Publication Number 2/98 Ventilation of Large Fires The Use of Computer Modelling

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Ventilation of Large Fires
The Use of Computer Modelling

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ABSTRACT

This report describes a programme of work undertaken by the Home Office with the intention of using computer modelling to develop practical guidance on the use of fire ventilation as a firefighting tactic.

The computer modelling was carried out under contract to the Fire Research and Development Group and included a survey of the models available, the application of a Computational Fluid Dynamics package, and comparison of its predictions with experimental results.

It was concluded that computer modelling was not yet at a stage where it could be used as a tool for exploring tactical ventilation, although major progress was achieved by the contractor in the modelling of weakly ventilated fires.

VENTILATION OF LARGE FIRES
THE USE OF COMPUTER MODELLING

MANAGEMENT SUMMARY

General

A programme of work has been carried out by the Home Office to develop practical guidance for the fire service on the use of ventilation as a firefighting tactic. This theoretical study explored the use of computer modelling to develop an understanding of the processes involved. It was hoped that the modelling would predict the effects of various tactical venting options without the need for expensive and time consuming large scale test fires. If successful then the predictions could be used to develop practical guidance for the fire service in terms which would be of use on the fireground.

The computer modelling work was carried out under contract to FRDG by AEA Technology Ltd

Review of Computer Models

The first phase of the work was to consider the computer models currently available and select the most suitable for the work.

The review of zone models concentrated on the codes which were the most promising candidates for fire venting. These were HAZARD I (FAST), CCFM.VENTS, CFAST and Harvard CFC V and VI. The conclusion was that NIST's CFAST zone model was the most suitable. This can model vertical flow through vents, and the modelling of wind effects had been implemented by NIST even though its use had not been proven.

Four CFD codes were considered, these were:

- CFX (developed by AEA Technology);
- FLUENT (developed at Sheffield University);
- JASMINE (developed by the Fire Research Station);
- KAMELEON (developed by the Norwegian laboratory SINTEFF).

All four codes were considered powerful for fire modelling in one way or another and were available commercially. CFX was preferred mainly because this code had been developed by AEA and the project team for this work were experienced in its use.

Trials to Obtain Experimental Data

It is necessary to show that the computer modelling accurately reflected the behaviour of real fires, if the results are to credible and of practical use. No reliable experimental data was identified for suitable fire scenarios and therefore, to make this comparison possible, trials were undertaken to obtain this data.
The Industrial B building at the Fire Service College was chosen for the work. This building has a relatively large open room (17m x 9m) on the first floor with two external doors, a pitched roof and four roof vents.

The fire was a class B fuel (95% heptane) which was allowed to burn for five minutes before ventilation commenced, using various combinations of doors and vents. The fuel volume allowed a ten minute burn period.

The building was instrumented to measure gas velocity, gas temperatures, smoke density, surface temperatures, heat flux, fuel depth and static pressure.

Preliminary runs of the zone and CFD models were completed before the trials. In these calculations the building was assumed to be perfectly sealed hydro-dynamically for the first five minutes and, as expected, the pressure rose to high values. In reality, the pressures would be considerably less than this due to leakage effects.

As the modelling indicated improbable high pressures in the building, it was concluded that air leakage from the building might be an important factor. Measurements were undertaken before the trials to determine the air leakage for the compartment as a whole. No attempt was made to divide this leakage between the various parts of the building.

Post-Trial Results

Following the trials, AEA was given the wind and ventilation conditions from two of the tests and requested to predict the results using the computer model without access to the experimental measurements.

The correlation of the predictions with the experimental results at this stage was not good and improvement was required. The experimental results showed temperature layers developing early in the fire. The layering of the temperatures (stratification) was maintained as the fire became oxygen starved although the temperatures did reduce. The computer predictions showed stratification collapse in the period before the vents were opened.

There were several areas in which alternative approaches may have improved the predictions. These were the air leakages, the turbulence modelling of the gas flow and the wall boundary conditions. AEA found that stratification was predicted by their model in the two extreme cases of a perfectly sealed building on the one hand and a well-ventilated one on the other. It was for this reason that the leakages in the building and their effects on the fire were considered critical.

This prompted further tests to quantify the leakage paths from the building and this information was then included in the AEA model.

Further modelling work by AEA then produced credible results for the first five minutes of the experiments without the collapse of the stratification, although no modelling was carried out after the vents were open, using the detailed leakage modelling.

Conclusions

AEA's modelling work has shown that fires are very sensitive to leakages if they become starved of oxygen in weakly-ventilated buildings. They concluded that during theoretical modelling, attention must be paid to the leakages, not only in the global sense but also with regard to the magnitudes and locations of the individual leakage paths. The importance of leakages should also be considered in the design of any future validation experiments

The modelling work carried out so far has involved non-spreading fires, and this was expected to be relatively straightforward, but it has turned out to be technically difficult, delaying the project. AEA persevered with the work, largely at their own expense, and reached a stage where credible results were obtained for the first five minutes of the test fires.

However, it was concluded by FRDG that the current state of modelling was not sufficiently advanced to be used as a tool for exploring ventilation. Major development of the flame spread model was still necessary and the post-ventilation model had yet to be fully validated. The flame spread model would require significant expenditure. The aim of the project was to use existing expertise, not to pay for advancing the whole field of CFD. Therefore it was decided that no further work would be carried out on the application of modelling to tactical ventilation.

Further work is now proposed to try to gain further information on ventilation tactics by carrying out a study of recent fires in large buildings in order to document the fires and see if useful lessons can be learned about ventilation tactics and effects. Such post-mortems would allow the problems of these fires to be analysed to assess the effectiveness of the current guidance. This may also identify whether further research is required.

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1. INTRODUCTION

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

The Joint Committee on Fire Brigade Operations requested a study of ways in which these fire losses could be reduced. This study identified over thirty areas where research might prove beneficial, and these were refined to eight detailed proposals which were presented to the committee. The committee requested Fire Research and Development Group (FRDG) to pursue a number of these projects, one of which was to look at the application of venting as a firefighting tactic.

The period of interest of this work was from the arrival of the brigade at the fire until the fire was extinguished. The use of fixed ventilators in the early stages of the fire, and smoke clearance after the fire, were both excluded from this study.

A programme of five stages of research was developed to investigate whether fire venting could be of benefit and how it could be introduced safely:

- a survey of the field of venting to determine the true state of the art;
- subsequent theoretical or small-scale experimental studies to investigate the theory in more depth;
- development of practical guidance for fire service use;
- large-scale experimental studies to make comparisons between venting and other firefighting tactics;
- development of safe working procedures.

As a first step, a survey of the field of venting of fires was carried out for FRDG by a contractor (1)* to determine the true state of the art. The consultants carrying out the survey concluded that there was scope for the more extensive application of ventilation tactics in the UK. They considered that there was a need for further research, aimed at assessing the effectiveness of various tactics and developing safe working practices.

The survey provided an overview of practical advice on tactical ventilation and this together with information from other sources was incorporated into a supplement to

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*Numbers in brackets relate to the references on page 17 the Manual of Firemanship (2). The supplement brought together all the existing advice available on the use of ventilation. Very often this advice was based on firefighter's experience and had not yet been supported by experimental experience. The supplement has been supported by a training video on ventilation which was completed at the end of September 1997.

After the survey, it was then agreed that a further programme of work should be carried out by the Home Office to undertake a theoretical exploration of the effects of tactical ventilation in a number of scenarios. This theoretical study would explore the use of computer modelling to develop an understanding of the processes involved. It was hoped that the modelling would predict the effects of various tactical venting options without the need for expensive and time-consuming large scale test fires. If successful, the predictions could then be used to develop practical guidance for the fire service in terms which would be of use on the fireground.

If the computer model was to be of practical use, it must be able predict the effects of tactical ventilation on the following:

- fire growth;
- smoke movement;
- temperature conditions in the building;
- fire spread to adjacent fire loads;

It must also be possible to explore :

- the ability of ventilation tactics to overcome adverse external wind effects;
- the effects of the position and area of the vent or vents;
- the effect of the time at the which the vent or vents are opened.

