



Home Office
Fire Research and Development Group

FIRE MODELS TRAINING MANUAL FOR FSO'S

VOLUME 3: HAZARD-I

by

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CONTENTS

	<u>Page</u>
PART 1: INTRODUCTORY NOTES	3
1. About this manual	3
2. Basic Review of Fire Development	3
3. What is a fire model?	5
4. Carrying out a fire modelling study	6
5. Assessment of hazard to life	8
6. Evacuation	9
7. Typographical conventions	9
PART 2: USING HAZARD-I	10
1. Installation	10
2. Accessing HAZARD-I	10
3. Opening menu	10
4. Creating input data file	12
5. Running HAZARD-I	14
6. Analysing the results	15
7. Using the fire properties database	17
PART 3 : HOUSE FIRE STUDY	19
1. Introduction	19
2. Initial scenario (HOUSE1)	19
2.1 Setting up the input data file	19
2.2 Running the fire model	32
2.3 Analysing the results	33
3. Closed window (HOUSE2)	41
4. Living room door and window closed (HOUSE3)	43
5. Different armchair fire (HOUSE4)	44
6. Sensitivity Analysis (HOUSE5 - HOUSE9)	46
PART 4: SHOP FIRE STUDY	48
1. Introduction	48
2. Initial scenario (SHOP1)	48
2.1 Setting up the input data file	49
2.2 Running the fire model	52
3. Polystyrene Foam Fire (SHOP2)	54
4. Polystyrene Foam Fire with Venting (SHOP3)	56
REFERENCES	58
ANSWERS TO EXERCISES	59
APPENDIX A - HAZARD ANALYSIS FORM	62
APPENDIX B - DATA FILES FOR HOUSE1	64

APPENDIX C - HOUSE FIRE STUDY - HAZARD ANALYSIS FORMS	70
APPENDIX D - DATA FILES FOR SHOP1 CASE	76
APPENDIX E - SHOP FIRE STUDY - HAZARD ANALYSIS FORMS	78

PART 1 : INTRODUCTORY NOTES

1. ABOUT THIS MANUAL.

The purpose of this manual is to provide training to Fire Safety Officer's (and other fire brigade staff) in the use of fire models to predict fire spread in a building and its consequences. The training is intended to familiarise FSO's with fire modelling through practical experience so that they can use fire models in connection with their work on assessment of the fire safety aspects of building designs. **However, it should be stressed that the predictions made by fire models should not be assumed to have any great accuracy but only serve to provide an indication of the likely outcome of the fire.**

This manual includes exercises in fire modelling which require the use of the model HAZARD -I which the reader will need access to. HAZARD -I is a package of fire modelling programs which includes the zone model "FAST". HAZARD -I is produced by:-

Building and Fire Research Laboratory,
National Institute of Standards and Technology,
Gaithersburg
MD 20899
USA

Copies of HAZARD-I may be obtained from:-

The One-Stop Data Shop
National Fire Protection Association
Fire Analysis and Research Division
1, Batterymarch Park, PO Box 9101
Quincy, MA 02269-9101
USA

This manual is one of a series available from the Fire Research and Development Group. The other volumes have a similar content but are based on the models ARGOS produced by the Danish Institute of Fire Technology, and FASTLITE produced by the National Institute of Standards and Technology, USA.

2. BASIC REVIEW OF FIRE DEVELOPMENT

Fire models are based on an understanding of the physical processes involved in a fire. The following is a description of these processes which are illustrated in Figure 1.

Here we are concerned exclusively with fires which occur in buildings. The fire normally begins at a single location in one room (although this is not always so, particularly in the case of arson).

The burning of a solid item involves two main processes. Firstly, the material is heated to the point where it vaporises, a process known as pyrolysis. Secondly, the vapour produced mixes with the air and undergoes an exothermic (heat producing) chemical reaction with the oxygen present, the process known as combustion.

From the ignition point on the surface of the burning item, the flames spread, increasing the burning area. The combustion process releases heat, smoke and gases which rise from the burning material in a plume. The gases produced typically include Carbon Dioxide, Carbon Monoxide, Hydrogen Cyanide and steam. Soot particles are produced from the incomplete combustion of the material, and these particles form smoke. On the other hand, oxygen is consumed by the fire which will cause the concentration of oxygen in the room to fall below the normal level which is 21% by volume.

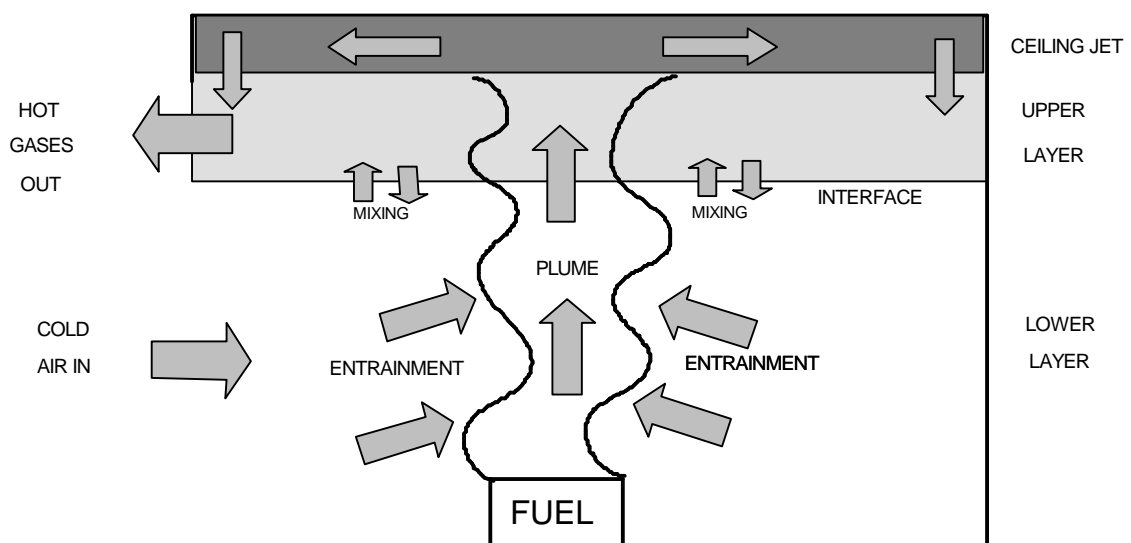


Figure 1 The Physical Processes of a Fire

The radiation from the fire heats the surfaces of further items in the room, causing further pyrolysis, and if the ignition temperature is reached, these items ignite and add to the fire. This process is called secondary ignition.

As the fire continues to grow, there may come a point where the radiation level in the room is high enough to cause a general ignition of all items, producing a sudden jump in the severity of the fire and the heat release rate. This process is known as flashover.

While the fire is burning, a plume of hot gases and smoke will rise from the fire. As the hot gases rise, driven by their buoyancy, further air is drawn into the plume from the surrounding space, a process known as entrainment. Usually, this plume reaches the ceiling, although this is not always the case if the fire is in a compartment of large height where a warmer air layer has already developed under the ceiling. When the plume reaches the ceiling, the hot gases delivered spread out under the ceiling in a layer called the ceiling jet. Fed by the ceiling jet, a layer of hot, smoky gases

gradually builds up under the ceiling. This layer is usually referred to in fire modelling as the upper layer.

The air in the room can be regarded as divided into two main volumes: the upper layer of hot smoky gases and the relatively clear lower layer, with an interface between. However, in a real fire, mixing between the two layers occurs so that the interface may not be distinct. As the fire proceeds, more gases are produced which are fed via the plume into the hot upper layer. The upper layer gets thicker and so the interface gradually descends towards the floor.

Openings to the fire room such as open doors or windows allow the fire products in the upper layer to spread to neighbouring rooms. These openings will also allow fresh air into the fire room which provide the fire with more oxygen and maintain combustion as long as there is fuel available.

If there are no openings to the fire room, the oxygen in the room is gradually consumed by the fire until the concentration has fallen to a level which can no longer support combustion when the fire stops burning.

Heat is transmitted around the fire compartment by three mechanisms.

- (i) Heat is carried around by the currents of hot gases such as the plume. This is known as convection.
- (ii) Heat is transmitted through materials by conduction. In the fire compartment heat is conducted into the walls, floor and ceiling where they are in contact with the hot gases.
- (iii) Heat is transmitted through space by radiation. In the fire compartment heat is radiated from the fire and from the hot upper layer, to the surroundings.

3. WHAT IS A FIRE MODEL?

Although there are other ways of modelling fire, this manual is concerned with the use of a computer model which predicts the spread of the fire and combustion products using mathematical calculations carried out by the computer.

There are two types of computer fire model in common use: zone models and field models.

The zone model is a more simple representation than the field model; it divides the fire compartment up into a few large sections called zones such as the plume of hot gases rising from the fire and the hot smoky gas layer which builds up under the ceiling, and relies on well established but empirical relationships for the transfer of heat and smoke between these zones.

A field model divides the compartment into a large number of cubes, and calculates heat and fluid flow between each cube and its neighbours using the fundamental equations of physics. For this reason, field models are likely to be more accurate but require more computing power and so are more expensive to use.

HAZARD-I, the subject of this manual, is a zone model.

4. CARRYING OUT A FIRE MODELLING STUDY.

The steps involved in a fire modelling study are as follows:-

- define the fire scenario(s)
- set up the input data
- run the model
- analyse the results

(i) **Definition of the Fire Scenario.** Once you have decided what you want to find out, the first step in the fire modelling study is to define the fire scenario of interest. This will include deciding where the fire will start, what materials are involved, whether doors and windows are open or closed, where the occupants of the building are located and whether any fire protection systems are present. If an overall hazard assessment of a building design is required, a range of scenarios should be considered, so that the main risks are covered.

(ii) **Setting up the Input Data.** Once the fire scenario has been decided, data is entered into the model to define the scenario. This data will include the following:-

- room dimensions
- locations and dimensions of doors and windows
- ceiling, floor and wall materials
- position of the fire
- heat release rate of the fire
- product generation rates (smoke and toxic gases) of the fire

Care must be taken in deciding on the input data. If the data entered is incorrect, the results will also be incorrect. When all input data has been entered, the data is saved to a file.

The heat release rate entered will typically have a critical effect on the results obtained. Typical heat release rates are given in Table 1. Other sources of data on heat release rate are the SFPE handbook (1) and the databases within the fire models HAZARD-I (2) and ARGOS. The software packages 'FPETOOL' produced by the Building and Fire Research Laboratory, National Institute of Standards and Technology, USA, and 'ASKFRS' produced by the UK Fire Research Station both give methods of calculating heat release rates.

(iii) **Running the model.** Once the input data file has been created, the model is set running to calculate the progress of the fire specified. The time taken for the model to complete the fire simulation can vary from a few seconds to a few hours depending on the type of computer equipment used and the complexity of the scenario. The more rooms that are included, the longer the run will take. For the simpler scenarios, HAZARD -I takes only a few minutes to run on a PC with a 486 or Pentium processor. As the simulation proceeds, the results are displayed graphically on the screen. The results are also written into a data file on disk for later analysis.

Furniture Item	Peak Rate of Heat Release (kW)
Waste-paper basket containing paper or milk cartons	4 - 18
Armchair	1000 - 2000
Sofa	1500 - 3000
Television	120 - 290
Mattress, twin-size	Up to 2800
Wardrobe, wooden, containing small amount of clothing	3000 - 6400

Table 1. Typical heat release rates of furniture items

(iv) **Analysis of the Results.** The results produced will include the following:-

- the temperature of the upper layer in each room
- upper layer depth in each room
- ceiling, floor and wall temperatures
- gas concentrations
- heat radiation
- smoke obscuration

The results may be analysed by plotting graphs using the “FASTPLOT” program (part of HAZARD-I) or by examining the data in the output file.

An important point is that the predictions from a fire model should not be assumed to have any great accuracy as there are many uncertainties in the modelling process.

There are uncertainties in the input data, for instance the heat release rate profile of the fire may be different in reality from the profile assumed. Also, many approximations are made in the model which reduce the accuracy of the results, for instance all zone models are based on the assumption that the upper and lower gas layers are of uniform temperature, smoke and gas density throughout their volume which is not the case in reality.

Because of the limited accuracy of the results, it is often more useful to look at the results comparatively to show the effect of making a change to the fire scenario. For instance the model could be run to predict the effect of an armchair fire and then repeated with a different armchair made of more fire resistant material.

Alternatively, the results from a single run of a model may be considered separately but it should be remembered that the results are only approximate. For this reason, it may be necessary to add a safety factor or margin for error to the results as this will not normally be included in the model.

It may also be useful to carry out a sensitivity analysis of the results to find out how sensitive the results are to variations in the different input parameters. This can be done with any or all of the input parameters to see which ones are more critical. A sensitivity analysis will show the size of the error in the results produced by uncertainty or inaccuracy in the input data.

5. ASSESSMENT OF HAZARD TO LIFE

Fire models may be used to predict the property loss or the hazard to life. It will be assumed here that the interest is in predicting the hazard to life. The prediction of the hazard to life of the occupants of the building is not a simple matter. First of all, hazard criteria need to be set to define the conditions which cause incapacitation or death.

There are a number of ways in which a fire causes a hazard to life to the building occupants. The main hazards are described below together with the criteria for hazard to life.

(i) **Direct contact with the fire**

This is not generally predicted by fire models.

(ii) **Heat radiation from the upper layer of hot gases.**

This is the hazard due to the downward radiation from the upper layer of hot gases when the interface between the upper and lower layers is above head height. A radiation level of 2.5kW/m^2 has been quoted as a threshold for human tenability (4).

Alternatively, an upper layer temperature level may be defined which implies a hazardous level of heat radiation. The hazard criterion quoted by Beard (3) is an upper layer temperature greater than or equal to 183°C (or 456°K).

(iii) **Direct contact with hot gases.**

The hazard due to contact with hot gases, both internal (due to inhalation) and external, occurs when the interface between the upper and lower layers descends below head level. The hazard criterion quoted by Beard (3) is an upper layer temperature greater than or equal to 100°C (or 373°K).

(iv) **Smoke obscuration.**

When the view across the room is obscured by smoke, this will make it more difficult for the occupants to find their way to the exits. Critical values quoted by Beard (3) are when the optical density at head height is greater than or equal to 0.065 per metre (0.65 dB/m) for people unfamiliar with the building and greater than or equal to 0.2 per metre (2.0 dB/m) for people familiar with the building.

(v) **Inhalation of toxic gases.**

The toxic gases commonly produced by a fire include Carbon Monoxide, Hydrogen Cyanide and Carbon Dioxide which are hazardous if the concentrations are high enough. The critical value quoted by Beard (3) for Carbon Monoxide is 3,000ppm or 0.3% by volume which is thought to cause death within 30 minutes and unconsciousness in a shorter time.

(vi) **Lack of Oxygen.**

The fire consumes oxygen as it burns, which reduces the concentration of oxygen in the room. Exposure to air with a low oxygen concentration causes incapacitation and death. Purser (5) discusses the effect of exposure to low oxygen levels and based on this work a critical oxygen concentration of 10% will be assumed.

A hazard analysis form has been included in Appendix A which may be used to help assess the hazard using the above criteria. Section 2.3.3 explains how to use this form to make a hazard analysis.

6. EVACUATION

To carry out a complete analysis of the fire safety of a building, it is necessary to assess the likelihood of the occupants making a safe escape. This can be done by estimating the time required to escape and comparing this with the conditions in the building as predicted by the fire model. The program 'EXITT' within the HAZARD-I package predicts escape times and the program 'TENAB' calculates whether occupants are incapacitated during escape. However, these parts of HAZARD-I are not covered within this manual.

7. TYPOGRAPHICAL CONVENTIONS

◆ indicates an action to be taken.

<Return> indicates a key to be pressed.

10.00 shading indicates data displayed on a HAZARD-I input screen which may be changed.

PART 2: USING HAZARD-I

1. INSTALLATION

Installation instructions are provided with the HAZARD-I software. The installation takes only a few minutes to complete. The release notes for HAZARD-I version 1.2 state that the hardware requirements are a PC which is a 386 or later with at least 2.5 megabytes of free extended memory. HAZARD-I also requires about 3 megabytes of free disk space.

It will be assumed here that HAZARD-I version 1.2 is being used. The manual may still be useful with earlier versions of HAZARD-I but there will be some differences. It is recommended that you obtain version 1.2 to use this manual.

2. ACCESSING HAZARD-I

To access HAZARD-I from the DOS prompt, change to the directory in which HAZARD-I was installed, usually C:\HAZARDI, and type "HAZARD", for instance from the DOS prompt type:-

```
C: <Return>
CD C:\HAZARDI<Return>
HAZARD<Return>
```

This will bring up the opening menu.

3. OPENING MENU

HAZARD-I consists of several separate programs. The fire model itself is called CFAST which is a zone model capable of modelling a building with up to 15 compartments or rooms. Other programs within HAZARD-I include a database of fire properties of materials, a data input program and programs to analyse the results from CFAST.

The opening menu of HAZARD-I has five options along the top menu bar, leading to further options as shown in Table 2.

This manual is limited to using the programs CFAST and CPLOT. The evacuation model EXITT has not been included as it is not easy to use, except for the pre-defined scenarios. To define a new scenario for EXITT, a data file must be written manually to define the building, occupants and escape routes. Details on using EXITT are given on page 128 of Software User's Guide for HAZARD-I.

Two other programs in the HAZARD-I package, TENAB and SURVIVAL, predict whether occupants are incapacitated by the fire. These programs use the output from EXITT which must be run first.

Detector response is predicted by DETACT-QS. This program runs independently and is limited to heat detectors only.

MENU OPTION	PROGRAM NAME	DESCRIPTION
1. FILE		Management of HAZARD-I Data Files
2. CREATE INPUT DATA		
- Data Input		Enter data into input file for CFAST.
- Multiple Fuel Packages	MLTFUEL	Calculates the total heat release rate for more than one fuel package. The result is then used as input data to CFAST.
- Examine Database		Database of fire properties of materials
- Detector Activation	DETECT-QS	Calculates the heat detector activation time.
3. RUN FIRE MODEL	CFAST	Runs the fire model CFAST
4. ANALYZE RESULTS		
- Examine Data	CPLOT	Plots graphs and creates data files of selected output data from CFAST.
- Egress	EXITT	Calculates progress in evacuation of occupants based on results from CFAST.
- Tenability	TENAB	Calculates whether occupants are incapacitated during escape based on results from CFAST and EXITT.
- Egress and Tenability	SURVIVAL	Combines EXITT and TENAB to calculate, in one step, whether the occupants survive
5. HELP		

Table 2 - Opening Menu of HAZARD-I

4. CREATING INPUT DATA FILE

This section describes how to use the “Create Input Data” programme to create an input data file. Full details about entering data in each input screen are given in part 3, section 2.1.

To create an input data file, select the option “Create Input Data” and “Interactive Data Input” from the opening menu of HAZARD-I. A screen titled “Initialization” will appear as in Figure 2.

