Study of Full Scale Fire Test Results Versus BRANZFIRE Zone Model Output

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Abstract

During 1995 a series of full scale rig tests were carried out by the Building Research Establishment (BRE) in the United Kingdom to study the tenability conditions in the lounge and upstairs bedroom of a typical domestic residence in the event of a fire in the lounge. A typical foam cushion chair was set alight in the lounge of the house and the temperature, smoke density, gas concentrations and smoke alarm activation times were measured in the rooms of the house. From this data the time to untenable conditions in the lounge and upstairs bedroom were calculated for each of the tests that was carried out.

The use of computational zone models for the prediction of conditions in enclosures has increased in the past two decades with the advent of cheap and powerful personal computers. One such zone model is BRANZFIRE which is a multi compartment two zone model that is based on a set of differential equations which are derived from the principles of conservation of energy and mass, and the ideal gas law.

The experimental setup from the BRE full scale rig was entered into BRANZFIRE and a series of the test scenarios were simulated. The simulations included defining the hallway, stair and landing rooms in two different methods, one using two compartments to describe the three rooms and the other using three compartments to describe the three rooms.

Two of the full scale rig tests with the lounge door closed were examined, and one of these tests was simulated with two arrangements for the door from the lounge to the hallway. One simulation used a small horizontal vent across the width of the door, the other used a narrow vertical vent the full height of the door.

The simulations showed BRANZFIRE to overestimate the compartment temperatures in the room of fire origin and to predict accurate results or under predict the temperature in other compartments in these tests. The oxygen concentration was generally predicted to lower to a greater extent than was seen in the full scale testing and the carbon dioxide concentration was under estimated by the simulations.

The optical density was over estimated by a significant factor in all of the rooms and this had an impact on the prediction of smoke alarm activation times with faster activation times predicted by the simulations than were seen in the full scale testing. The predicted time for an occupant

to receive a fractional effective dose of 1.0 due to heat was predicted well when compared to the full scale rig testing. The time to receive an incapacitating fractional effective dose due to asphyxiant gases was under estimated by the simulations.

The comparison between the simulation results and the full scale rig testing data highlighted the sensitivity of the simulation outputs to the information that is input into the simulation. Wherever possible a sensitivity analysis for both the inputs and the compartment geometries should be carried out.

Acknowledgments

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1 Introduction

The study of fire growth and fire product spread within the compartments of a building to predict the time to reach untenable conditions is of significant importance to fire engineers. A large part of the study of fire growth and spread of toxic products has been based on small scale laboratory testing and theories have been developed based around the data from this testing. To be of use for the design of structures the methods for predicting the time to untenable conditions need to be able to be applied to multi compartment buildings.

To aid in the design of buildings, software based on zone models is often used. It is necessary to develop software models for design because it is not possible to carry out tests, especially full scale tests of all the possible combinations of fuel types, fuel loads and compartment configurations. The software available for carrying out these calculations varies in capability and complexity. The output from these models is used in the design of buildings in terms of egress from buildings, smoke venting and structural design to ensure the building does not collapse. Fire design requirements of the New Zealand Building Code by the Department of Building and Housing (2005) focus on life safety rather than property protection and the safe egress of occupants from a building is an important component of any fire design.

During 1995 a series of tests were carried out by the BRE at their facility at Cardington in the United Kingdom to study the transport of toxic products and the time to untenable conditions in a full scale rig fire. The results of the testing are presented in reports by Purser et al (1998) and Purser et al (1997). The results of the testing were also reported by Purser et al (1999) at the Interflam 1999 conference and by Purser (2000) in Polymer International.

Purser et al (1998) commented in the executive summary that most large scale tests used as design fires and for the development of fire engineering calculation methods are conducted in open laboratories or in enclosed rigs with large vents. Such fires tend to be well ventilated with efficient combustion and low toxic product yields. Such fires may be unrealistic and underestimate the life hazard from fires in multi-enclosure buildings.

This report presents the results of the comparison of data recorded during the full scale testing by the BRE and the output from BRANZFIRE, which is a two zone computational model. The comparison has been carried out to determine the ability of BRANZFIRE to predict conditions and life hazard in a multi compartment building.

2 Background

2.1 Computational Models

Walton (2002) presents a summary of computer modelling software and notes that advances in computational power over the previous two decades has seen an increase in the use of computational models for predicting conditions in enclosure fires. There is a range of software available which are based on different approaches. Stochastic or probabilistic models determine the conditions in an enclosure based on mathematical rules which govern the transition from one fire state to another based on probabilities determined from historical fire data and relevant experimental data.

Deterministic models calculate the conditions in an enclosure based on interrelated mathematical expressions based on physics and chemistry. The basis of these models is the conservation of mass or energy within a control volume and the change in each variable in the compartment is affected by the change in each of the other variables in the compartment.

The control volume can be defined as any area within the compartment and the transfer of mass and energy between each of the control volumes can be determined to solve the conservation of mass and energy equations. In the simplest of models the control volume is defined as the entire compartment with loss of mass and energy to the external environment if there are vents.

The next level of complexity is represented by two zone enclosure models. These models are constructed with an upper layer and lower layer and the conservation of mass and energy equations are applied between the upper and lower control volumes, with losses to the external environment where vents exist. Software based on a two zone model includes ASET-B by Walton (1985), CFAST by Jones et al (2000) and Peacock et al (2000) and BRANZFIRE by Wade (2004a).

Two zone models have typically been developed by combining a series of formulas that have are based on the results of small scale laboratory testing or in large scale tests with good ventilation and large extraction vents. Their applicability to large scale enclosures with under ventilated fire conditions needs to be addressed for their application to building design.

The most complex level of software is represented by field models which subdivide a compartment into a number of smaller control volumes and then apply the continuity equations along the boundaries of all of the control volumes. These are referred to as computational fluid dynamics models. One example of this type of software is the Fire Dynamics Simulator (FDS) developed by the United States National Institute of Standards and Technology (NIST), see McGratten (2006) and McGratten and Forney (2006). Other computational fire dynamics software programs are JASMINE and SOFIE associated with the Fire Research Station of the BRE. The level of accuracy is dictated by the size of the control volume or grid used for the simulation. With a smaller gird size and a greater level of accuracy comes a greater demand for computational power. The required level of accuracy must be balanced against the computational power and the time for running simulations that is available.

One of the greatest difficulties with trying to recreate the results of testing in a model is to accurately describe all of the variables in the full scale test. Accurate information about the fuel and its constituents, the construction of the compartment including its dimensions and the materials used are all needed to generate a model to provide accurate results.

2.2 Full Scale Rig Testing

During 1995 a series of tests were carried out by the BRE at their Cardington facility in the United Kingdom. The tests were carried out using three different testing rigs to determine the spread of fire products in compartment fires with varying compartment configurations. The testing simulated vitiated fires as well as more well ventilated fires. The experiments were conducted to represent realistic building fire scenarios using realistic fuels including domestic furniture.

The three rig setups used were a room-corridor rig, a room-corridor-room rig and a full scale house rig. The testing which is compared with the BRANZFIRE simulation output in this report is the testing carried out in the full scale house rig.

A total of ten tests were carried out using the full scale house rig. These included a mixture of non-flaming and flaming fires and were described as tests CDT14 – CDT23. The full scale house rig was a two storey domestic residence with an entrance hallway, lounge, kitchen and dining room on the ground floor and three bedrooms and a bathroom on the upper floor. The two floors were connected by a stairwell from the hallway on the ground floor to a landing on the first floor. The rig was constructed using brick veneer and timber wall and floor framing, with a tile roof. The house rig was designed to represent a typical British house during winter.

An external photo of the house rig from the BRE CD ROM is shown in Figure 2.1.

Figure 2.1 External photo of house rig

Figure 2.2 from the BRE CD ROM shows a detailed layout of the ground floor of the full scale rig. The figure indicates the location of the fire object on the load cell and the sampling equipment installed in the house rig.