The computer modelling work was carried out under contract to FRDG by AEA Technology Ltd[1*]. The first phase of the work was to consider the computer models currently available and select the most suitable for the work.

It would then be necessary to show that computer modelling accurately reflected the behaviour of real fires, if the results were to be credible and of practical use. No reliable experimental data was identified for suitable fire scenarios and therefore, to make this comparison possible, it was decided that the FRDG Fire Experimental Unit (FEU) should undertake trials to obtain this data.

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[*] Numbers in superscripts refer to the notes on page 18

2. REVIEW OF COMPUTER CODES FOR MODELLING VENTILATION

2.1 General

The first stage in the computer modelling work was a review of the computer codes for modelling the ventilation of large scale fires. There are two types of computer fire models in common use: zone models and field models. A zone model is a more simple representation than a field model.

Zone models divide the compartment of interest into a smaller number of zones (usually two) where each zone is assumed to have uniform composition and temperature. The two zones are usually an upper layer containing the hot combustion gases and a cooler lower layer. The plane dividing the two zones is the hot layer interface, the height of which will change during a fire. The model relies on well established but empirical relationships for the transfer of heat and smoke between the zones.

The term field model is synonymous with Computational Fluid Dynamics (CFD). In these models the domain of interest is divided into many cells or small volumes. A grid (or mesh) is produced for the modelled region which determines the size of each cell. The cells may not be of equal size; smaller cell sizes may be required near the fire walls or where conditions are more variable and more detail is needed. The region may include external areas of the building when the flow through vents and the effects of wind are to be considered.

The exchange of various parameters between each cell and its neighbours is defined by a set of mathematical statements of the fundamental laws of nature, covering conservation of mass, momentum, thermal energy, concentrations of various gases and transfer of radiant energy. The solution of these equations and others is carried out by the CFD software.

The mesh must be generated for each building from plans - a task which requires expert knowledge of the modelling processes to optimise the mesh. The accuracy of the predictions is improved by increasing the number of cells, but there will be a consequential increase in the processing time because more calculations will be necessary.

Field models are likely to be more accurate and give greater detail than zones models but they require more setting up and more computing power, and therefore are more expensive to use.

2.2 Conclusions from the Review

2.2.1 Zone Models

The AEA review of zone models (3) concentrated on the codes which by their judgement were the most promising candidates for fire venting. These were HAZARD I (FAST), CCFM.VENTS, CFAST and Harvard CFC V and VI.

Although all these codes modelled the main aspects of a fire in a building, there were two requirements which were considered particularly important for this work. These were the ability of the models to calculate vertical flow through vents and to take account of wind effects.

The conclusion was that NIST's CFAST zone model was the most suitable. This can model vertical flow through vents, and the modelling of wind effects had been implemented by NIST even though its use had not been proven.

2.2.2 Field Models

Four CFD codes were considered; these were:

- CFX (developed by AEA Technology);
- FLUENT (developed at Sheffield University);
- JASMINE (developed by the Fire Research Station);
- KAMELEON (developed by the Norwegian laboratory SINTEFF).

All four codes were considered powerful for fire modelling in one way or another and were available commercially. CFX was preferred mainly because this code had been developed by AEA and the project team for this work were experienced in its use. They had a good relationship with the code developers which gave them access to pre-release versions and code adaptations.

It was considered that all of the codes could be used to calculate fire spread with suitable user input, although none were specifically designed to do so.

3. COMPUTER MODELLING PRIOR TO THE TRIALS

3.1 The Building

Before the models could be validated, it was first necessary to identify a scenario for the modelling and experimental work. The Industrial B building at the Fire Service College was chosen for the work. This was the most suitable building available to represent a building of the type in which high fire losses have occurred. Industrial B was also considered a relatively simple building structure for modelling.

Figures 1 and 2 show general views of the building from the south-east and north-west. This building has a relatively large open room (17m x 9m) on the first floor with two external doors, a pitched roof and four roof vents. This arrangement gave the opportunity to explore the effects of various combinations of roof vents and doors although, for the tests, only two of the roof vents and the two external doors were used for ventilation. The large room has a small extension in the south-west corner with a conventional ceiling 3.3m high. To simplify the computer model, this room was partitioned off using metal sheeting for the trials. There was also an internal door at the south end that was kept closed throughout the tests.

Doors at the south-west and north-east corners of the room connect onto the surrounding balcony, and the windows along the two long sides are glazed. The upper part of the windows can be opened but were kept closed during the tests. Drenchers were already installed in the building to protect the windows during fires and these were turned on for the duration of the tests. Inside the building there were internal partition walls to a height of 1.8m and these were included in the model.

3.2 The Fire Source

A class B fuel and was chosen for the tests because FEU experience had shown that these produced more repeatable fires than Class A fuels. It was decided to use 95% n-heptane (Norpar 7[2]) as the fuel in these trials. This was preferred to the cheaper alternative of Solvent 50 used in other FEU trials because it was purer in composition and would be simpler to define in the computer model.

The fire would be allowed to burn for five minutes before ventilation commenced, and the fuel volume would have to allow a ten minute burn period.

The aim was to have as large a fire as possible in the building whilst paying due regard to safety and to minimizing the risk of damage to the building.

Preliminary experiments were carried out by FEU to obtain initial fuel burning rates for use in the modelling.

3.3 Preliminary Computer Modelling

3.3.1 General

In the early stages of planning the trials, guidance was required on the fire size and the optimum positions in which to deploy instrumentation. For this reason, exploratory runs of the zone model were undertaken with two fuel tray areas (4.5 m^2 and 3.6 m^2). A preliminary run of the CFD model was also completed to simulate the 4.5 m^2 heptane fire (4,5).

The CFD mesh for Industrial B was generated using plans of the building and a series of photographs. Internal and external meshes were produced which were connected at the doors and the vents of the building so that wind effects could be taken into account. Some simplification of the building was necessary but nonetheless nearly 40,000 cells were necessary in the mesh. Figure 3 shows a vertical slice through a vent showing the CFD mesh and Figure 4 shows a representation of the building from the model.

3.3.2 CFAST Predictions

The CFAST zone model showed the interface height between the two zones falling to 1.5m (above the floor) 100 seconds after the start of the fire. The interface continued to fall and was only 12.5 mm (above the floor) 100 seconds after the start of the fire. This effectively meant that the model only predicted a single temperature for the whole building at this time. The predicted temperatures of the upper and lower layers and the interface height are shown in Figures 5, 6 and 7.

3.3.3 CFX Predictions

A preliminary run of the CFD model was completed in which it was assumed that the building was sealed for the first five minutes and then a representative wind speed and direction was used during the second five minute period when the building was vented.

The model produced predictions which included the following parameters:

- temperatures for the temperature trees;
- optical density;
- velocities at the doors and vents;
- oxygen mass fraction;
- fire power;
- fuel evaporation rate (which was coupled to the radiative field).

The predictions can be presented as plots of the parameter against time (for example - Figure 8) or as contours of the parameter through a chosen plane in the building at a given time. An examples of a contour plot is shown in Figure 9.

Contours of the various parameters can be viewed on a workstation monitor with the appropriate software. The ability to change the parameter and viewed plane through the building is a powerful feature of CFD modelling. However it is important to assess the reliability of the data and not be impressed by the high quality visual presentation possible with this type of modelling.

In these calculations the building was assumed to be perfectly sealed hydro-dynamically for the first five minutes and, as expected, the pressure rose to high values. In reality, the pressures would be considerably less than this due to leakage effects.

3.3.4 Conclusions from Preliminary Modelling

The results from the zone model (CFAST) and CFD runs showed qualitative agreement except for the overpressure inside the building and the re-growth of the fire after ventilation.

Following the assessment of the results of the zone model runs of the two fire sizes and the available space in the building for the fire trays, a fire size of 3.9 m^2 was agreed for the tests, this giving a heat output of about 11MW.

Both models suggested that the fire was still burning at the time that the vents were opened but AEA considered that there was a risk of extinction. The safety procedure for the trials allowed for this possibility.

