SPRAY. 'E' → 'C'

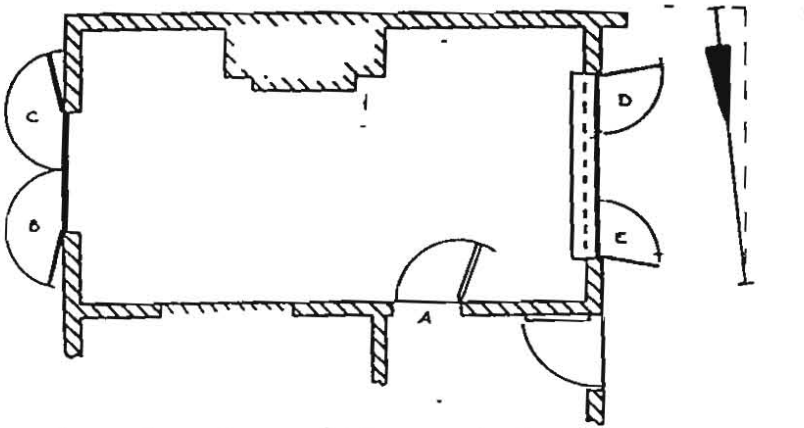
Figure 50 Average Natural Wind Velocity Diagrams
Trials No. 3 and 26 (scale: 1cm = 1 M/sec)



TEST No. 4. FAN. 'C'→'E'

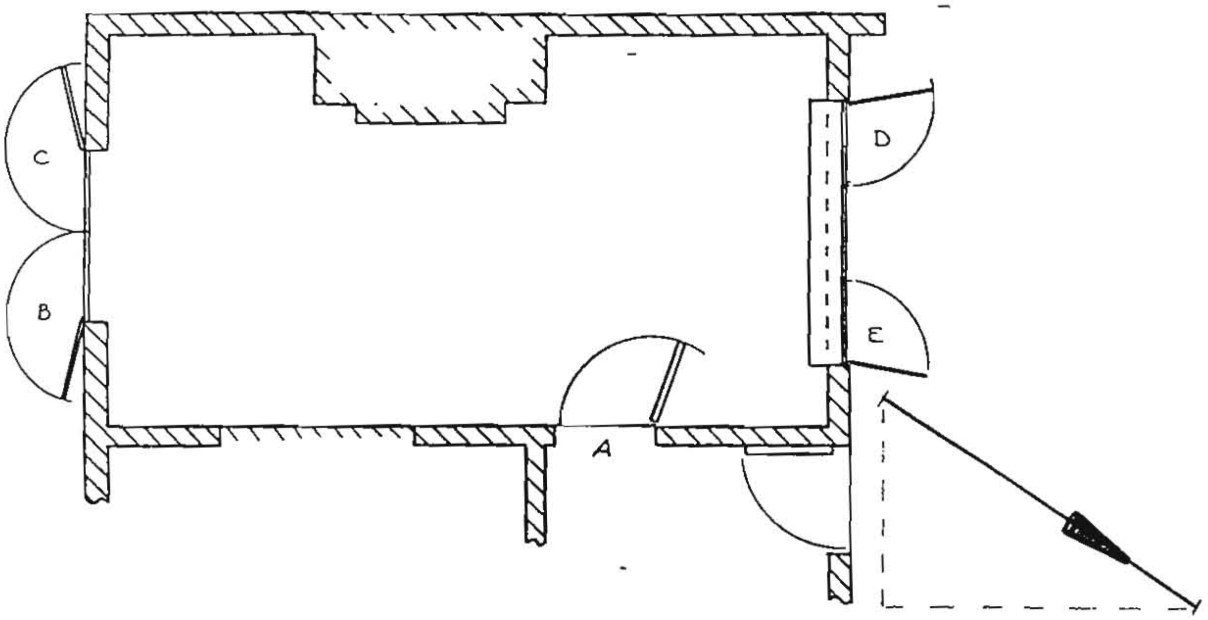


TEST No. 5. NO FAN. 'C' AND 'E' OPEN.

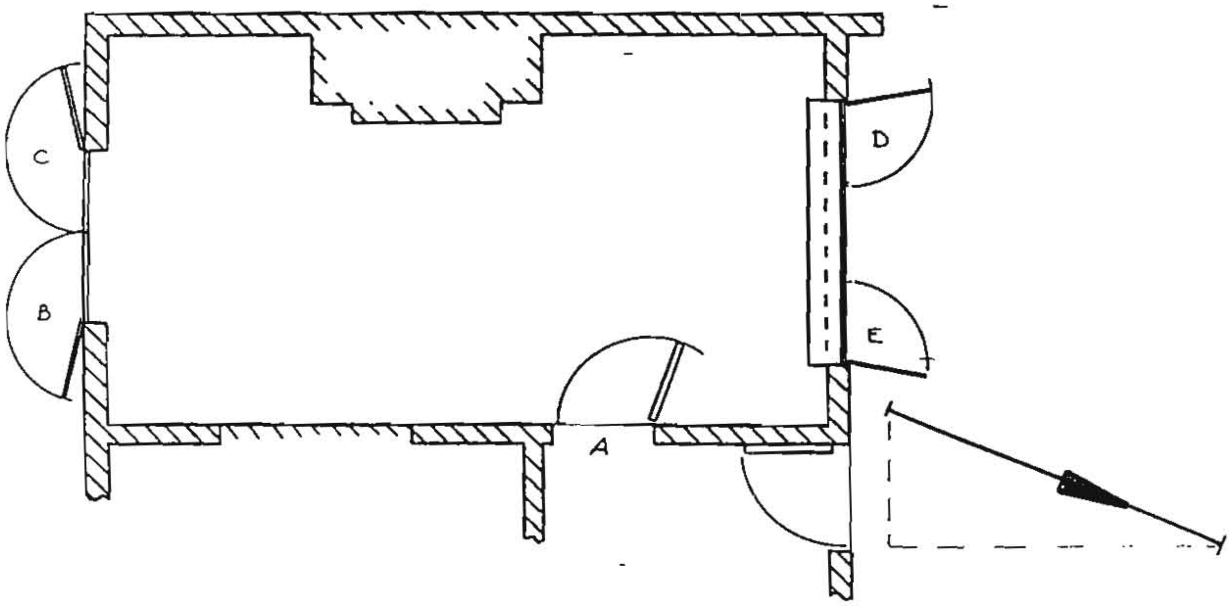


TEST No. 11. NO FAN. 'C' AND 'E' OPEN.

Figure 51 Average Natural Wind Velocity Diagrams
Trials No. 4, 5 and 11 (scale: 1cm = 1 M/sec)

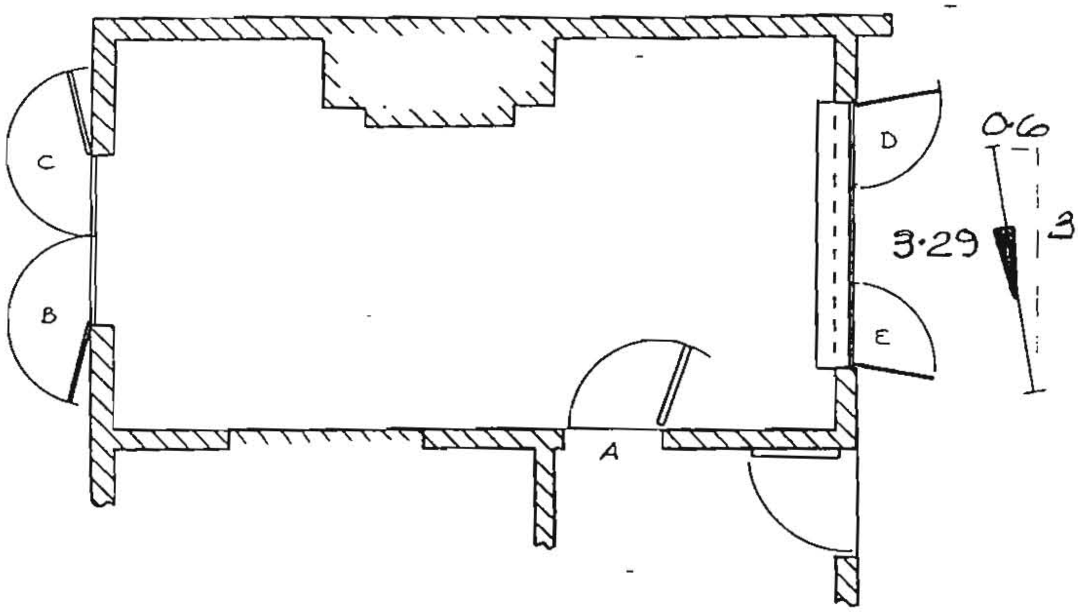


TEST No. 7. SMOKELOG UPSTAIRS - NO FAN,
OPEN FRONT DOOR. CLOSE 'A'.

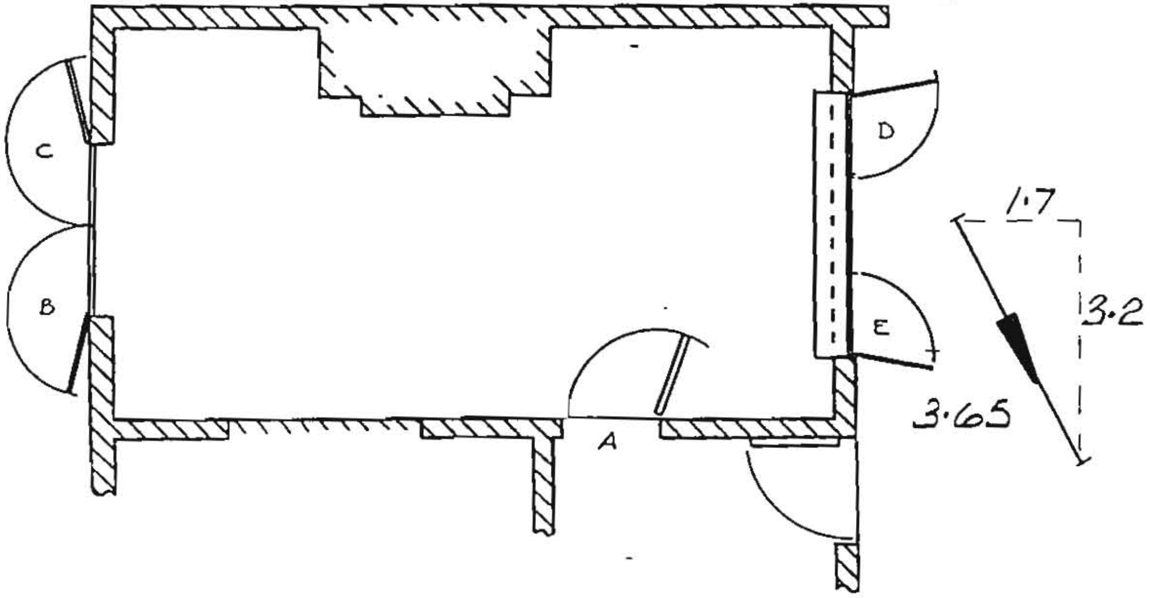


TEST No. 8. SMOKELOG UPSTAIRS - FAN AT FRONT DOOR,
CLOSE 'A'.