Figure 2.2 Detailed layout of ground floor

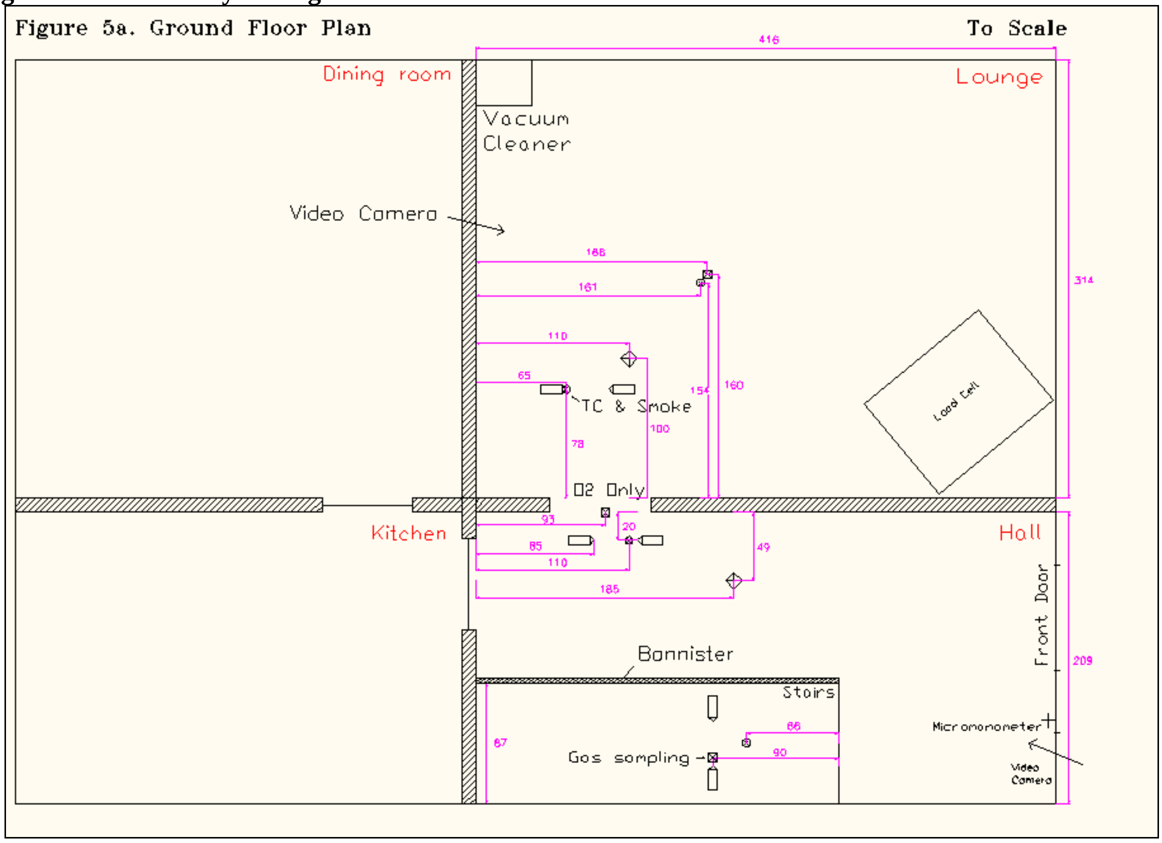


Figure 2.3 from the BRE CD ROM shows a detailed layout of the first floor of the full scale rig. The figure indicates the location of the sampling equipment installed in the house rig.

Figure 2.3 Detailed layout of first floor

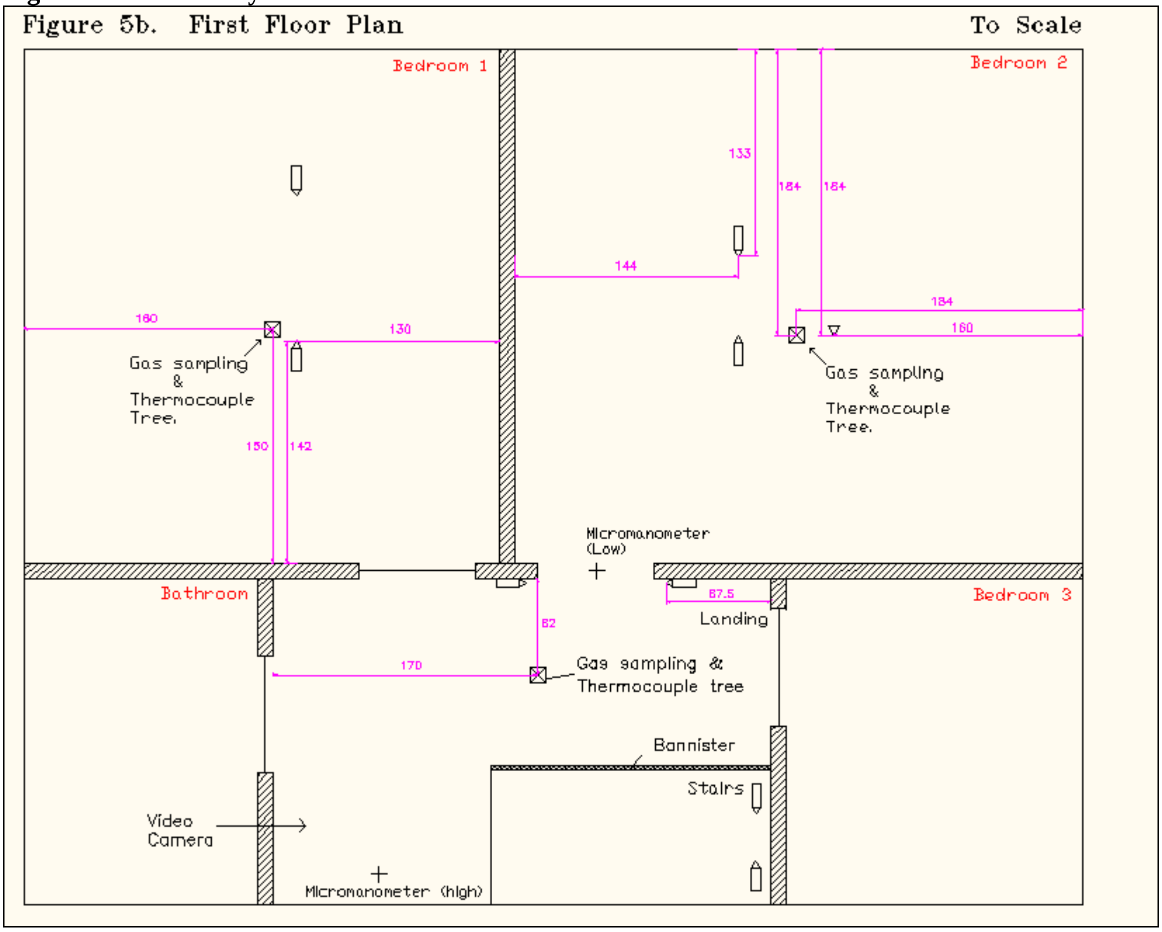
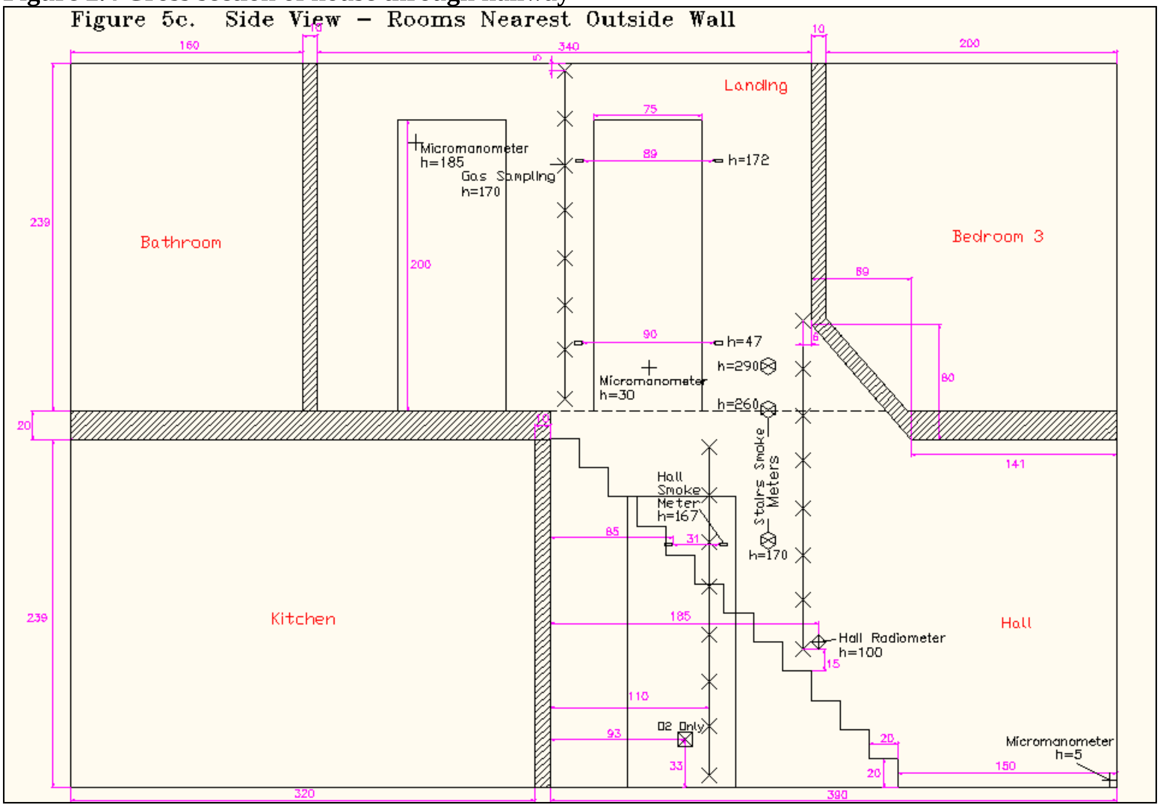


Figure 2.4 from the BRE CD ROM shows a cross section of the house through the stairwell and shows the geometry of the hallway, stairs and landing. These will be discussed in greater detail in the following sections of this report.

Figure 2.4 Cross section of house through hallway



Figures 2.5 and 2.6 from the BRE CD ROM are photographs of the stair arrangement, the former taken from the front door and the latter from the top of the stairs on the landing.

Figure 2.5 Photograph of stairs from front door

Figure 2.6 Photograph of stairs from landing

All of the windows and external doors in the full scale rig were closed and the tests were conducted with different scenarios of the internal doors being open. The fire was placed in the lounge to represent an upholstery fire caused by an electrical fault. The doors to the kitchen and dining room on the ground floor were closed during all of the tests and no sampling equipment was placed in these rooms. On the first floor the doors to the bathroom and bedroom 3 were closed in all of the tests and no sampling equipment was placed in these two rooms. The door to bedroom 2 was open in all of the tests while the door to bedroom 1 was closed in all of the tests. Sampling equipment was placed in both bedrooms 1 and 2.

In tests CDT14 and CDT16 the lounge door was closed and in the remainder of the tests it was open. In tests CDT21 – CDT23 additional ventilation was provided in the lounge by opening the chimney flue and providing air bricks through the external wall. The three tests where extra ventilation was provided were carried out with the lounge door open. Sampling equipment was placed in the lounge at the centre of the room and also close to the door to the hallway. Sampling equipment was placed extensively throughout the hallway and landing. The sampling equipment included temperature thermocouples, smoke density, gas concentration, thermal radiation detectors, optical and ionisation smoke alarms as well as a load cell to measure the mass loss of the fire object. All output from the various data recorders was logged electronically.