3.3.5 Measurement of Air Leakage

As the modelling indicated improbable high pressures in the building, it was concluded that air leakage from the building might be an important factor. Data measurements were undertaken before the trials by BSRIA[3].

A double fanblower system was installed in the north-east door opening with the remaining area of the door opening blocked off. The vents, internal door and SW door were closed as they were for the trials. The building had a large number of 150mm circular holes along 3 sides which could be closed or partly closed by a sliding door on the inside. The tests were carried out with the holes covered in the same way as they were in the actual tests.

The air-flow rate through the fans and the resulting pressure differentials were measured for a range of flow rates. From the results, the air leakage coefficient and exponent were determined for the compartment as a whole. No attempt was made to divide this leakage between the various parts of the building.

4 FIRE VENTILATION TRIALS

4.1 General

These trials were carried out in the Industrial B Building at the Fire Service College during the week commencing 20 November 1995. A total of 8 tests was undertaken and subsequently a report was produced which included the experimental results (6).

After the fire had been allowed to burn for 5 minutes, venting took place using various combinations of roof vents and doors. One test was carried out with a Positive Pressure Ventilation (PPV) fan fitted into one of the doors. Although it was not physically possible to deploy the fan in the appropriate position for accepted PPV methods, a test with a fan was included to give experience of its use in a large building. AEA Technology were not asked to model the use of a fan.

4.2 Instrumentation

The building was instrumented to measure the parameters listed in the table below:

Parameter	Details
Gas Velocity	The velocity of the gases through one open vent and one door were measured at a number of points using bi-directional probes in conjunction with sensitive micromanometers. The temperatures at each of the probes were also measured.
Gas Temperatures	Gas temperatures were measured by using vertical temperature trees of 4 and 5 metres in height at four positions in the building.
Smoke Density	Smoke density was measured at one position but two heights using equipment which consisted of a light projector and photocell
Surface Temperatures	Measurements of the surface temperature of the walls were required to assist with assessing the energy transfer into the walls. These measurements were obtained by fitting a thermocouple into the back of four of the tiles used to line the surface of the building. The back of these tiles were insulated so that the only path for heat transfer was from the front surface.
Heat Flux	Heat flux was measured with four radiometers: • one facing the roof • one facing the floor • two facing the fire

Parameter	Details
Fuel depth	The depth of the fuel in one tray was measured using an ultrasonic depth gauge. The gauge measured the depth in a small tray connected to the fuel tray and acting as a hydraulic balance. This technique did not prove successful, because the tray distorted during the fire.
Static Pressure	Static pressure was measured inside the building and at a number of points outside using a sensitive micromanometer.

To explore fire spread, pieces of wood were mounted on wooden poles and examined for signs of charring after each trial. In the later tests thermocouples were mounted above some of the wooden pieces and the temperature logged. The idea was that flaming would be accompanied by a rapid rise in the local temperature and this would be indicated by the thermocouple readings.

All the tests were recorded using colour video equipment from cameras in the following positions:

- high level external camera (at 20 metres) showing the whole building;
- wide angle camera inside the fire room;
- cameras viewing the external doors.

4.3 Results

The results are presented as graphs in Reference 6 and all the data is available on computer spreadsheet files. A graph showing typical results from a temperature tree is shown in Figure 10.

4.4 Discussion

The instrumentation performed satisfactorily although possible improvements have been identified for future work and are discussed in the report. The measurement of fuel regression rate proved unreliable.

The various tactical venting options used in the tests were compared by producing a figure of merit for the temperature changes after ventilation. There were no surprises in the results and the ranking order would no doubt have been predicted by experienced firefighters:-

- The most effective ventilation was with one door and two roof vents open. The least effective was the cross-ventilation case with two doors open and no roof vents open.

- When one roof vent and one door were used, then an upwind door and a downwind vent were the best. A door and vent at opposite ends of the building were more effective than a door and vent at the same end.

- The fire became ventilation-limited after the first minute and this lasted until ventilation took place at five minutes. The fire remained ventilation-limited after venting unless an upwind door and at least one roof vent were open.

- The PPV fan mounted into a doorway produced very similar results to natural ventilation. The comparison was made with very similar wind conditions where a fresh breeze was blowing directly into the door.

The trials provided valid experimental results for a limited range of wind and ventilation conditions.

5. COMPUTER MODELLING AFTER THE TRIALS

5.1 Initial Post-Trial Results

Following the trials, AEA was given the wind and ventilation conditions from two of the tests (Tests 5 and 7) and requested to predict the results using the computer model (7). The ventilation conditions for these tests after five minutes were:

Test 5	SW door and N vent
Test 7	SW and NE doors - no vents.

The predictions from the modelling were compared with the experimental results for all the parameters measured but, for the purpose of this report, a convenient comparison is of the temperature trees in the building and this is shown for Test 5 in (Figure 10).

Figure 10 shows that in the tests, temperature layers develop early in the fire. The layering of the temperatures (stratification) was maintained as the fire became oxygen starved although the temperatures did reduce. The predictions from the model showed that the stratification collapsed in the period before the vents were opened.

The comparison of the predictions at this stage was not good and improvement was required. There were several areas in which alternative approaches may have improved the predictions. These were the air leakages, the turbulence modelling of the gas flow and the wall boundary conditions. AEA found that stratification was predicted by their model in the two extreme cases of a perfectly sealed building on the one hand and a well-ventilated one on the other (with two doors assumed to be fully opened throughout). It was for this reason that the leakages in the building and their effects on the fire were considered critical. A further sensitivity study confirmed that the leakage proportions are capable of influencing the fire substantially.

The significance of leakages in the building increased as the work progressed. The initial trials in November 1995 included measurements to determine the overall air leakage from the fire compartment (Section 4.5). The problems with the modelling then prompted further tests to quantify the individual leakage paths from the building.

5.2 Further Leakage Measurements

A further series of leakage measurements was carried by BSIRA in July 96. Before these tests all the vents, windows and doors were sealed using plastic sheet and tape. The air-flow rate through a large fan and the resulting pressure differentials were measured for a range of flow rates to enable the airleakage coefficient and exponent to be determined. The measurements were then repeated after sequentially removing the seals. The results were then passed to AEA to provide a breakdown for the model of the various leakage paths.

The leakage measurements were made without a fire and it was accepted that the leakage characteristics could be changing during a fire because the vents might move or flex due to pressure loading and thermal distortion.

5.3 Subsequent Modelling

Further modelling work by AEA did produce credible results for the first five minutes of the experiments without the collapse of the stratification(8). The improvement appeared to hinge on more detail leakage modelling.

During the work several models and meshes were created which explored various ways of representing the leakages in the building. The largest mesh encompassed the inside and some of the external atmosphere which meant that this model was able to consider the interaction between the fire inside the building, the leakages and the wind. However this large mesh required very long times to run the model and to reduce these, smaller compromise meshes were developed for use in the first five minutes before the vents were opened. Although the wind was not modelled in this period, leakage effects were taken into account. The plan was to use the predictions obtained from the smaller mesh at the end of the first five minutes as the initial conditions for the second five minutes. The larger mesh would then have been used and the wind conditions during the trial would be modelled.

Figure 11 shows the latest results from the modelling for the first five minutes, prior to the vents being opened.

No modelling was carried out after the vents were open, using the detailed leakage modelling. The results in Figure 10 show some qualitative agreement with the experimental data during the ventilated phase but further runs are required of the vented stage, starting from the credible predictions at five minutes.

6. DISCUSSION

6.1 General

Figure 11 represents the final predictions carried out by AEA with the CFD model for a non-spreading fire in the Industrial Building for the period prior to the vents being opened.

Initially both zone and CFD models were assessed for this work but as the modelling work progressed the emphasis shifted from zone models towards CFD, because there was doubt over the ability of zone models to take account of wind and leakage effects and to quantify parameters in the fire in sufficient detail.

The proposal to use computer modelling in the way proposed was a sensible option at the time. The technical difficulties that have been encountered have meant that the early stages of the work took longer than anticipated. However, there is still much work required to move forward to the position where CFD can be used as a tool for this type of modelling. It should be noted that these difficulties were not predicted by any of the organisations responding to the tender invitation for this work.