Figure 52 Average Natural Wind Velocity Diagrams
Trials Nos. 7 and 8 (scale: 1cm = 1 M/sec)

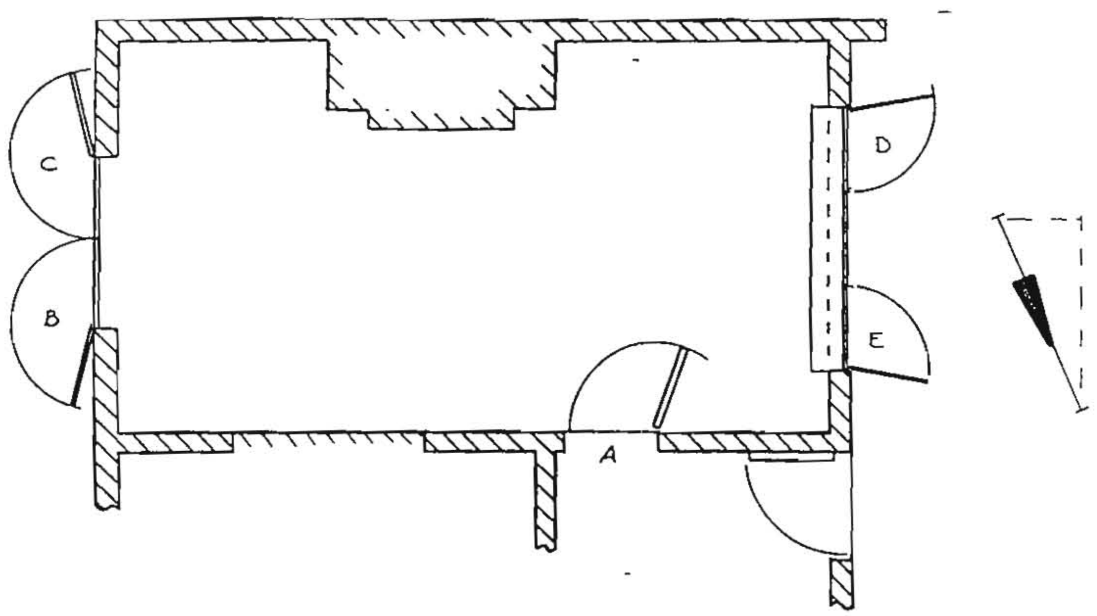


TEST No. 9. FAN. C → (D+E)

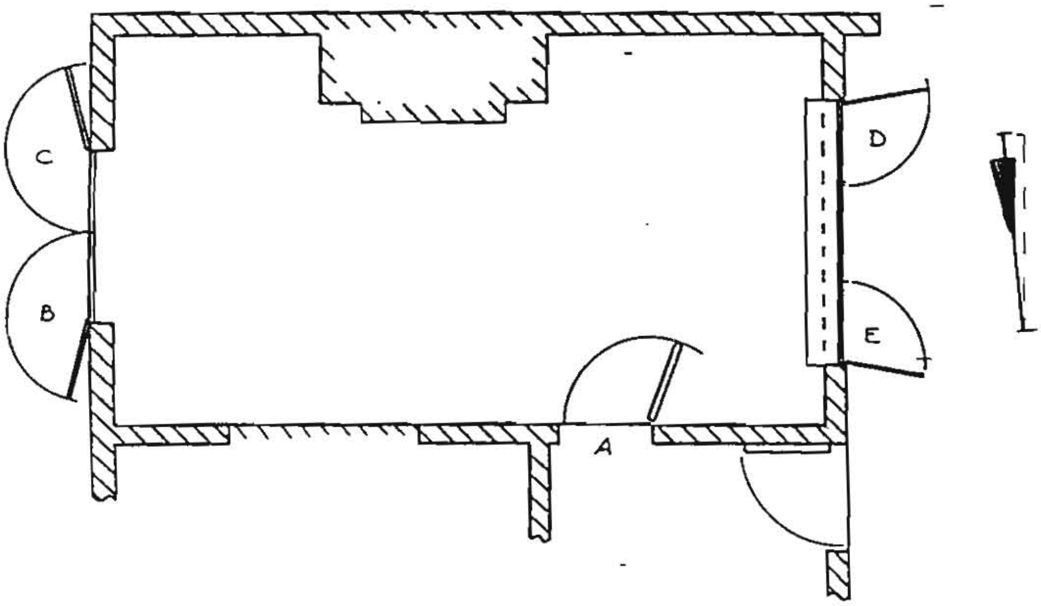


TEST No. 10. NO FAN 'C', 'D' AND 'E' OPEN.

Figure 53 Average Natural Wind Velocity Diagrams
Trials Nos. 9 and 10 (scale: 1cm = 1 M/sec)

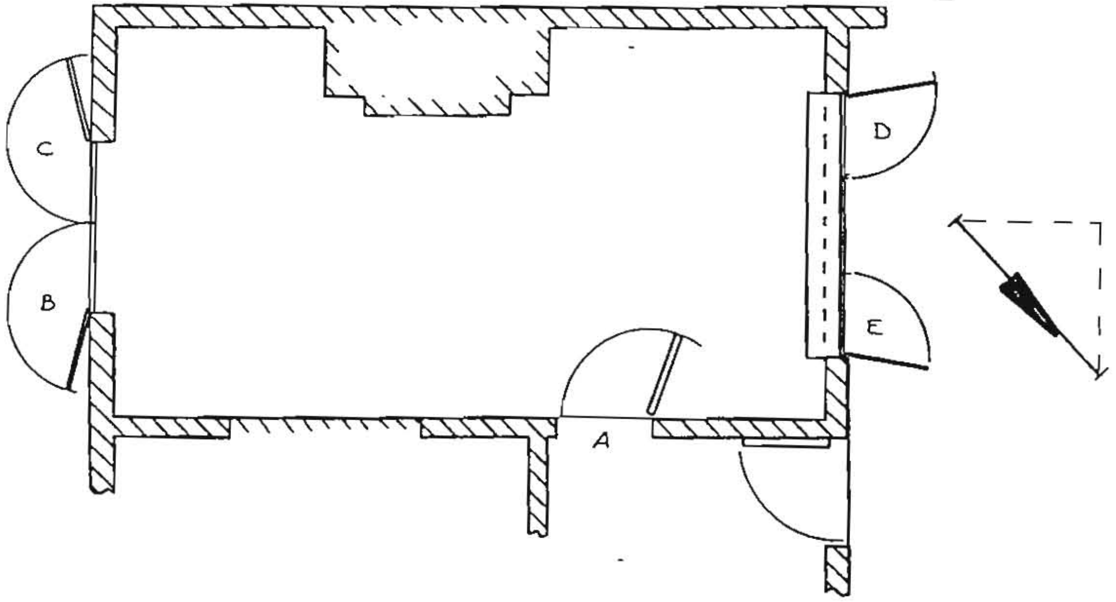


TEST No. 12. FAN. ('B' + 'C') → 'E'.

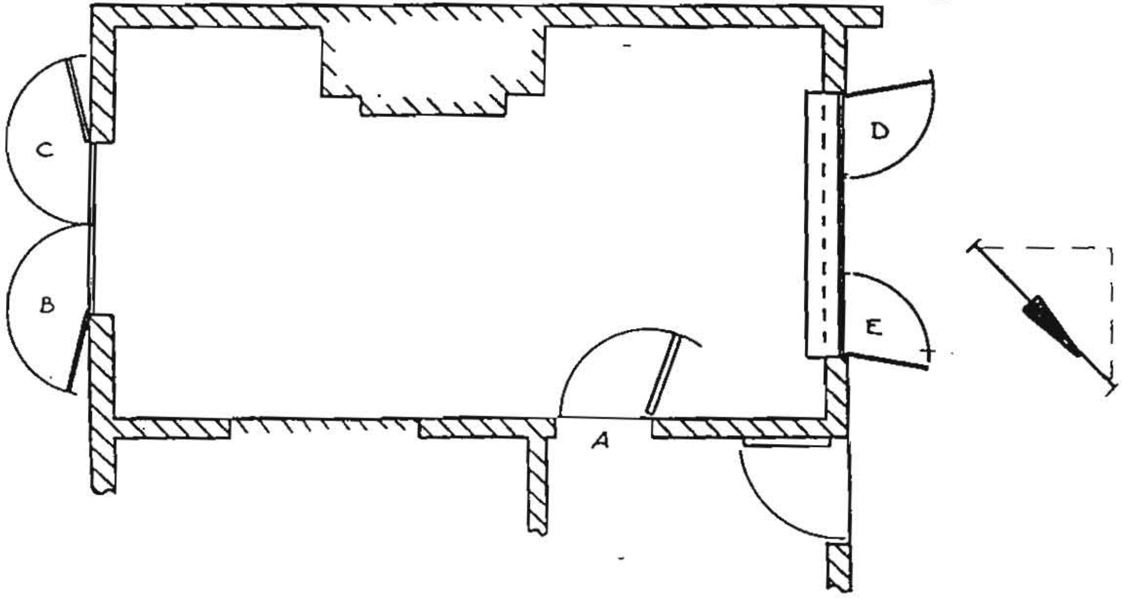


TEST No. 13. NO FAN. 'B', 'C' AND 'E' OPEN.

Figure 54 Average Natural Wind Velocity Diagrams
Trials Nos. 12 and 13 (scale: 1cm = 1 M/sec)

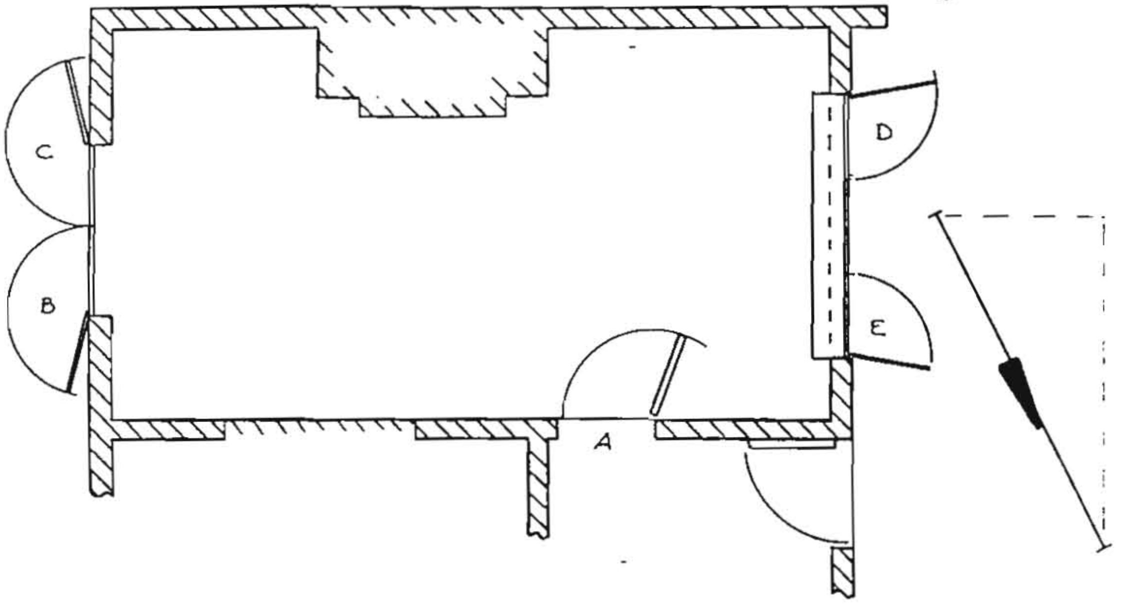


TEST No. 14. FAN AT FRONT DOOR (VIA 'A') → 'E'.

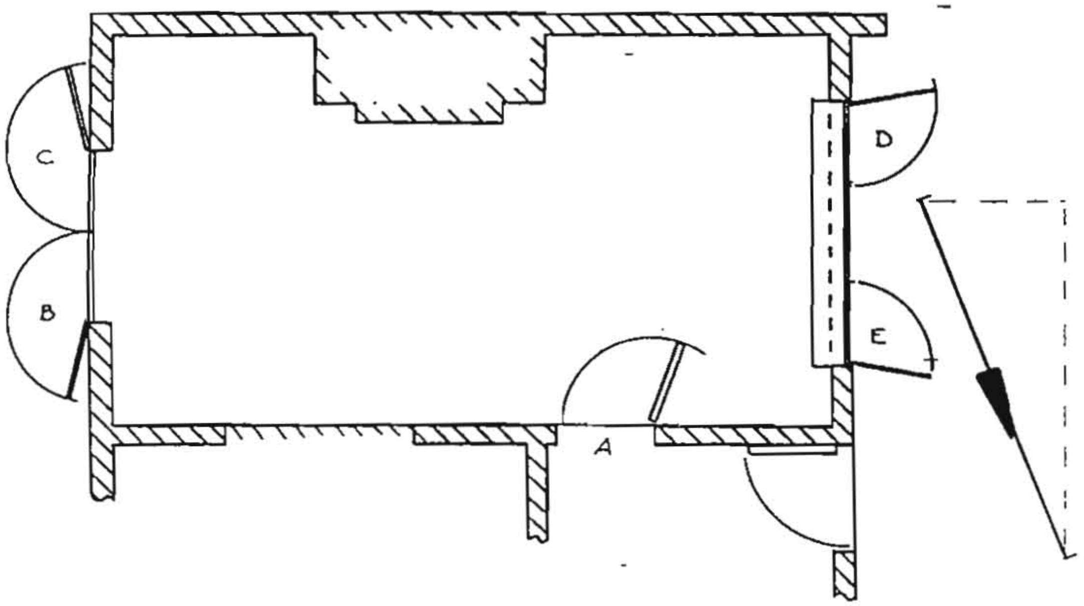


TEST No. 15. NO.FAN: FRONT DOOR 'A' AND 'E' OPEN.

Figure 55 Average Natural Wind Velocity Diagrams
Trials No. 14 and 15 (scale: 1cm = 1 M/sec)

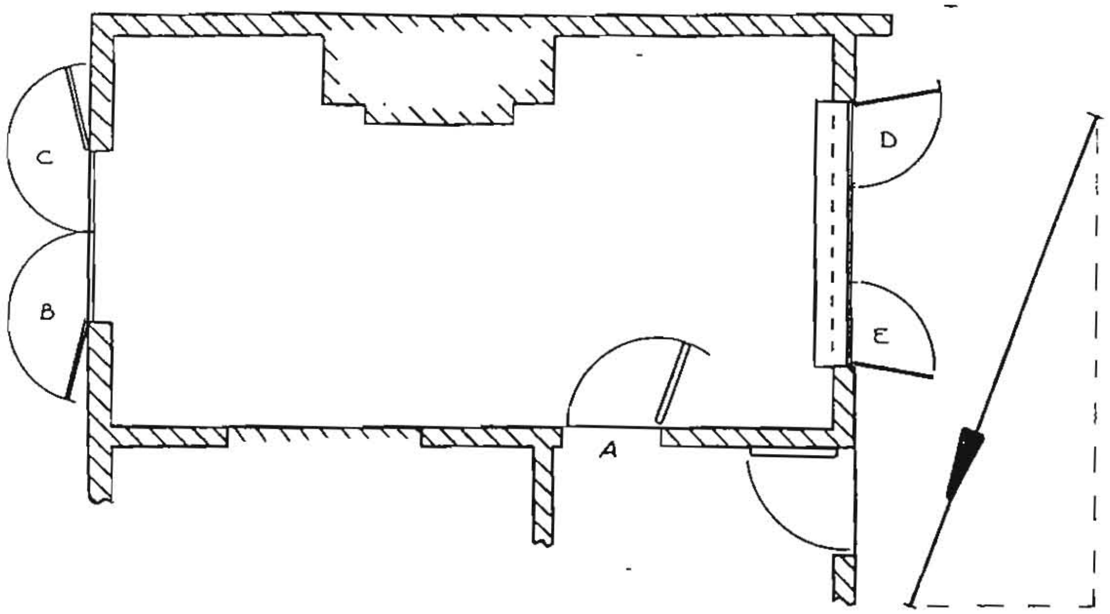


TEST No. 16. FAN. 'E' → 'C'.