The fire object was a single armchair in six of the tests with two armchairs used in one of the tests. In the three remaining tests a single armchair was used, with additional fuel added. In one test the additional fuel was broken polyurethane cushions, in another the additional fuel was scattered cushions with vinyl wallpaper and a polystyrene coving. In the final test the lounge was loaded with additional fuel which included vinyl wallpaper, curtains, carpet, bookcases, books, a video player and a television.

A summary of the testing is shown the Table 2.1.

Table 2.1 Testing scenario summary

Test #	Fire condition	Chair fuel	Additional fuel	Lounge door condition	Additional ventilation
CDT14	Non flaming	CMHR polyether foam and FR cotton	Nil	Shut	Nil
CDT15	Non flaming	CMHR polyether foam and FR cotton	Nil	Open	Nil
CDT16	Flaming	CMHR polyether foam and FR cotton	Nil	Shut	Nil
CDT17	Flaming	CMHR polyether foam and FR cotton	Nil	Open	Nil
CDT18	Flaming	CMHR foam and FR cotton backed Dralon	Nil	Open	Nil
CDT19	Flaming	CMHR polyether foam and FR cotton (2 chairs)	Nil	Open	Nil
CDT20	Flaming	CMHR polyether foam and FR cotton	Nil	Open	Nil
CDT21	Flaming	HR polyether foam, non-FR acrylic cover	Broken PU cushions	Open	Air bricks and chimney flue
CDT22	Flaming	CMHR polyether foam with FR cotton backed Dralon	Polystyrene coving, Vinyl wallpaper, Scatter cushions	Open	Air bricks and chimney flue
CDT23	Flaming	CMHR polyether foam, non-FR acrylic	Vinyl wallpaper, Curtains, carpet, Bookcases, books, Video, TV	Open	Air bricks and chimney flue

CMHR = Combustion modified high resilience

FR = Flame retardant

HR = Heat Resistant

PU = Polyurethane (Foam)

All of the fires in the tests were ignited by placing a small timber crib on the armchair. A cotton swab partially soaked in methylated spirits was placed on the crib and was ignited via a heating coil wrapped around a match to ignite the cotton swab.

Figure 2.7 from the BRE CD ROM shows the setup of the chair for test CDT17 prior to ignition.

Figure 2.7 Photograph of chair prior to ignition (Test CDT17)

Figure 2.8 shows the same chair after the test. Note the limited extent of burning of the fire object.

Figure 2.8 Photograph of chair following testing (Test CDT17)

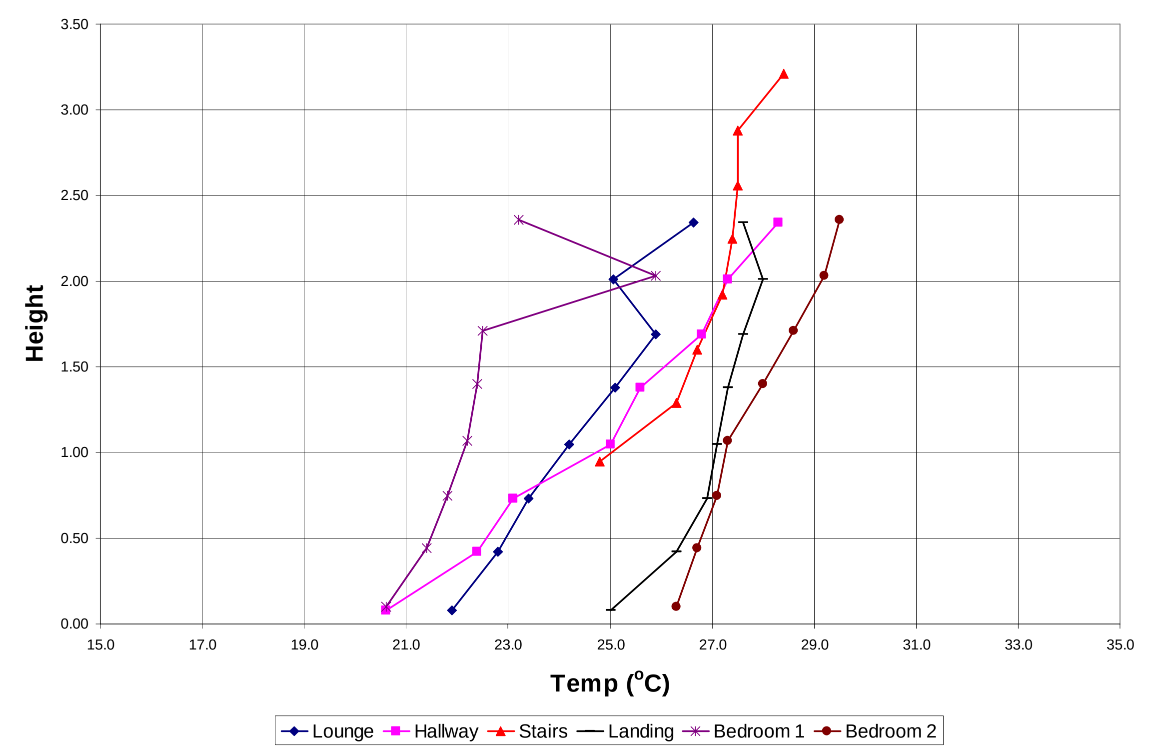
It was noted by Purser et al (1998) in the description of the experimental setup used in the BRE testing that the rig was set up to reflect a typical British domestic residence during winter and that the rooms were heated by oil filled radiators to maintain the temperature inside the rig.

Spearpoint (1996) noted that the presence of the radiators caused air flow patterns due to the convective heating and he presents figures showing the direction of the airflow patterns that were observed in the full scale rig using a smoke puffer. In the lounge the airflow pattern forced smoke towards the door to the hallway. The airflow patterns in the hallway forced air towards the stair and up into the landing. Because of the orientation of the stair the airflow once it reached the landing was directed towards bedroom 1 which had its door closed during the testing. The location of the radiator in bedroom 2 forced air from the external wall towards the door to the landing, creating an area of dead air at the door between the bedroom and the landing.

It is not possible to include these airflow patterns in the BRANZFIRE simulations and the airflow will have an impact on the predicted movement of smoke in the early stages of the fire. This will affect the predicted smoke alarm activation times.

The presence of the radiators also caused a clear temperature gradient within the rooms. The ambient temperature and the strength of the temperature gradients in each of the rooms was a function of the size of radiator in proportion to the volume of the room. Figure 2.9 shows the ambient temperatures and temperature gradients in the rooms of the full scale rig for test CDT17.

Figure 2.9 Room ambient temperatures and temperature gradients.



The temperature effect of the radiators can be allowed for in the BRANZFIRE simulations by setting the internal and external temperatures to 25°C to represent an average temperature from the full scale rig testing. Setting the internal and external temperatures to the same value will reduce any conduction losses from the internal to the external environment. Although the external temperature at the time of testing was not given by Purser et al (1998) it is likely that it would have been significantly less than 25°C.

However, BRANZFIRE allows the user to specify the ambient internal and external temperatures for the simulation as a whole and not for each individual compartment. The ambient temperature is applied to both the upper and lower zone and variations in the ambient temperature in a compartment can not be specified. In compartments where there is a large increase in the temperature during the simulation this effect will be negligible. However in simulations with the lounge door closed the effect will be more pronounced in rooms remote from the fire origin where very small temperature increases were observed.

2.3 Summary of Full Scale Rig Tests

A brief summary of the full scale rig test scenarios which are simulated in BRANZFIRE follows. The values given below for the smoke alarm activation times and times to untenability have been taken from tables 14 and 15 of Purser et al (1998) for the lounge and open bedroom respectively. It should be noted that the figures presented in Sections 5 to 7 of this report have been generated from the data on the BRE CD-ROM and in some cases do not agree with the tables from Purser et al (1998).

2.3.1 Test CDT14

Test CDT 14 was conducted with non flaming fire conditions and the lounge door closed. There was no discernible increase in temperature in the room of fire origin or in any of the rooms remote from the fire. There was also very little change in the gas concentrations in the room of fire origin or in any of the rooms remote from the fire. The optical density in the lounge did increase from zero to approximately $0.6m^{-1}$ during the fire and there was a slight increase in the value recorded on the stairs.

There was also an increase in optical density to approximately $0.1m^{-1}$ recorded on the landing and in the open bedroom which had its door open. No change in optical density was recorded in bedroom 1 which had its door closed. The increase in optical density in rooms remote from the lounge suggests that the lounge became completely smoke logged and smoke leaked under the closed lounge door or that there was leakage around the upper parts of the door frame.

The conditions in the lounge were determined as being untenable after 53 minutes due to smoke. This time coincides with a second peak in the optical density readings. The optical smoke alarm activated in approximately 21 minutes and the ionisation alarm after 49 minutes, which coincides with the first peak in the optical density readings. In the open bedroom the time to untenability was assessed as being greater than 60 minutes and the smoke alarms did not activate.

This test was not simulated in BRANZFIRE due to the limitations of the software. This is discussed further later in this report.

2.3.2 Test CDT15

Test CDT 15 was conducted with the lounge door open and was started as a non flaming fire. Spearpoint (1996) reported a steady rate of smoke generation and after 14.04 minutes the visibility in the lounge was greatly reduced. Flaming ignition was initiated manually after 37.06 minutes. With greater availability of oxygen for this test a much greater increase in temperature was measured in the lounge with a peak temperature of approximately 275°C recorded following the forced ignition after around 42.5 minutes from the start of the test. A temperature of approximately 180°C was recorded in the hall, 120°C on the stairs, 70°C on the landing but no discernible change was observed in the open bedroom. The peak temperatures in rooms remote from the fire also occurred at approximately 42.5 minutes from ignition.