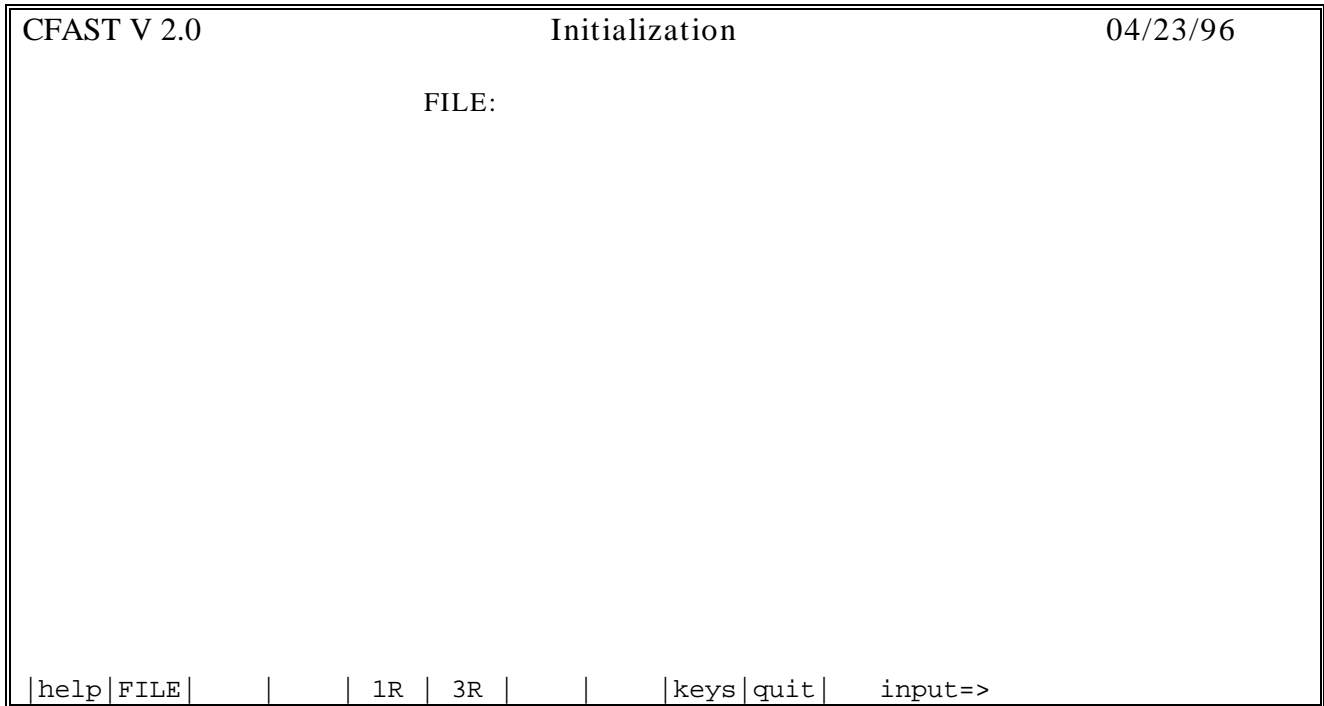


Figure 2 CFAST menu “Initialization”

CFAST V 2.0		Overview		04/23/96	
File:		Title: DEMO #1 a single compartment calculation			
<u>Geometry</u>	<u>Time</u>	<u>Ambient Conditions</u>		<u>(external)</u>	
Compartments	1	Simulation	180	Temperature	300.00 288.00
Doors,...	1	Print	10	Pressure	1.0E+05 1.0E+05
Ceiling vents	0	History	0	Station elv.	0.0 0.0
MV connects	0	Display	0	Wind speed	0.0
		Restart	0	Ref. height	10.00
				Power law	0.1600
 <u>Fire Specification</u>					
	Type	Specified fire (constrained)			
	Species tracked	O2	CO2	CO	HCN HCL TUHC H2O OD
	Ceiling jet	OFF			
 Range: Alphanumeric (50) Units: Name or Title					
help	go				unit keys quit input=>
F1	F2	F3	F4	F5	F6 F7 F8 F9 F10 <= Function keys

Figure 3 CFAST menu “Overview”

The menu bar along the bottom of the screen shows the options which may be selected by pressing one of the function keys. Reading from left to right, these options are activated by function keys F1 to F10.

First of all, an existing file must be selected. If a new file is to be created it must be based on one of the files supplied.

- ◆ Select “1R” (F5 key) for a 1 room case or “3R” (F6 key) for a 3 room case.

Once a case has been selected, the first input screen, titled “Overview”, will appear (see Figure 3).

Moving between Input Screens

The Overview screen is the first of a series of 11 screens.

- ◆ To see a list of these screens, select the “Go” option (press <F2>).

The eleven input screens are as follows:-

Screen Title	Parameters Defined
Overview	Title of case, simulation time, time intervals
Ambient Conditions	Temperature and pressure (internal and external), wind speed
Geometry	Width, depth and height of compartments
Vents (doors,...)	Height and width of doors and windows
Vents (ceiling,...)	Shape and area of vents in ceilings
Fans, Ducts,...	Powered ventilation between compartments
Thermal Properties	Thermal properties of ceiling, floor and wall materials
Fire Specification	Definition of fire: heat of combustion, heat release rate, species production
Objects	Alternative and additional fires
Files	Names of data files. Save data to file.
Version and Settings	Version of HAZARD-I model, setting of display colours and physical units

You can move to any screen by selecting it with the cursor and pressing **<Return>**. Alternatively, instead of using the “Go” option, you can move through the screens sequentially using the PageUp and PageDown keys.

Layout of Input Screens

The Input Screens for HAZARD-I all follow the same basic format. It is worth familiarising yourself with the different parts of the screen before beginning.

The title of the screen appears centrally at the top.

The menu bar along the bottom of the screen shows the options which may be selected by pressing one of the function keys. Reading from left to right, these options are activated by function keys F1 to F10.

The range and units are displayed one line above the menu bar at the bottom of the screen. These define the valid range and the units of the data to be entered. The values quoted here apply to the data currently selected by the cursor. No value may be entered outside the range quoted. To change the units used, select the “Units” option (F8 key).

The rest of the screen is taken up with data. When you first enter the screen, default values for each parameter will appear. These may be left as they are or changed. You will see that the data appears in two different colours. This is to differentiate between the data which may be changed on the current screen which appears in the bolder colour, and the data which is quoted for reference only and which can only be changed on another screen. To change an item of data, use the arrow keys to move the cursor to highlight the data to be changed and type in the new value.

Help is given by pressing the F1 key. A separate help screen is displayed for each input screen.

Ending the “Create Input Data” programme

Once all data has been entered, the information is saved from the “Files...” screen where the names of the data files are defined. This is explained in Section 2.1.11 but in this case you can just quit without saving the data.

- ◆ Quit the “Create Input Data” programme by selecting the Quit option (F10 key).

5. RUNNING HAZARD-I

Once an input data file has been created, you can run the fire model CFAST to simulate the fire scenario that you have defined.

- ◆ Select “Run Fire Model” from the opening menu and then select the required input and output files. For instance you can select one of the example files which are included in HAZARD-I, e.g. SCEN-1.DAT which is a fire of a smouldering cigarette on a sofa. The details of these example cases are given in the HAZARD-I manuals. The different lines on the graphs show the conditions in different rooms. In some cases there may appear to be fewer lines than rooms but this is because some lines are hidden beneath others.

- ◆ Now select “Begin Simulation” and press <Return>.

Four graphs appear on the screen as the simulation proceeds. These graphs show the following parameters as they vary with time:

- Upper-layer temperature (top left)
- Oxygen concentration (top right)
- Layer interface height (bottom left)
- Fire Size (bottom right)

You may terminate the simulation at any time by pressing the <Esc> key.

If more than one room is being modelled, the conditions in each room are shown by a different coloured line on the graph. The graph axes are rescaled as the simulation proceeds. The run-time can be from a few minutes upwards depending on the complexity of the case and the specifications of your computer.

6. ANALYSING THE RESULTS

Once the model has been run on your input data you will want to analyse the results.

- ◆ From the opening menu, select “Analyse Results”, “Examine Data”.

This will invoke the program CPLOT (or FASTPLOT in earlier versions of HAZARD-I). CPLOT reads in the data from the history file created by running the fire model CFAST and plots selected data on the screen. CPLOT will also display the data in tabular form on the screen or save data to a file.

A typical session will now be described. Commands and responses which the user must type in appear in **bold**. A commentary, not displayed on the screen, appears in italics. It will be assumed that a history file has already been created.

Command>	HELP <Return>	<i>to list all other commands available with CPLOT.</i>
Command>	FILE <Return>	<i>to select a history file for analysis.</i>
History file	HOUSE1.DMP <Return>	<i>or the name of the history file required.</i>
Command>	VARIABLE <Return>	<i>to display a list of variables predicted by CFAST which appear in the history file. Any of these variables may be selected for analysis.</i>

You must now create a list of variables which you wish to analyse. You do this by adding variables to a list.

Command>	ADD <Return>	<i>to add a variable to the list.</i>
Enter variable(s) to add to the list:		
<Enter> to initiate read	TEMPERATURE <Return>	<i>(this may be shortened to TEMP)</i>
What compartment number (1 ... 5) for Temperature	1 <Return>	
And which layer (u,l)	U <Return>	
Variable matched to Temperature in compartment 1, layer = U		

- ◆ Once you have carried out the above commands repeat this procedure to add a second variable to your list. For instance, add the upper layer temperature in compartment 2.
- ◆ When you have added to the list all the variables that you want, press <Return> to initiate the read. This causes data for the selected variables to be read into the program for analysis.

You may now plot the data on the screen as follows:

Command>	PLOT <Return>
----------	----------------------

A list of the variables you have selected will appear.

- ◆ Select by number the variable(s) you wish to plot, e.g. **1** or **(1 2)**.

CPLOT will now proceed to plot your data on the screen.

In the same way, the LIST command may be used to display the data in a table on the screen. In the same way as the PLOT command, this will only display the values selected from the list.

The SAVE command may be used to save the data for the selected variables in a file.

Finally you can end the session. Note that once you end the session you will lose the list of variables you created, although you will still retain any data you have saved.

Command> **END** <Return> *to end your session with CPLOT.*

7. USING THE FIRE PROPERTIES DATABASE

HAZARD-I also includes a database of fire properties on a number of materials and items of furniture. The data held here may be used as input data for the CFAST model but the data must be re-entered manually.

- ◆ To use this database, from the main menu select “Create Input Data”, “Examine Database”.
- ◆ Type **L** <Return> to select the “List” option. This will list out the materials in the database.
- ◆ Now select “M” for material codes and then select “S” for screen output or “P” for printer output.
- ◆ Press <Return> for the first material code and press <Return> again for the last material code.

A full list of all materials in the database will appear. Four types of data are held in the database:

M - Material property,
T - Toxicity,
C - Cone Calorimeter and
F - Furniture Calorimeter

The “True” and “False” flags (T and F) indicate which types of data are held for each material.

- ◆ Type **S** to stop the listing and then select “Exit” to return to the first menu.
- ◆ Now select “Find” to look up data on a particular material or item of furniture.
- ◆ At the next prompt, “Enter material name” enter a material of interest, e.g. “Chair” or “Foam”.
- ◆ Now select the type of data, e.g. type “F” for furniture calorimeter.
- ◆ A list of the materials which satisfy the search criteria will be listed. You may find that no materials are listed in which case you should repeat the search but selecting another material or data type.
- ◆ Press <Return> to continue and at the prompt “Enter MATERIAL CODE or EXIT”, enter a material code selected from the list.
- ◆ The selected data will then be displayed.

- ◆ When you have finished with the data, select “Exit” then enter the following:

Search for next record (y/n): **n**

Press any key to continue <**Return**>

Enter material name: <**Return**>

Then select “Exit” to return to the first screen.

Other options in the database programme allow the data to be Added, Edited or Deleted.

PART 3 : HOUSE FIRE STUDY

1. INTRODUCTION

This section contains a set of exercises for you to perform in modelling a house fire. An initial scenario must first be set up by entering data in the input file. After running this initial case, a series of modifications will be made to the scenario and the model will be run again and any changes in the results noted. The results will be analysed to determine the hazard to life.

2. INITIAL SCENARIO

The initial scenario to be considered is of an armchair fire in the living room of a two-storey house. The armchair is assumed to burn with only a brief smouldering phase. The door from the living room to the hall is open and there is an open window in the living room. Doors from the hall to the kitchen and lounge are closed. The floor plan and input data are shown in Figure 4 and Table 3.

2.1 Setting up the input data file.

For the basics of getting around HAZARD-I, see Part 2 of this manual.

2.1.1 Opening the input data file.

- ◆ Invoke HAZARD-I (see Part 2 for instructions about doing this).
- ◆ From the opening menu, select “Create Input Data”, then select “Interactive Data Input”.

A set of options are displayed on the bar at the bottom of the screen.

- ◆ Select 3R (3 rooms) by pressing <F6> .

A basic data file will be opened containing default values for a building with 3-rooms.

2.1.2 Input Screen: Overview

On the overview screen (see Figure 3), only the numbers in the column headed “Time” may be changed. These numbers are displayed on the screen in a different colour to the rest. In Figure 3 the numbers which may be changed are shown on a shaded background.

- ** Change the title to “HOUSE FIRE - INITIAL SCENARIO”
- ** Change the simulation time to 1000 seconds. This sets the period over which the simulation is carried out. When the simulation reaches 1000 seconds it will stop and return the user to the menu.
- ** Change the print time to 10 seconds. This sets the interval at which the results calculated by HAZARD-I are recorded in the output file for printing.

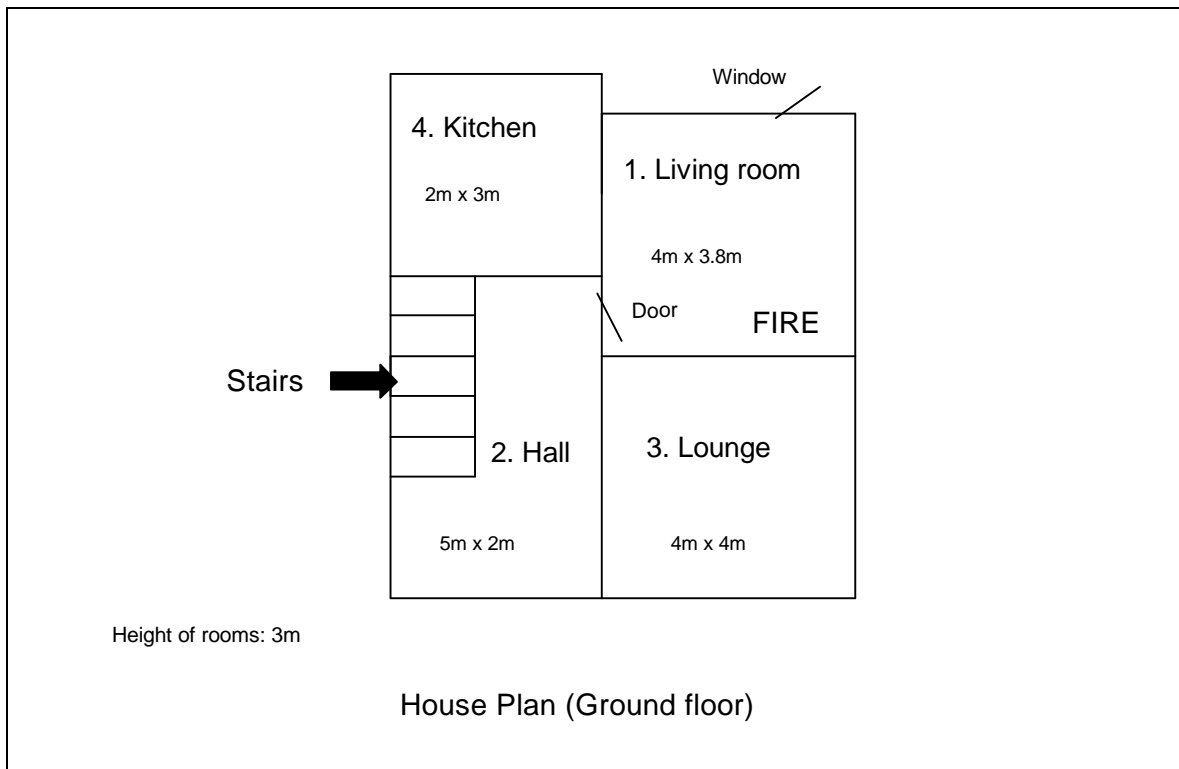


Figure 4. House fire scenario - floor plan.

OPENINGS		
<u>Connecting rooms</u>	<u>Type of opening</u>	<u>Dimensions</u>
Living room/hall	Door, open	sill height = 0m soffit height = 2m width = 1m
Living room/outdoors	Window, open	sill height = 1m soffit height = 2m width = 1m
WALLS, FLOORS AND CEILINGS		
Walls	Concrete	
Floor	Concrete	
Ceiling	Gypsum board, 13mm thick	
FIRE		
Armchair in living room.		

Table 3. House fire scenario - input data.

- ** Change the history time to 10 seconds. This sets the interval at which the results are recorded in the “dump file” for use in other programs within HAZARD-I.
- ** Change the display interval to 10 seconds. This sets the interval at which the results are displayed as graphs during the simulation.
- ** Leave the restart time at zero.

Your screen should now appear as in Figure 5.

CFAST V 2.0		Overview		04/23/96	
File:		Title: House Fire - Initial Scenario			
<u>Geometry</u>	<u>Time</u>	<u>Ambient Conditions</u>		<u>(external)</u>	
Compartments	3	Simulation	1000	Temperature	300.00 288.00
Doors,...	3	Print	10	Pressure	1.0E+05 1.0E+05
Ceiling vents	0	History	10	Station elv.	0.0 0.0
MV connects	0	Display	10	Wind speed	0.0
		Restart	0	Ref. height	10.00
				Power law	0.1600
 <u>Fire Specification</u>					
	Type	Specified fire (constrained)			
	Species tracked	O2	CO2	CO	HCN HCL TUHC H2O OD
	Ceiling jet	OFF			
Range: Alphanumeric (50)			Units: Name or Title		
help go			unit keys quit input=>		

Figure 5 CFAST menu “Overview”

2.1.3 Input Screen: Ambient Conditions

- ◆ Press <PageDown> to display the “Ambient Conditions” screen.

This screen sets the ambient conditions both within and outside the building. This includes the temperature, pressure and station elevation and information on the external wind conditions.

- ◆ Set the internal temperature to 293°Kelvin (20°C). Make sure you know what units are selected. The units are displayed at the bottom of the screen above the menu bar and apply to the parameter currently selected by the cursor.

The other parameters should be left unchanged. Your screen should now appear as in Figure 6. The pressure is given as 1.0E+05 Pascals. This is scientific notation for 1.0×10^5 or 100,000 Pascals.