AEA did eventually produce credible results for the first five minutes and, in achieving this, they have identified a critical parameter. Their work has shown that fires are very sensitive to leakages if they become starved of oxygen in weakly-ventilated buildings. They concluded that, during theoretical modelling, attention must be paid to the leakages, not only in the global sense but also with regard to the magnitudes and locations of the individual leakage paths. The term weakly-ventilated above relates to the first five minutes of the fire when the compartment was nominally closed but where there were still leakage paths around closed doors, vents etc.

Large fires can be oxygen-starved in well-ventilated buildings and therefore detailed knowledge of the leakages may also be necessary in modelling other fire scenarios.

The modelling work described above has involved non-spreading fires and was expected to be relatively straightforward, but turned out to be technically difficult and incurred delays. AEA persevered with the work, largely at their own expense, and had reached a stage where credible results were obtained for the first five minutes of the test fires. To progress further and reach a stage where there would be any confidence in the use of modelling to assist the overall project aims, it was necessary to complete the following areas of work:-

Complete the modelling for the ventilated stage of the validation tests

The latest predictions for the second five minutes (after the vents had been opened) are shown in Figure 10. These were not carried out starting from the credible predictions at five minutes produced using the most recent leakage modelling.

Further runs of the model were required to obtain results for the second five minutes for two of the validation tests. This work was necessary before the model results could be compared with the experimental data for a complete test to assess the level of credibility of the results.

The AEA view was that credible predictions for the ventilated phase are possible without further development and this is supported by the qualitative agreement with the experimental data shown in Figure 10.

Develop a model for fire spread and carry out validation tests of this model

No work had been carried out by AEA on fire spread as part of this contract. Fire spread is obviously an essential parameter to be considered in any comparison of firefighting ventilation tactics. There had already been problems with the simpler problem of a non-spreading fire and the modelling of fire spread is acknowledged to be difficult. The development of the fire spread model would inevitably take some time and be expensive. Once the model had been developed, comparison with experimental data would be necessary.

It was concluded by FRDG that the current state of modelling was not sufficiently advanced to be used as a tool for exploring ventilation. Major development of the models was still necessary and this would require significant expenditure. The aim of the project was to use existing expertise, not to pay for advancing the whole field of CFD. Therefore it was decided that no further work would be carried out on the application of computer modelling to tactical ventilation.

Although computer modelling has not proved the way forward for this project, it is not to say that this will be the case in the future. CFD modelling is complex and still requires development for fire modelling of large fires in buildings. A structured research programme supported by experimental work would be necessary to advance this field. This would be an expensive programme but may well show long term benefits. However, such a programme would be beyond the support of this project.

6.2 Proposed Further Work

If the modelling work had been successful then it was planned to use it to predict the effect of tactical ventilation and its ability to overcome adverse external wind effects. The modelling did not achieve these aims and it is now necessary to consider alternative approaches.

Further progress could possibly be addressed by experimental work but this would require a large building in which test fires could be carried out. No suitable facility was identified and the construction of a suitable steel structure on the FSC fireground was abandoned after the cost estimate was found to be prohibitive.

The use of small-scale modelling was also considered. This modelling was also known to be difficult because of the different scaling factors necessary for the various processes involved. This technique would also require validation to show that it reflected the behaviour of large fires.

The approach now proposed, to try to gain further information on the ventilation problem, is to carry out a study of recent fires in large buildings in order to document the fires and see if useful lessons can be learned about ventilation tactics and effects. Such post-mortems would allow the problems of these fires to be analysed and the effectiveness of the current guidance and any research needs to be assessed.

7. CONCLUSIONS

Following the extensive work carried on with computer modelling it has been concluded that there is still much work required to move forward to the position where CFD can be used as a tool for producing practical guidance on ventilation.

Credible predictions were eventually obtained for the first period of the test. Significant further work was required before there would be confidence in using modelling in other buildings and in fire spread situations.

AEA's modelling work has shown that fires are very sensitive to leakages if they become starved of oxygen in weakly-ventilated buildings. They concluded that during theoretical modelling, attention must be paid to the leakages, not only in the global sense but also with regard to the magnitudes and locations of the individual leakage paths. The importance of leakages should also be considered in the design of any future validation experiments.

Further work is now proposed to try to gain further information on ventilation tactics by carrying out a study of recent fires in large buildings, in order to document the fires and see if useful lessons can be learned about ventilation tactics and effects. Such post-mortems would allow the problems of these fires to be analysed to assess the effectiveness of the current guidance. This may also identify where further research is required.

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Dr Yehuda Sinai was the AEA Technology project officer for the computer modelling contract. His dedication to the technical aspects of this work is gratefully acknowledged.

REFERENCES

1. FRDG Publication 6/94, A Survey of Fire Ventilation, Dr A Hay (Warrington Fire Research), 1994.

2. Manual of Firemanship, The Behaviour of Fire, Tactical Ventilation of Buildings & Structures, HMSO 1996.

3. RCEC/16420036/Z01 Issue 2, Review of Computer Codes for Modelling the Ventilation of Large Scale Fires, S A Ramsdale, Y L Sinai, B S Kandola and D Kay (AEA Technology), February 1995.

4. AEA/CS/RCEC/16420036/Z/03, Issue 2, Work Completed by AEA Technology on Behalf of the Home Office for the period 6 February to 20 March 1995, Y L Sinai, M P Owens, D Kay and S Ramsdale, June 1995.

5. AEA/CS/RCEC/16420036/Z/05, Issue 2, Computer Modelling Studies of Ventilation of Large Fires: Progress to 31 October 1995, Y L Sinai, M P Owens, D Kay (AEA Technology) February 1996.

6. FRDG Publication Number 15/96, Fire Ventilation Trials November 1995, J A Foster, G V Roberts, 1996.

7. AEA/CS/RCEC/16420036/Z/06, Issue 3, Computer Modelling Studies of Ventilation of Large Fires: Resume of Results of Activities G to L January - March 1996, Y L Sinai, M P Owens, (AEA Technology) August 1996.

8. CFDS/CONS/REP96/359.1, Computer Modelling Studies of Ventilation of Large Fires - Management Report, Y L Sinai (AEA Technology), June 1997.

NOTES

[1] There were changes to the name of the contractor during the period of this work. The name and address in October 1997 was AEA Technology plc, CFX International, 8.19 Harwell, Didcot, Oxfordshire, OX11 0RA. Throughout this report the company has been referred to as AEA or AEA Technology.

[2] Chemitrade , Station House, 81-83 Fulham High Street, London SW6 3JW. Chemitrade supplied Norpar 7 to their specification dated November 4 1991. Norpar 7 is one of the range of Exxon Chemicals products.

[3] The Building Services Research and Information Association (BSRIA), Old Bracknell Lane West, Bracknell, Berkshire RG12 7AH.