Significant decreases in the oxygen level and increases in the carbon dioxide level were recorded in the lounge, on the stairs and on the landing. Only minor changes in the oxygen and carbon dioxide levels were recorded in the open bedroom. A large increase in the carbon dioxide and carbon monoxide levels and a sharp decrease in the oxygen content was recorded in bedroom 1 which had its door closed. This is surprising given the lack of ventilation to this room with the door closed.

The optical density in the lounge increased to levels greater than $8m^{-1}$ which was beyond the range of the instrumentation. The optical density on the stairs increased to greater than $4m^{-1}$ with similar readings on the landing and in bedroom 1 but negligible readings were recorded in the open bedroom. This also suggests that the data for bedrooms 1 and 2 may be transposed as the door to bedroom 1 is reported as being closed while the door to bedroom 2 is stated as being open. It appears that the data for the two bedrooms has been swapped and it will be assumed that this is the case in the analysis of the results.

The time to untenability due to smoke in the lounge was assessed as being greater than 60 minutes. The optical smoke alarm in the lounge operated after 9 minutes and the ionisation alarm after 16 minutes, much faster than for test CDT14 suggesting greater smoke densities in the lounge. In the open bedroom the time to untenability was assessed as being greater than 60 minutes and the smoke alarm did not activate.

The chair mass loss readings for this test generate an erratic graph when plotted against time with readings of approximately 0.6kg and then returning to zero. This is in stark contrast to the later tests with flaming fire conditions where the chair mass graphs indicate a gradual decrease during the test with total mass losses in the order of three to four kilograms. This makes the test very difficult to simulate in BRANZFIRE which requires a mass loss rate to predict the change in zone temperatures, gas concentrations and smoke production.

2.3.3 Summary of Test CDT16

Test CDT16, the first of the tests conducted with a flaming fire source was conducted with the lounge door closed. The temperature in the lounge increased to approximately 300°C which is of a similar magnitude to test CDT15. Temperatures in the hall increased approximately 30°C above ambient and there were negligible temperature increases on the landing and in bedroom 1 or 2.

The oxygen level decreased to approximately 14%, the carbon dioxide level increased to approximately 6% and carbon monoxide increased to 2% in the lounge but no change in gas concentrations were recorded in the other rooms of the house. The optical density in the lounge increased to a reading of greater than $6m^{-1}$ which was beyond the range of the instrumentation after approximately 5 minutes. Changes in optical density were also recorded on the stairs, landing and in bedroom 1 which suggests that smoke spread through a large part of the house despite the lounge door being closed. The data for bedroom 1 and 2 may be transposed for this test also.

Conditions in the lounge were assessed as being untenable after 2.6 minutes due to smoke and 4.66 minutes due to asphyxia. The ionisation smoke alarm activated after 1 minute and the optical smoke alarm after 3 minutes. In the open bedroom conditions were assessed as being untenable after 7.16 minutes due to smoke and irritants and after 6.83 minutes due to asphyxia. The ionisation smoke alarm activated after 4.5 minutes and the optical smoke alarm after 4.6 minutes.

2.3.4 Tests CDT17 & CDT18

In tests CDT17 & CDT18 with flaming fire conditions in the lounge and the lounge door open, significant increases in the temperature in all of the rooms that were monitored were observed. Peak temperatures in the lounge were in the range of 400°C to 500°C with temperatures in the hall between 200°C and 300°C. Temperatures in the landing were in the order of 100°C and approximately 70°C in bedroom 2.

The oxygen concentration dropped to below 12% in the lounge in both of the tests and carbon dioxide levels increased to between 6 and 8%. Significant changes in the gas concentrations were also observed in all of the rooms fitted with sampling equipment.

Optical densities in the lounge, stairs, landing and open bedroom increased to greater than $6m^{-1}$ and were beyond the range of the instrumentation after approximately 6 minutes in both of the tests. Increases in the optical density were also observed in the bedroom which had its door closed.

Times to untenability in the lounge due to smoke were all in the order of 2.5 – 3.5 minutes with times due to asphyxia in the order of 6.5 minutes. Ionisation smoke alarm activation times ranged from 0.5 minutes to 1 minute with activation times for optical smoke alarms in the range of 1.5 minutes to 3 minutes.

In the open bedroom times to untenability due to smoke were between 5 and 7 minutes and greater than 8 minutes due to asphyxia. Time to activation for the ionisation smoke alarms ranged from 2.5 to 4.5 minutes and from 3.5 to 4.5 minutes for the optical smoke alarms.

Test CDT18 used an armchair with fire resistant cotton backed Dralon acrylic covers. The hydrogen cyanide concentration produced by this fuel was higher than the other fires greatly affecting the times to untenable conditions.

2.3.5 General Findings

Purser et al (1998) describe the results of the testing and present conclusions based on the testing. The general conclusions from the testing in the full scale house rig are that the fires were generally found to remain small and to not spread to adjacent fuel items. This included the tests where additional ventilation was provided by having the lounge door the chimney flue open. The fire became extinguished when the oxygen concentration in the air supplying the fire decreased to values in the range of 15 – 16%.

The conditions became untenable in the room of fire origin after a few minutes due to the presence of toxic gases, particularly hydrogen cyanide. It was determined that the domestic smoke alarms activated sufficiently early to improve the chances of survival for a sleeping occupant in the fire room.

It was found that the chances of survival of occupants in a room remote from the fire origin were greatly increased if the door of the fire origin room was closed. This dramatically reduced the temperatures, smoke density and toxic gas concentrations in the rooms and hallway remote from the room of fire origin. The presence of domestic smoke alarms in the room of fire origin or in the hallway and landing provided early warning which also increased the chances of survival, even when the lounge door was shut and the smoke alarm was placed outside the lounge.

3 BRANZFIRE Simulation

An evaluation version of BRANZFIRE 2004 (Version 2004.33) was used to perform the simulations of the full scale rig tests. The simulation in BRANZFIRE for each fire scenario was set up with variables as per each individual test including the mass loss rate and doors open or closed. The reader should refer to the BRANZFIRE user's guide Wade (2004a) and technical reference guide by Wade (2004b) for further information relating to the BRANZFIRE zone model. For previous work on the validation of the zone model the reader should refer to the verification data report by Wade (2004c). The verification work carried out to date focuses on each of the individual routines in BRANZFIRE and comparison against full scale testing in a three compartment room-corridor-room rig has been carried out.

3.1 General Simulation Setup

Dimensions for the rooms were taken from the plans supplied with test report by Purser et al (1997). Where dimensions were not supplied they were scaled off the drawing. Rooms where sampling equipment was not installed during the BRE testing were not included in the simulations to reduce the amount of computational power required for each simulation. This includes the kitchen and dining room on the ground floor as well as the bathroom and bedroom 3 on the first floor.

The reference floor level for all rooms on the ground floor was taken as 0m. The stud height in all rooms was taken as 2.39m as shown on the drawings and all of the rooms were modelled with a flat ceiling. An interfloor height of 0.2m as shown on the drawings was used so all rooms on the first floor have a floor elevation height of 2.59m.

Ambient temperature inside the compartment in the models was taken as 25°C, as this represents the numerical average from the lowest to the highest thermocouple in most of the rooms in the full scale rig testing. The BRE testing was set up to represent a typical residence during winter with all windows and doors closed and with electric powered oil radiators in the house. External temperature information was not given in by Purser et al (1998) but was taken as 25°C to reduce the temperature loss to the external environment and to simulate the effect of the radiators. It is likely that the external temperature during the full scale rig testing was significantly less than 25°C. Information on relative humidity was not reported by Purser et al (1998) and was taken as the default value in BRANZFIRE of 65%.

The rooms on the ground floor were specified as having a 0.1m thick concrete floor in the simulations. The floor surfaces of the rooms on the first floor were specified as 0.012m thick medium density fibreboard and the timber joist substrate was not included in the simulation. Ceilings throughout the model were specified as 0.01m thick painted paper faced gypsum board in the simulations. BRANZFIRE allows the user to specify only one wall lining type for each compartment. All walls were specified as though they were external walls with 0.01m paper faced gypsum board linings and a 0.07m brick substrate in the simulations. All of the rooms of the house have two external walls except for the landing which has one. Information on the details of the construction of the house rig were not provided in the report and the values chosen have been taken to represent typical domestic construction.

All windows were modelled as being 0.004m thick domestic glass with a 0.015m shaded width around the perimeter. Default values for glass in BRANZFIRE as shown in Table 3.1 were used in the models. As noted by Purser et al (1997) windows in the test rig were wired Georgian glass and were therefore specified as being allowed to fracture but were not allowed to fall out in the BRANZFIRE simulations.

Table 3.1 BRANZFIRE default values for glass

Variable	Value
Fracture Stress	47 MPa
Expansion Coefficient	9.5E-06 / °C
Conductivity	0.76 W/mK
Diffusivity	3.6E-07 m^2/s
Youngs Modulus	70,000 MPa

The door to bedroom 1 which was closed in all of the tests was simulated with a 0.02m high leakage strip across the bottom of the door. All doors which were open were specified as 2.0m high and 0.75m wide in the simulations. These dimensions are consistent with the drawings supplied by Purser et al (1997).

The smoke alarms used in the BRE testing were manufactured to BS5446 which requires activation prior to a maximum optical density of at least $0.15m^{-1}$ during certification testing, however smoke alarms may activate at a lower optical density. Smoke alarms were specified in the BRANZFIRE simulations in compartments which had smoke alarms installed during the full scale rig testing. Smoke alarms in the BRANZFIRE simulations were specified as complying to normal sensitivity to AS1603.2 which requires an optical density of $0.097m^{-1}$ at activation. The user may also specify high sensitivity smoke alarms with an activation optical density of $0.055m^{-1}$ or very high sensitivity with an activation optical density of $0.013m^{-1}$. There was no suppression or mechanical ventilation used in the simulations.