CFAST V 2.0		Ambient conditions		04/23/96
	(internal)	(external)		
Temperature	293.00	288.00		
Pressure	1.0E+05	1.0E+05		
Station elv.	0.0	0.0		
Wind speed		0.0		
Ref. height		10.00		
Power law		0.1600		
Compartments	3	Maximum pressure differential	0.0	
Doors,...	3	Maximum elevation change	2.44	
Ceiling vents	0	Total internal volume	106.57	
MV connects	0			
Range: 200.00 to 350.00 Units: Temperature in KELVIN				
help go unit keys quit input=>				

Figure 6 CFAST menu “Ambient Conditions”

2.1.4 Input Screen: Geometry

- ◆ Press <PageDown> to display the “Geometry” screen.

The room dimensions are entered from this screen. If the 3R option was selected when the input data file was opened, 3 rooms should already be present. In this example we need four rooms so you will need to add another.

- ◆ First, set the width, depth, height and floor elevation for rooms 1, 2 and 3. (See Figure 4 for the room numbers and dimensions).
- ◆ Now use the Add function (F4 key) to add a fourth room and enter the dimensions of this room.

When you have entered data for all rooms your screen should appear as in Figure 7.

CFAST V 2.0		Geometry				04/23/96	
Dimensions							
Compartment Number:		1	2	3	4		
Width:		4.00	5.00	4.00	2.00		
Depth:		3.80	2.00	4.00	3.00		
Height:		3.00	3.00	3.00	3.00		
Floor elevation:		0.0	0.0	0.0	0.0		
Range: 0.0 to 150.00		Units: Distance in METER					
help	go	ADD	DEL		unit	keys	quit input=>

Figure 7 CFAST menu “Geometry”

2.1.5 Input Screen: Vents (doors,...)

- ◆ Press <PageDown> to display the “Vents (doors,...)” screen.

On this screen, any doors and windows or other openings between two rooms or between one room and the outside are defined. The outside is defined as a room and is numbered after the last room in the building. Therefore in this example, where there are four rooms, the outside is defined as room 5.

The top half of the screen displays the room dimensions which were entered on the previous screen. The bottom half of the screen shows the vents linking different rooms. Each line of data defines a different vent.

In this example, two vents need to be defined (see Figure 4): the door linking the living -room to the hall (room1 to room 2) and the window in the living-room (room 1 to room 5).

First, the vents supplied need to be removed.

- ◆ Place the cursor on the first pre-defined vent and delete it using <F5>.
- ◆ Remove the other vents in the same way.

Now, you need to add the vents required. First, add the door between the living room and the hall. The room numbers are shown in Figure 4.

- ◆ Add a vent by pressing <F4> and completing the data entry box for the vent joining rooms 1 and 2 using the dimensions given in Table 3. The vent number should be 1 which indicates that this

is the first vent between these two rooms. The wind coefficient which defines the angle of the wind to the vent opening, for openings to the outside, should be left as zero.

- ◆ Press <F2> to accept this data.
- ◆ Select the O/C option (open/closed) by pressing <F6> to set the position of the door. The door position is defined on a scale of 0 to 1 where 0 is completely closed and 1 is completely open. The graph which appears shows that the door will be open throughout the simulation. Leave this unchanged by pressing <Esc>.
- ◆ Using the same procedure, add a vent to represent the open window from the living room to the outside, using the dimensions in Table 3. Again, the vent number is 1, and the wind coefficient is zero.

Now that the two vents have been defined, your screen should appear as in Figure 8.

CFAST V 2.0		Vents (doors,...)				04/23/96				
Dimensions										
Compartment Number:	1	2	3	4						
Width:	4.00	5.00	4.00	2.00						
Depth:	3.80	2.00	4.00	3.00						
Height:	3.00	3.00	3.00	3.00						
Floor elevation:	0.0	0.0	0.0	0.0						
Vents (doors,...)										
with respect to first room					wrt second room			- absolute -		
#	width	sill	soffit	wind	#	sill	soffit	a_sil	a_sof	Vent(1->
1	1.00	0.0	2.0	0.0	2	0.0	2.0	0.0	2.0	1
1	1.00	1.0	2.0	0.0	5	1.0	2.0	1.0	2.0	1
Range: 0.0 to 4.00 Units: Distance in METER										
help go ADD DEL O/C unit keys quit input=>										

Figure 8 CFAST menu “Vents (doors,...)”

2.1.6 Input Screen: Vents (Ceilings...)

- ◆ Press <PageDown> to display the “Vents (Ceilings...)” screen.

This screen refers to openings in the ceiling. No inputs are required here for this simulation.

2.1.7 Input Screen: Fans, Ducts...

- ◆ Press <PageDown> to display the “Fans, Ducts...” screen.

This screen refers to mechanical ventilation. No inputs are required here for this simulation.

2.1.8 Input Screen: Thermal Properties

- ◆ Press <PageDown> to display the “Thermal Properties” screen.

This screen defines the thermal properties of the materials which make up the ceiling, floor and walls of each room. The entries need to be changed to look like those in Figure 9.

- ◆ To change a material, place the cursor on the relevant entry and select “Data” (F6 key). This brings up the data file of thermal properties. Move the cursor to the required material name and select “Pick” (F6 key).
- ◆ To switch off an entry, select “Off” (F5 key). In this case the heat loss to that surface is not computed.

Repeat for each entry until your screen looks like Figure 9.

```

CFAST V 2.0                               Thermal properties                               04/23/96

                                     Dimensions

Compartment Number:      1           2           3           4
      Width:             4.00       5.00       4.00       2.00
      Depth:             3.80       2.00       4.00       3.00
      Height:            3.00       3.00       3.00       3.00
      Floor elevation:    0.0        0.0        0.0        0.0

                                     Thermal properties from THERMAL.DF

Ceiling properties:      GYP1/2   GYP1/2   GYP1/2   GYP1/2
Floor properties:       CONCRETE CONCRETE CONCRETE CONCRETE
Wall properties:        CONCRETE CONCRETE CONCRETE CONCRETE

Range:  Alphanumeric ( 8)           Units:  Name or Title
|help| go |FILE|ADD |OFF |DATA|      |keys|quit| input=>

```

Figure 9 CFAST menu “Thermal properties”

2.1.9 Input Screen: Fire Specification

◆ Press <PageDown> to display the “Fire Specification” screen.

In this screen the values of all parameters shown in bold type in Figure 10 may be defined. There are two rows of parameters with a graph in between. The parameters in the upper row are constant throughout the fire whereas the parameters in the lower row vary with time. The graph refers to the parameter currently highlighted by the cursor and shows how that parameter varies with time throughout the fire.

To define the time-varying parameters in the bottom row, a series of values must be entered for each time point. Only one series of time points may be defined and these are used for all time-varying parameters.

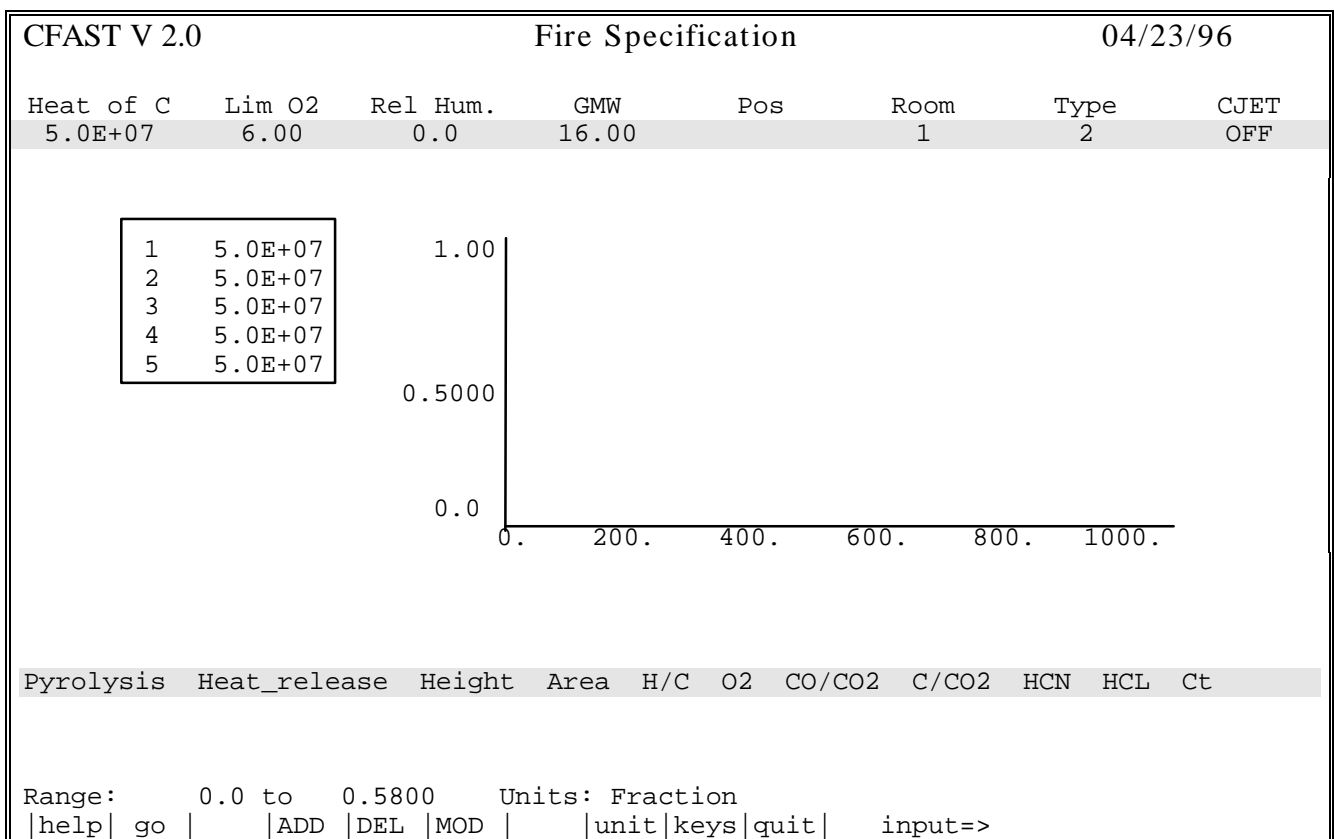


Figure 10 CFAST menu “Fire Specification”

2.1.9.1 Time Points

The time points are shown in the box on the left-hand side of the screen. These must be set to the values shown in Figure 11.

- ◆ To change the time points, select “MOD” (press <F6>).

Initially you may find that the first time point is non-zero and cannot be changed. It may be possible to rectify this by saving the file, exiting and opening the file again (see Section 2.1.11).

- ◆ Add further time points by pressing <F4> until you have a total of 5 points.
- ◆ Now enter the values shown in Figure 11.
- ◆ When all values have been entered, press <Esc> to exit.

The graph displayed should now show the simulation period from 0 to 1000 seconds on the horizontal axis.

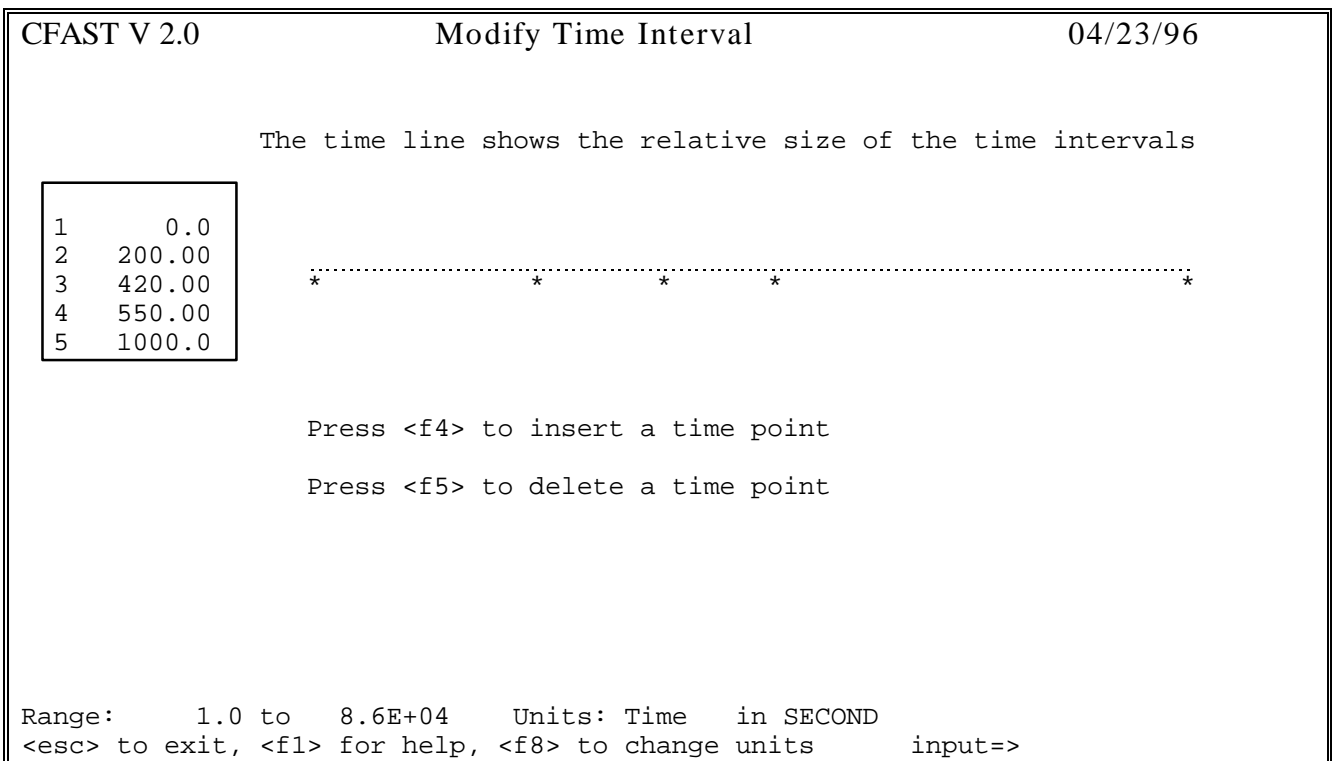


Figure 11 CFAST menu “Modify Time Interval”

2.1.9.2 Heat of Combustion (Heat of C)

On the top row of the “Fire Specification” screen the first parameter is “Heat of C”. This parameter is the heat of combustion of the fuel, which is the amount of heat produced per unit mass of fuel consumed.

- ◆ From the “Fire Specification” screen, highlight “Heat of C” and set this to 17 MJ/kg. Be careful about the units of measurement. For instance, if your units are Joule/kilogram, you should enter 1.7 E+07 (i.e. 1.7 x 10⁷). You can change the units by selecting the “Units” option (press <F8>).

The value entered for “Heat of C” will be automatically applied to all time points as you will see from the table and graph.

2.1.9.3 Limiting oxygen index (Lim O2)

This parameter is the minimum concentration of oxygen in the air which will allow a flame to continue to burn.

- ◆ Set “Lim O2” to 10%.

2.1.9.4 Relative Humidity

- ◆ Set “Rel Hum.” to zero.

2.1.9.5 Gramme-Molecular-Weight (GMW)

This parameter is the molecular weight of the fuel vapour, but is not used in the calculations in this case and the default value of 16 should be kept.

2.1.9.6 Position

This parameter is the position of the fire in the room. The X, Y and Z co-ordinates must be given. These are the distances from a corner of the room in each direction, where Z is the height above the floor. Note that you are not asked which corner the fire is in, as this is not used in the calculations.

- ◆ Enter the following values: X=1.0m, Y=1.0m and Z=0.0m.

These values place the fire near one corner of the room, near the floor.

2.1.9.7 Room

This parameter is the room number in which the fire is located. The room numbers were defined in the “Geometry” input screen.

- ◆ Enter 1 here to indicate that the fire is in the living room.

2.1.9.8 Type

The “Type” parameter defines the fire as one of two types. Type 1 is an unconstrained fire which means that it will be assumed that there is enough oxygen in the room to sustain the fire according to the heat release rate specified. A “Type 2” fire is constrained by the amount of oxygen in the room. For the case of a “Type 2” fire, HAZARD-I will automatically reduce the heat release rate as the oxygen concentration falls.

◆ Enter 2 here to select fire type 2, a constrained fire.

2.1.9.9 Ceiling Jet

This parameter is a new addition in HAZARD-I version 1.2 to allow a calculation of the ceiling jet.

◆ Set “CJET” to OFF.

2.1.9.10 Pyrolysis

Moving to the bottom row of parameters on the “Fire Specification” screen, the first parameter is “Pyrolysis”. This is the rate of consumption of fuel by mass specified at each time point throughout the duration of the fire. The pyrolysis rate does not need to be set as it is automatically calculated from the heat release rate and the heat of combustion from the following formula:

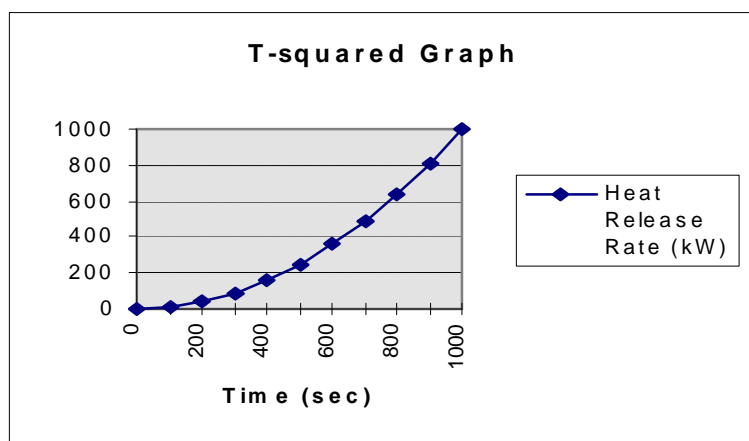
$$\text{Pyrolysis Rate} = \frac{\text{Heat Release Rate}}{\text{Heat of Combustion}}$$

Alternatively, the pyrolysis rate may be entered first and HAZARD-I will calculate the heat release rate. However, in this case ignore the pyrolysis rate and set the heat release rate instead.

2.1.9.11 Heat Release Rate

It is now necessary to set the heat release rate to define the fire growth. Note that this is not predicted by the model but must be entered by the user. The model predicts the consequences of the defined fire on the conditions in the building.

Heat release rates may be defined from mathematical formulae, e.g. a “ t^2 fire” where the heat release rate increases with the square of the time. Many fires follow this pattern in the early growth phase. An example of a t^2 fire is shown below.



For a single item of furniture such as an armchair the best source of data is from an experimental test carried out in free-burn conditions. Published sources of such data are listed in Part 1 Section 4 of this manual. In this case, a typical heat release rate of an armchair fire is used.

The heat release rate is entered here for each time point.

- ◆ Place the cursor on “Heat Release”.

The heat release rate values currently defined are shown in the box to the left of the graph.

- ◆ Enter the values shown in Table 4 but be careful of the units of measurement used. Remember that 1kW equals 1 kilojoule per second.