Figure 1: Industrial B building from the south-east

Figure 2: Industrial B building from the north-west

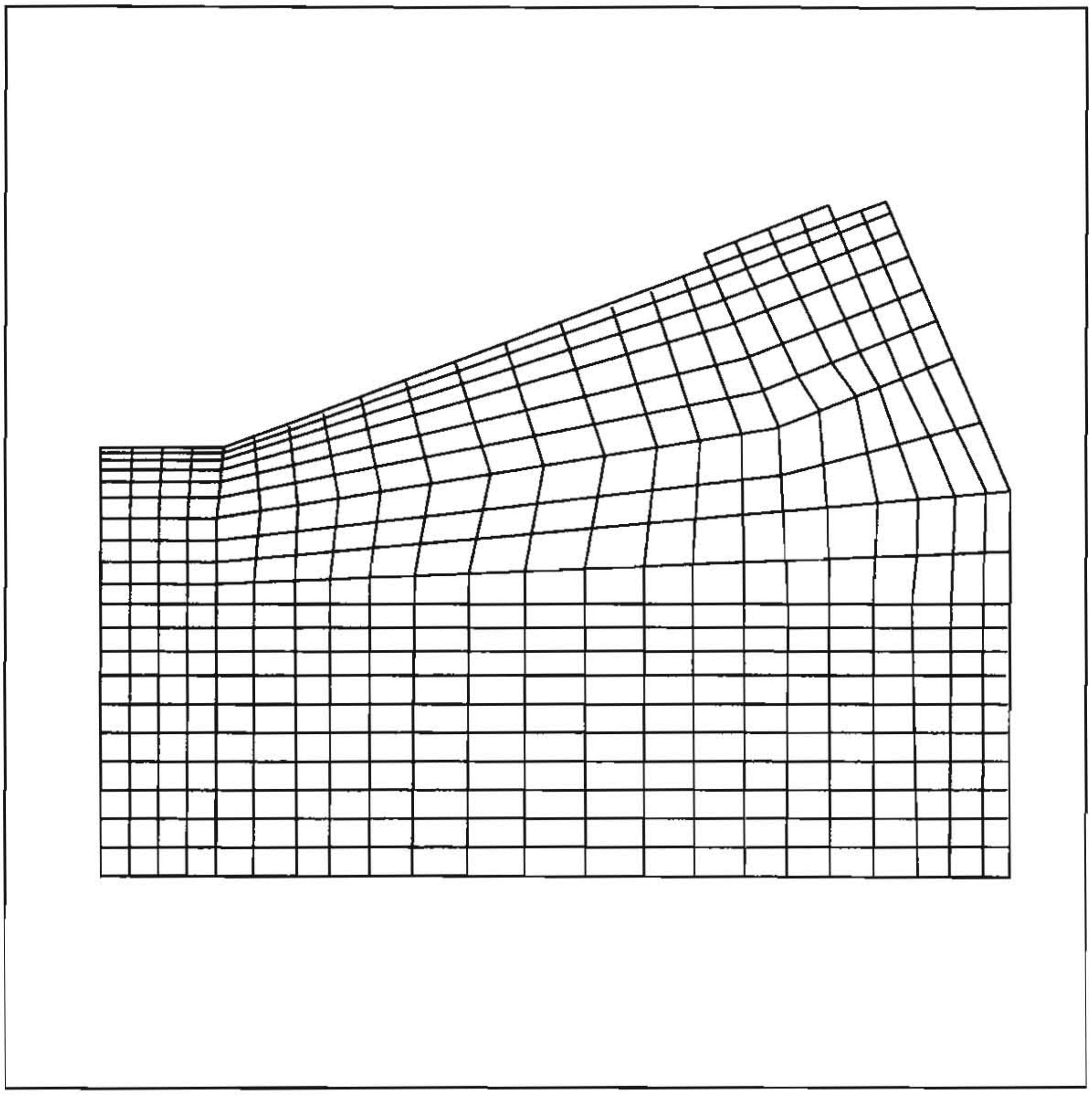


Figure 3: Vertical slice through a vent, showing the CFD mesh inside the compartment

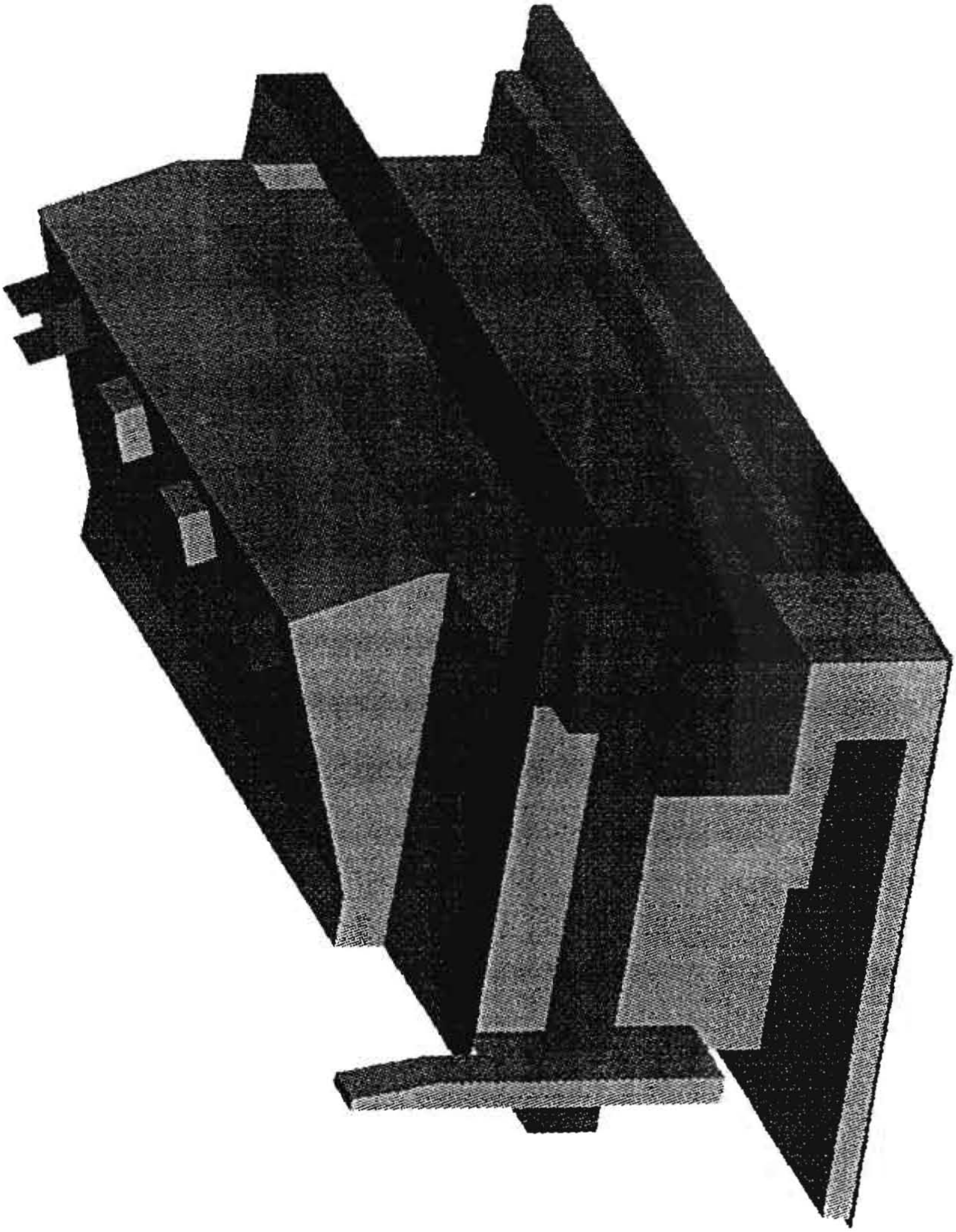


Figure 4: The CFD geometry, viewed from the south (vents open)