The simulations in BRANZFIRE were run over a period of 800 seconds or 13 minutes. This typically represents the period of time over which the heat release rate predicted by the mass loss rate was greater than zero.

The post flashover model and fire growth model for room lining materials in BRANZFIRE were not activated based on the comment by Purser et al (1998) that the fires rapidly self extinguished with little or no spread to adjacent items. The tests have been simulated with only the fire object burning. The burning rate was not enhanced due to hot layer effects as the chair mass loss rate represents the actual burning rate of the object. The fuel load was specified as unlimited because the heat release rate determined from the full scale testing describes the extent of burning of the chair.

The McCaffrey (default) plume model was used and the fire was specified as being in a corner as per the full scale rig testing. The ceiling jet model was selected as the NIST ceiling jet model described by Davis (1999) in the simulations.

The default values for flexible polyurethane foam were used for the mass loss rate per m^2, the radiant loss fraction, soot absorption coefficient, soot alpha yield constant and the soot yield epsilon constant.

3.2 Heat Release Rate / Fuel Characteristics

The heat release rate for each of the simulations was based on the mass loss rate recorded by the load cell for each of the tests. Because of “noise” and some negative values in the readings for the mass loss rate, a floating five point average of the readings was used. This averages the reading at each time increment with the two prior readings and the two following readings to give a value at each time step. This has the result of reducing the peak heat release rate which was recorded at a single time step. A floating 5 point average still has a degree of noise in the plot but using a 7 or 10 point floating average caused a greater decrease in the peak heat release rate. Although the peak heat release rate is reduced, the troughs are increased and the curve increases sooner and drops off more slowly. Using a five point floating average decreased the peak heat release rate by approximately 10% whereas using a ten point floating average would have decreased the peak heat release rate by approximately 30%. Because of the large decrease for the ten point floating average and the noise in the unaveraged heat release rate it was decided to use the five point floating average.

The material for the fire load in the BRE testing was described as combustion modified polyether foam with a variety of fabrics including cotton, Dralon and acrylic coverings. The specific heat release rate used in the simulations was based on the foam inner as it was decided that this provided the greatest component of the fuel load. The heat release rate was determined based on data from Tewarson (2002), the SFPE handbook 3rd edition appendices and Enright and Fleischman (1999). The various values are shown in the Tables 3.2 to 3.4. In the values from Tewarson (2002) for Polyetheretherketone, Polyethersulfone and Polyetherimide the materials were described as synthetic solid materials but they were not described as foams used in the production of domestic furniture. The values for flexible polyurethane foam are also presented as it is often used in domestic furniture manufacture, although there is no information to suggest it was used in the chairs for the BRE testing.

Table 3.2 Data from Tewarson (2002) - from table 3-4.14

Material	ΔH_T (MJ/kg)
Polyetheretherketone	31.3
Polyethersulfone	25.2
Polyetherimide	30.1
Polyurethane (GM21)	26.2
Polyurethane (GM23)	27.2
Polyurethane (GM25)	24.6
Polyurethane (GM27)	23.2

Table 3.3 Data from SFPE Handbook Appendix C - from table C.3

Material	ΔH_T (MJ/kg)
Polyether, chlorinated	17.84

Table 3.4 Data from Enright and Fleischman (1999) - from table 3

Sample No.	Description	$\Delta H_{c,eff}$ (MJ/kg)
1	Polyether foam pad, polyester and other blends	46.5
2	Polyether foam pad, polyester and other blends	32.8
3	Polyether foam pad, polyester and other blends	36.2
4	Nylon pile with polyester backing	29.5
5	Polypropylene fibre	49.9
6	Nylon pile and 65/35 polyester cotton base	35.9
7	Nylon pile	31.3
8	Polypropylene fibre	41.0

Specific heat release rate information for the fuel was not given by Purser et al (1998) because it was not possible to conduct calorimetry during the full scale rig testing.

Due to the range in values for the heat of combustion in Tables 3.2 to 3.4 a series of simulations were run to give an indication of the likely magnitude of the value of the heat of combustion. Simulations with values for the heat of combustion of 20, 26, 30 and 38 MJ/kg were run in a room with the same dimensions as the lounge of the full scale rig and with the door open. The mass loss rate used for the various values of the heat of combustion was as determined for test CDT17.

Figure 3.1 shows the upper layer temperature predicted by the BRANZFIRE simulations for the varying values of the heat of combustion. The upper layer temperature predicted by the BRANZFIRE simulations is compared against the upper layer temperature predicted by the N% method described in Section 3.4 for test CDT17 with N =20.

Figure 3.1 Lounge upper layer temperature for varying heat of combustion

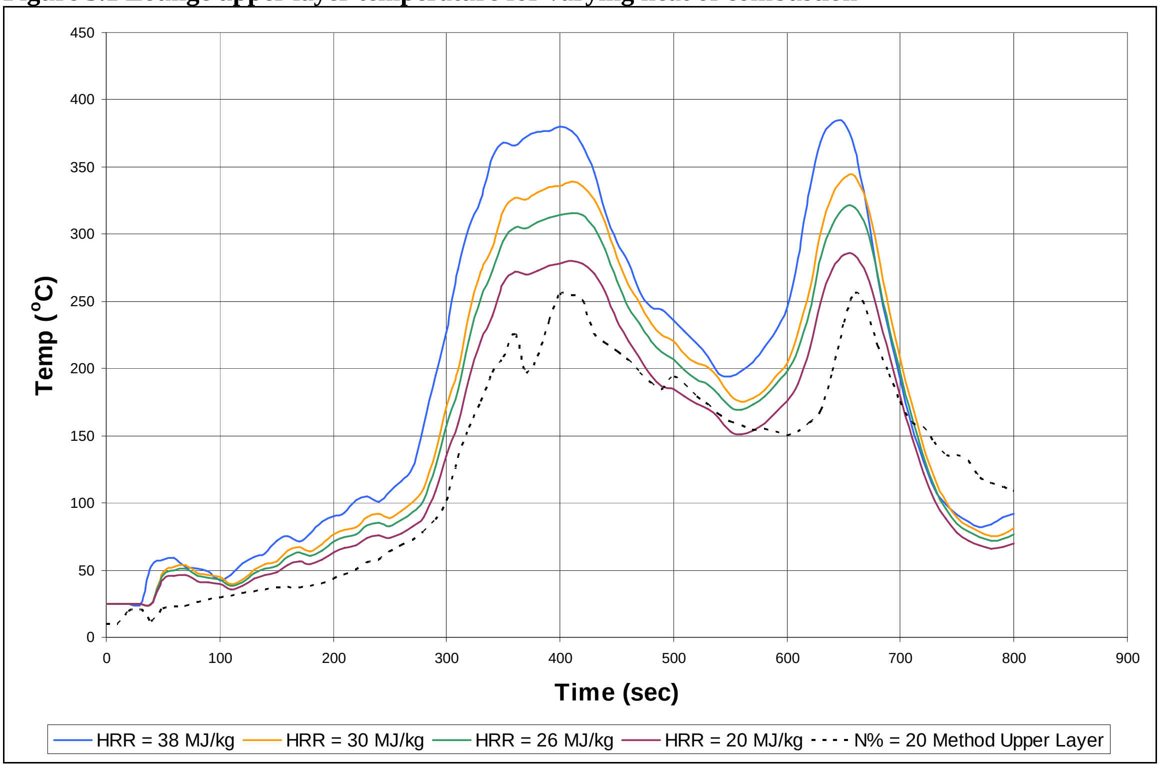


Figure 3.1 shows a variation of 100°C (approx. 25%) in the temperature predicted in both the first and second peak of the temperature curve for the various values of the heat of combustion. This indicates that the results will be sensitive to the value that is chosen for the heat of combustion. In Figure 3.1 it can be seen that for a value of 20 MJ/kg for the heat of combustion

the upper layer temperature is over predicted by approximately 25°C in comparison to the N% method.

From the results presented in Figure 3.1 it was considered that values for the heat of combustion of greater than 30 MJ/kg were not representative of the fuel used in the full scale rig testing and that the values from the CBUF testing of Enright and Fleischman (1999) were not suitable.

It was decided to select a value based on the information taken from Tewarson (2002) and the SFPE handbook appendices. The average of the values for the various polyethers and polyurethanes is 26.83 MJ/kg or the average of the values under 30 MJ/kg is 25.28 MJ/kg. Based on this it was decided to use a value of 26 MJ/kg for the heat of combustion for the BRANZFIRE simulations.

Study of the results of the full scale rig testing has previously been carried out by Brammer (2002) who used FDS to predict the activation time of smoke alarms in various compartments of the house and compared the predicted times against the activation times observed during the full scale testing. Brammer (2002) used a heat of combustion of 30 MJ/kg for the simulation of test CDT17. This value for the heat of combustion was found to give a good correlation between lounge temperatures predicted by the FDS simulation and those recorded during the full scale rig testing for test CDT17. The value of the heat of combustion used by Brammer (2002) is of similar magnitude to the value used in the simulations described by this report.

BRANZFIRE requires the user to specify the location and height of the fire object. Purser et al (1998) reported that the chair was placed on a load cell frame which elevated it above the floor and in Figure 2.7 it can be seen that the crib used to ignite the chair was placed in the seat of the chair. The height of the seat of the chair was not given by Purser et al (1998) and has been estimated from the photos as 0.5m above floor level and specified as this value in the BRANZFIRE simulations. Also as shown in Figure 2.7 the fire object was specified as being in a corner in the BRANZFIRE simulations.

Wade (2004b) and Karlsson & Quintiere (2002) note that where a fire is situated in a corner the mass flow rate of the fire plume is approximately one third to one quarter of the mass flow rate for an unbounded fire due to reduced entrainment of air. A simulation with a corner fire may then produce higher upper layer temperatures in the room of fire origin in comparison to a simulation with an unbounded fire plume. The effect of the fire location on the compartment results could be studied further.