Time (sec)	Heat Release Rate (kW)
0	1
200	58
420	830
550	450
1000	120

Table 4. Heat Release Rate Data

2.1.9.12 Height

This is the height of the base of the flames above the floor.

- ◆ Enter 0.5m here for each time point.

2.1.9.13 Area

This is the burning area of the fire.

- ◆ Enter 0.5m² here for each time point.

2.1.9.14 Species Production Rates

The remaining parameters on the bottom row are the species production rates which are defined as fractions. For instance, CO/CO₂ is the fraction of carbon monoxide to carbon dioxide produced by mass. The amounts of these species produced by the fire cannot be predicted by HAZARD-I and must therefore be entered by the user. HAZARD-I will use the values given to calculate the concentrations of these gases in each room. Some of these species are toxic gases and so the value entered will have a critical effect on the hazard-to-life calculation when the results are analysed.

The production rates can vary according to the burning conditions, such as the amount of ventilation, but the following fractions are fairly typical in some circumstances:-

H/C - the hydrogen/carbon fraction in the unburnt fuel	0.08
CO/CO ₂ - carbon monoxide/carbon dioxide	0.02
C/CO ₂ - carbon/carbon dioxide	0.02

- ◆ Set the production rates for the above species. For each species, set the value as shown above for each time point.

The other species will not be considered here and may be left as zero.

This concludes the input to the “Fire Specification” screen.

2.1.10 Input Screen: Objects

- ◆ Press <PageDown> to display the “Objects” screen.

In this screen, further fires may be defined. However, we will not consider other fires here so this screen should be disregarded.

2.1.11 Input Screen: Files

- ◆ Press <PageDown> to display the “Files” screen.

From the “Files” screen you can save your data file.

- ◆ Press <F6> to select “append display file”. This will cause graphs to be displayed on the screen as the simulation proceeds.
- ◆ Press <F7> to move to the second “Files” screen.
- ◆ Enter HOUSE1.DAT as the main data file. This file will contain all input data.
- ◆ Enter HOUSE1.DMP as the history file. This file will contain output data for use by other parts of HAZARD-I.
- ◆ Point the cursor to the main data file. An asterisk should be present to indicate that the file has not yet been saved.
- ◆ Press the return key to save this file and, if necessary, confirm that you wish to replace the file. When you have saved the file the asterisk will disappear.
- ◆ Press <Esc> to exit from the second “Files” screen.

2.1.12 Versions and Settings Screen

- ◆ Press **<PageDown>** to display the “Versions and Settings” screen.

This screen displays the version of the program which is running and allows settings such as display colours to be changed.

2.1.13 Quitting the Input Program

Now that all data has been entered and saved, quit the program by pressing **<F10>**.

2.2 Running the Fire Model

Before running the model, first view the input data file you have created (HOUSE1.DAT) to check that it is the same as the one in Appendix B.

- ◆ From the main menu, select “File”, then select “View File” and type in your file name, e.g. “HOUSE1.DAT” and select OK.
- ◆ When you have finished viewing the file, press **<Esc>** to exit.

If any changes to the file need to be made you can do this either by selecting the “Edit File” option or by going back into the “Create Input Data” section. The latter method is preferable as it is easier to see which parameters are being changed.

When you are satisfied that your input data file is correct, you can proceed to run the model:-

- ◆ From the main menu, select “Run Fire Model”
- ◆ Place the cursor on “Input File”, press **<Return>**, then press **<Tab>** to move to the list of data files and select the name of the input file you created, e.g. “HOUSE1.DAT”. If no files appear, go back to the main menu and select “File”, “Setup” and check that the working directory indicates where your data files are held e.g. C:\HAZARDI\DATA.
- ◆ The output file name should now be the same as the input file except that it will have a .LST extension, e.g. “HOUSE1.LST”. Whatever file name you use, the extension should be “.LST” so that the file is recognised as an output file.
- ◆ Select “Begin Simulation”.

The simulation will now proceed and should take no more than a few minutes on a PC with a 486 processor or similar. During the course of the simulation, graphs should appear on the screen showing the progress of the fire. You can pause the simulation by pressing **<Pause>** and then press another key to continue. To abort the simulation at any time, press **<Esc>**. Different coloured lines are displayed on the graph, each line showing the conditions in a different room. In this simulation, the two varying lines show the conditions in the living room and hall. The other rooms

appear as a single horizontal line as the doors to these rooms are closed and the conditions remain unchanged.

If no graphs appear, this may be for one of the following reasons:-

- the “append file” option was not selected from the “Files” screen when the input data file was set up, or
- no display interval was set on the “Overview” screen, or
- the display interval selected on the “Overview” screen was too small. The HAZARD-I manual states that a maximum of 50 intervals may be plotted. The number of intervals is equal to the simulation time divided by the display interval. Both of these parameters are defined on the “Overview” screen.

2.3 Analysing the Results

2.3.1 Viewing the Output File

To view the output file created by the simulation, go to the opening menu of HAZARD-I and select “File”, “View File” and then type in the filename “HOUSE1.LST” and press <Tab> to select OK and press <Return>. If the file is not found, select “File”, “Setup” and check that the setting for the Data Sub-directory points to where the file is held. An extract from HOUSE1.LST is given in Appendix B. This file does not contain a full record of all results predicted by HAZARD-I, but only gives the five parameters shown. A full set of output data is recorded in the history file (“HOUSE1.DMP”) for use with other parts of the HAZARD-I package but this file may not be read by the user.

Further results may be recorded in the output file by running HAZARD-I from DOS using the CFAST command. For instance, the following command from the DOS prompt will give a record of species concentrations in the file HOUSE1.OUT:

```
C:\HAZARDI> CFAST HOUSE1.DAT HOUSE1.OUT /R:S
```

Other options which may be used with this command to give different output data are :W, :I, :N, :F and :T. For details of these options, see the HAZARD-I manual: “An Update Guide for HAZARD -I Version 1.2”, May 1994, Section 6.2.

Once the simulation is complete the results may be examined by selecting HOUSE1.OUT from the “View File” option.

2.3.2 Plotting and Tabulating the Results

The full record of results in the history file (HOUSE1.DMP) may be analysed using the program CPLOT. To run CPLOT, from the main menu select “Analyse Results”, “Examine Data”. With this program, graphs and tables of selected variables may be displayed on the screen and data may be saved to file. For instructions on using CPLOT see Part 2, Section 6 of this manual.

You may like to try out the following exercises in using CPLOT. The answers appear at the end of this manual.

- ◆ Plot on your screen the upper layer temperatures in the living room and the hall. (HINT: Use the FILE command to select the file HOUSE1.DMP and then use the ADD command to add these two variables to your list, using Figure 4 to find the compartment numbers, then use the PLOT command and select both these variables by typing “(1 2)”.)

Q1. From the screen display, what is the peak temperature reached in the living room, and the time after ignition when this peak is reached?

Q2. Repeat Q1 for the hall.

- ◆ Now plot the interface height (this is the height of the underside of the smoke layer) in these two rooms. (HINT: The variable name is INTERFACE)

Q3. What is the lowest level reached by the smoke layer in the living room and in the hall?

- ◆ Now plot the Carbon Monoxide concentration in the upper layer in each room. (HINT: The variable name is SPECIES and the species type is CO).

Q4. What are the peak Carbon Monoxide concentrations reached in each room?

- ◆ And finally, plot the optical densities in each room. (HINT: The variable name is SPECIES and the species type is OD).

Q5. What are the peak optical densities reached in the living room and the hall?

2.3.3 Assessment of Hazard to Life

In this section it will be shown how to assess the hazard to life using the results from HAZARD-I. First check your output file HOUSE1.LST with the one in Appendix B to make sure that the results are approximately the same. You can use either the View or Print options to examine your file but note that the file is about 30 pages long. If you want a smaller print-out you should re-run the simulation with a larger print interval.

In Part 1, Section 5, the different types of hazard are described along with the criteria which define whether a hazard exists. For each type of hazard in turn, you need to decide whether the criterion has been reached and if so, at what time after ignition. In Appendix A you will find a Hazard Analysis Form which will help you make this assessment. You may wish to photocopy this form for future use.

Table 5 shows the parameters calculated by HAZARD-I which are relevant to hazard assessment and which will be used for the hazard analysis. Of these parameters, only temperature is included in the standard output file HOUSE1.LST. The other parameters can be analysed by running CPLOT (select: “Analyse Results”, “Examine Data” from the HAZARD-I main menu). The corresponding variable name used by CPLOT for each parameter is also shown in Table 5.

An alternative method of obtaining data is to run CFAST from DOS with an output option to select the parameters required (see section 2.3.1). This will create an output file with the required information.

PARAMETER	CPLOT variable name
Interface height	INTERFACE
Heat release rate	HEAT RELEASE
Heat radiation	TARGET
Upper and lower layer temperature	TEMP
Upper and lower layer smoke	SPECIES, then select OD
Upper and lower layer CO	SPECIES, then select CO
Upper and lower layer oxygen	SPECIES, then select O2

Table 5. Hazard parameters calculated by HAZARD-I

Next, you need to use CPLOT to analyse your results. See Part 2, Section 6 for instructions on using CPLOT. An example of a session with CPLOT is shown in Figure 12 where information entered by the user is shown in bold.

- ◆ Select: “Analyse Results”, “Examine Data” from the HAZARD-I main menu. This will run the CPLOT program.
- ◆ Using the “FILE” command, select the file HOUSE1.DMP which contains a full set of output data from CFAST.
- ◆ Now, using the “ADD” command, add the two variables INTERFACE and HEAT RELEASE to your list, following Figure 12, and then press <Return> to read in the data.

```

**      Cplot Version  2.0.1  Run  7/25/96      **

Command>  FILE
History file HOUSE1.DMP

CFAST V 2.0 Created  2/3/94, Run  7/25/96   4 Compartments, main fire in  1

Command>  ADD

  Enter variable(s) to add to the list:
<ENTER> To initiate read  INTERFACE
What compartment number (1 ... 5) for Interface  1
Variable matched to Interface   in compartment  1, layer=U

  Enter variable(s) to add to the list:
<ENTER> To initiate read  HEAT
What compartment number (1 ... 5) for Heat release  1
Variable matched to Heat release   in compartment  1, layer=U

Enter variable(s) to add to the list:
<ENTER> To initiate read  <Return>

Now reading in the data values.....

Time Step at  1000.  101
The largest possible time step is  101
Command>  SAVE
File name HOUSE1A.DOC
The present list is as follows:
#  Variable   Comp Lay Spec      File
-----
 1  Interface   1   U      HOUSE1.DMP
 2  Heat release 1   U          "
List the channels to save  (1 2)
Save is done
Command>  END

To add SPECIES variables to your list:

Command>  ADD

  Enter variable(s) to add to the list:
<ENTER> To initiate read  SPECIES
What compartment number (1 ... 5) for Species  1
And which layer (u,l)  U
What species  OD
Matched to Species      , comp = 1, layer = U, species = OD

  Enter variable(s) to add to the list:
<ENTER> To initiate read

```

Figure 12. Example session with CPLOT.

There is too much data to display on the screen so you need to print it out. The method described below involves saving the data to a file and editing the file from DOS.

[Alternatively, if you do not wish to use DOS, you can display sections of the data on your screen using the LIST command and pressing the <PrintScrn> button. The time interval to be displayed is selected by entering the range in brackets e.g. (10 20) to display the intervals 10 to 20 inclusive, but note that this refers to the interval numbers and not the time in seconds.]

- ◆ Use the “DEFAULT” command to set the format for saved files to columns. Keep pressing <Return> until the prompt “Type of save file” is reached and type “1” to select “column”. Press <Return> to ignore each of the remaining variables.
- ◆ Use the “SAVE” command to save the data to a file, enter a filename to identify the data, e.g. HOUSE1A.DOC, and select both variables (i.e. 1 and 2) from your list by typing (1 2). If more variables had been added to the list, you would need to specify each one e.g. (1 2 3 4 5).
- ◆ Now go back to DOS, check that your file containing the saved data is present
. Then edit the file to check that the data is the same as in Appendix B, e.g. type:-

```
CD C:\HAZARDI <Return>
DIR <Return> (to list files in directory)
EDIT HOUSE1A.DOC <Return>
```

You will find that there are no titles to the columns of data so you will need to add them at this point. The first column is Time, and the next columns are the parameters in the order that you selected them for saving. Also, add the units which are displayed by CPLOT when you type the VARIABLE command. When you have made these changes print out the data.

- ◆ Now repeat the procedure to obtain printouts of the following variables:
 - heat radiation, (W/m²)
 - upper layer temperature, (deg C)
 - lower layer temperature, (deg C)
 - upper layer optical density (smoke), (per m)
 - lower layer optical density (smoke), (per m)
- ◆ Again, check your data file with the one in Appendix B, then add titles to the columns using the editor and print out.
- ◆ Repeat the procedure once more for the following variables:
 - upper layer Carbon Monoxide
 - lower layer Carbon Monoxide
 - upper layer Oxygen
 - lower layer Oxygen
- ◆ As before, check your data file with the one in Appendix B, then add titles to the columns using the editor and print out the data.

You are now ready to analyse the data and complete the Hazard Analysis Form. A separate hazard analysis must be carried out for each room in the building and therefore a separate form should be completed for each room. Begin with the living room.

- ◆ Make a copy of the Hazard Analysis Form in Appendix A.
- ◆ Box A. Fill in the scenario name “HOUSE 1”.
- ◆ Box B. Fill in a description of the scenario as a reminder of the main conditions.
- ◆ Box C. Fill in the room “Living Room”.
- ◆ Box D. The head height is the height at which gases are inhaled. Opinions differ as to what this height should be. Whatever value you enter will affect the results of the hazard analysis. In this case use 1.5 metres.
- ◆ Box E. The output interval is the interval selected for your print-out which was 10 seconds. This serves as a reminder of the precision of the results.

The remaining boxes may be filled by examining the print-outs from CPLOT.

- ◆ Box F. Find the time when the interface reaches head height. Follow down the column “Interface” in your print-out which gives the height of the interface between the upper and lower layers, and note the point at which this height descends to the head height (1.5 metres). You should find this occurs at 150 seconds after ignition, in which case enter this time in the form at box F.
- ◆ Column 2. For each variable in column 1 of the table, follow down the relevant column of the print-out to find the peak value reached and enter the value in column 2, making sure that you use the correct units
- ◆ Column 3. The hazard criteria are taken from the values quoted in Part 1 Section 5. Enter the following values:
 - heat radiation 2.5 kW/m²,
 - upper and lower layer temperature 100°C,
 - upper and lower layer smoke 0.2 per metre,
 - upper and lower layer Carbon Monoxide 3,000ppm,
 - upper and lower layer oxygen concentration 10% or less.
- ◆ Column 4. Follow down each column of the print-out to find the point at which each variable reaches the hazard criterion given in column 3. Enter the time at which this occurs in column 4. If the criterion is not reached, enter “N/R”.
- ◆ Column 5. In the case of the conditions in the upper layer, a hazard is only present when the upper layer has descended below head height. To find out if this is the case, look up the interface height corresponding to the time given in column 4 and enter this height in column 5.

- ◆ **Column 6.** Compare the height in column 5 with the height in box D and enter Yes or No accordingly.
- ◆ **Column 7.** If you entered “Yes” in column 6, the upper layer was below head height when the hazard criterion was reached and you should enter the contents of column 4 in column 7.

If you entered “No” in column 6, the upper layer was still above head height when the hazard criterion was reached, and the hazard will only occur when the upper layer reaches head height. Therefore, enter the contents of box F in column 7.

If column 6 did not apply (i.e. for heat radiation and the lower layer conditions) copy the contents of column 4 to column 7.

A completed hazard analysis form for this scenario is shown in Appendix C, Table C1. Now that you have completed the hazard analysis form you can compare the time to hazard for each variable and comment on the hazard level of the scenario that you have simulated. In this case, the onset of hazard occurred 2 mins. 30 seconds after ignition due to smoke in the upper layer. The next hazard to occur was at 3 min. 50 seconds after ignition due to the temperature of the upper layer.

As mentioned earlier in this manual, no great accuracy should be assumed when using these results as they depend on the accuracy of the model and the many assumptions made when setting the input data. The criteria for hazard are also open to debate and if different values had been assumed, different times to hazard would have been obtained.

Use CPLOT to examine the data for the hall (compartment number 2). Plot the optical density in the upper and lower layers. [Hint: From within CPLOT, specify the file HOUSE1.DMP, add SPECIES, species type OD, compartment 2, upper and lower layers, then use the PLOT command to plot the data on the screen.] Compare your graph with the example in Appendix B.

Q6. How do you explain the behaviour of the optical density in the lower layer in the hall?

- ◆ Now repeat the hazard analysis for the hall using the same process as described above but disregard the high values in the lower layer after 530 seconds.

A completed form for the hall is shown in Appendix C, Table C2. This shows that only two of the hazard criteria were reached and that the initial hazard, as in the living room, was due to the upper layer smoke. The onset of hazard in the hall occurred at 2 minutes 50 seconds due to upper-layer smoke and at 5 minutes due to upper-layer temperature.

If we consider the case of an occupant escaping from any part of the house other than the living-room where the fire began, his main escape route is through the hall. He will have only 2 minutes and 50 seconds from the time of ignition in which to escape before the hall is obscured with smoke.

During this time he will need to become aware of the fire, whether by a smoke alarm, by his own observation or from another person, then decide to escape and then make good his escape. Alternatively he may decide to rescue another person in the house which will take up more time.

Q7. What would be the time to hazard in the living room if the more conservative value of 2.0 metres was assumed for the head height? You can deduce the answer from the hazard analysis form which you have already completed.

Q8. How does the peak heat release rate calculated by HAZARD-I compare with the peak heat release rate in the input data? What do you conclude?

3. CLOSED WINDOW (HOUSE2)

In the previous scenario (HOUSE1), the window in the living room was open. In this scenario we will look at the effect of closing the window.

- ◆ Make a copy of the input file for the initial house fire scenario (HOUSE1.DAT) and call the new file HOUSE2.DAT. You can do this by going back to DOS and giving the following commands:

```
C: <Return>  
CD C:\HAZARDI\DATA <Return>  
COPY HOUSE1.DAT HOUSE2.DAT <Return>
```

Alternatively, you may be able to copy the file from within HAZARD-I by selecting the options “File”, “Copy File” from the main menu. When you have done this, check the result with the “View File” option. If this does not work, check your setting for the data file directory in the “Setup” option.