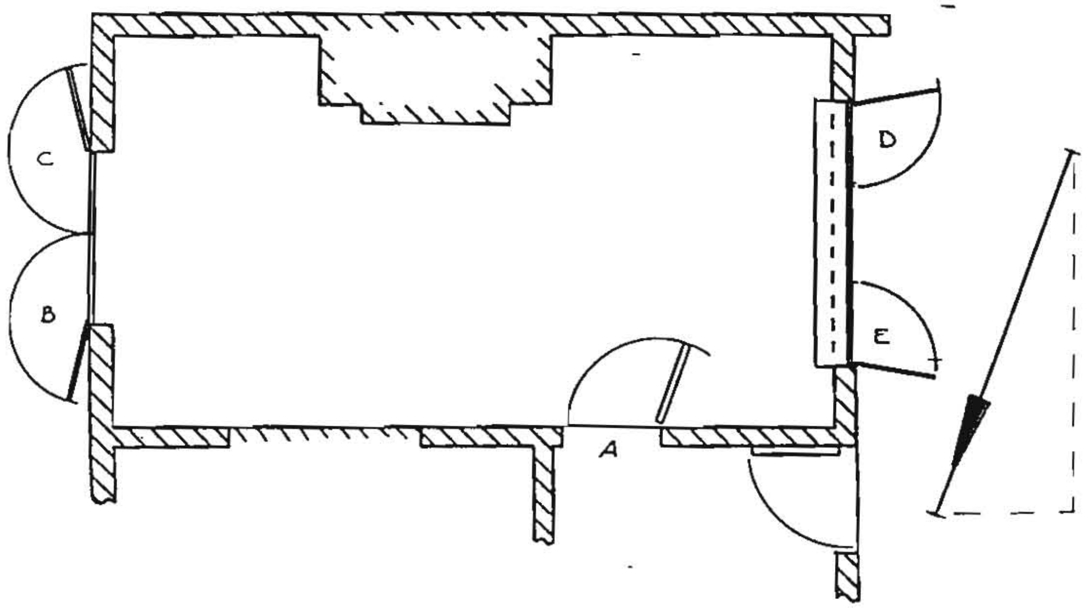


TEST No. 17 NO FAN. 'E' AND 'C' OPEN.

Figure 56 Average Natural Wind Velocity Diagrams
Trials No. 16 and 17 (scale: 1cm = 1 M/sec)

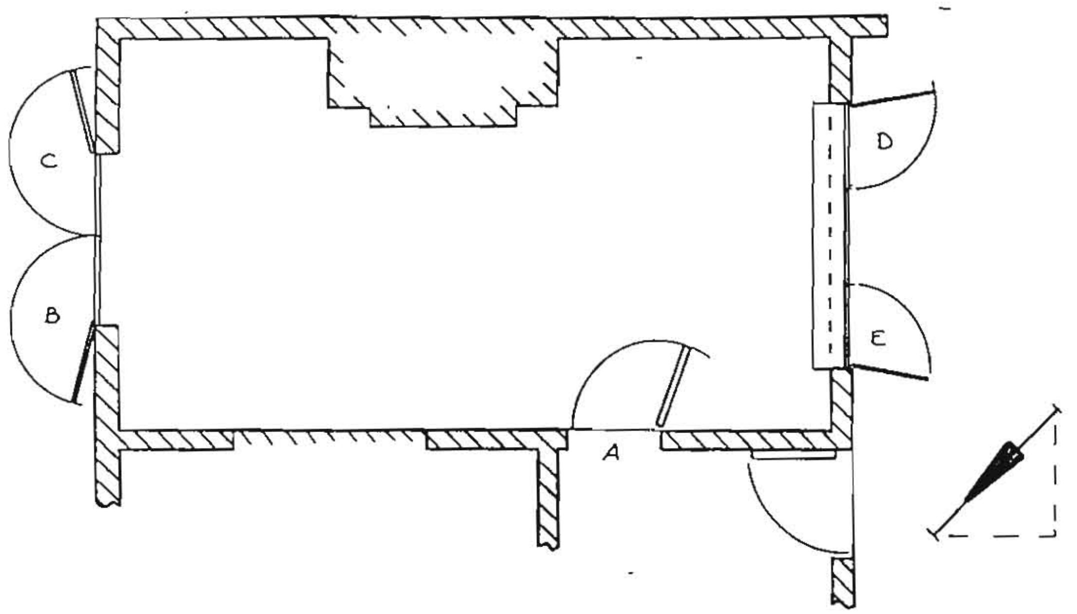


TEST No. 18. FAN. 'E'→'C'.

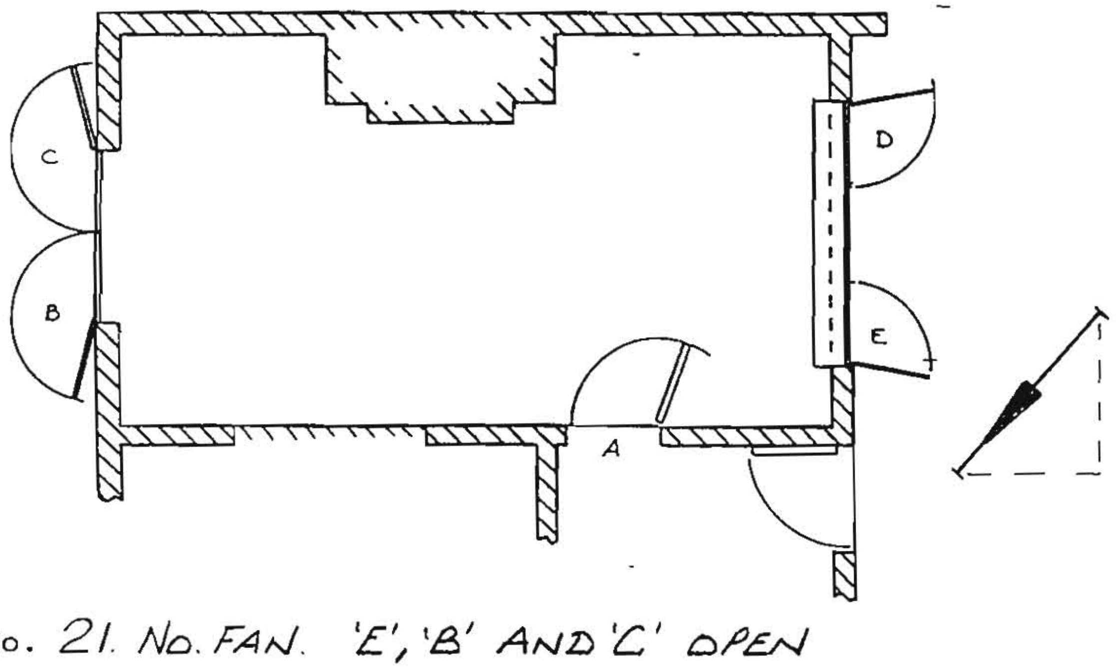


TEST No. 19. NO FAN. 'E' AND 'C' OPEN.

Figure 57 Average Natural Wind Velocity Diagrams
Trials No. 18 and 19 (scale: 1cm = 1 M/sec)

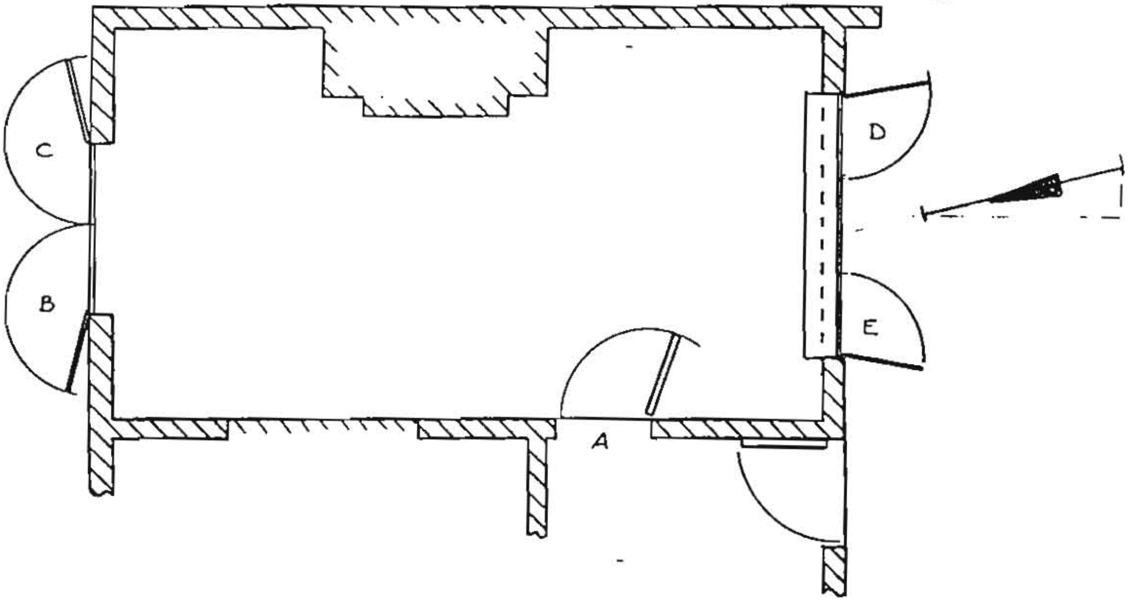


TEST No. 20. FAN. 'E' → ('B' + 'C')

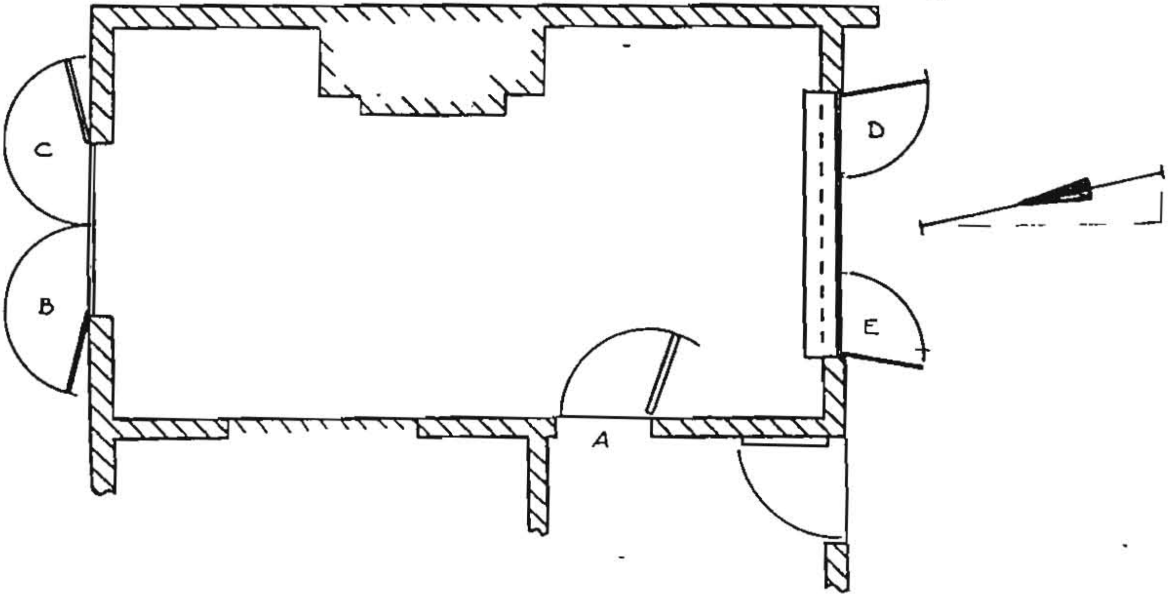


TEST No. 21. No. FAN. 'E', 'B' AND 'C' OPEN

Figure 58 Average Natural Wind Velocity Diagrams
Trials No. 20 and 21 (scale: 1cm = 1 M/sec)