BRANZFIRE also requires the user to specify values for the yield of carbon dioxide (y_{CO_2}) and the yield of soot (y_s) as a proportion of the mass of the fuel. These values are then used in the simulation to predict the generation of carbon dioxide and soot based on the mass loss rate of the fire object.

Values from Tewarson (2002) for the yield of carbon dioxide and soot for the materials considered for the heat of combustion are presented in Table 3.5.

Table 3.5 SFPE Handbook Chapter 3 - from table 3-4.14

Material	y_{CO_2} (g/g)	y_s (g/g)
Polyetheretherketone	1.6	0.008
Polyethersulfone	1.5	0.021
Polyetherimide	2.0	0.014
Polyurethane (GM21)	1.55	0.131
Polyurethane (GM23)	1.51	0.227
Polyurethane (GM25)	1.50	0.194
Polyurethane (GM27)	1.57	0.198

Values of y_{CO_2} = 1.55 g/g and y_s =0.20 g/g were used in the simulations. The chosen values are based on the averages of the values given by Tewarson (2002) for the polyurethane foams. The hydrogen cyanide production rate in the BRANZFIRE simulations was selected as being calculated based on combustion chemistry for polyurethane flexible foam.

3.3 Compartment Arrangement / Vent Flow

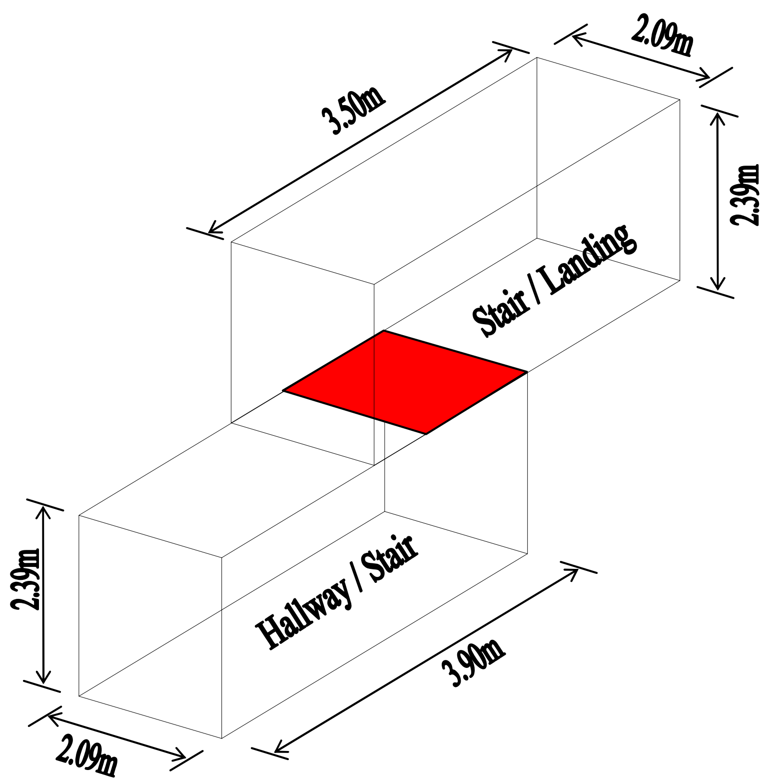
The lounge where the fire was located during the full rig testing is linked to the upper bedrooms by the hallway, stairs and landing. In Figure 2.2 and Figures 2.4 – 2.6 it can be seen that the stair occupies approximately half of the width and slightly more than half of the length of the hallway. The upper surface of the stairs is sloped and the ceiling of the hallway slopes at approximately 45°, parallel to the stairs to provide adequate head room for occupants.

This geometry presents a challenge to BRANZFIRE as it is only able to model rectangular compartments of uniform height, or with a sloping ceiling over the entire compartment. Once the smoke layer or ceiling jet reaches the start of the sloped ceiling in the hallway it will begin to rise to the upper landing compartment and there will be mixing effects caused by this transition which can not be simulated in BRANZFIRE. The stair arrangement occupies volume in the compartment which can not be included in the BRANZFIRE simulation. This will affect the layer height prediction and smoke filling of this compartment.

This combination of rooms was simulated in two different ways for tests CDT17 and CDT18 to determine which gave the best approximation of the temperatures, smoke layers and transport of toxic products to the first floor.

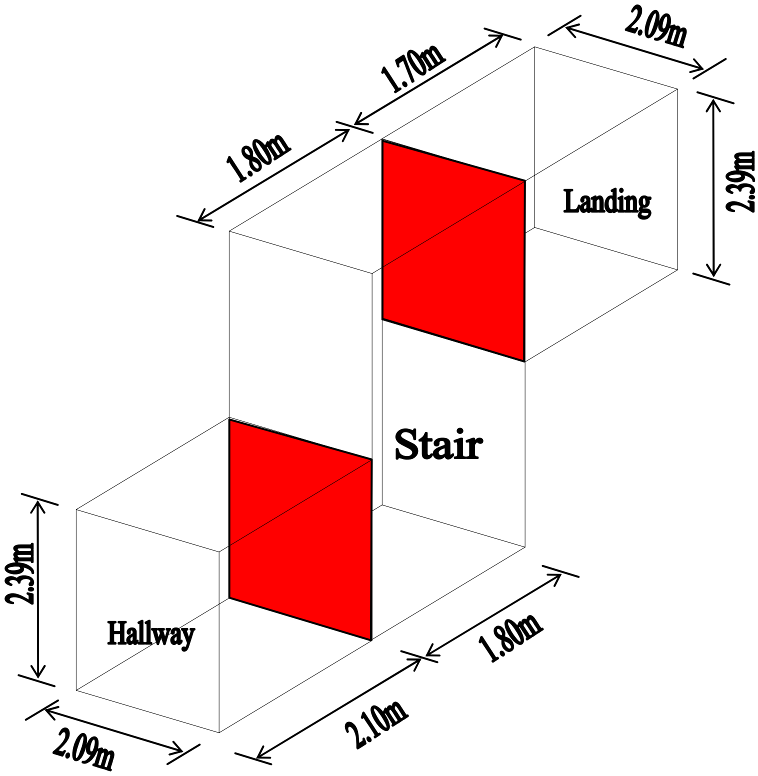
The first arrangement involved using two long compartments, one above the other with a horizontal vent in the ceiling of the lower compartment to transfer the fire products to the upper floor. This is referred to as the two compartment simulation in this report. The lower compartment represents the hallway and lower part of the stairs and the upper compartment represents the upper part of the stairs and the landing. A graphical representation of the compartment arrangement is shown in Figure 3.2.

Figure 3.2 Two compartment arrangement (not to scale)



The second arrangement is based on using three compartments to represent the hallway, stairs and landing. This is referred to as the three compartment simulation in this report. The compartment representing the stairs is the full height of the building whereas the two other compartment heights are based on the individual floor stud heights. The central compartment is linked to the two other compartments by a wall vent. The arrangement of the compartments is shown in Figure 3.3 below.

Figure 3.3 Three compartment arrangement (not to scale)



The mass flow rate through a vent is described by the formula given by Karlsson and Quintiere (2000) which states:

$$\dot{m} = C_d A V \rho \qquad \text{(Equation 3.1)}$$

where: $\dot{m}$ = the mass flow rate through the vent (kg/s)
A = vent area (m^2)
C_d = drag coefficient for the vent (dimensionless)
V = vent flow velocity (m/s)
ρ = gas density (kg/m^3)

The vents between the compartments for the two arrangements are only required in the model and are not a part of the full scale rig in which the rooms described by the compartments are not subdivided. By creating separate compartments and having vents between them, BRANZFIRE will calculate a mass flow through the theoretical vent and applies a drag coefficient of C_d = 0.68 Wade (2004b). This will lead to a reduced mass flow rate between compartments in the model in comparison to the full scale testing.

To compensate for the drag coefficient that BRANZFIRE applies to the mass flow rate through vents, the vent area was multiplied by a factor of 0.68^{-1}. When creating ceiling vents between compartments BRANZFIRE allows the user to specify a vent area but not the dimensions of the vent. In the simulations where the rooms were described by the two compartment simulations the vent area was multiplied by 0.68^{-1}.

For wall vents connecting two compartments BRANZFIRE requires the user to input the vent height and width, and then calculates the vent area from these dimensions. The user is also required to enter the sill height of the vent. BRANZFIRE then uses these dimensions along with the compartment floor elevation to determine the elevation of the vent soffit. This elevation is then used to determine the mass flow rate to the adjacent compartment once the layer height in the originating compartment descends below the vent soffit.

For the arrangement where the hallway, stair and landing were simulated using the three compartment simulation the vent width was multiplied by 0.68^{-1} and the vent height was left unchanged. This has the result of increasing the vent area by the factor of 0.68^{-1} but does not affect the sill height of the vent and therefore the mass flow rate which is dependent on the layer height in the compartment. The vent height was entered as the stud height of the room in the compartments representing the hallway and the landing.

Because the vent connecting the compartments is in effect the total width of the hallway, once it is multiplied by 0.68^{-1} the vent width becomes wider than the compartment on either side of the vent. BRANZFIRE is a two zone model and considers an upper and lower layer over the whole compartment therefore it does not consider the effect of contractions around vents. The calculation of the vent flow is therefore not affected by the vents being larger than the compartments on either side.

This method for creating vents when subdividing long corridors was suggested by Shesoptal (2003) for use in CFAST. Chow (1996) also suggested that such a method may be required based on carrying out simulations of a large building that was subdivided into nine compartments using CFAST.

There is debate about the use of this method as there is concern that it is extending the software beyond its capabilities. Forney (2003) expressed concern about using the method proposed by Shestopal (2003) to subdivide a large room into smaller compartments due to the assumption used in CFAST that the flows within a compartment layer are negligible. Boverman (2003) also commented that using the method proposed by Shestopal (2003) to adjust the vent area is extending the zone model beyond its capabilities but suggested that the use of virtual rooms is CFAST is acceptable.