- ◆ Now you need to open the file HOUSE2.DAT to make the changes required. From the main menu of HAZARD-I, select “Create Input Data”, “Interactive Data Input” and enter the filename “HOUSE2.DAT”.
- ◆ From the “Overview” screen change the title to “House Fire - Closed Window”.
- ◆ Go to the “Vents (doors,...)” input screen. (To do this, press <F2> key and select the screen from the list.) Move the cursor to highlight the row which defines the vent connecting compartments 1 and 5. This is the window connecting the living-room to the outside. Press <F6> to select the “Open/Close Vents” option and at each time step enter the value 0.0 to indicate that the window is closed. Then press <Esc> to return to the “Vents” screen.
- ◆ Go to the “Files” screen to save the changes. Press <F7> to save the data files. Set the main data file to HOUSE2.DAT and the history file to HOUSE2.DMP. Note the asterisk displayed next to the main data file which indicates that the file has been modified and not saved. Save the file HOUSE2.DAT by selecting it with the cursor, pressing <Return> and confirming that you wish to replace the existing file. Check that the asterisk has disappeared before leaving this screen.
- ◆ Now that you have saved the file, exit from the data input programme using the “Quit” option by pressing <F10>.
- ◆ Now select the option “Run Fire Model”, selecting file names HOUSE2.DAT and HOUSE2.LST and then select “Begin Simulation”.
- ◆ In the same way as for the HOUSE1 case, use CPLOT to carry out hazard analyses for the living room and the hall and compare your results with those in Appendix C, Tables C3 and C4.

Q9. How does the peak heat release rate compare with the HOUSE1 case? What do you conclude?

Q10. What is the time to the initial hazard in the living room and how does this compare with the HOUSE1 case?

Q11. How does the hazard in the hall compare with the HOUSE1 case?

4. LIVING-ROOM DOOR AND WINDOW CLOSED (HOUSE3)

In this scenario the door connecting the living-room to the hall will be closed which should improve conditions in the hall. The living-room window will also be closed so that it might be expected that the fire would be constrained by lack of an air supply to the room.

- ◆ Make a copy of the HOUSE2.DAT and call it HOUSE3.DAT.
- ◆ Now edit the file HOUSE3.DAT by selecting “Create Input Data”, “Interactive Data Input” from the HAZARD-I main menu.
- ◆ On the “Overview” screen, change the title to “House fire - door and window closed”
- ◆ Go to the “Vents (doors,...)” input screen. Move the cursor to highlight the row which defines the vent connecting compartments 1 and 2. This is the door connecting the living-room to the hall. Press <F6> to select the “Open/Close Vents” option and at each time step enter the value 0.0 to indicate that the door is closed. Then press <Esc> to return to the “Vents” screen.
- ◆ Go to the “Files” screen to save the changes. Press <F7> to save data files and set the main data file to HOUSE3.DAT and the history file to HOUSE3.DMP. Now save the file HOUSE3.DAT and exit from the data input programme.
- ◆ Now run the fire model with the HOUSE3.DAT data set. (Select the option “Run Fire Model”, selecting file names HOUSE3.DAT and HOUSE3.LST and then begin the simulation.)
- ◆ Examine the results using CPLOT.

Q12. What are the conditions like in the hall?

Q13. What is the peak heat release rate of the fire in this case?

In reality, a closed door will still allow gases to pass through the cracks between the door and the frame. A more realistic case would be to assume some leakage through the door cracks by setting the door opening factor to a small percentage rather than to zero as in the HOUSE3 case. It can be calculated from the geometry of the door that a 3mm crack is roughly equal to 1% of the area of the door. This is achieved by setting the opening factor to 1%.

- ◆ Copy the HOUSE3.DAT file to HOUSE3A.DAT.
- ◆ Edit HOUSE3A.DAT and change the door opening factor to 1%, i.e. 0.01.
- ◆ Save the file and repeat the simulation for the new case (HOUSE3A).
- ◆ Complete a hazard analysis form for HOUSE3A for the hall and compare with Appendix C, Table C5.

Q14. What are the conditions like in the hall now?

5. DIFFERENT ARMCHAIR FIRE (HOUSE4)

So far, the fire used has been an armchair with a heat release rate as defined in Table 4 (Section 2.1.9.11). However, different armchairs may burn with different heat release rates depending on the materials they are made of. The database of fire properties that comes with HAZARD-I contains heat release rate data from several different types of armchair.

- ◆ Use the fire properties database to find the heat release rates for the different armchairs present.

Guidance on using the database is given in Part 2 Section 7. The armchairs are identified by material codes UPC001 - UPC005.

Q15. How much do the heat release rates vary between armchair types and how do they compare with the heat release rate used earlier in this manual for the armchair fire?

Next we will take the HOUSE1 case and change the fire to the armchair UPC001 in the database.

- ◆ Make a copy of HOUSE1.DAT and call it HOUSE4.DAT.
- ◆ Change the title on the “Overview” screen to “House fire - different armchair fire”.
- ◆ Now go to the “Fire Specification” screen to enter the data for the new armchair as in the table below. First you will need to modify the time line. To do this, select the “MOD” option (press <F6>). Insert new time points until you have enough for the new set of data, then set the time points as in the table below.
- ◆ Return to the “Fire Specification” screen and enter the new values for heat release rate at each time point. Before doing this, check which units you are working in, as displayed at the bottom of the screen. (Hint: 1 kilojoule/second = 1 kilowatt.)

Time (s)	Heat Release Rate (kW)
0	0
60	0
150	90
200	450
260	2100
325	600
450	150
600	150
900	90
2,000	0

- ◆ Look at the other variables on the bottom row of the “Fire Specification” screen. Do this by selecting the variable with the cursor and then look at the graph. These variables may be varied with time but in this case they have been left constant, so they will not be affected by the

changes to the time points. The only exception is the pyrolysis rate which is defined by the heat release rate.

- ◆ Go to the “Files” screen and select “save data files”. Then select the main data file and history file names as required and save your data file. Then exit from the input programme.
- ◆ Run CFAST for the HOUSE4 case.
- ◆ Use the CPLOT programme (select “Analyze Results”, “Examine Data”) to look at your output. Use the “List” command to list out the variables on your screen. Select the variables required. You will then be asked to select a time interval to display a section of the data. The time interval to be displayed is selected by entering the range in brackets e.g. (10 20) to display the intervals 10 to 20 inclusive, but note that this refers to the interval numbers and not the time in seconds. Thus, if the time interval of the output data is 10 seconds, a range of 100 - 200 seconds will be displayed.
- ◆ Using the “List” command, find out the peak values of each variable in the HOUSE4 case and compare your results with Table C6 in Appendix C.

Q16. How do the peak values compare with the HOUSE1 case with the original armchair fire?

6. SENSITIVITY ANALYSIS (HOUSE5 - HOUSE9)

As already mentioned, the accuracy of the results of a computer modelling study is always limited. One source of error is the input data supplied by the user. There will always be a degree of uncertainty in the input parameters, for instance in the heat release rate of the fire or the height of the fire. In this exercise different input parameters will be varied from the values used in the initial case (HOUSE1) and the effect on the results noted. This will show the sensitivity of the results to the different input parameters and therefore which input parameters are more critical.

In the following sensitivity study, input parameters will be varied to see the effect on the following output parameters:

- peak heat release rate
- peak upper-layer temperature in living-room
- peak lower-layer temperature in living-room

- ◆ Make a copy of HOUSE1.DAT and call it HOUSE5.DAT.
- ◆ Edit HOUSE5.DAT and on the “Thermal Properties” screen change the ceiling material in all rooms to CONCRETE. While doing this you can check how the thermal properties in the materials database vary between GYPSUM and CONCRETE. Notice that the thermal conductivity of concrete is more than ten times that of gypsum so that the concrete would be expected to conduct the heat away more rapidly.
- ◆ Save HOUSE5.DAT and run the simulation.
- ◆ Now use “Analyze Results” and the LIST command to find the peak values of the heat release rate, upper-layer temperature and lower-layer temperature in the living-room and compare your results with the peak values reached in the HOUSE1 case (these should be on the Hazard Analysis Form).
- ◆ Now copy HOUSE1.DAT to HOUSE6.DAT and this time change the fire type to “Type 1” (unconstrained). Run the simulation and compare the peak values as before.
- ◆ In the next case, HOUSE7, make a copy of HOUSE1.DAT and turn on the ceiling jet calculation by selecting “CJET, ALL” from the “Fire Specification” screen. Again, run the simulation and compare the peak values.
- ◆ In case HOUSE8, make a copy of HOUSE1.DAT and change the fire height to 1m for all time points. Again, run the simulation and compare the peak values.
- ◆ Finally, in case HOUSE9, make a copy of HOUSE1.DAT and change the fire area to 1 square metre for all time points. Again, run the simulation and compare the peak values.

Q17. Compare your results for each of the above cases with the results for HOUSE1 and identify the input parameters which produce the most variation in the results and which produce the least.

Note that two input parameters, fire type and fire area, produced no variation at all in the results. The definition of these parameters is therefore not critical to the HOUSE1 case.

PART 4 : SHOP FIRE STUDY

1. INTRODUCTION

Part 4 contains a set of exercises for you to perform in which a shop fire is modelled. In the same way as the house fire study (Part 3), an initial scenario is modelled and then a series of modifications are applied. The results are analysed to determine the hazard to life in each case.

2. INITIAL SCENARIO (SHOP1)

The initial scenario to be considered is of a fire on a large sales floor measuring 30 metres in each direction. The fire load is a display of polyurethane foam furniture. There is a door in the compartment which is assumed to be closed.

The input data are shown in Table 6.

OPENINGS								
<u>Connecting rooms</u>		<u>Type of opening</u>			<u>Dimensions</u>			
Sales floor/surroundings		Door, closed			sill height = 0m soffit height = 2.13m width = 1m			
WALLS, FLOORS AND CEILINGS								
Walls	Gypsum							
Floor	Concrete							
Ceiling	Gypsum							
FIRE								
<u>Material</u>								
Polyurethane foam furniture								
<u>Time (min)</u>	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0
<u>Heat Release Rate (MW)</u>	0.0	1.0	2.6	2.8	2.6	2.0	0.3	0.0
Table 6. Shop fire scenario - input data.								

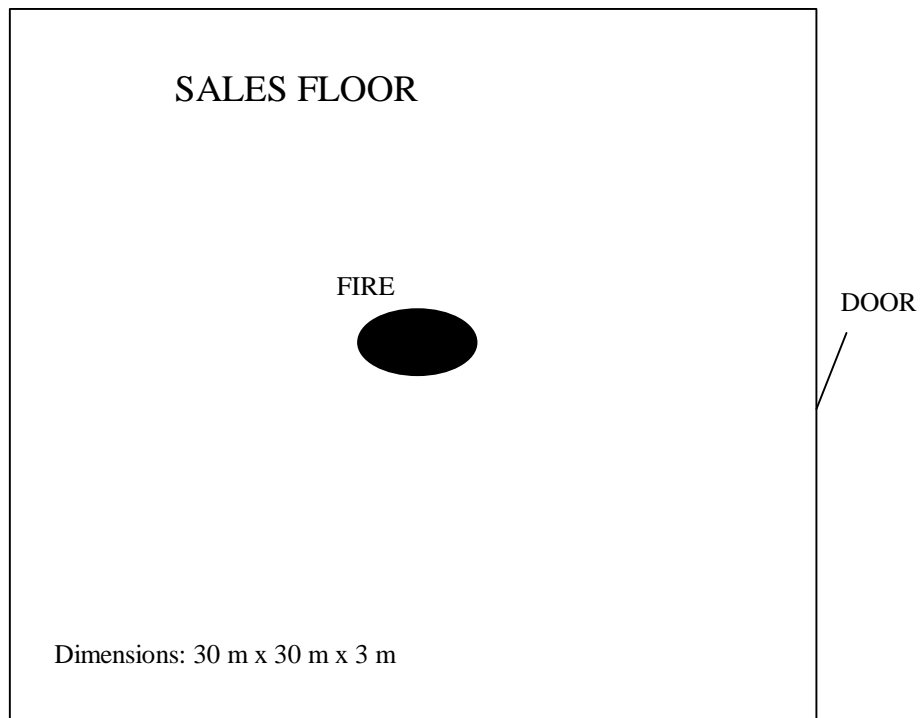


Figure 13. Shop Fire Scenario - Floor Plan

2.1 Setting up the input data file.

For instructions on using HAZARD-I, see Part 2 of this manual. For more detailed instructions, see the user manual that comes with HAZARD-I (6). In this section there is some repetition of the instructions in Part 3 to cater for readers who have skipped Part 3.

2.1.1 Opening the input data file.

- ◆ Start HAZARD-I, e.g. by typing the following commands:-

```
C: <Return>  
CD C:\HAZARDI<Return>  
HAZARD<Return>
```

- ◆ Open a new file. To do this, select “Create Input Data”, “Interactive Data Input” and press **<Return>**. The “Initialization” screen will be displayed.
- ◆ At the “Initialization” screen select a single room scenario by pressing **<F5>**, as indicated on the menu bar at the bottom of the screen.

The single compartment demo file is loaded and the “Overview” screen is displayed.

2.1.2 Input Screen: Overview

- ◆ Change the title of the simulation to “SHOP1: SALES FLOOR EXAMPLE”.
- ◆ Change the time data to the values in Table 7, but first remember to check the units you are using which are indicated at the bottom of the screen above the menu bar when the element of data is highlighted by the cursor.

Simulation	420 seconds	length of simulation
Print	10 seconds	data interval recorded in output file
History	10 seconds	data interval in “dump file”
Display	10 seconds	data interval for run-time display
Table 7. Input data for “Overview” screen		

2.1.3 Input Screen: Ambient Conditions

- ◆ Press <Page Down> to move to the next screen, “Ambient Conditions”. Keep these conditions the same but change the internal temperature to 293 °K (20°C).

2.1.4 Input Screen: Geometry

- ◆ On the “Geometry” screen, enter the width, depth and height of compartment 1, the sales floor, as in Figure 13. Keep the floor elevation as zero.

2.1.5 Input Screen: Vents(doors,...)

- ◆ On the “Vents(doors,...)” screen, one vent is already pre-defined, connecting compartment 1 (the sales floor) to compartment 2 (the outside). Edit the width, sill and soffit values so that they are the same as in Table 6. Keep the wind coefficient as zero. When you enter the soffit height as 2.13 metres, notice that only 2.1 is displayed. However, later when you look at the input data file you will see that 2.13 has been recorded.
- ◆ Still on the Vents screen, check the position of the door. To do this, use the O/C option (open/closed) on the bottom menu bar by pressing <F6>. By default, the vent is set open, indicated by a value of 1 throughout the time period of the simulation.
- ◆ Alter each point to zero so that the door is closed throughout. To do this, select each time point in turn with the cursor and type “0 <Return>” to change each point to zero. When all points are zero, press <Esc> to return to the Vents screen.

2.1.6 Input Screen: Thermal Properties

- ◆ No input is required for the next two screens, “Vents(ceiling,...)” and “Fans, Ducts,...”, so press **<Page Down>** until you reach the “Thermal Properties” screen.
- ◆ Set the thermal properties of the ceiling, floor and walls to the materials shown in Table 6. To do this, do the following:-
 - highlight the property on the screen,
 - press **<F6>** to display data (indicated on the menu bar),
 - select the material required with the cursor, (for gypsum, different thicknesses are listed, so select 0.016 metre thickness),
 - press **<F6>** to “Pick” the data and return to the thermal properties screen.

2.1.7 Input Screen: Fire Specification

- ◆ When thermal properties of all surfaces have been defined, press **<Page Down>** to move to the “Fire Specification” screen.
- ◆ Set the following values to define the fire:

Heat of Combustion	1.8E+07 J/kg
Minimum oxygen for combustion	10%
Relative humidity	0
Gramme Molecular Weight	16 (not used in calculation)
Position of fire	Centre of compartment, i.e. x = 15 metres, y = 15 metres, z = 0
Room of fire	1
Type of fire	2, i.e. constrained fire
CJET	OFF, i.e. ceiling jet calculation off
Table 8. Fire Specification input data	

The bottom row of the “Fire Specification” screen contains time-dependent parameters. Before setting these you need to define the time scale.

- ◆ Press **<F6>** (“MOD” option on bottom menu bar), to display the “Modify Time Interval” screen. Insert or delete further time points until you have 8 points and then define the times shown in Table 6, which are in minutes. Be careful that you are using the correct units. When all time points have been defined, return to the “Fire Specification” screen.

- ◆ Ignore the pyrolysis rate as this is defined by the heat release rate and the heat of combustion. Select “Heat_release” and input the values shown in Table 6, which are in MegaWatts. Be careful that you are using the correct units. Remember that 1 Joule/second = 1 Watt.
- ◆ Define the following values for each time point:-

height of the fire	0.5 metres
area of the fire	4 square metres
H/C (hydrogen/carbon fraction in unburnt fuel)	0.08
CO/CO2 production	0.02
C/CO2 production	0.02

HCN, HCL and Ct parameters may be ignored.

2.1.8 Input Screen: Files

- ◆ When you have completed data entry on the “Fire Specification” screen, press **<Page Down>** to move to the “Files,...” screen, ignoring the “Objects” screen.
- ◆ Press **<F7>** to save data files. Enter the name “SHOP1.DAT” for the main data file and “SHOP1.DMP” for the history file. Now save the main data file by highlighting SHOP1.DAT and pressing **<Return>**. Once the file has been saved, press **<Esc>** to return to the main “Files,...” screen.
- ◆ From the main “Files,...” screen press **<F10>** to quit the program.

2.2 Running the Fire Model.

- ◆ Before running the model, view your input data file (SHOP1.DAT) to check that it is the same as the one in Appendix D. To do this, go to the main menu of Hazard-I and select “File”, “View File”. When you have finished viewing your file, press **<Esc>** to exit.
- ◆ If you have found any differences, go back to the “Create Input Data” option and amend your data.
- ◆ When you are sure that your data file is correct, proceed to run the model. From the main menu, select “Run Fire Model”, select the input file SHOP1.DAT and the output file SHOP1.LST. Then select “Begin Simulation”.

The simulation will now proceed. This should take no more than one minute on a PC with a 486 processor or similar.

Either by using the program CPLOT (see Part 2, Section 6 of this manual) or by viewing the output file SHOP1.LST, (see Part 3, Section 2.3.1), answer the following questions:-

Q18. What is the calculated peak heat release rate in the fire compartment?

Q19. How does the calculated peak heat release rate compare with the peak heat release in the input data? What do you conclude?

Q20. What is the peak value of the upper layer temperature in the fire compartment?

Q21. What is the smallest distance above the floor reached by the smoke layer?

- ◆ In the same way as for the House Fire study in Part 3 of this manual, carry out a hazard analysis for the sales floor and compare your results to Appendix E, Table E1.

Q22. What is the initial hazard predicted by HAZARD-I and when does it occur?

The results obtained and the conclusions drawn from fire modelling studies depend, amongst other things, on the assumptions made and the input data supplied by the user. One assumption we made in the SHOP1 case was that the head height was 1.5 metres. As an illustration of the dependence of the results on the assumptions made, try changing the assumed head height to 2.0 metres.

Q23. Assuming head height to be 2.0 metres, what is the initial hazard predicted by HAZARD-I and how has it changed? (HINT: the only new information you need to find is the time when the interface reaches 2.0 metres above the floor.)