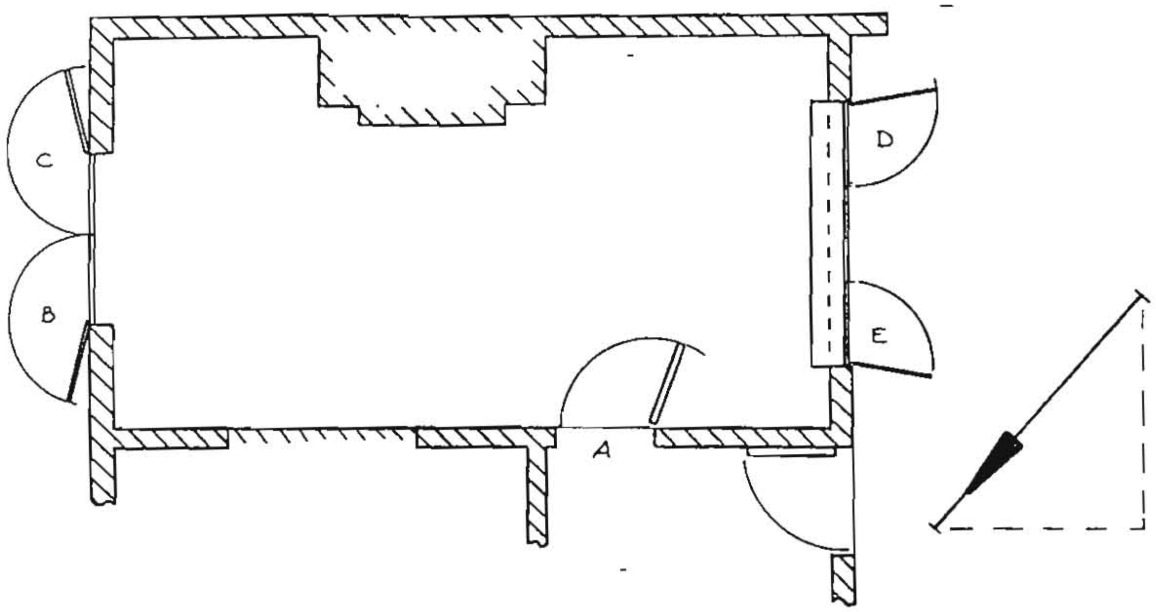


TEST No. 22. FAN AT FRONT DOOR (VIA 'A') → 'C'

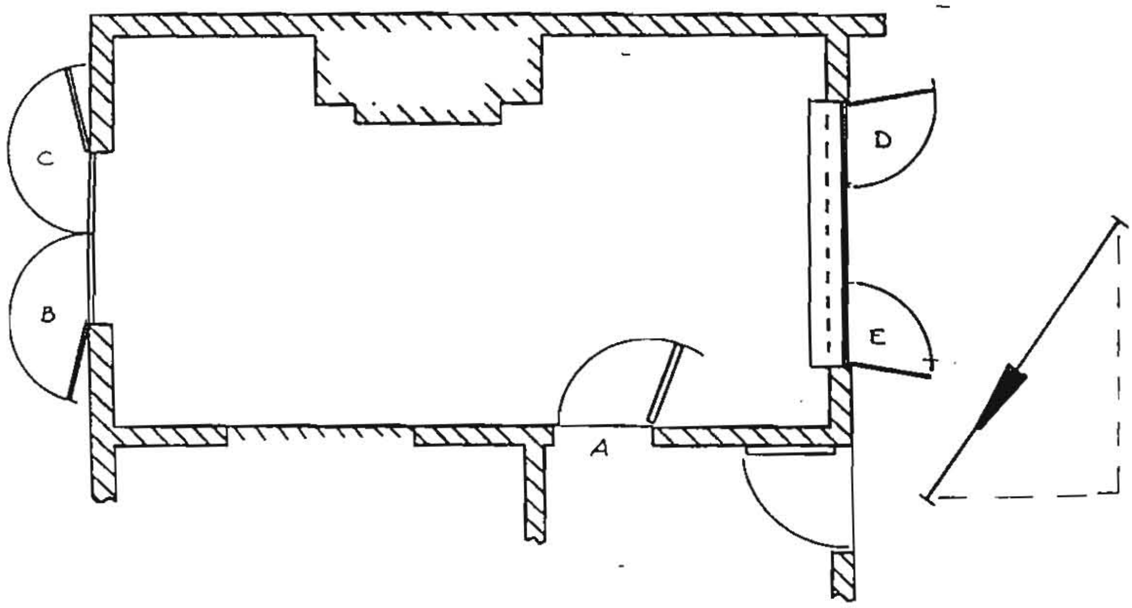


TEST No. 23. NO FAN: FRONT DOOR, 'A' AND 'C' OPEN.

Figure 59 Average Natural Wind Velocity Diagrams
Trials No. 22 and 23 (scale: 1cm = 1 M/sec)

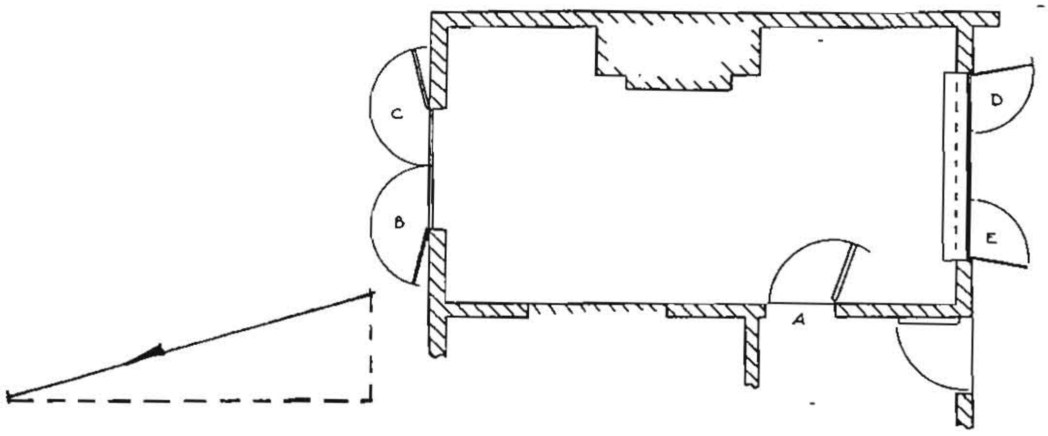


TEST No. 24. PROTOTYPE FAN WITH WATER SPRAY: 'E'→'C'.

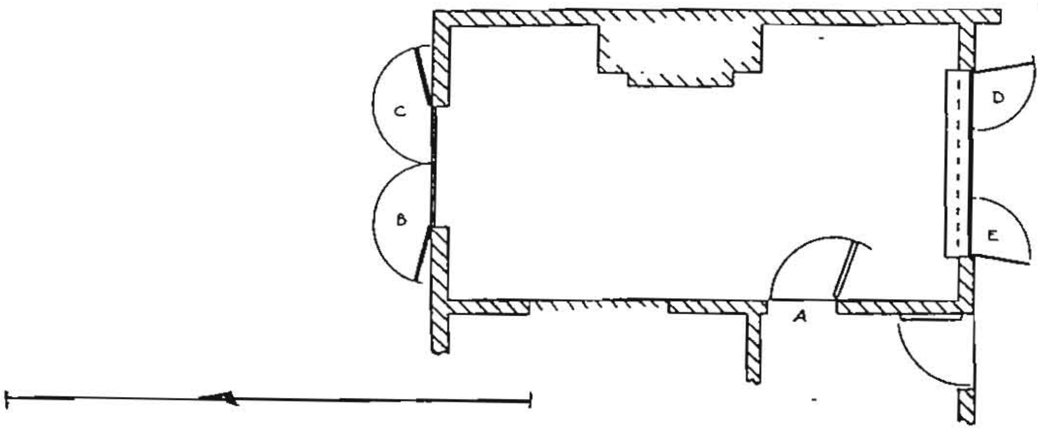


TEST No. 25. PROTOTYPE FAN WITHOUT WATER SPRAY: 'E'→'C'.

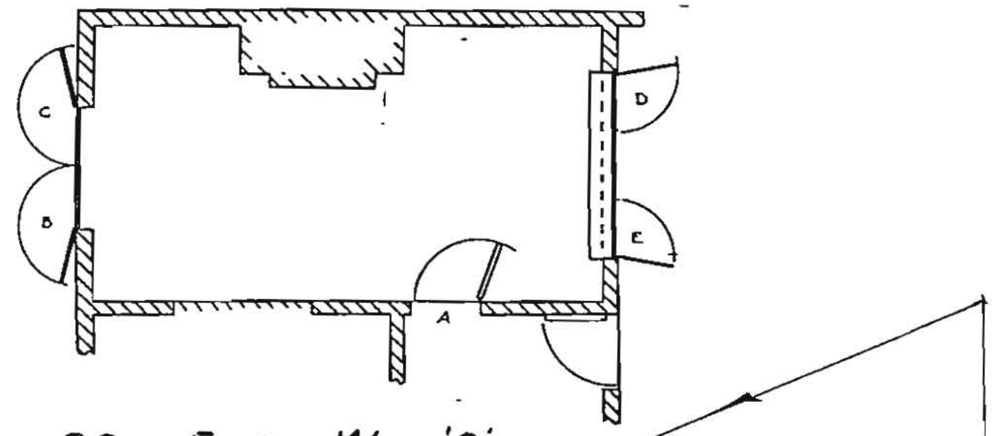
Figure 60 Average Natural Wind Velocity Diagrams
Trials No. 24 and 25 (scale: 1cm = 1 M/sec)



TEST No. 27. FAN. 'A' → 'C/2'

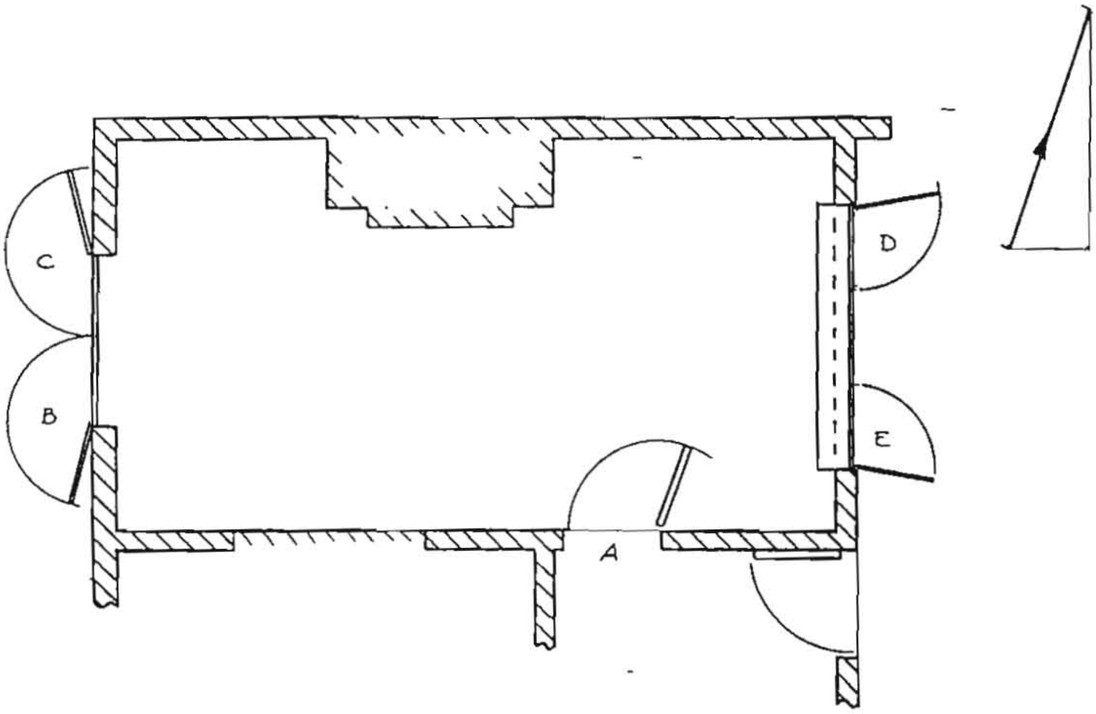


TEST No. 28. No FAN. 'A' & 'C/2'