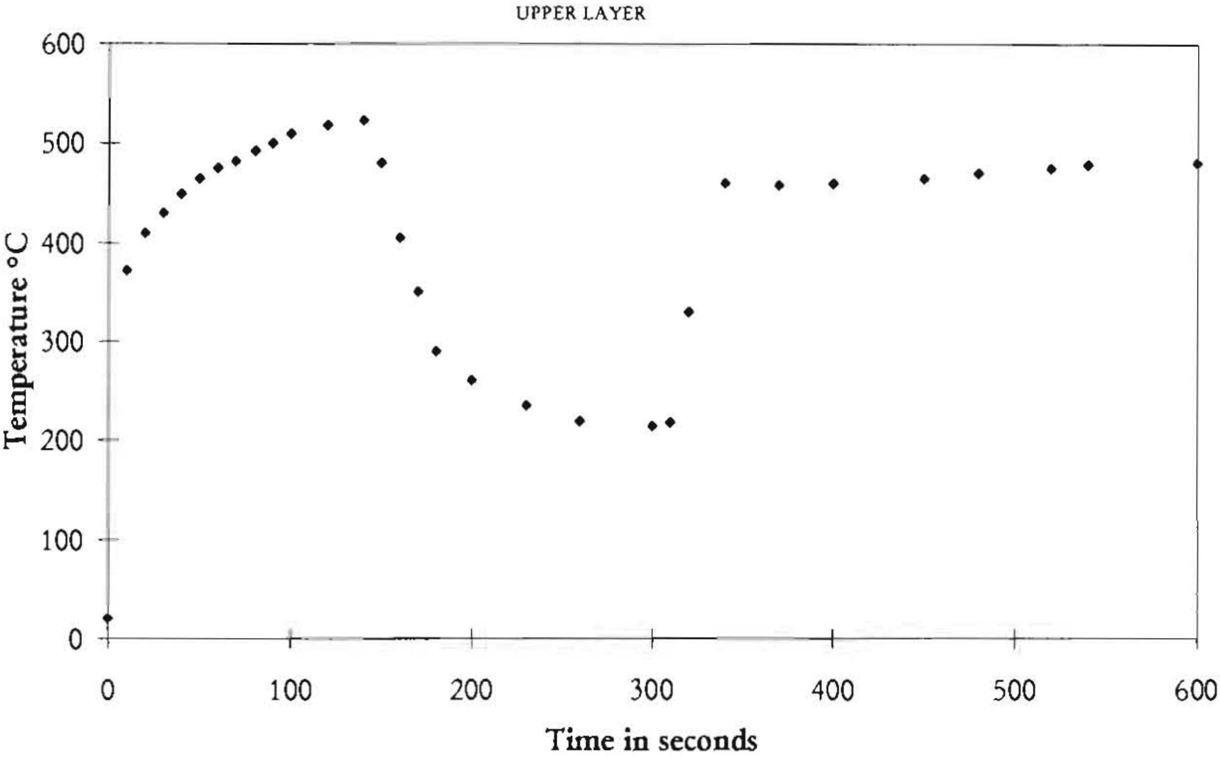


Figure 5: CFAST: Upper layer temperature against time (Fire Size 4.5m²)

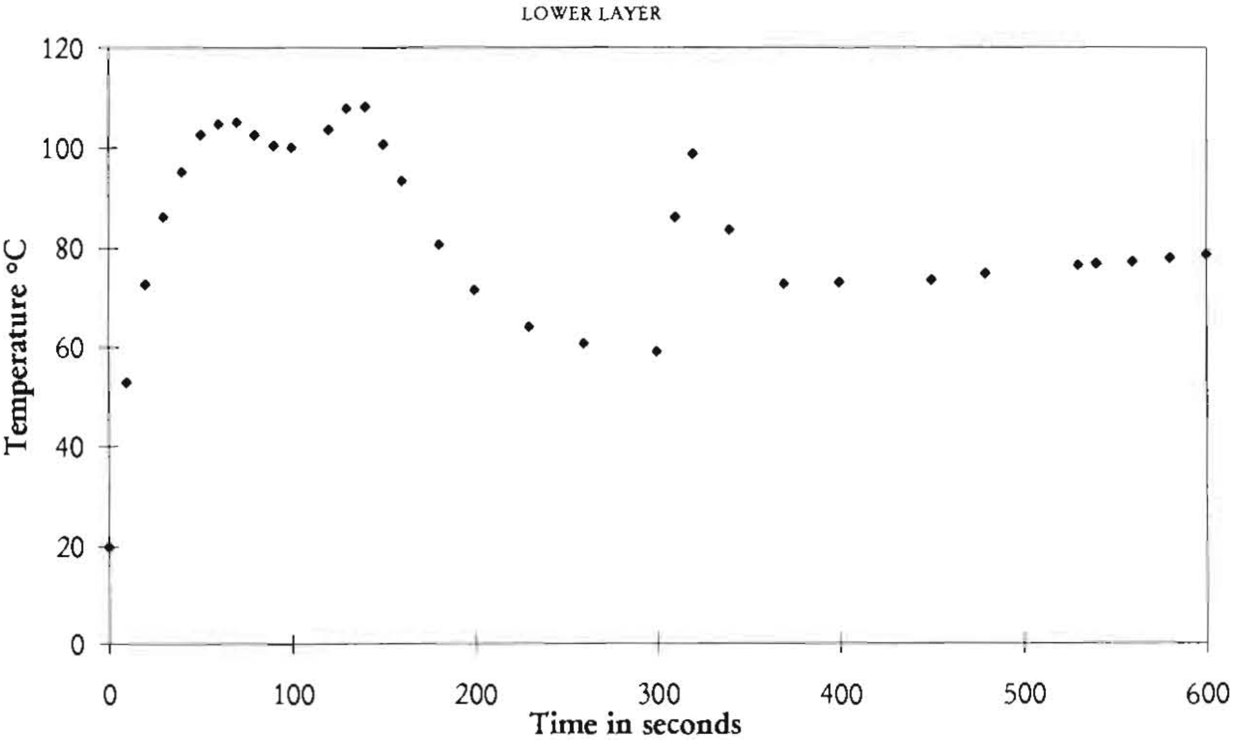


Figure 6: CFAST: Lower layer temperature against time (Fire Size 4.5m²)

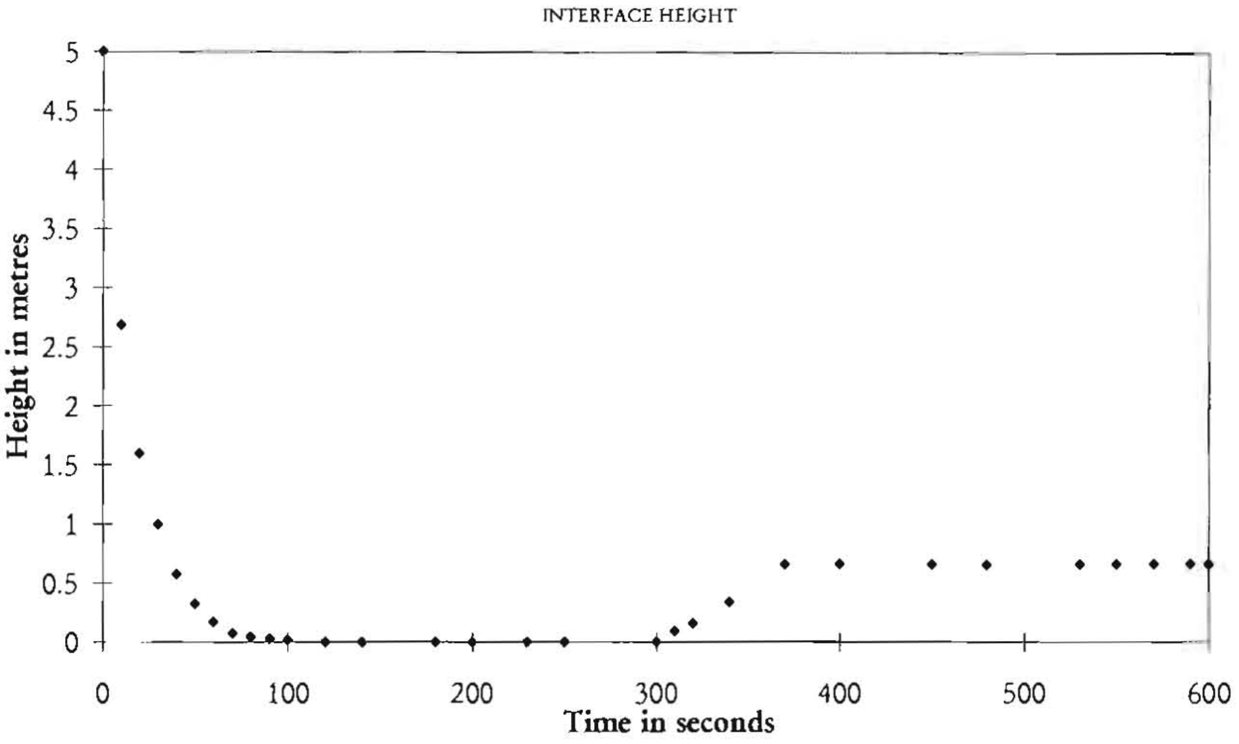


Figure 7: CFAST: Interface height against time (Fire Size4.5m²)