3. POLYSTYRENE FOAM FIRE (SHOP2)

In this scenario the fire load will be changed to polystyrene foam in cartons. This is a larger fire load than used for SHOP1. The heat release rate of the new fire, taken from an independent source, is shown in Table 9.

Time (min.)	0	2	4	6	8	10	12	14	16
Heat release rate (MW)	0.0	4.4	9.7	14.9	15.4	12.6	6.9	1.8	0.0

Table 9. Heat release rate of polystyrene foam fire

- ◆ Make a copy of SHOP1.DAT and call it SHOP2.DAT. You can do this by selecting the options “File”, “Copy File” from the main menu of HAZARD-I and check the result with the “View File” option. If this does not work check your setting for the data file directory in the “Setup” option. Alternatively, you can copy the file by going back to DOS and giving the following commands:

```
C: <Return>
CD C:\HAZARDI\DATA <Return>
COPY SHOP1.DAT SHOP2.DAT <Return>
```

- ◆ Now you need to open the file SHOP2.DAT to make the changes required. From the main menu of HAZARD-I, select “Create Input Data”, “Interactive Data Input” and enter the filename “SHOP2.DAT”.
- ◆ On the “Overview” screen change the title to “SHOP2 - Polystyrene Foam Fire”.
- ◆ Still on the “Overview” screen, change the simulation time to 16 minutes as this is the duration of the fire.
- ◆ Move to the “Fire Specification” screen to enter the details of the new fire.
- ◆ Set the Heat of Combustion to 3.3 E+07 Joules/kilogram which is the appropriate value for polystyrene foam.
- ◆ Modify the time points to give the set of times in Table 9. To do this, use the “MOD” option by pressing <F6>. You will need to insert an extra point to give the correct number (press <F4>). Press <Esc> to return to the main “Fire Specification” screen.
- ◆ Enter the heat release rates shown in Table 9.
- ◆ Go to the “Files” screen to save your changes. Press <F7> to save the files. Set the main data file to SHOP2.DAT and the history file to SHOP2.DMP. Highlight the main data file and press <Return>.
- ◆ Now that you have saved the file, exit from the data input program using the “Quit” option by pressing <F10>.

- ◆ Now select the option “Run Fire Model”, selecting file names SHOP2.DAT and SHOP2.LST and then select “Begin Simulation”.
- ◆ In the same way as for the SHOP1 case, carry out a hazard analysis for the sales floor and compare your results with those in Appendix E, Table E2.

Q24. How do the conditions reached in the SHOP2 case compare with those for SHOP1?

Q25. What is the initial hazard predicted by HAZARD-I for SHOP2 and when does it occur?

The completed hazard analysis form (Table E2) shows that HAZARD-I predicts hazards due to heat radiation, upper-layer temperature, upper-layer smoke and oxygen depletion. As expected, the larger fire load has produced a more severe hazard in the compartment.

4. POLYSTYRENE FOAM FIRE WITH VENTING (SHOP3)

This scenario uses the same fire as for SHOP2, but this time natural venting will be added to see if this reduces the hazard on the sales floor. To allow natural venting, an opening will be defined in the wall of the compartment.

HAZARD-I does not appear to run when a large vent in the ceiling is defined. I therefore suggest that both the inlet and outlet vents are placed in a wall.

- ◆ Make a copy of SHOP2.DAT and call it SHOP3.DAT.
- ◆ Now open the file SHOP2.DAT to make the changes required.
- ◆ On the “Overview” screen change the title to “SHOP3 - Polystyrene Foam Fire with Venting”.
- ◆ Go to the “Vents (doors,...)” screen.

Two vents need to be defined, one for inlet and one for outlet. An area of 30 square metres will be used for both vents to provide a sufficient flow rate out of the compartment. This is achieved by defining vents which run the entire length of the compartment (30 metres) with an opening height of 1 metre. The outlet vent extends 1 metre below the ceiling and the inlet vent extends 1 metre above the floor. The required dimensions are given in Table 10.

Vent No.	Width	Sill height	Soffit height
1	30	0	1
2	30	2	3

Table 10. Vent dimensions

- ◆ On the “Vents (doors,...)” screen, add the two vents as described above. The existing door can be converted into one of the vents.
- ◆ When you have added the vents check that they are both set to open. To do this, select the vent on the screen and use the “O/C” option (press <F6>) to display the “Open/Close Vents” screen. Set the value to 1 for all time points. Return to the main vents screen when complete by pressing <Esc>.
- ◆ Go to the “Files” screen to save your changes. Press <F7> to save the files. Set the main data file to SHOP3.DAT and the history file to SHOP3.DMP. Highlight the main data file and press <Return>.
- ◆ Now that you have saved the file, exit from the data input program using the “Quit” option by pressing <F10>.

- ◆ Now select the option “Run Fire Model”, selecting file names SHOP3.DAT and SHOP3.LST and then select “Begin Simulation”.
- ◆ Carry out a hazard analysis for the sales floor and compare your results with those in Appendix E, Table E3.

Q26. Has the addition of vents improved the conditions in the compartment?

Q27. How do you explain the effect of the vents on the conditions?

REFERENCES

1. "The SFPE Handbook of Fire Protection Engineering", section 2 chapter 1, Society for Fire Protection Engineers, Boston, USA and National Fire Protection Association, Quincy, USA, 1988.
2. "HAZARD-I Fire Hazard Assessment Method", Building and Fire Research Laboratory, National Institute of Standards and Technology, USA.
3. A Beard, "Evaluation of Fire Models: Report 6 - ASET: Quantitative Assessment" (page 26), Unit of Fire Safety Engineering, University of Edinburgh, October 1990, report to the Home Office.
4. L Y Cooper and D W Stroup, "ASET- A Computer Program for Calculating Available Safe Egress Time", Fire Safety Journal, 9 (1985) 29 - 45.
5. D A Purser, "Toxicity Assessment of Combustion Products", SFPE Handbook of Fire Protection Engineering, September 1988.
6. "Reference Guide for HAZARD-I", NIST Handbook 146, National Institute of Standards and Technology, USA.

ANSWERS TO EXERCISES

- Q1.** 370°C at 430 seconds after ignition.
- Q2.** 180°C at 430 seconds after ignition.
- Q3.** 0.55 metres in the living room and 0.0 metres in the hall, i.e. floor level
- Q4.** 2,200 ppm (parts per million) in the living room and 2,100 ppm in the hall.
- Q5.** 4.1 per metre in the living room, and 5.6 per metre in the hall. (The units of measurement are not clear from the graph but may be checked by looking at the output data file when running CFAST with the /R:S option.)
- Q6.** Some of the conditions in the lower layers, e.g. optical density, show a discontinuity (i.e. a sudden leap) at 530 seconds. Look at the interface height at this time and you should find that it is only fractionally above floor level. It is therefore likely that the discontinuity is due to a mathematical error in calculating the conditions in a very small volume and any values at or after this point should be ignored. The lower layer is in any case not relevant to the hazard calculation by this time.
- Q7.** The upper layer smoke density reaches the hazard criterion at 1:30 when the interface height is 1.58 metres. This is already below the assumed head height of 2.0 metres and so the first hazard occurs at 1:30.
- Q8.** The peak heat release rate calculated by HAZARD-I is 826kW in the HOUSE1 case compared with 830kW in the input data. This very slight difference indicates that the fire has not been significantly constrained by any lack of oxygen in the room.
- Q9.** The peak heat release rate is now 829kW compared with 826kW, an insignificant change. This shows that closing the window has not caused the fire to be constrained by lack of oxygen.
- Q10.** The initial hazard in the living room now occurs at 1:30 due to upper layer smoke compared to 2:30 in the HOUSE1 case. The reason for the difference can be seen from the hazard analysis forms: in the HOUSE1 case it took longer for the interface to descend to head height due to smoke escaping through the open window. With the window closed the effect has been to allow the smoke to build up more quickly.
- Q11.** The initial hazard in the hall now occurs at 2:30 due to upper layer smoke compared with 2:50 in the HOUSE1 case. Closing the window in the living room has therefore made the conditions in the hall slightly worse. Also there are two additional hazards which did not occur in the HOUSE1 case: at 6:30 due to heat radiation and at 8:10 due to low oxygen concentration in the upper layer.
- Q12.** In the HOUSE3 case, the conditions in the hall do not change during the fire. This indicates that the living-room door completely seals off the room, allowing nothing to pass through into the hall.

- Q13.** The peak heat release rate of the fire in the HOUSE3 case is 653kW. This means that the fire has been constrained by lack of oxygen in the living-room.
- Q14.** Adding a door crack has caused significant amounts of smoke to pass into the upper layer in the hall. The temperatures of both the upper and lower layers in the hall have risen. Onset of hazard occurs in the hall at 4:10 due to smoke in the upper layer.
- Q15.** The heat release rates may be compared by looking at the peak values and the times at which they occurred. These are:

Material Code	Peak Heat Release Rate (kW)	Time at which peak was reached (s)
Armchair used in this manual	830	420
UPC001	2,100	260
UPC002	700	450
UPC003	2,000	260
UPC004	730	420
UPC005	1,000	235

It can be seen that the armchair used in this manual has a heat release rate similar to UPC002 and UPC004. However, UPC001 and UPC003 have much higher peak values and these occur much earlier.

- Q16.** The peak heat release rate and the heat radiation have more than doubled. The peak temperatures of the upper and lower layers have increased significantly. There have been smaller changes in the peak values of the smoke and carbon monoxide levels and in the minimum value of the oxygen concentration.
- Q17.** The peak values reached are as follows:

Output parameter	HOUSE1	HOUSE5	HOUSE6	HOUSE7	HOUSE8	HOUSE9
Peak heat release rate (kW)	826	827	826	828	827	826
Peak upper-layer temp. (deg. C)	367	356	367	319	403	367
Peak lower-layer temp. (deg. C)	98.1	96.3	98.1	71.8	83.4	98.1

The most variation is produced by the ceiling jet calculation (HOUSE7) and the fire height (HOUSE8). The least variation is produced by the fire type (HOUSE6) and the fire area (HOUSE9).

- Q18.** 2,799 kilowatts
- Q19.** They are the same and therefore the fire as not been constrained by lack of oxygen. This is to be expected in a large compartment.
- Q20.** 164°C
- Q21.** 1.4 metres
- Q22.** Initial hazard at 4 minutes 40 seconds due to upper layer temperature and smoke obscuration.
- Q23.** Initial hazard now occurs at 2 minutes 50 seconds due to upper layer temperature and smoke. By assuming a different head height, there has been a substantial reduction in the estimated time to hazard.
- Q24.** The peak upper layer temperature is 413 °C compared to 164°C for SHOP1. The clear air layer is reduced to 0.5 metres above the floor at the lowest point compared to 1.4 metres for SHOP1.
- Q25.** The initial hazard occurs at 2:20 due to heat radiation. This compares with a time to hazard of 4:40 for SHOP1.
- Q26.** The upper layer no longer descends to head height so that hazards due to upper layer conditions are removed. However, the heat radiation hazard still occurs and the time to hazard is now slightly less than compared to the SHOP2 case. On this basis, it could be concluded that the conditions are slightly worse than before.
- Q27.** The effect of the vents has been to remove some of the hot upper layer and so reducing its depth. However, the upper layer is still as hot as before causing high heat radiation.

APPENDIX A
HAZARD ANALYSIS FORM

Hazard Analysis of Results of HAZARD-I Fire Simulation						
A) Scenario name:						
B) Scenario description:						
C) Room:						
D) Head height (metres): (i.e. the height at which gases are inhaled)				E) Time interval of output data (seconds): All times recorded below are to this level of precision.		
F) Time when the interface reaches head height (min:sec):						
(1)	Peak value (2)	Hazard criterion (3)	Time to Reach Hazard Criterion (min:sec) (4)	Interface height at this time (metres) (5)	Upper layer below head height? (6)	Time to Hazard (min:sec) See note below (7)
Heat release rate (kW)						
Heat rad. (kW/m ²)						
Upper-layer temp. (°C)						@
Lower-layer temp. (°C)						
U.L. smoke (per m)						@
L.L. smoke (per m)						
Upper-layer CO (ppm)						@
Lower-layer CO (ppm)						
Upper-layer O2 (%)						@
Lower-layer O2 (%)						
Comments:						
KEY: N/R = Hazard not reached						
Note for column (7). For parameters of the upper layer only, which are marked with a "@":-						
If column (6) = Yes, enter contents of column (4) If column (6) = No, enter contents of box (F)						

APPENDIX B

DATA FILES FOR HOUSE1

HOUSE1.DAT

VERSN 2HOUSE FIRE - INITIAL SCENARIO
 TIMES 1000 200 10 10 0
 TAMB 293. 101300. 0.
 EAMB 288. 101300. 0.
 HI/F 0.00 0.00 0.00 0.00
 WIDTH 4.00 5.00 4.00 2.00
 DEPTH 3.80 2.00 4.00 3.00
 HEIGH 3.00 3.00 3.00 3.00
 HVENT 1 2 1 1.000 2.000 0.000
 HVENT 1 5 1 1.000 2.000 1.000 0.000
 CVENT 1 2 1 1.00 1.00 1.00 1.00 1.00
 CVENT 1 5 1 1.00 1.00 1.00 1.00 1.00
 CEILI GYP1/2 GYP1/2 GYP1/2 GYP1/2
 WALLS CONCRETE CONCRETE CONCRETE CONCRETE
 FLOOR CONCRETE CONCRETE CONCRETE CONCRETE
 CHEMI 16. 0. 10.0 17000000. 300. 388. 0.150
 LFBO 1
 LFBT 2
 FPOS 1.00 1.00 0.00
 FTIME 200. 420. 550. 1000.
 FMASS 0.0001 0.0034 0.0488 0.0265 0.0071
 FHIGH 0.50 0.50 0.50 0.50 0.50
 FAREA 0.50 0.50 0.50 0.50 0.50
 FQDOT 1.00E+03 5.78E+04 8.30E+05 4.50E+05 1.21E+05
 CJET OFF
 HCR 0.080 0.080 0.080 0.080 0.080
 CO 0.020 0.020 0.020 0.020 0.020
 OD 0.020 0.020 0.020 0.020 0.020
 STPMAX 5.00
 DUMPR EX1.DMP
 DEVICE 1
 WINDOW * 0. -100. 1280. 1024. 1100.
 GRAPH 1 100. 50. 0. 600. 475. 10. 3 TIME HEIGHT
 GRAPH 2 100. 550. 0. 600. 940. 10. 3 TIME CELSIUS
 GRAPH 3 720. 50. 0. 1250. 475. 10. 3 TIME FIRE_SIZE(kW)
 GRAPH 4 720. 550. 0. 1250. 940. 10. 3 TIME O|D2|O(%)
 HEAT 0 0 0 3 1 U
 HEAT 0 0 0 3 2 U
 HEAT 0 0 0 3 3 U
 HEAT 0 0 0 3 4 U
 TEMPE 0 0 0 2 1 U
 TEMPE 0 0 0 2 2 U
 TEMPE 0 0 0 2 3 U
 TEMPE 0 0 0 2 4 U
 INTER 0 0 0 0 1 1 U
 INTER 0 0 0 0 1 2 U
 INTER 0 0 0 0 1 3 U
 INTER 0 0 0 0 1 4 U
 O2 0 0 0 0 4 1 U
 O2 0 0 0 0 4 2 U
 O2 0 0 0 0 4 3 U
 O2 0 0 0 0 4 4 U

OUTPUT FROM CPLOT FOR HOUSE1 CASE - PART 1

Conditions in compartment 1

Time (s)	Interface (m)	Heat release (kW)	Time (s)	Interface (m)	Heat release (kW)	Time (s)	Interface (m)	Heat release (kW)
0.000	3.00	1.00	330.	0.569	512.	660.	0.637	369.
10.0	2.63	2.74	340.	0.562	547.	670.	0.641	361.
20.0	2.29	4.60	350.	0.557	582.	680.	0.646	354.
30.0	2.02	6.58	360.	0.554	617.	690.	0.651	347.
40.0	1.82	8.67	370.	0.551	652.	700.	0.657	340.
50.0	1.69	10.9	380.	0.551	687.	710.	0.663	332.
60.0	1.63	13.2	390.	0.551	722.	720.	0.670	325.
70.0	1.60	15.6	400.	0.551	757.	730.	0.678	318.
80.0	1.59	18.2	410.	0.550	792.	740.	0.686	310.
90.0	1.58	20.9	420.	0.550	826.	750.	0.695	303.
100.	1.58	23.6	430.	0.554	797.	760.	0.704	296.
110.	1.58	26.5	440.	0.557	768.	770.	0.714	289.
120.	1.56	29.6	450.	0.559	739.	780.	0.725	281.
130.	1.54	32.7	460.	0.563	710.	790.	0.736	274.
140.	1.51	35.9	470.	0.567	681.	800.	0.748	267.
150.	1.49	39.3	480.	0.571	652.	810.	0.762	259.
160.	1.47	42.8	490.	0.576	623.	820.	0.776	252.
170.	1.45	46.4	500.	0.581	594.	830.	0.791	245.
180.	1.43	50.1	510.	0.586	565.	840.	0.807	238.
190.	1.42	53.9	520.	0.593	536.	850.	0.825	230.
200.	1.40	57.8	530.	0.600	507.	860.	0.844	223.
210.	1.36	92.9	540.	0.609	477.	870.	0.864	216.
220.	1.30	128.	550.	0.621	448.	880.	0.886	208.
230.	1.24	163.	560.	0.627	441.	890.	0.910	201.
240.	1.17	198.	570.	0.628	434.	900.	0.937	194.
250.	1.10	233.	580.	0.627	427.	910.	0.965	187.
260.	1.03	268.	590.	0.626	419.	920.	0.995	179.
270.	0.957	303.	600.	0.626	412.	930.	1.02	172.
280.	0.853	338.	610.	0.627	405.	940.	1.04	165.
290.	0.745	373.	620.	0.629	398.	950.	1.06	157.
300.	0.661	408.	630.	0.630	390.	960.	1.08	150.
310.	0.609	443.	640.	0.632	383.	970.	1.10	143.
320.	0.582	478.	650.	0.635	376.	980.	1.12	135.
						990.	1.14	128.
						1.000E+03	1.16	121.