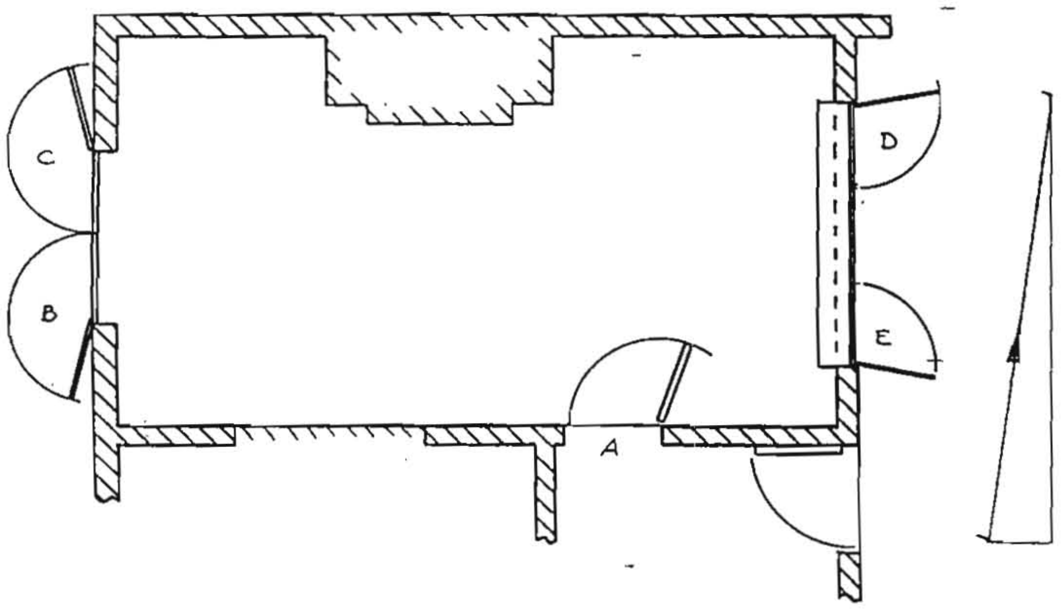


TEST No. 29. FAN. 'A' → 'C/2'

Figure 61 Average Natural Wind Velocity Diagrams
Trials No. 27, 28 and 29 (scale: 1cm = 1 M/sec)

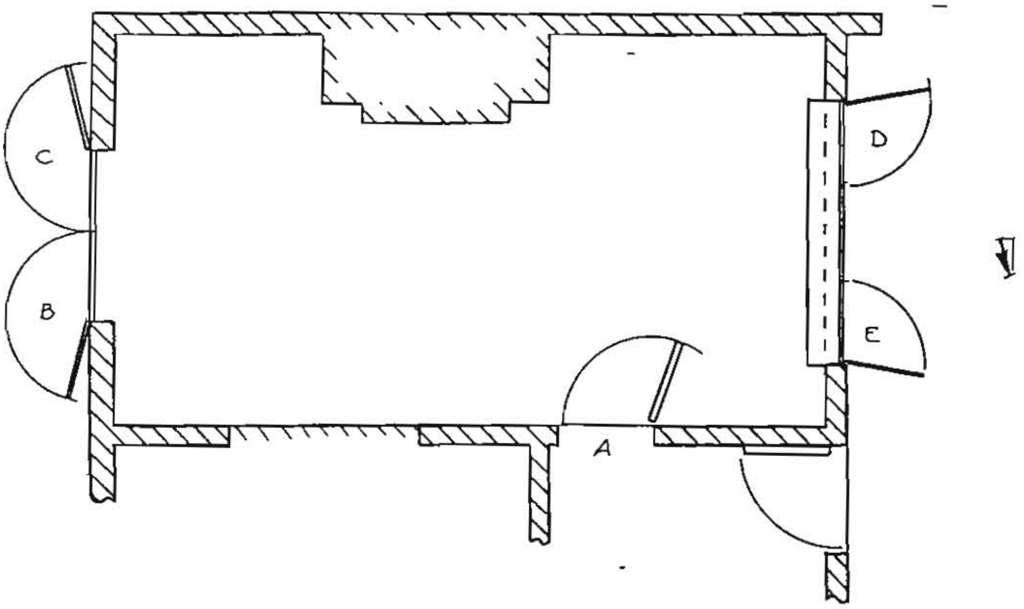


TEST No. 30. FAN. 'C' → 'E'

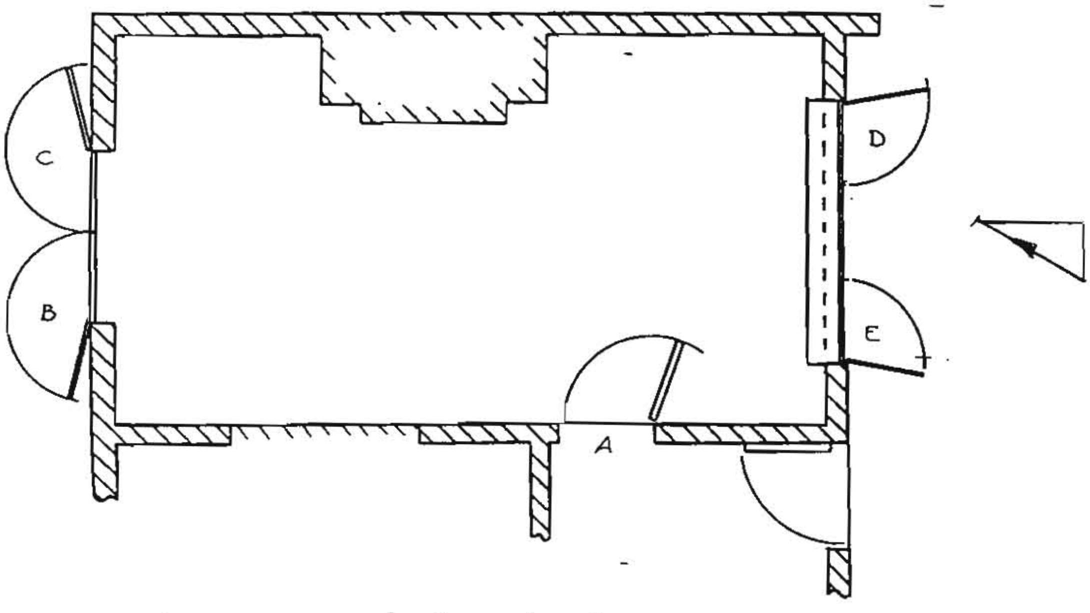


TEST No. 31. NO FAN. 'C' & 'E'

Figure 62 Average Natural Wind Velocity Diagrams
Trials No. 30 and 31 (scale: 1cm = 1 M/sec)



TEST No. 32. FAN. 'C' → 'E'



TEST No. 33. No FAN 'C' & 'E'

Figure 63 Average Natural Wind Velocity Diagrams
Trials No. 32 and 33 (scale: 1cm = 1 M/sec)

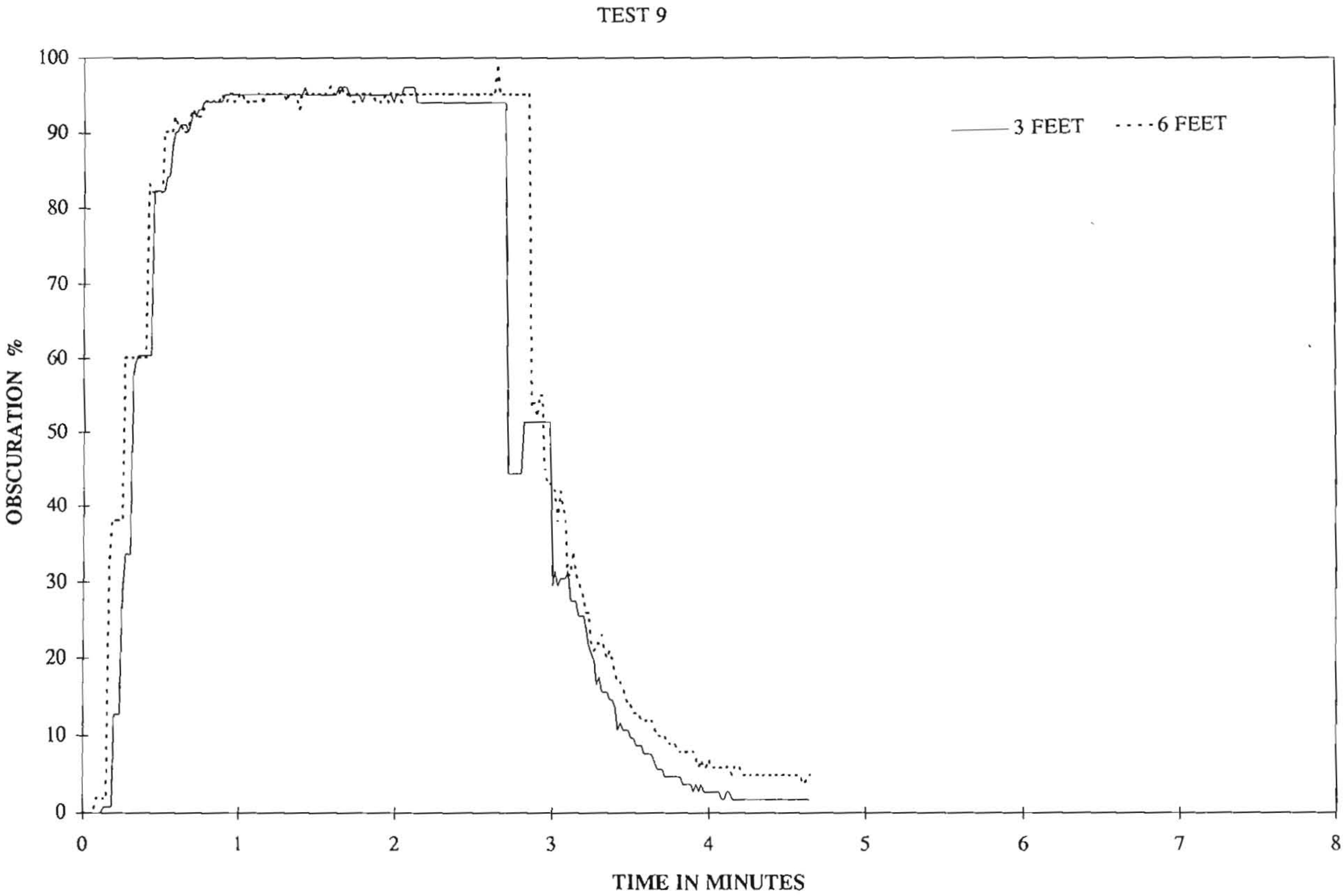


Figure 64. Typical plot of smoke obscuration Vs. time.

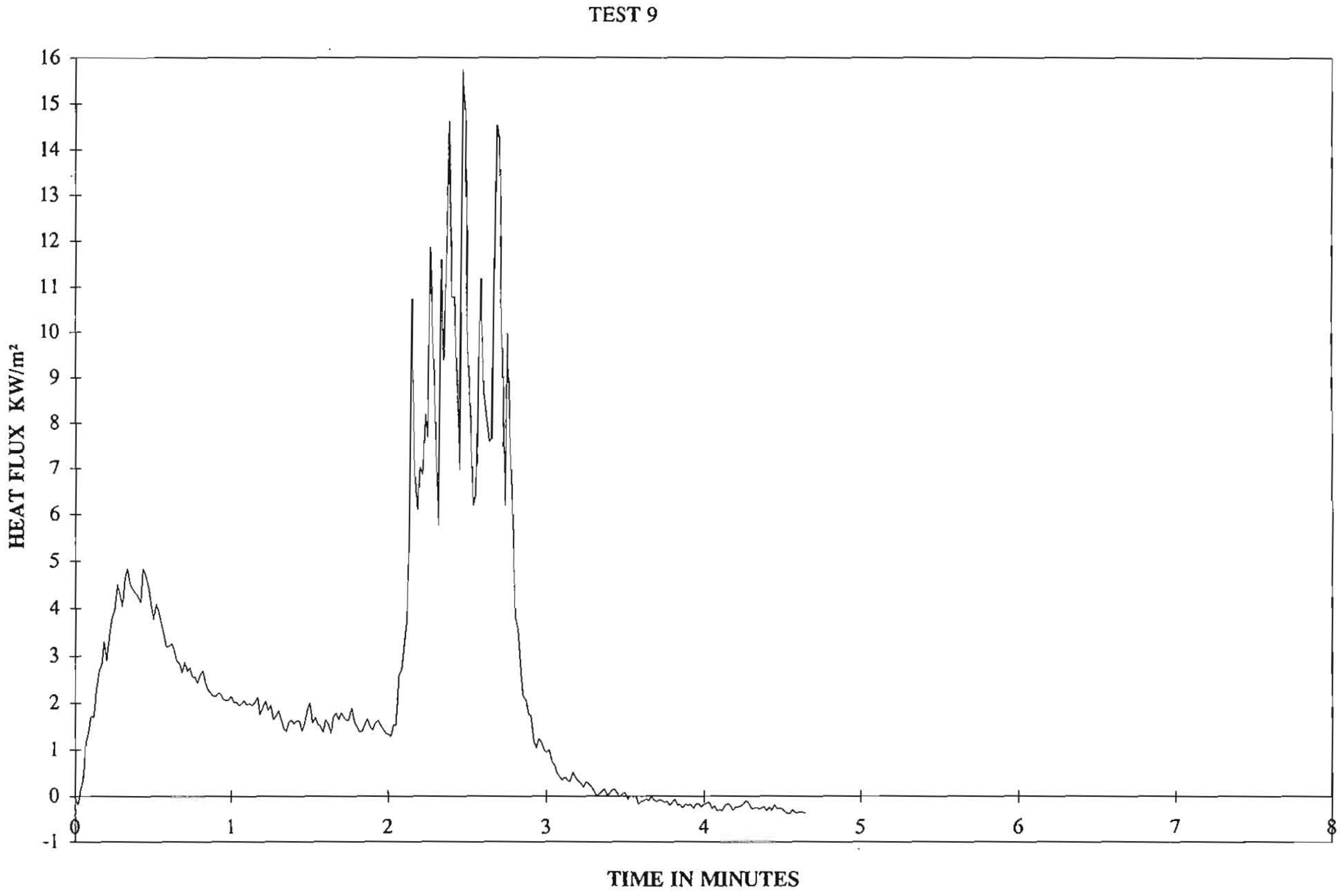


Figure 65. Typical plot of thermal radiation flux Vs. time.