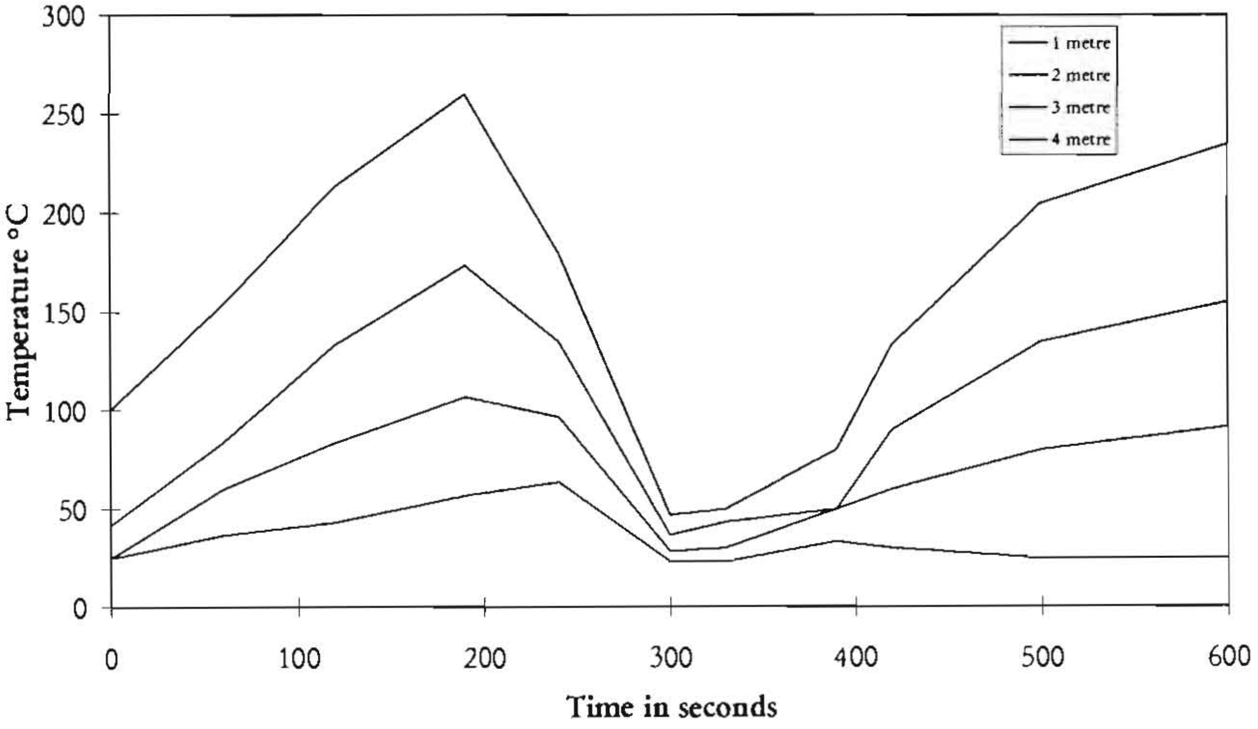


Figure 8: CFX: Temperature against time for one temperature tree

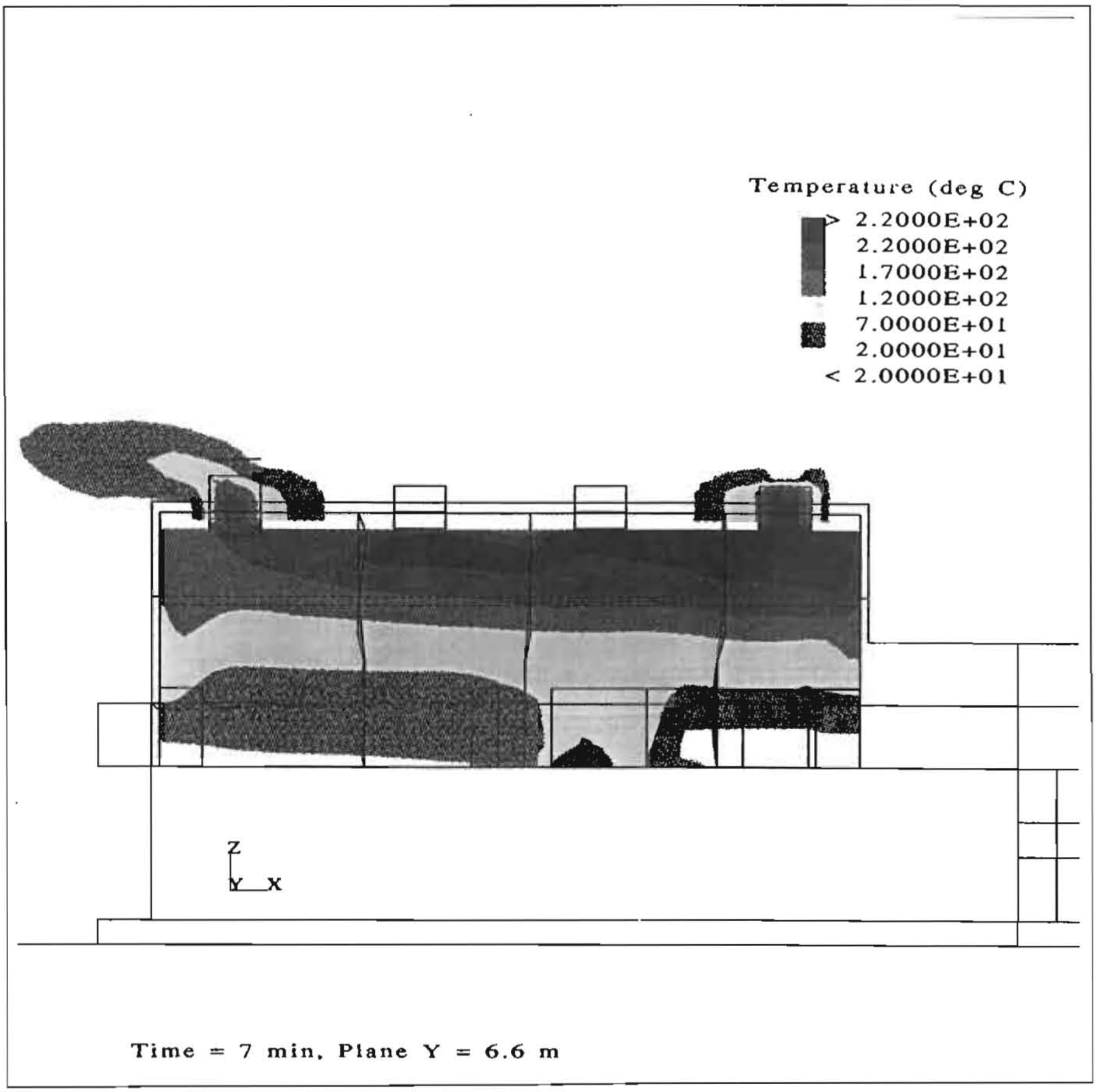


Figure 9: CFX Temperature Contours in a plane through the vents

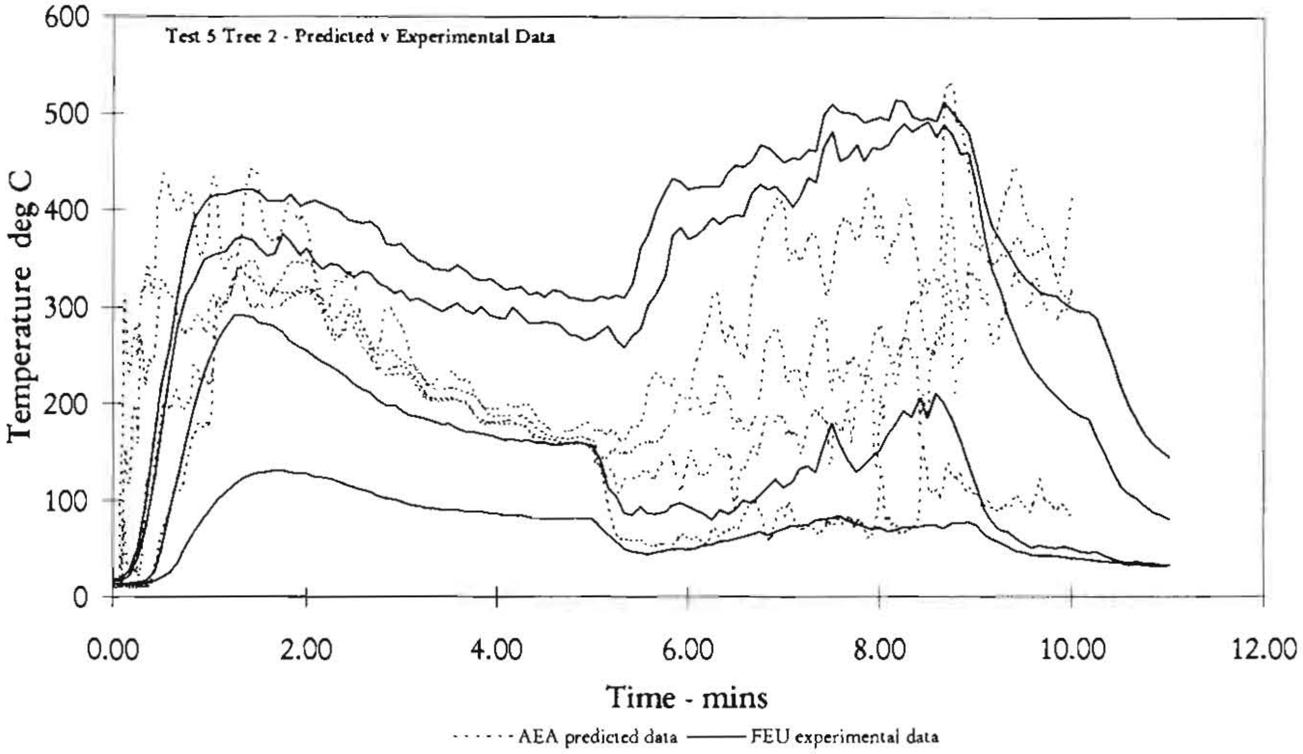