OUTPUT FROM CPLOT FOR HOUSE1 CASE - PART 2

Conditions in compartment 1

Time (s)	Heat flux (W/m ²)	U.Temp (°C)	L.Temp (°C)	U.Smoke (per m)	L.Smoke (per m)	Time (s)	Heat flux (W/m ²)	U.Temp (°C)	L.Temp (°C)	U.Smoke (per m)	L.Smoke (per m)
0.000	0.000	20.0	20.0	0.000	0.000	500.	6.626E+03	321.	91.1	4.17	1.80
10.0	14.0	22.4	19.9	2.326E-02	0.000	510.	6.264E+03	314.	90.0	4.16	1.80
20.0	21.5	23.7	19.8	3.560E-02	0.000	520.	5.904E+03	306.	88.8	4.15	1.80
30.0	30.8	25.3	19.7	5.131E-02	0.000	530.	5.548E+03	297.	87.6	4.12	1.80
40.0	42.0	27.1	19.6	7.111E-02	1.689E-05	540.	5.203E+03	289.	86.4	4.09	1.79
50.0	55.1	29.3	19.5	9.385E-02	9.658E-05	550.	4.865E+03	280.	85.1	4.05	1.77
60.0	70.2	31.7	19.4	0.120	2.757E-04	560.	4.636E+03	274.	84.2	4.00	1.77
70.0	87.5	34.3	19.3	0.150	5.661E-04	570.	4.493E+03	270.	83.7	3.95	1.77
80.0	107.	37.2	19.2	0.183	9.952E-04	580.	4.376E+03	267.	83.3	3.91	1.77
90.0	128.	40.3	19.1	0.218	1.451E-03	590.	4.273E+03	264.	83.0	3.87	1.76
100.	151.	43.6	19.1	0.256	1.797E-03	600.	4.178E+03	261.	82.6	3.84	1.75
110.	176.	47.0	19.0	0.295	2.088E-03	610.	4.088E+03	259.	82.2	3.80	1.73
120.	200.	50.3	18.9	0.334	2.560E-03	620.	3.999E+03	256.	81.9	3.76	1.71
130.	225.	53.4	18.9	0.371	3.414E-03	630.	3.913E+03	253.	81.5	3.72	1.70
140.	249.	56.4	18.9	0.407	4.771E-03	640.	3.828E+03	251.	81.2	3.69	1.68
150.	273.	59.4	18.9	0.442	6.744E-03	650.	3.744E+03	248.	80.8	3.65	1.66
160.	297.	62.3	19.0	0.476	9.414E-03	660.	3.662E+03	246.	80.5	3.61	1.65
170.	322.	65.2	19.1	0.509	1.285E-02	670.	3.582E+03	243.	80.1	3.57	1.63
180.	348.	68.2	19.3	0.542	1.709E-02	680.	3.504E+03	240.	79.7	3.54	1.62
190.	375.	71.1	19.5	0.575	2.218E-02	690.	3.426E+03	238.	79.3	3.50	1.60
200.	402.	74.0	19.8	0.607	2.825E-02	700.	3.350E+03	235.	78.9	3.46	1.59
210.	474.	81.4	20.2	0.657	3.503E-02	710.	3.274E+03	233.	78.5	3.42	1.57
220.	617.	94.9	21.0	0.736	4.470E-02	720.	3.199E+03	230.	78.1	3.38	1.56
230.	807.	111.	22.4	0.831	6.196E-02	730.	3.125E+03	228.	77.7	3.35	1.55
240.	1.025E+03	127.	25.1	0.931	9.233E-02	740.	3.051E+03	225.	77.3	3.31	1.54
250.	1.260E+03	142.	29.4	1.03	0.142	750.	2.978E+03	222.	76.9	3.27	1.53
260.	1.505E+03	157.	35.9	1.13	0.216	760.	2.906E+03	220.	76.4	3.23	1.51
270.	1.759E+03	170.	44.2	1.23	0.315	770.	2.835E+03	217.	76.0	3.19	1.50
280.	2.027E+03	183.	52.1	1.33	0.414	780.	2.764E+03	214.	75.6	3.16	1.49
290.	2.337E+03	197.	58.9	1.45	0.508	790.	2.695E+03	212.	75.1	3.12	1.48
300.	2.712E+03	212.	65.2	1.59	0.602	800.	2.626E+03	209.	74.7	3.08	1.47
310.	3.148E+03	228.	70.8	1.75	0.698	810.	2.558E+03	206.	74.2	3.04	1.46
320.	3.628E+03	244.	75.5	1.92	0.791	820.	2.490E+03	203.	73.8	3.00	1.44
330.	4.127E+03	260.	79.3	2.10	0.881	830.	2.424E+03	201.	73.3	2.97	1.43
340.	4.634E+03	274.	82.4	2.28	0.966	840.	2.358E+03	198.	72.8	2.93	1.42
350.	5.147E+03	287.	85.0	2.46	1.05	850.	2.294E+03	195.	72.4	2.89	1.41
360.	5.665E+03	300.	87.2	2.63	1.13	860.	2.230E+03	192.	71.9	2.85	1.40
370.	6.191E+03	312.	89.2	2.81	1.21	870.	2.168E+03	190.	71.4	2.81	1.39
380.	6.735E+03	324.	91.1	2.98	1.28	880.	2.106E+03	187.	70.9	2.77	1.37
390.	7.286E+03	335.	92.9	3.15	1.36	890.	2.046E+03	184.	70.4	2.73	1.36
400.	7.847E+03	346.	94.7	3.32	1.43	900.	1.987E+03	181.	69.9	2.69	1.35
410.	8.419E+03	356.	96.4	3.48	1.51	910.	1.929E+03	179.	69.4	2.65	1.34
420.	9.001E+03	366.	98.1	3.65	1.58	920.	1.872E+03	176.	68.8	2.61	1.33
430.	9.039E+03	367.	98.1	3.80	1.64	930.	1.816E+03	173.	67.6	2.57	1.31
440.	8.751E+03	362.	97.1	3.92	1.68	940.	1.760E+03	170.	65.8	2.53	1.27
450.	8.418E+03	356.	96.1	4.00	1.71	950.	1.705E+03	167.	63.7	2.50	1.23
460.	8.074E+03	350.	95.1	4.07	1.74	960.	1.650E+03	164.	61.6	2.47	1.18
470.	7.717E+03	343.	94.2	4.11	1.77	970.	1.594E+03	161.	59.4	2.43	1.13
480.	7.355E+03	336.	93.2	4.14	1.78	980.	1.538E+03	158.	57.3	2.40	1.08
490.	6.991E+03	329.	92.2	4.16	1.79	990.	1.482E+03	155.	55.1	2.36	1.03
						1.000E+03	1.426E+03	152.	53.0	2.33	0.983

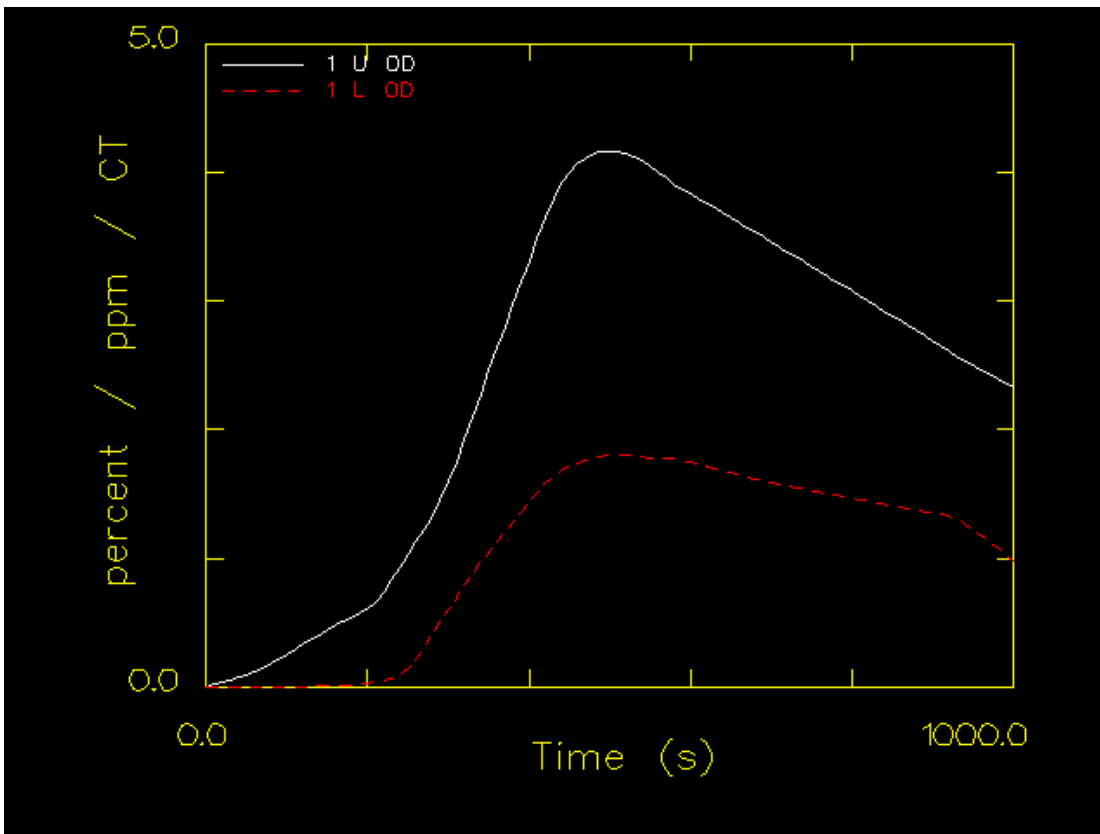
**OUTPUT FROM CPLOT FOR HOUSE1
CASE - PART 3**

Conditions in compartment 1

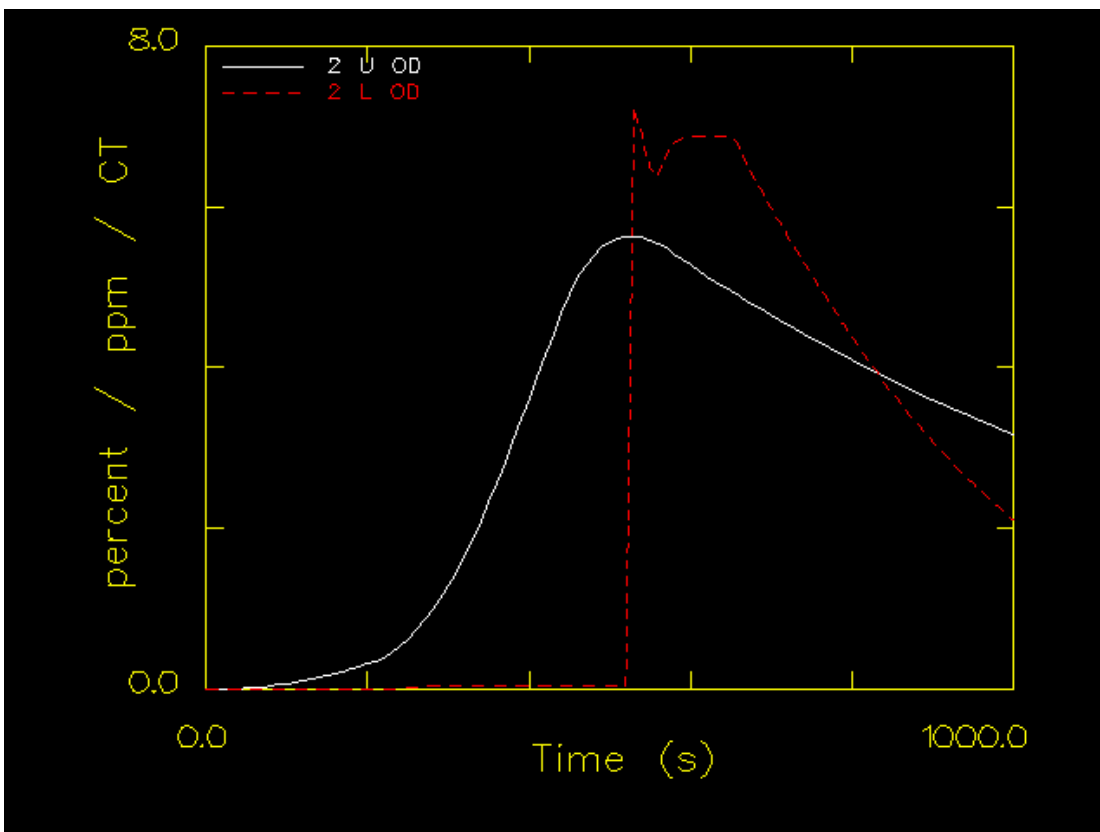
Time (s)	U.CO (ppm)	L.CO (ppm)	U.O ₂ (%)	L.O ₂ (%)
0.000	0.000	0.000	20.7	20.7
10.0	5.77	0.000	20.7	20.7
20.0	8.87	0.000	20.7	20.7
30.0	12.8	0.000	20.7	20.7
40.0	17.9	4.148E-03	20.6	20.7
50.0	23.8	2.372E-02	20.6	20.7
60.0	30.7	6.768E-02	20.6	20.7
70.0	38.7	0.139	20.6	20.7
80.0	47.6	0.244	20.5	20.7
90.0	57.4	0.356	20.5	20.7
100.	68.0	0.441	20.4	20.7
110.	79.3	0.512	20.4	20.7
120.	90.6	0.628	20.3	20.7
130.	102.	0.837	20.3	20.7
140.	113.	1.17	20.2	20.7
150.	123.	1.65	20.2	20.7
160.	134.	2.31	20.1	20.7
170.	145.	3.15	20.1	20.7
180.	155.	4.19	20.1	20.7
190.	166.	5.45	20.0	20.7
200.	177.	6.94	20.0	20.7
210.	195.	8.62	19.9	20.7
220.	227.	11.0	19.7	20.7
230.	268.	15.4	19.6	20.7
240.	312.	23.1	19.4	20.6
250.	360.	36.1	19.2	20.6
260.	408.	56.0	19.0	20.5
270.	457.	83.8	18.8	20.4
280.	511.	113.	18.5	20.2
290.	574.	142.	18.3	20.1
300.	649.	171.	17.9	20.0
310.	737.	201.	17.6	19.9
320.	835.	232.	17.1	19.7
330.	939.	261.	16.7	19.6
340.	1.046E+03	288.	16.2	19.5
350.	1.155E+03	315.	15.8	19.4
360.	1.265E+03	341.	15.3	19.3
370.	1.377E+03	367.	14.8	19.2
380.	1.490E+03	392.	14.3	19.0
390.	1.605E+03	417.	13.8	18.9
400.	1.721E+03	442.	13.4	18.8
410.	1.837E+03	468.	12.9	18.7
420.	1.954E+03	493.	12.4	18.6
430.	2.039E+03	509.	12.0	18.5
440.	2.084E+03	521.	11.8	18.5
450.	2.109E+03	530.	11.7	18.4
460.	2.121E+03	538.	11.6	18.4
470.	2.123E+03	544.	11.6	18.4
480.	2.115E+03	548.	11.7	18.4

Time (s)	U.CO (ppm)	L.CO (ppm)	U.O ₂ (%)	L.O ₂ (%)
490.	2.098E+03	550.	11.7	18.4
500.	2.075E+03	550.	11.8	18.4
510.	2.046E+03	549.	12.0	18.4
520.	2.011E+03	547.	12.1	18.4
530.	1.970E+03	543.	12.3	18.4
540.	1.926E+03	539.	12.5	18.4
550.	1.879E+03	533.	12.7	18.4
560.	1.835E+03	530.	12.9	18.4
570.	1.799E+03	530.	13.0	18.4
580.	1.769E+03	529.	13.1	18.5
590.	1.742E+03	526.	13.3	18.5
600.	1.717E+03	521.	13.4	18.5
610.	1.692E+03	516.	13.5	18.5
620.	1.668E+03	511.	13.6	18.5
630.	1.643E+03	505.	13.7	18.6
640.	1.619E+03	500.	13.8	18.6
650.	1.594E+03	494.	13.9	18.6
660.	1.570E+03	489.	14.0	18.6
670.	1.546E+03	483.	14.1	18.7
680.	1.522E+03	478.	14.2	18.7
690.	1.498E+03	474.	14.3	18.7
700.	1.475E+03	469.	14.4	18.7
710.	1.451E+03	464.	14.5	18.7
720.	1.428E+03	460.	14.6	18.7
730.	1.404E+03	456.	14.7	18.8
740.	1.381E+03	452.	14.8	18.8
750.	1.358E+03	448.	14.9	18.8
760.	1.335E+03	444.	15.0	18.8
770.	1.312E+03	440.	15.1	18.8
780.	1.290E+03	436.	15.2	18.9
790.	1.267E+03	432.	15.3	18.9
800.	1.245E+03	428.	15.4	18.9
810.	1.222E+03	424.	15.5	18.9
820.	1.200E+03	420.	15.6	18.9
830.	1.178E+03	416.	15.7	18.9
840.	1.156E+03	412.	15.8	19.0
850.	1.134E+03	409.	15.9	19.0
860.	1.112E+03	405.	16.0	19.0
870.	1.090E+03	401.	16.1	19.0
880.	1.068E+03	397.	16.1	19.0
890.	1.047E+03	393.	16.2	19.0
900.	1.025E+03	389.	16.3	19.1
910.	1.004E+03	385.	16.4	19.1
920.	983.	381.	16.5	19.1
930.	962.	373.	16.6	19.1
940.	942.	361.	16.7	19.2
950.	924.	347.	16.8	19.2
960.	905.	331.	16.8	19.3
970.	887.	316.	16.9	19.4
980.	868.	300.	17.0	19.4
990.	850.	285.	17.1	19.5
1.000E+03	831.	269.	17.2	19.6

CPLOT Graph of Optical density in the Living Room



CPLLOT Graph of Optical density in the Hall



APPENDIX C

HOUSE FIRE STUDY: HAZARD ANALYSIS FORMS

Hazard Analysis of Results of HAZARD-I Fire Simulation						
A) Scenario name: <i>HOUSE1</i>						
B) Scenario description: <i>House fire - Initial Scenario</i>						
C) Room: <i>Living room</i>						
D) Head height (metres): <i>1.5</i> (i.e. the height at which gases are inhaled)			E) Time interval of output data (seconds): <i>10</i> All times recorded below are to this level of precision.			
F) Time when the interface reaches head height (min:sec): <i>2:30</i>						
	Peak value	Hazard criterion	Time to Reach Hazard Criterion (min:sec)	Interface height at this time (metres)	Upper layer below head height?	Time to Hazard (min:sec) See note below
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Heat release rate (kW)	826					
Heat rad. (kW/m ²)	9.0	2.5	5:00			5:00
Upper-layer temp. (°C)	367	100	3:50	1.24	YES	@ 3:50
Lower-layer temp. (°C)	98	100	N/R			N/R
U.L. smoke (per m)	4.17	0.2	1:30	1.58	NO	@ 2:30
L.L. smoke (per m)	1.80	0.2	4:20			4:20
Upper-layer CO (ppm)	2,123	3,000	N/R	---	---	@ N/R
Lower-layer CO (ppm)	550	3,000	N/R			N/R
Upper-layer O2 (%)	11.6	10 or less	N/R	---	---	@ N/R
Lower-layer O2 (%)	18.4	10 or less	N/R			N/R
Comments: <i>Onset of hazard occurs at 2 minutes 30 seconds after ignition due to smoke in the upper layer. A further hazard occurs at 3 minutes 50 seconds due to the temperature of the upper layer.</i>						
KEY: N/R = Hazard not reached						
Note for column (7). For parameters of the upper layer only, which are marked with a “@”:- If column (6) = Yes, enter contents of column (4) If column (6) = No, enter contents of box (F)						
Table C1. HOUSE1 Hazard Analysis - Living Room						