3.4 Compartment Layer Heights and Temperatures

As noted previously BRANZFIRE is a two zone model and the output generated from the model is reported for both the upper and lower layers. This information includes temperature, gas concentrations and optical densities. The data captured during the full rig testing included temperatures for each of the thermocouple trees with thermocouple elevations of 0.08, 0.42, 0.73, 1.05, 1.38, 1.69, 2.01 and 2.34m above floor level in the lounge and similar spacings on the stairs and in the bedrooms.

To allow comparison against the BRANZFIRE simulation output, the temperature data from the full scale rig tests was converted to an upper and lower layer temperature. Firstly the height of the upper and lower layer interface was determined using the N% method by Cooper (1982). This is given is Equation 3.2 and 3.3 below.

$$\Delta T_{ref}(t) = T_{\max}(H_{top}, t) - T_{amb}(H_{top}) \qquad \text{(Equation 3.2)}$$

Where: $\Delta T_{ref}(t) =$ upper layer reference temperature at time t

$T_{\max}(H_{top}, t) =$ maximum temperature at the maximum height in the time period between t = 0 and t = t

$T_{amb}(H_{top}) =$ ambient temperature at maximum height, i.e. $T(H_{top}, t = 0)$

Using the N% method the interface is defined as passing the elevation $H_i(t)$ at that time t when H_i first satisfies Equation 3.3.

$$T(H_i, t) - T_{amb}(H_i) = \frac{N\Delta T_{ref}}{100} \qquad \text{(Equation 3.3)}$$

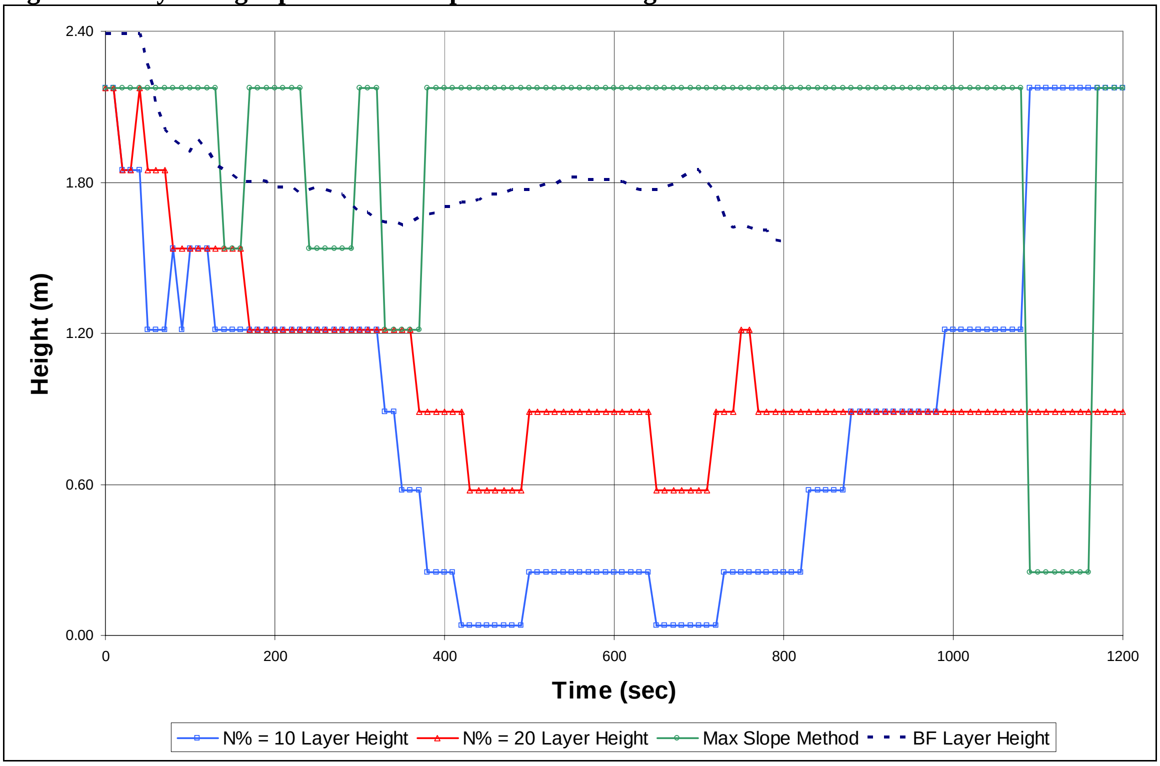
Where: $T(H_i, t) =$ Temperature at interface height H_i at time t

$T_{amb}(H_i) =$ Ambient temperature of interface height H_i

Cooper (1982) used values of 10%, 15% and 20% for 25kW, 100kW, 225kW fires in a single room compartment with a vent to the outside, and found that 10% gave the best results while He (1997) used 15%. Weaver (2000) found that the N% method was less successful when the vent led to a neighbouring compartment.

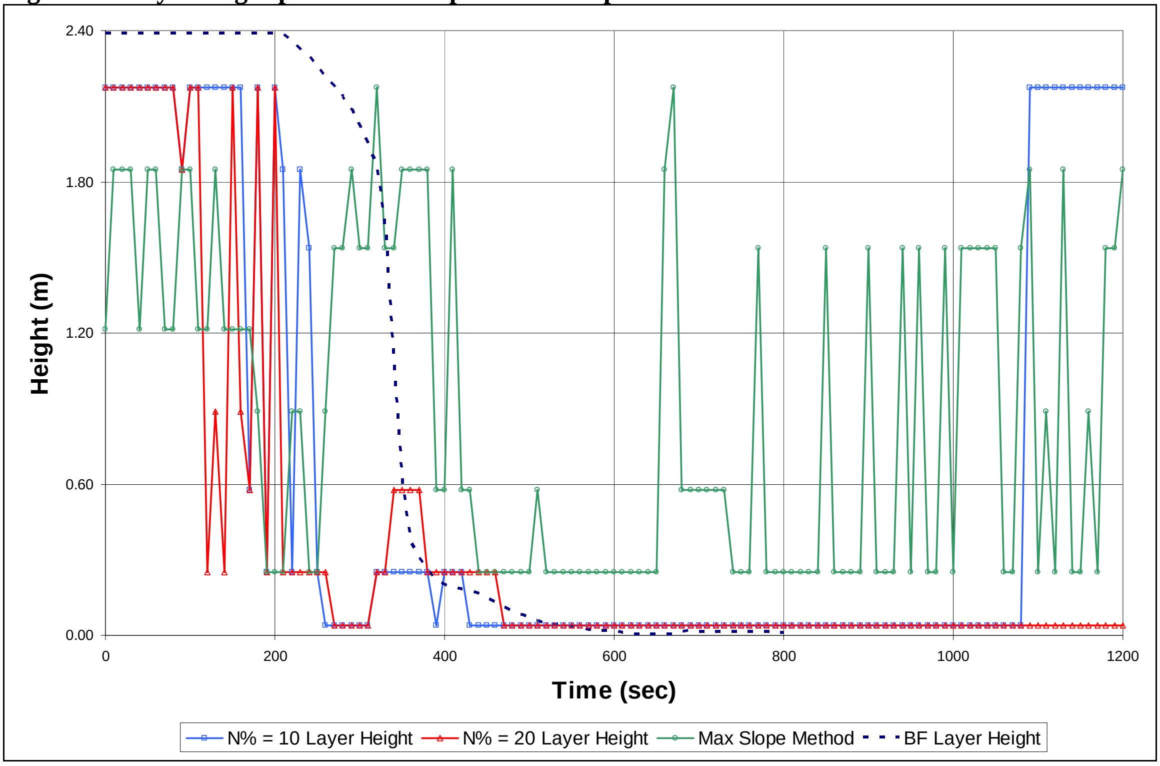
Emmons (2002), and Janssens & Tran (1992) state that the maximum slope method defines the layer as being at the height where the greatest change in temperature with respect to height occurs. The maximum slope method was compared against the N% method for both the lounge and the open bedroom for test CDT17 using the two compartment simulation. The results of the comparison are shown in Figure 3.4 for the lounge and Figure 3.5 for the open bedroom. Note that in Figures 3.4 and 3.5 BRANZFIRE has been abbreviated to BF in the data series legend.

Figure 3.4 Layer height prediction comparison for Lounge



In Figure 3.4 it can be seen that in the lounge the N% method with N = 10 over predicts the lowering of the layer interface in comparison to the results of the BRANZFIRE simulation. The N% method with N = 20 also over predicts the lowering of the layer interface but not to the same extent as using N = 10. The maximum slope method predicts four brief periods of lowering of the layer interface which does compare well with the results of the BRANZFIRE simulation.