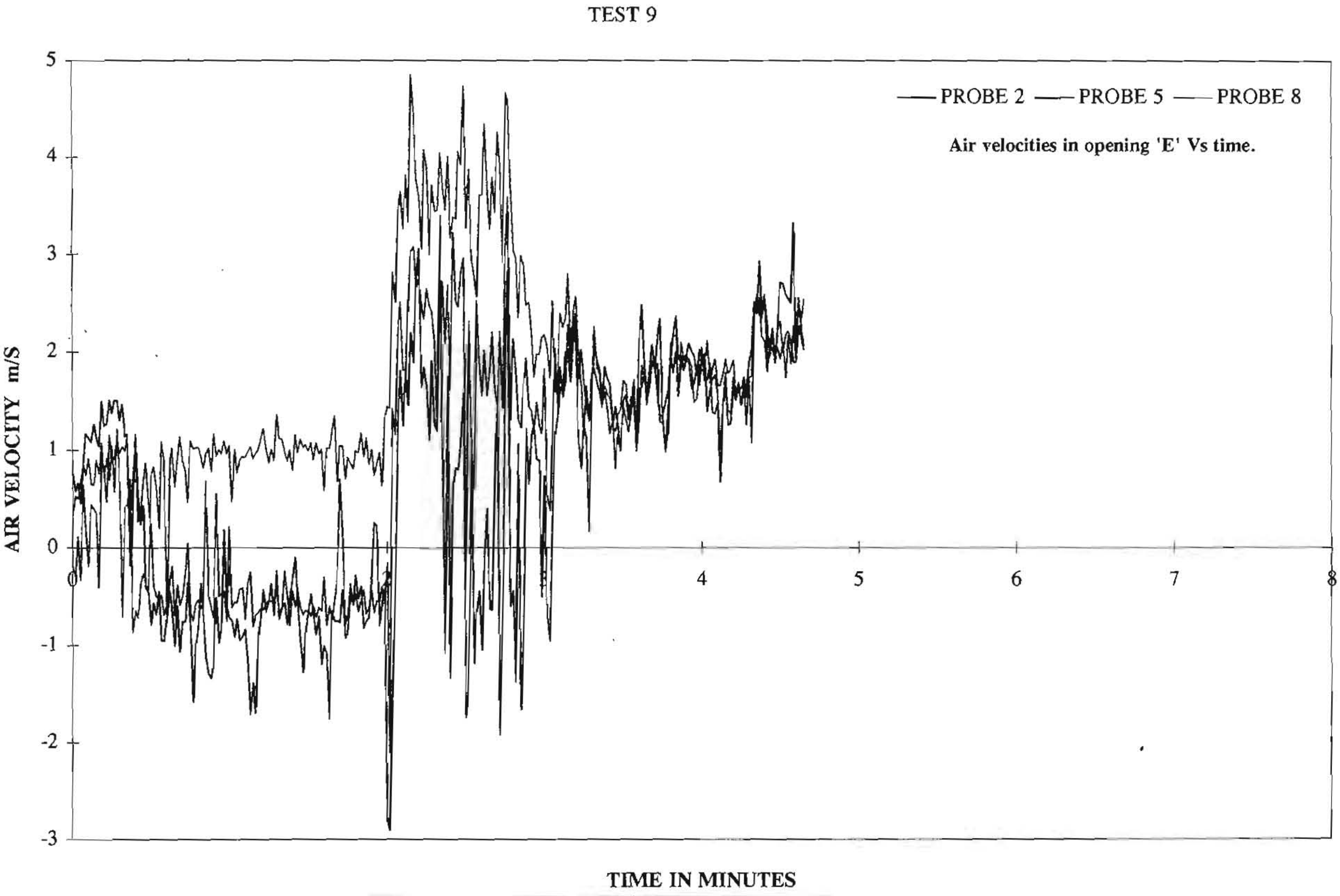


Figure 66. Typical plot of outlet air velocities Vs. time. - opening 'E'.

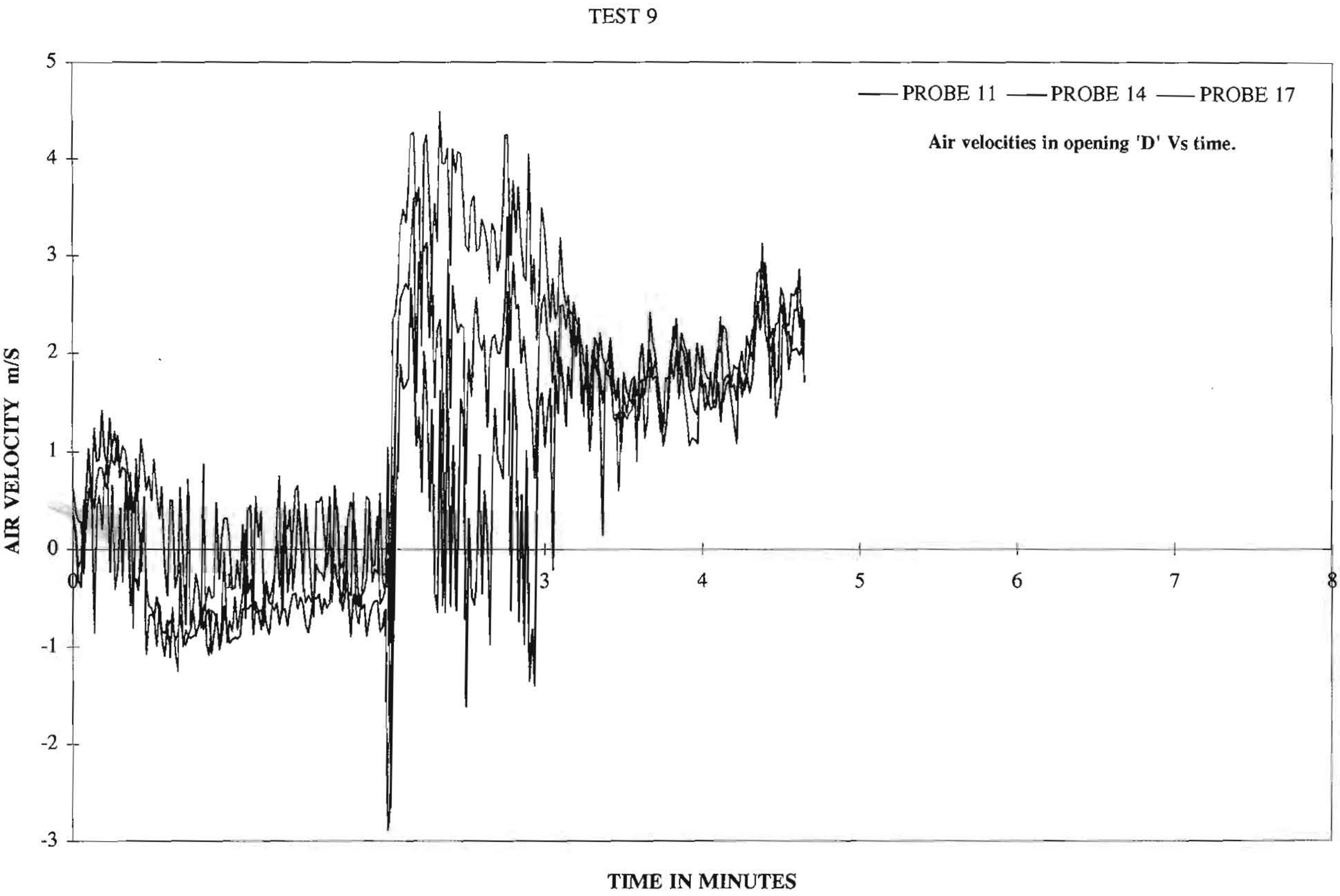


Figure 67. Typical plot of outlet air velocities Vs. time. - opening 'D'.

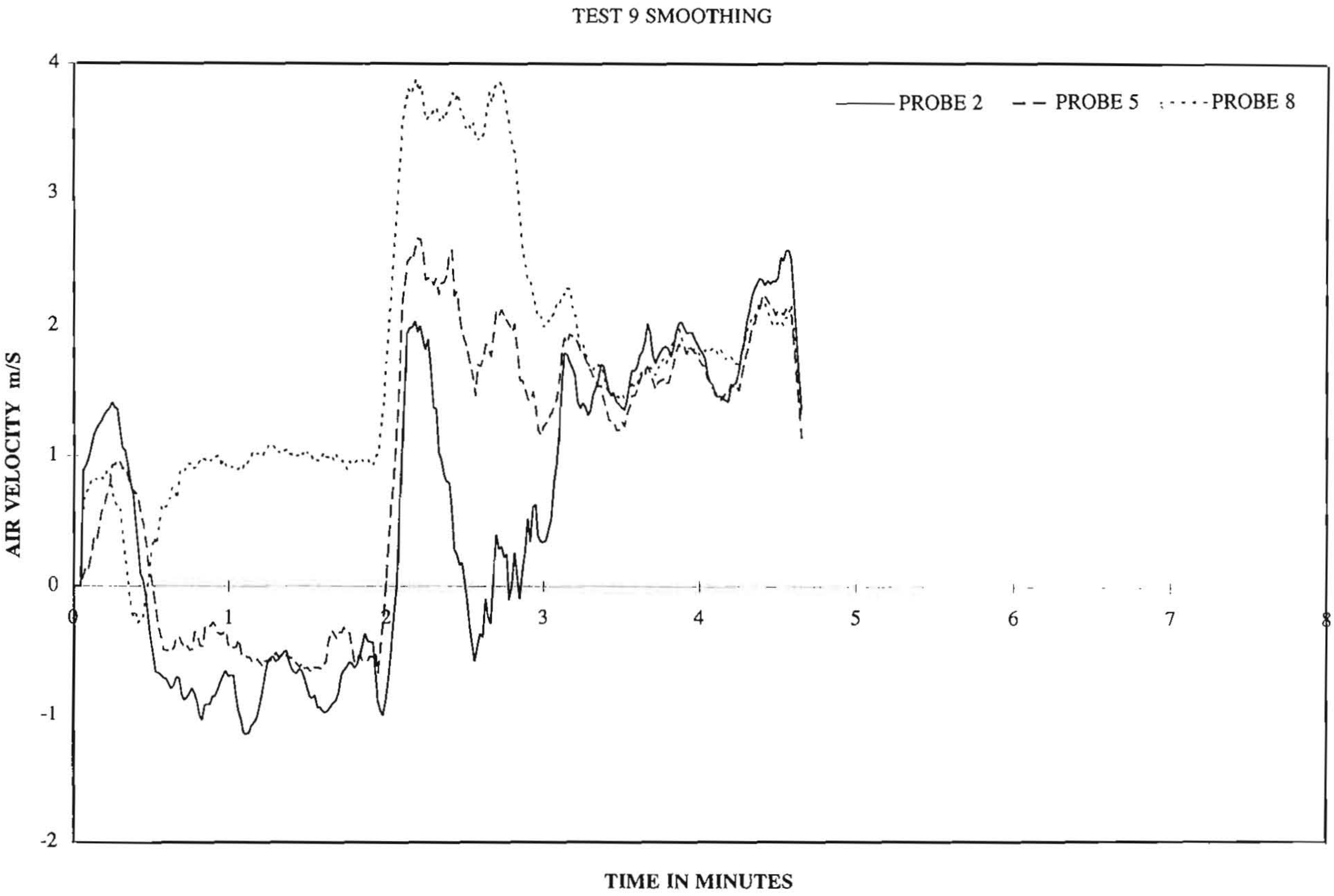


Figure 68. Typical 'smoothed' plot of outlet air velocities Vs. time - opening 'E'.