Hazard Analysis of Results of HAZARD-I Fire Simulation						
A) Scenario name: <i>HOUSE1</i>						
B) Scenario description: <i>House fire - initial scenario.</i>						
C) Room: <i>Hall.</i>						
D) Head height (metres): <i>1.5</i> <small>(i.e. the height at which gases are inhaled)</small>				E) Time interval of output data (seconds): <i>10</i> All times recorded below are to this level of precision.		
F) Time when the interface reaches head height (min:sec): <i>2:00</i>						
	Peak value	Hazard criterion	Time to Reach Hazard Criterion (min:sec)	Interface height at this time (metres)	Upper layer below head height?	Time to Hazard (min:sec) See note below
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Heat release rate (kW)	826					
Heat rad. (kW/m ²)	1.93	2.5	N/R			N/R
Upper-layer temp. (°C)	179	100	5:00	0.08	YES	@ 5:00
Lower-layer temp. (°C)	28.9	100	N/R			N/R
U.L. smoke (per m)	5.63	0.2	2:50	1.15	YES	@ 2:50
L.L. smoke (per m)	0.03	0.2	N/R			N/R
Upper-layer CO (ppm)	2,050	3,000	N/R	---	---	@ N/R
Lower-layer CO (ppm)	7.4	3,000	N/R			N/R
Upper-layer O2 (%)	11.9	10 or less	N/R	---	---	@ N/R
Lower-layer O2 (%)	20.7	10 or less	N/R			N/R
Comments: <i>Onset of hazard occurs at 2 minutes 50 seconds after ignition due to smoke in the upper layer. A further hazard occurs at 5 minutes due to the temperature of the upper layer.</i>						
KEY: N/R = Hazard not reached						
Note for column (7). For parameters of the upper layer only, which are marked with a "@":- If column (6) = Yes, enter contents of column (4) If column (6) = No, enter contents of box (F)						
Table C2. HOUSE1 hazard analysis - Hall						

Hazard Analysis of Results of HAZARD-I Fire Simulation						
A) Scenario name: <i>HOUSE2</i>						
B) Scenario description: <i>House fire - closed window</i>						
C) Room: <i>Living room</i>						
D) Head height (metres): <i>1.5</i> (i.e. the height at which gases are inhaled)				E) Time interval of output data (seconds): <i>10</i> All times recorded below are to this level of precision.		
F) Time when the interface reaches head height (min:sec): <i>1:10</i>						
	Peak value	Hazard criterion	Time to Reach Hazard Criterion (min:sec)	Interface height at this time (metres)	Upper layer below head height?	Time to Hazard (min:sec) See note below
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Heat release rate (kW)	829					
Heat rad. (kW/m ²)	9.8	2.5	4:50			4:50
Upper-layer temp. (°C)	379	100	3:50	0.43	YES	@ 3:50
Lower-layer temp. (°C)	55.7	100	N/R			N/R
U.L. smoke (per m)	11.4	0.2	1:30	1.45	YES	@ 1:30
L.L. smoke (per m)	0.0	0.2	N/R			N/R
Upper-layer CO (ppm)	2,661	3,000	N/R	---	---	@ N/R
Lower-layer CO (ppm)	0.13	3,000	N/R			N/R
Upper-layer O2 (%)	7.55	10 or less	7:10	0.03	YES	@ 7:10
Lower-layer O2 (%)	20.7	10 or less	N/R			N/R
Comments:						
KEY: N/R = Hazard not reached						
Note for column (7). For parameters of the upper layer only, which are marked with a "@":- If column (6) = Yes, enter contents of column (4) If column (6) = No, enter contents of box (F)						
Table C3. HOUSE2 hazard analysis - Living room						

Hazard Analysis of Results of HAZARD-I Fire Simulation						
A) Scenario name: <i>HOUSE2</i>						
B) Scenario description: <i>House fire - closed window</i>						
C) Room: <i>Hall</i>						
D) Head height (metres): <i>1.5</i> (i.e. the height at which gases are inhaled)				E) Time interval of output data (seconds): <i>10</i> All times recorded below are to this level of precision.		
F) Time when the interface reaches head height (min:sec): <i>1:30</i>						
	Peak value	Hazard criterion	Time to Reach Hazard Criterion (min:sec)	Interface height at this time (metres)	Upper layer below head height?	Time to Hazard (min:sec) See note below
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Heat release rate (kW)	829					
Heat rad. (kW/m ²)	3.2	2.5	6:30			6:30
Upper-layer temp. (°C)	231	100	4:30	0.0	YES	@ 4:30
Lower-layer temp. (°C)	33.4	100	N/R			N/R
U.L. smoke (per m)	11.9	0.2	2:30	0.75	YES	@ 2:30
L.L. smoke (per m)	0.0	0.2	N/R			N/R
Upper-layer CO (ppm)	2,473	3,000	N/R	---	---	@ N/R
Lower-layer CO (ppm)	0	3,000	N/R			N/R
Upper-layer O2 (%)	7.8	10 or less	8:10	0.0	YES	@ 8:10
Lower-layer O2 (%)	20.7	10 or less	N/R			N/R
Comments:						
KEY: N/R = Hazard not reached						
Note for column (7). For parameters of the upper layer only, which are marked with a “@”:- If column (6) = Yes, enter contents of column (4) If column (6) = No, enter contents of box (F)						
Table C4. HOUSE2 hazard analysis - Hall						

Hazard Analysis of Results of HAZARD-I Fire Simulation						
A) Scenario name: <i>HOUSE3A</i>						
B) Scenario description: <i>House fire - Closed window and closed door with 1% door crack area</i>						
C) Room: <i>Hall</i>						
D) Head height (metres): <i>1.5</i> (i.e. the height at which gases are inhaled)				E) Time interval of output data (seconds): <i>10</i> All times recorded below are to this level of precision.		
F) Time when the interface reaches head height (min:sec): <i>2:50</i>						
	Peak value	Hazard criterion	Time to Reach Hazard Criterion (min:sec)	Interface height at this time (metres)	Upper layer below head height?	Time to Hazard (min:sec) See note below
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Heat release rate (kW)	<i>583</i>					
Heat rad. (kW/m ²)	<i>0.27</i>	<i>2.5</i>	<i>N/R</i>			<i>N/R</i>
Upper-layer temp. (°C)	<i>59.2</i>	<i>100</i>	<i>N/R</i>	<i>---</i>	<i>---</i>	@ <i>N/R</i>
Lower-layer temp. (°C)	<i>41.6</i>	<i>100</i>	<i>N/R</i>			<i>N/R</i>
U.L. smoke (per m)	<i>3.64</i>	<i>0.2</i>	<i>4:10</i>	<i>0.86</i>	<i>YES</i>	@ <i>4:10</i>
L.L. smoke (per m)	<i>0.0</i>	<i>0.2</i>	<i>N/R</i>			<i>N/R</i>
Upper-layer CO (ppm)	<i>645</i>	<i>3,000</i>	<i>N/R</i>	<i>---</i>	<i>---</i>	@ <i>N/R</i>
Lower-layer CO (ppm)	<i>0.0</i>	<i>3,000</i>	<i>N/R</i>			<i>N/R</i>
Upper-layer O2 (%)	<i>16.2</i>	<i>10 or less</i>	<i>N/R</i>	<i>---</i>	<i>---</i>	@ <i>N/R</i>
Lower-layer O2 (%)	<i>20.7</i>	<i>10 or less</i>	<i>N/R</i>			<i>N/R</i>
Comments:						
KEY: N/R = Hazard not reached						
Note for column (7). For parameters of the upper layer only, which are marked with a "@":- If column (6) = Yes, enter contents of column (4) If column (6) = No, enter contents of box (F)						
Table C5. HOUSE3A Hazard Analysis - Hall						

Hazard Analysis of Results of HAZARD-I Fire Simulation						
A) Scenario name: HOUSE4						
B) Scenario description: House fire - as HOUSE1 but different armchair fire						
C) Room: Living room						
D) Head height (metres): (i.e. the height at which gases are inhaled)				E) Time interval of output data (seconds): 10 All times recorded below are to this level of precision.		
F) Time when the interface reaches head height (min:sec):						
(1)	Peak value (2)	Hazard criterion (3)	Time to Reach Hazard Criterion (min:sec) (4)	Interface height at this time (metres) (5)	Upper layer below head height? (6)	Time to Hazard (min:sec) See note below (7)
Heat release rate (kW)	<i>1,814</i>					
Heat rad. (kW/m ²)	<i>23.7</i>	<i>2.5</i>				
Upper-layer temp. (°C)	<i>536</i>	<i>100</i>				@
Lower-layer temp. (°C)	<i>128</i>	<i>100</i>				
U.L. smoke (per m)	<i>4.3</i>	<i>0.2</i>				@
L.L. smoke (per m)	<i>1.97</i>	<i>0.2</i>				
Upper-layer CO (ppm)	<i>2,630</i>	<i>3,000</i>				@
Lower-layer CO (ppm)	<i>636</i>	<i>3,000</i>				
Upper-layer O2 (%)	<i>8.23</i>	<i>10 or less</i>				@
Lower-layer O2 (%)	<i>17.5</i>	<i>10 or less</i>				
Comments:						
KEY: N/R = Hazard not reached						
Note for column (7). For parameters of the upper layer only, which are marked with a "@":-						
If column (6) = Yes, enter contents of column (4) If column (6) = No, enter contents of box (F)						
Table C6. HOUSE4 - Peak values reached.						

APPENDIX D
DATA FILES FOR SHOP1 CASE

SHOP1.DAT

VERSN 2SHOP1
 TIMES 420 10 10 10 0
 TAMB 293. 101300. 0.
 EAMB 288. 101300. 0.
 HI/F 0.00
 WIDTH 30.00
 DEPTH 30.00
 HEIGH 3.00
 HVENT 1 2 1 1.000 2.130 0.000 0.000
 CVENT 1 2 1 0.00 0.00 0.00 0.00 0.00 0.00 0.00
 CEILI GYPSUM
 WALLS GYPSUM
 FLOOR CONCRETE
 CHEMI 16. 0. 10.0 18100000. 300. 388. 0.150
 LFBO 1
 LFBT 2
 FPOS 15.00 15.00 0.00
 FTIME 60. 120. 180. 240. 300. 360. 420.
 FMASS 0.0000 0.0553 0.1438 0.1546 0.1436 0.1105 0.0165 0.0000
 FHIGH 0.50 0.50 0.50 0.50 0.50 0.50 0.50 0.50
 FAREA 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00
 FQDOT 0.00 1.00E+06 2.60E+06 2.80E+06 2.60E+06 2.00E+06 3.00E+05 0.00
 CJET OFF
 HCR 0.080 0.080 0.080 0.080 0.080 0.080 0.080 0.080
 CO 0.020 0.020 0.020 0.020 0.020 0.020 0.020 0.020
 OD 0.020 0.020 0.020 0.020 0.020 0.020 0.020 0.020
 STPMAX 5.00
 DUMPR SHOP1.DMP
 WINDOW -50 0 -100 1280 1024 1100
 GRAPH 1 100. 050. 0. 600. 475. 10. 3 TIME HEIGHT
 GRAPH 2 100. 550. 0. 600. 940. 10. 3 TIME CELSIUS
 GRAPH 3 720. 050. 0. 1250. 475. 10. 3 TIME FIRE_SIZE(kW)
 GRAPH 4 720. 550. 0. 1250. 940. 10. 3 TIME O|D2|O(%)
 INTERFA 0 0 0 0 1 1 U
 TEMPERA 0 0 0 0 2 1 U
 HEAT 0 0 0 0 3 1 U
 O2 0 0 0 0 4 1 U

APPENDIX E

SHOP FIRE STUDY: HAZARD ANALYSIS FORMS

Hazard Analysis of Results of HAZARD-I Fire Simulation					
A) Scenario name: <i>SHOP1</i>					
B) Scenario description: <i>Polyurethane foam furniture in centre of sales floor</i>					
C) Room: <i>Sales floor</i>					
D) Head height (metres): <i>1.5</i> (i.e. the height at which gases are inhaled)			E) Time interval of output data (seconds): <i>10</i> All times recorded below are to this level of precision.		
F) Time when the interface reaches head height (min:sec): <i>4:40</i>					
(1)	Peak value (2)	Hazard criterion (3)	Time to Reach Hazard Criterion (min:sec) (4)	Upper layer below head height? (5)	Time to Hazard (min:sec) See note below (6)
Heat release rate (kW)	<i>2,799</i>				
Heat rad. (kW/m ²)	<i>1.64</i>	<i>2.5</i>	<i>N/R</i>		<i>N/R</i>
Upper-layer temp. (°C)	<i>164</i>	<i>100</i>	<i>1:10</i>	<i>NO</i>	@ <i>4:40</i>
Lower-layer temp. (°C)	<i>39</i>	<i>100</i>	<i>N/R</i>		<i>N/R</i>
U.L. smoke (per m)	<i>3.03</i>	<i>0.065</i>	<i>0:10</i>	<i>NO</i>	@ <i>4:40</i>
L.L. smoke (per m)	<i>0.0</i>	<i>0.065</i>	<i>N/R</i>		<i>N/R</i>
Upper-layer CO (ppm)	<i>812</i>	<i>3,000</i>	<i>N/R</i>	---	@ <i>N/R</i>
Lower-layer CO (ppm)	<i>0</i>	<i>3,000</i>	<i>N/R</i>		<i>N/R</i>
Upper-layer O2 (%)	<i>17.2</i> <i>(minimum)</i>	<i>10 or less</i>	<i>N/R</i>	---	@ <i>N/R</i>
Lower-layer O2 (%)	<i>20.7</i> <i>(minimum)</i>	<i>10 or less</i>	<i>N/R</i>		<i>N/R</i>
Comments: <i>Onset of hazard occurred at 4:40 due to upper layer temperature and smoke obscuration.</i>					
KEY: N/R = Hazard not reached					
Note for column (6). For parameters of the upper layer only, which are marked with a “@”:- If column (5) = Yes, enter contents of column (4) If column (5) = No, enter contents of box (F)					
Table E1. SHOP1 hazard analysis					

Hazard Analysis of Results of HAZARD-I Fire Simulation					
A) Scenario name: <i>SHOP2</i>					
B) Scenario description: <i>Polystyrene foam cartons fire in centre of sales floor</i>					
C) Room: <i>Sales floor</i>					
D) Head height (metres): <i>1.5</i> (i.e. the height at which gases are inhaled)			E) Time interval of output data (seconds): <i>10</i> All times recorded below are to this level of precision.		
F) Time when the interface reaches head height (min:sec): <i>3:00</i>					
(1)	Peak value (2)	Hazard criterion (3)	Time to Reach Hazard Criterion (min:sec) (4)	Upper layer below head height? (5)	Time to Hazard (min:sec) See note below (6)
Heat release rate (kW)	<i>15,160</i>				
Heat rad. (kW/m ²)	<i>12.1</i>	<i>2.5</i>	<i>2:20</i>		<i>2:20</i>
Upper-layer temp. (°C)	<i>413</i>	<i>100</i>	<i>0:30</i>	<i>NO</i>	@ <i>3:00</i>
Lower-layer temp. (°C)	<i>95</i>	<i>100</i>	<i>N/R</i>		<i>N/R</i>
U.L. smoke (per m)	<i>12.5</i>	<i>0.065</i>	<i>0:10</i>	<i>NO</i>	@ <i>3:00</i>
L.L. smoke (per m)	<i>0.0</i>	<i>0.065</i>	<i>N/R</i>		<i>N/R</i>
Upper-layer CO (ppm)	<i>2,906</i>	<i>3,000</i>	<i>N/R</i>	<i>---</i>	@ <i>N/R</i>
Lower-layer CO (ppm)	<i>0</i>	<i>3,000</i>	<i>N/R</i>		<i>N/R</i>
Upper-layer O2 (%)	<i>6.66</i> <i>(minimum)</i>	<i>10 or less</i>	<i>7:00</i>	<i>YES</i>	@ <i>7:00</i>
Lower-layer O2 (%)	<i>20.7</i> <i>(minimum)</i>	<i>10 or less</i>	<i>N/R</i>		<i>N/R</i>
Comments: <i>Onset of hazard occurred at 2:20 due to heat radiation.</i>					
KEY: N/R = Hazard not reached					
Note for column (6). For parameters of the upper layer only, which are marked with a “@”:- If column (5) = Yes, enter contents of column (4) If column (5) = No, enter contents of box (F)					
Table E2. SHOP2 hazard analysis					

Hazard Analysis of Results of HAZARD-I Fire Simulation					
A) Scenario name: <i>SHOP3</i>					
B) Scenario description: <i>Polystyrene foam cartons fire in centre of sales floor. Two wall vents 30 square metres area, dimensions 30 metres x 1 metre.</i>					
C) Room: <i>Sales floor</i>					
D) Head height (metres): <i>1.5</i> (i.e. the height at which gases are inhaled)			E) Time interval of output data (seconds): <i>10</i> All times recorded below are to this level of precision.		
F) Time when the interface reaches head height (min:sec): <i>N/R</i>					
(1)	Peak value (2)	Hazard criterion (3)	Time to Reach Hazard Criterion (min:sec) (4)	Upper layer below head height? (5)	Time to Hazard (min:sec) See note below (6)
Heat release rate (kW)	<i>15,400</i>				
Heat rad. (kW/m ²)	<i>9.8</i>	<i>2.5</i>	<i>2:00</i>		<i>2:00</i>
Upper-layer temp. (°C)	<i>379</i>	<i>100</i>	<i>0:30</i>	<i>NO</i>	@ <i>N/R</i>
Lower-layer temp. (°C)	<i>23</i>	<i>100</i>	<i>N/R</i>		<i>N/R</i>
U.L. smoke (per m)	<i>2.05</i>	<i>0.065</i>	<i>0:10</i>	<i>NO</i>	@ <i>N/R</i>
L.L. smoke (per m)	<i>0</i>	<i>0.065</i>	<i>N/R</i>		<i>N/R</i>
Upper-layer CO (ppm)	<i>1,116</i>	<i>3,000</i>	<i>N/R</i>	---	@ <i>N/R</i>
Lower-layer CO (ppm)	<i>0</i>	<i>3,000</i>	<i>N/R</i>		<i>N/R</i>
Upper-layer O2 (%)	<i>15.9</i> <i>(minimum)</i>	<i>10 or less</i>	<i>N/R</i>	---	@ <i>N/R</i>
Lower-layer O2 (%)	<i>20.7</i> <i>(minimum)</i>	<i>10 or less</i>	<i>N/R</i>		<i>N/R</i>
Comments: <i>Onset of hazard occurred at 2:00 due to heat radiation.</i>					
KEY: N/R = Hazard not reached					
Note for column (6). For parameters of the upper layer only, which are marked with a “@”:- If column (5) = Yes, enter contents of column (4) If column (5) = No, enter contents of box (F)					
Table E3. SHOP3 hazard analysis					