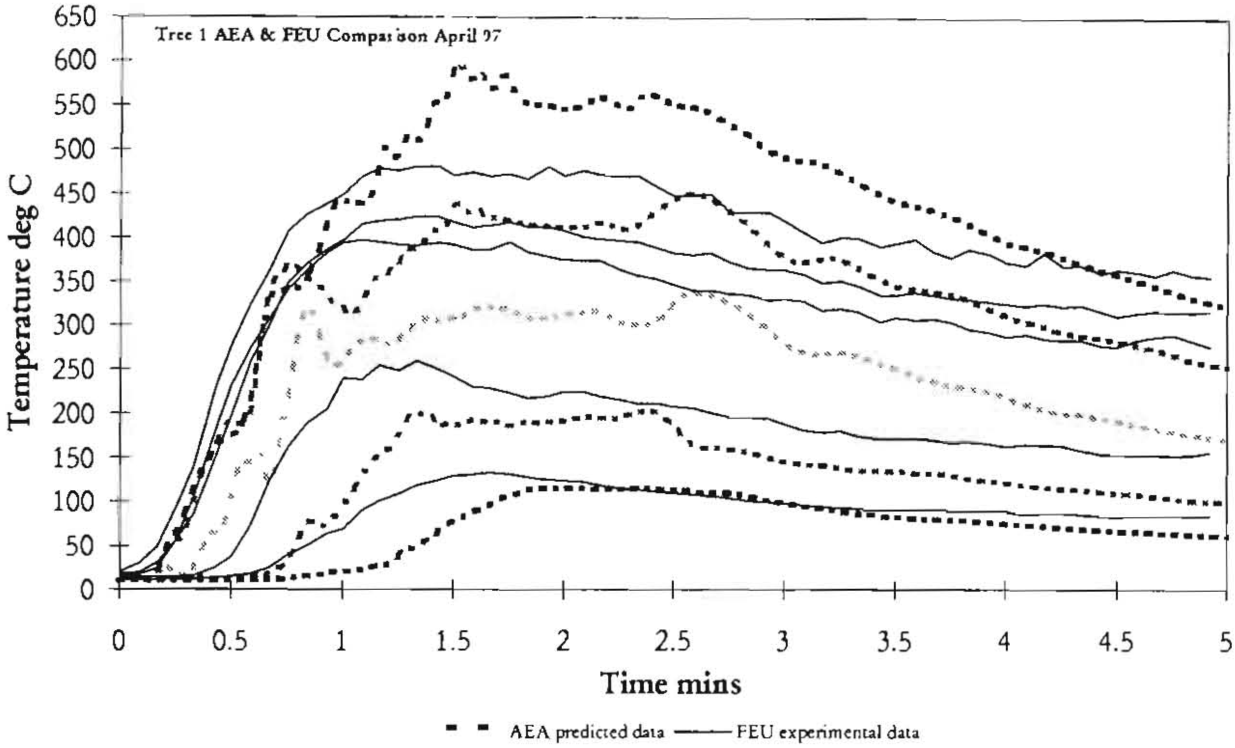


Figure 10 : Early Comparison of Experimental and Predicted Results for one temperature tree. Thermocouples at 1 metre intervals.



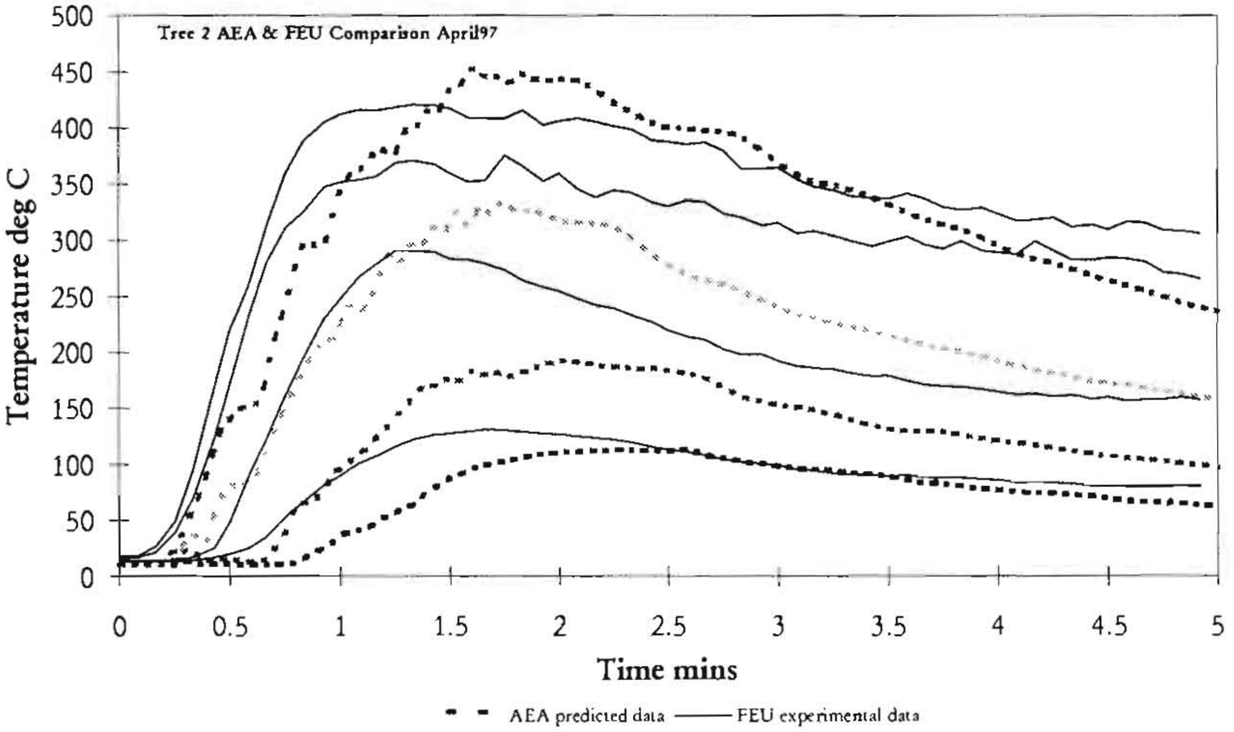


Figure 11: Comparisons of latest predictions for two temperature trees.