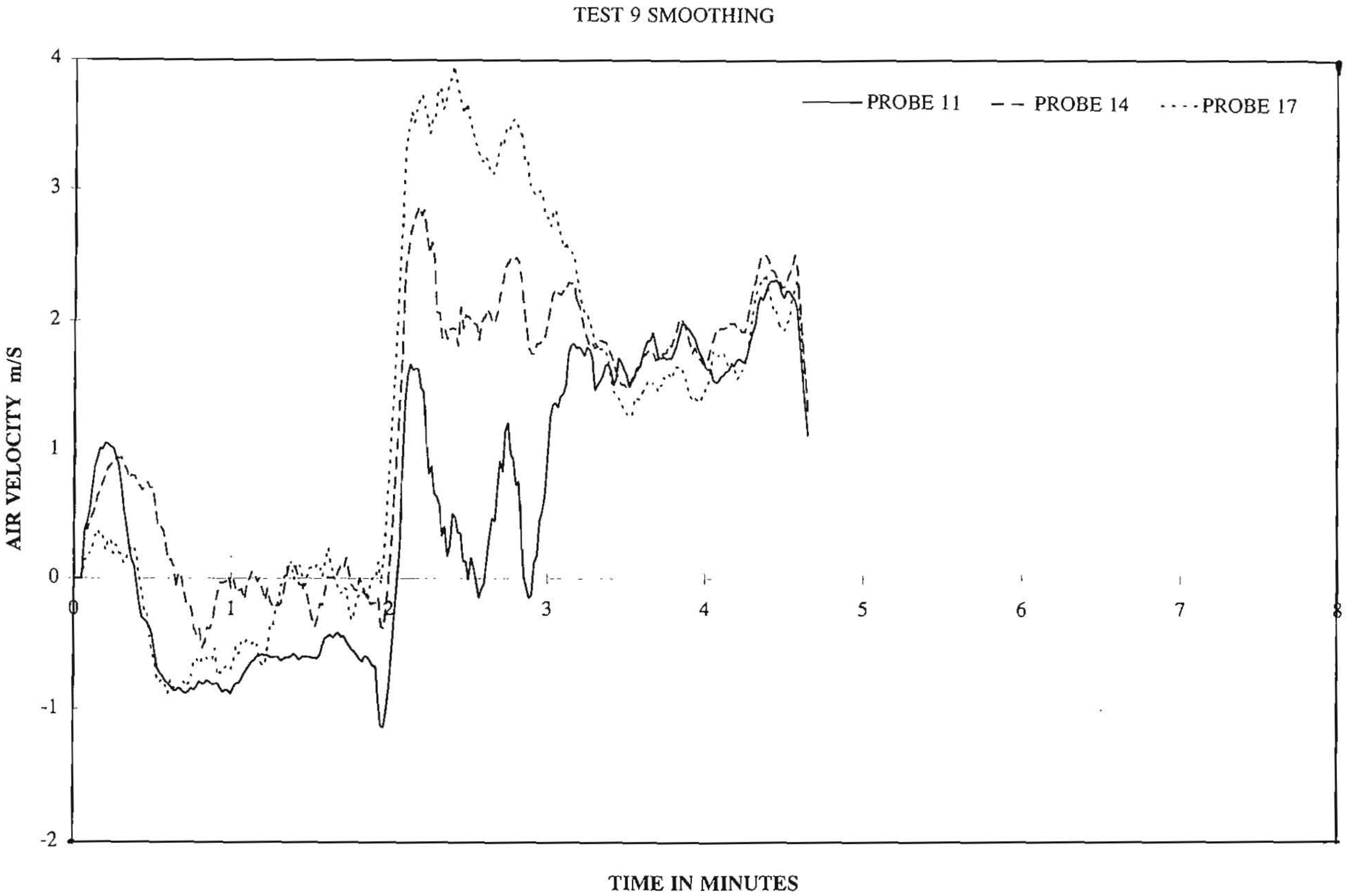


Figure 69. Typical 'smoothed' plot of outlet air velocities Vs. time - opening 'D'.

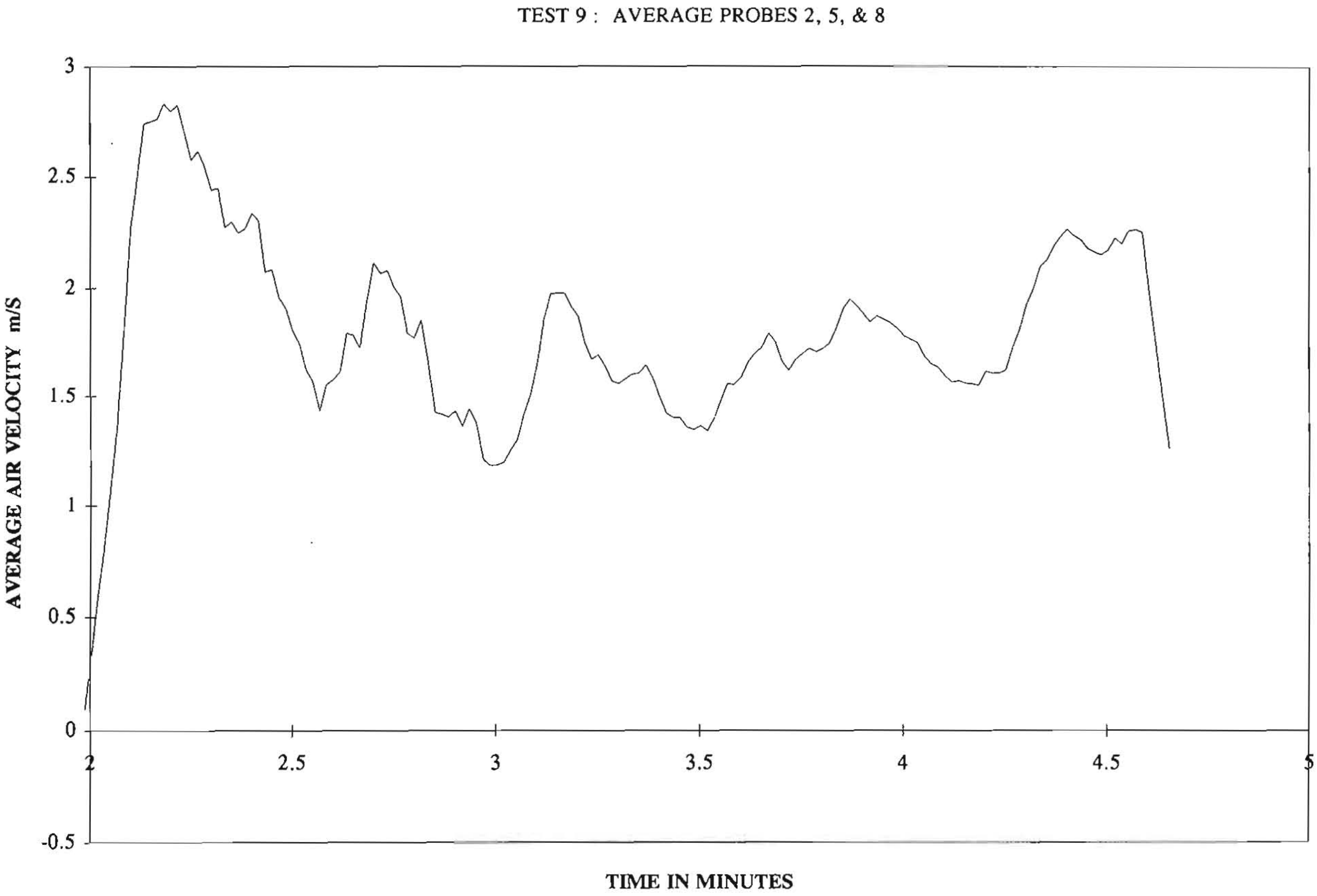


Figure 70. Typical plot of average outlet air velocity Vs. time, from when the room was first opened. - opening 'E'.

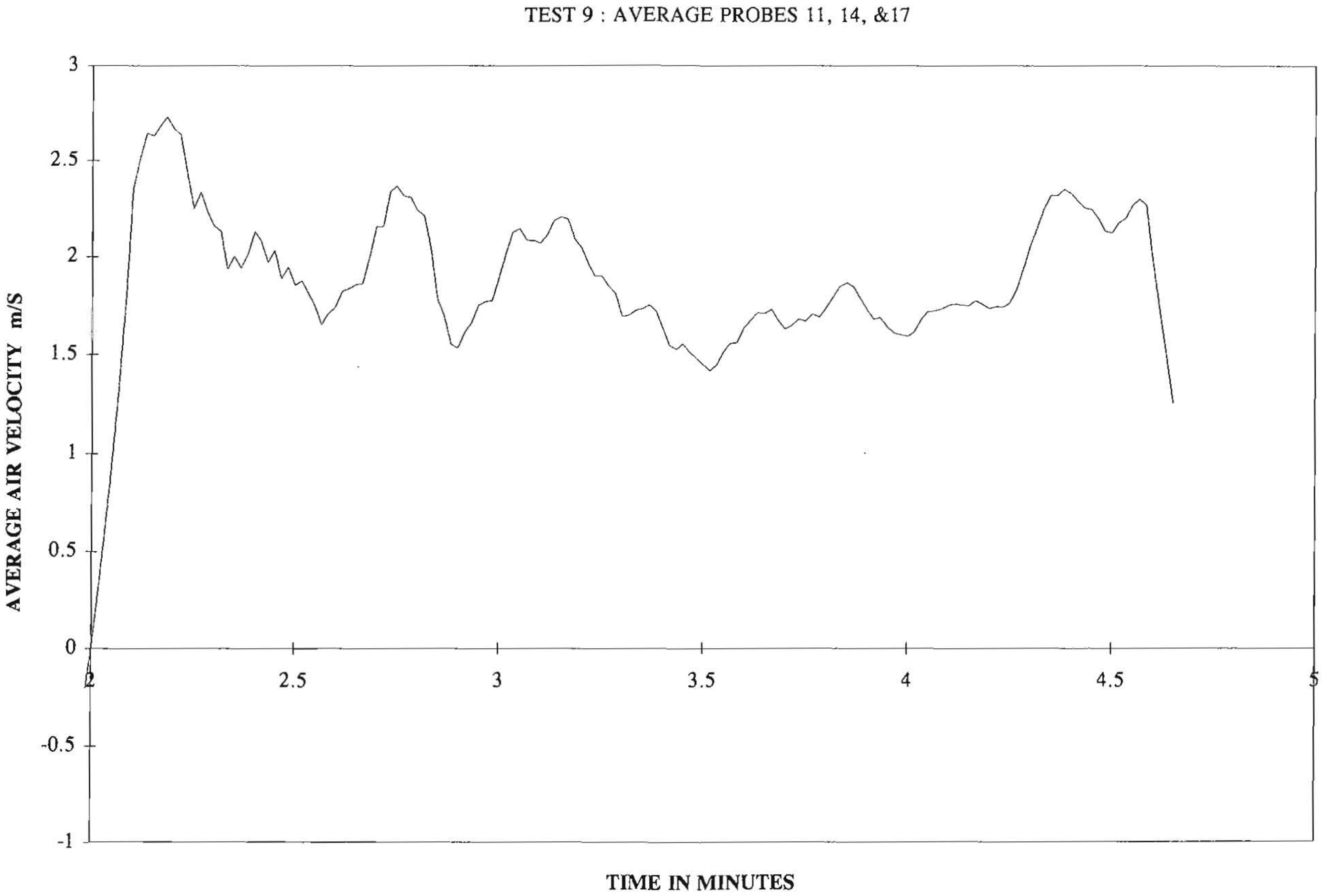


Figure 71. Typical plot of average outlet air velocity Vs. time, from when the room was first opened. - opening 'D'.

TEST 9		
AIR VELOCITY 2,5,& 8		
	1.798516	
AIR VELOCITY 11,14, & 17		
	1.877452	
O/A AVG	1.838	

Figure 72. Typical print out of average air velocities, in metres / second.

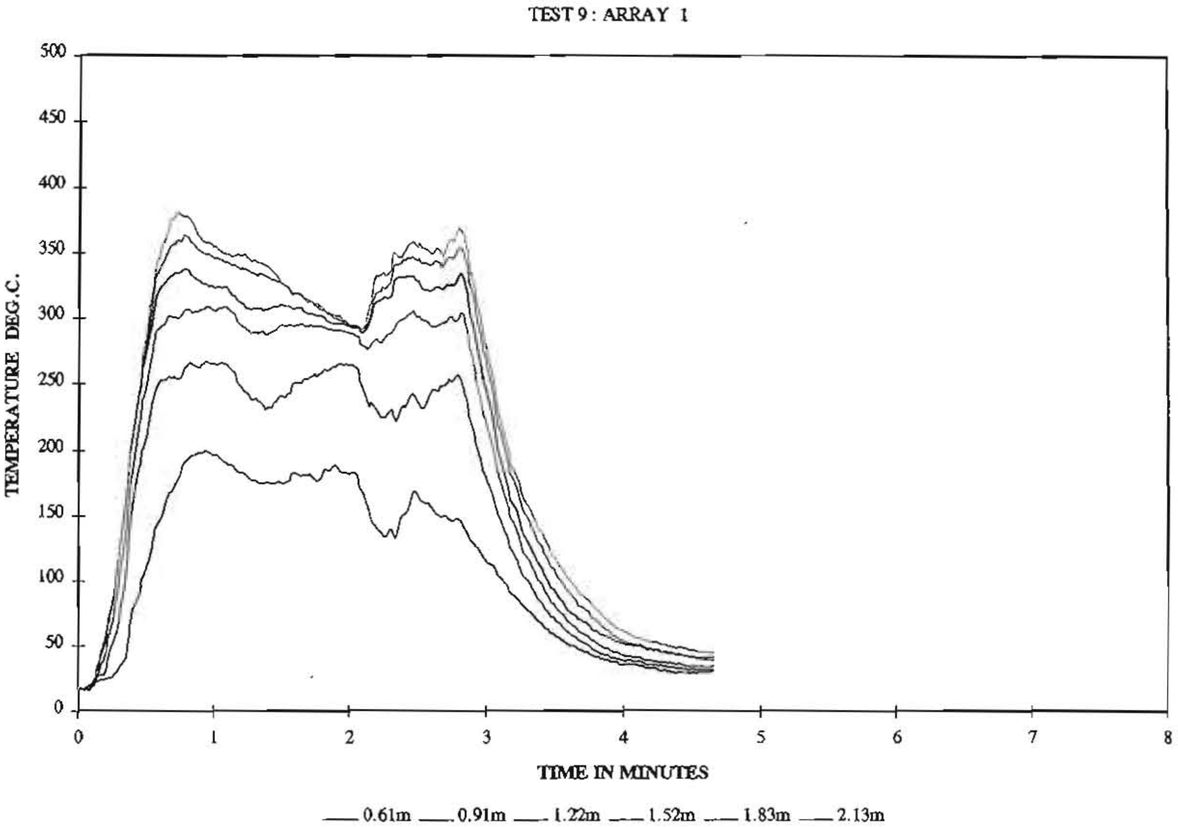


Figure 73. Typical plot of room 'air' temperatures Vs time. (thermocouple array 1)

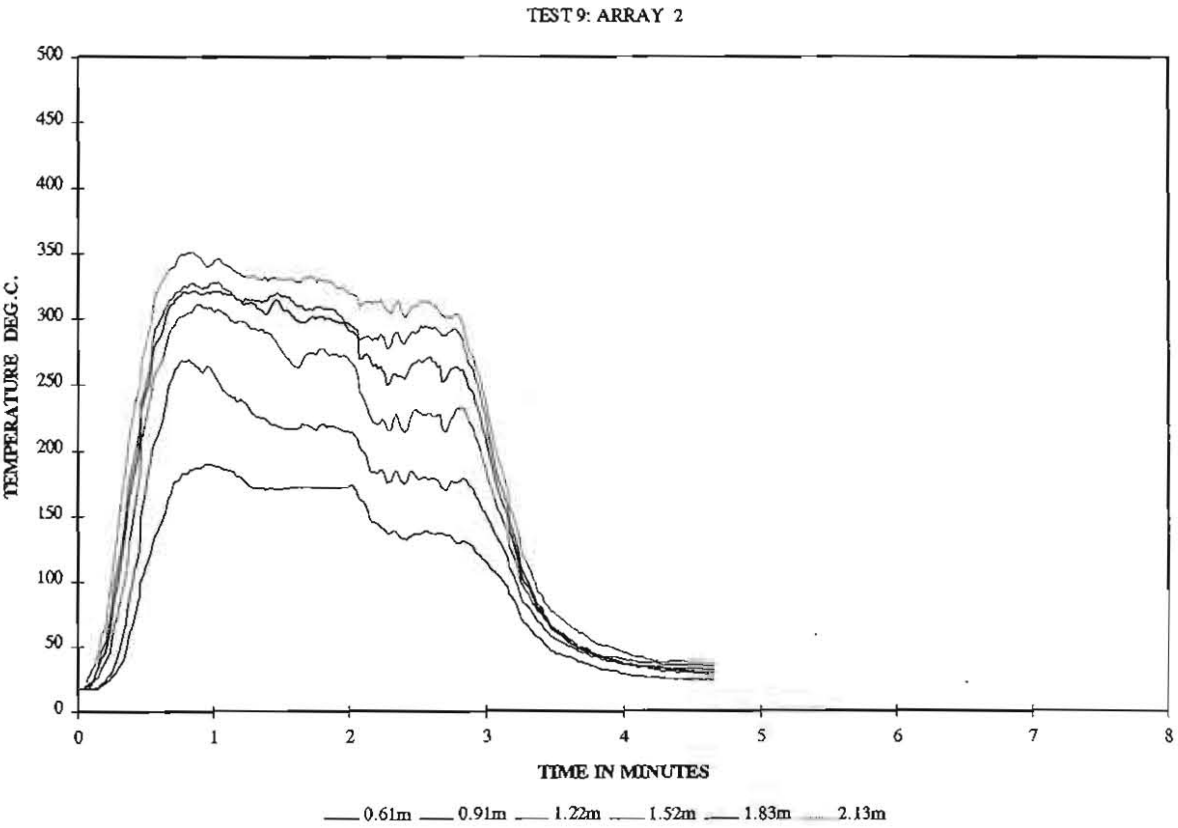


Figure 74. Typical plot of room 'air' temperatures Vs time. (thermocouple array 2)

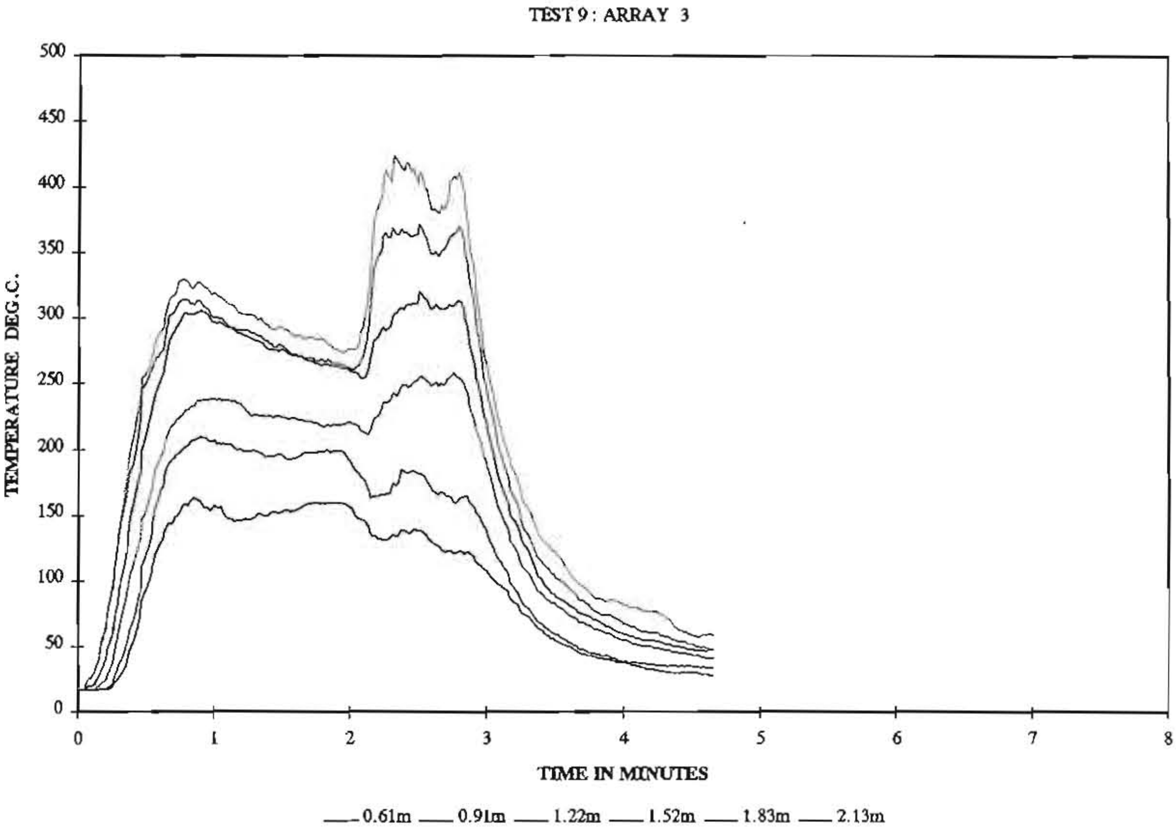


Figure 75. Typical plot of room 'air' temperatures Vs time. (thermocouple array 3)

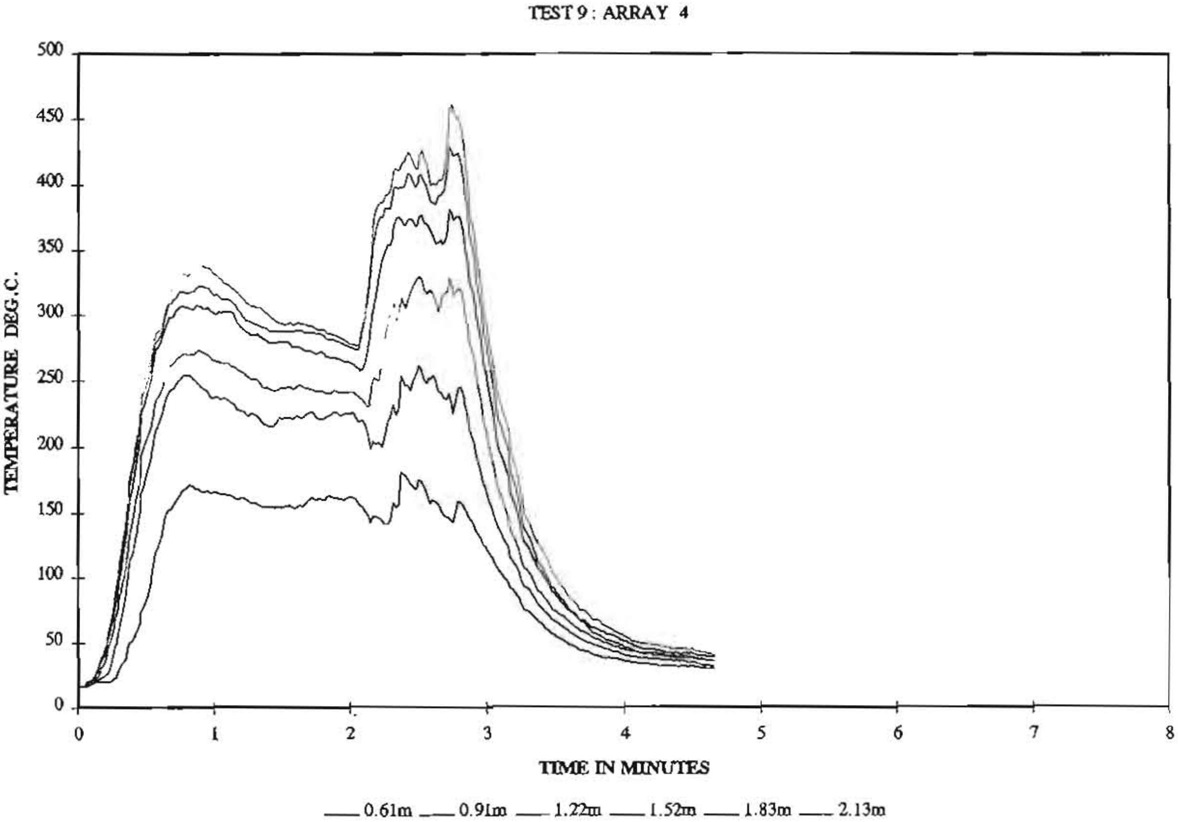


Figure 76. Typical plot of room 'air' temperatures Vs time. (thermocouple array 4)

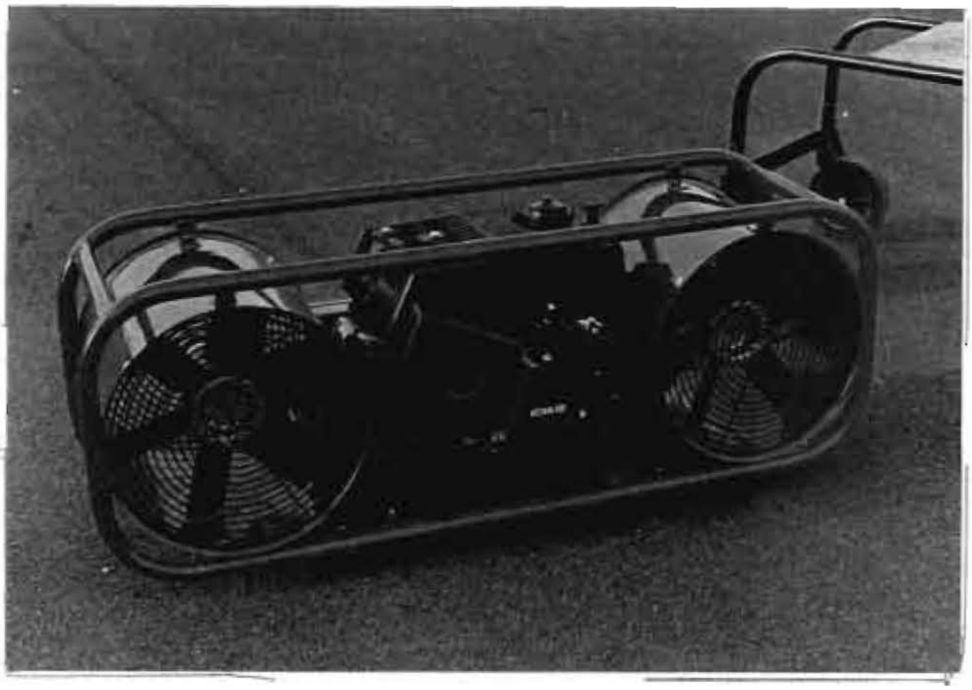


Figure 77 Doman Airdriver PPV Fan - used in Trials numbered 24 and 25