Figure 3.5 Layer height prediction comparison for Open Bedroom



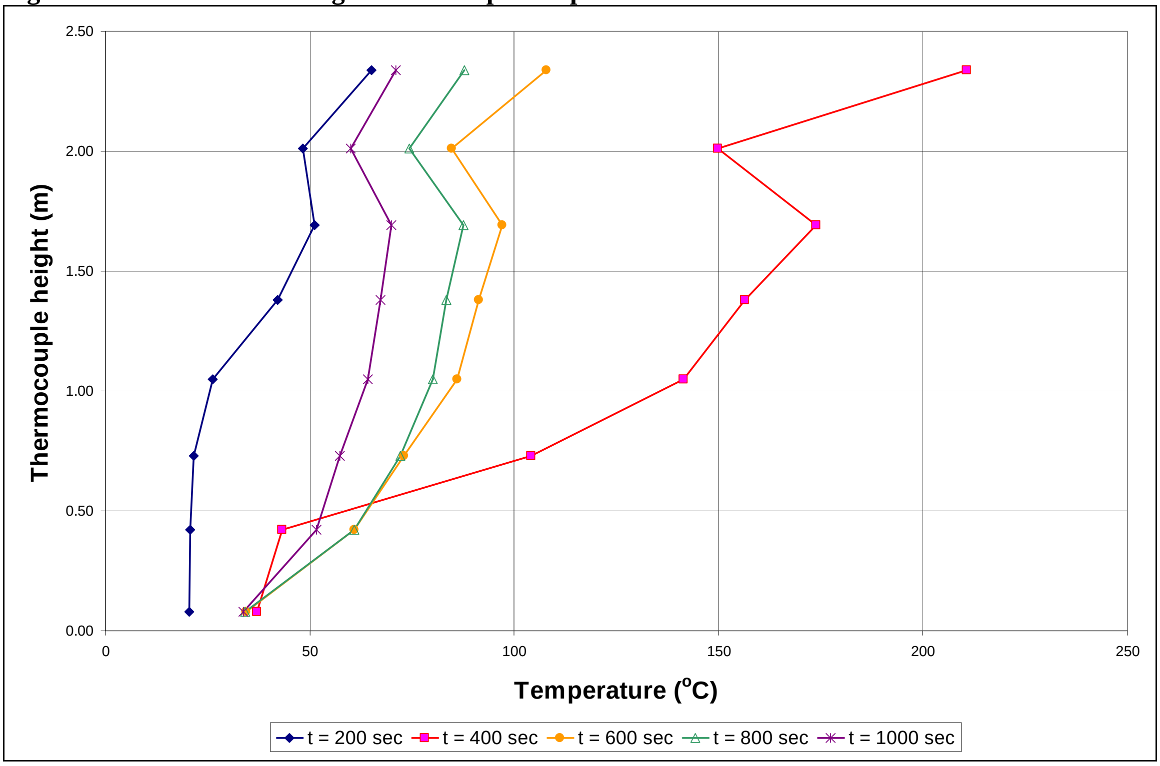
From Figure 3.5 it can be seen that the maximum slope method makes a very erratic prediction of the layer interface in the open bedroom and does not compare well against the results of the BRANZFIRE simulation. The N% method using N = 10 and N = 20 also make erratic predictions of the layer height up to 200 seconds after which both predict the layer height to lower to floor level and remain there for the remainder of the test. The layer interface predicted by N = 10 lowers slightly later than the prediction with N = 20. The layer height prediction with N = 10 is a better comparison against the results of the BRANZFIRE simulation.

From the results shown in Figures 3.4 and 3.5 it was considered that the N% method using a value of N = 20 gave a better prediction of the layer height in the two rooms than using N = 10 or using the max slope method. Therefore N = 20 has been used in the analysis of the layer height in this report.

In tests CDT14 and CDT16 with the lounge door closed, there is a very small temperature increase in the open bedroom. In tests CDT15, CDT17 and CDT18 with the lounge door open the temperature increase in the open bedroom is in the order of 40°C – 50°C. The temperature difference between adjacent thermocouples is at times very small which makes it difficult for the equations to predict the height of the upper and lower layer interface.

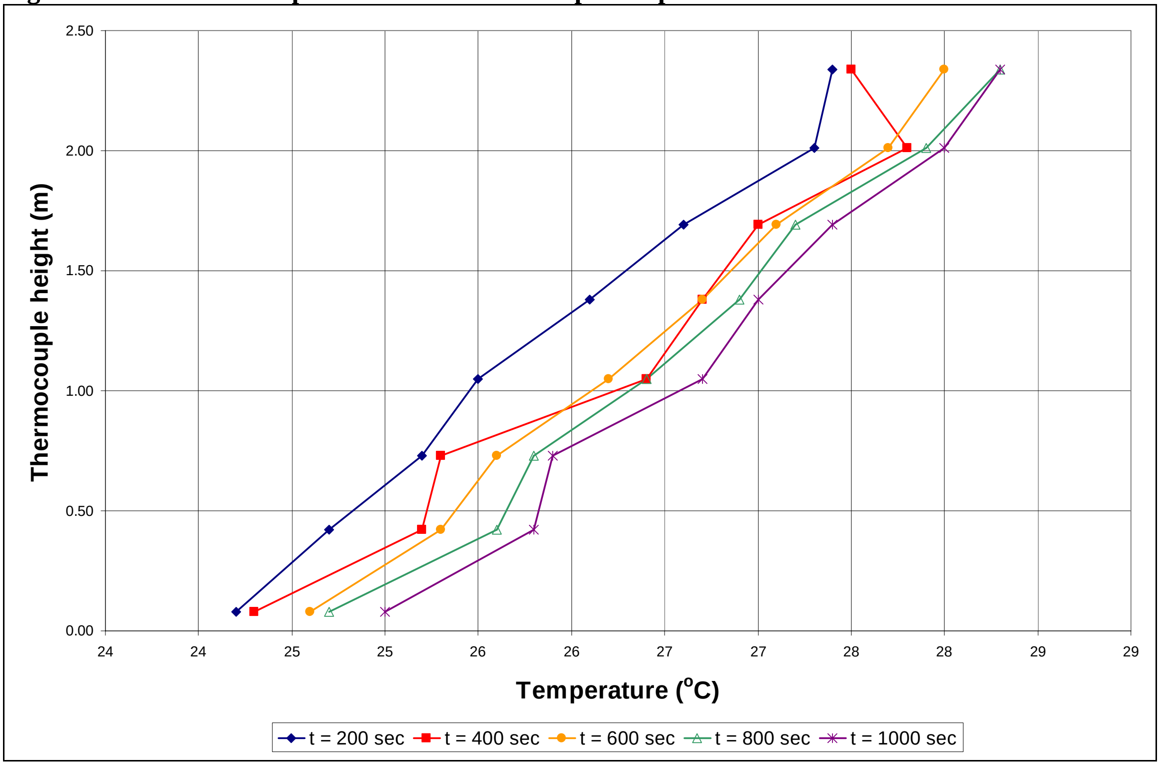
Figures 3.6 shows the temperatures recorded by the thermocouples in the lounge for test CDT16 which had the door closed at time intervals of 200, 400, 600, 800 and 1000 seconds. In Figure 3.6 it can be seen that even at 400 seconds, when the highest temperatures are recorded, the location of the upper and lower layer interface is not clearly defined.

Figure 3.6 Test CDT16 Lounge thermocouple temperatures at time intervals



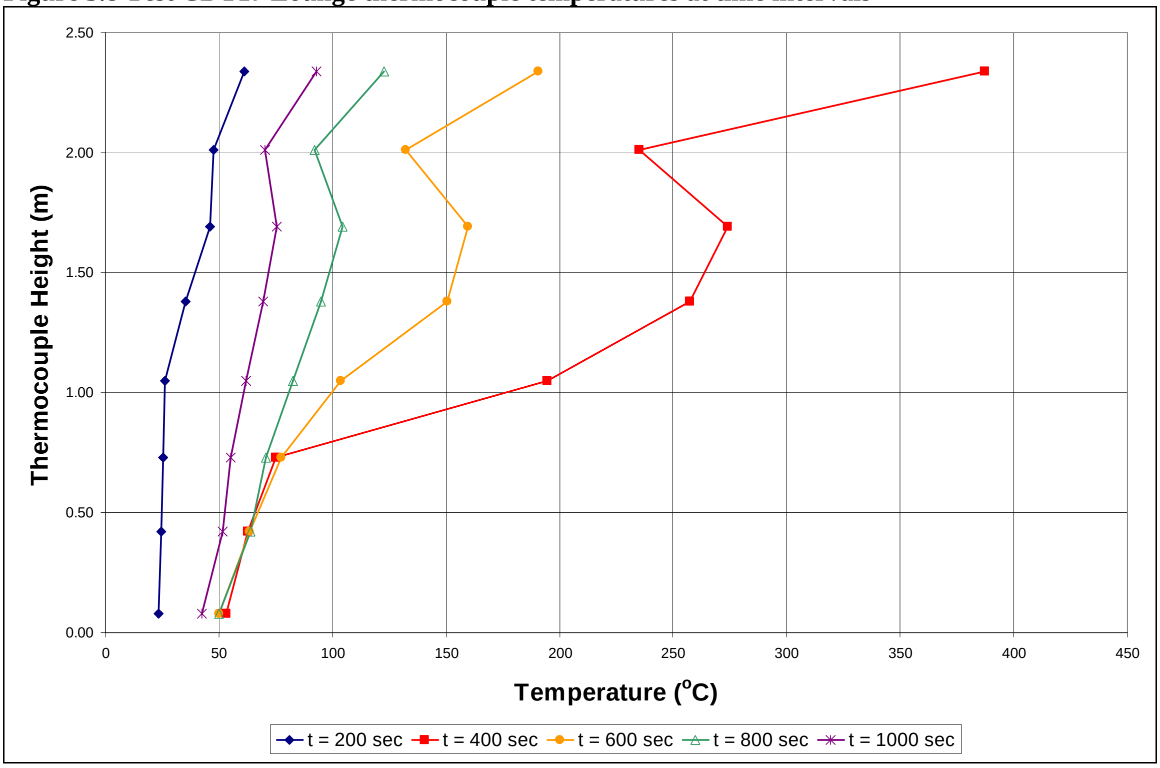
Figures 3.7 shows the temperatures recorded by the thermocouples in the open bedroom for test CDT16 at time intervals of 200, 400, 600, 800 and 1000 seconds. In Figure 3.7 the layer height is not clearly defined at any time.

Figure 3.7 Test CDT16 Open Bedroom thermocouple temperatures at time intervals



Figures 3.8 shows the temperatures recorded by the thermocouples in the lounge for test CDT17 which had the lounge door open at time intervals of 200, 400, 600, 800 and 1000 seconds.

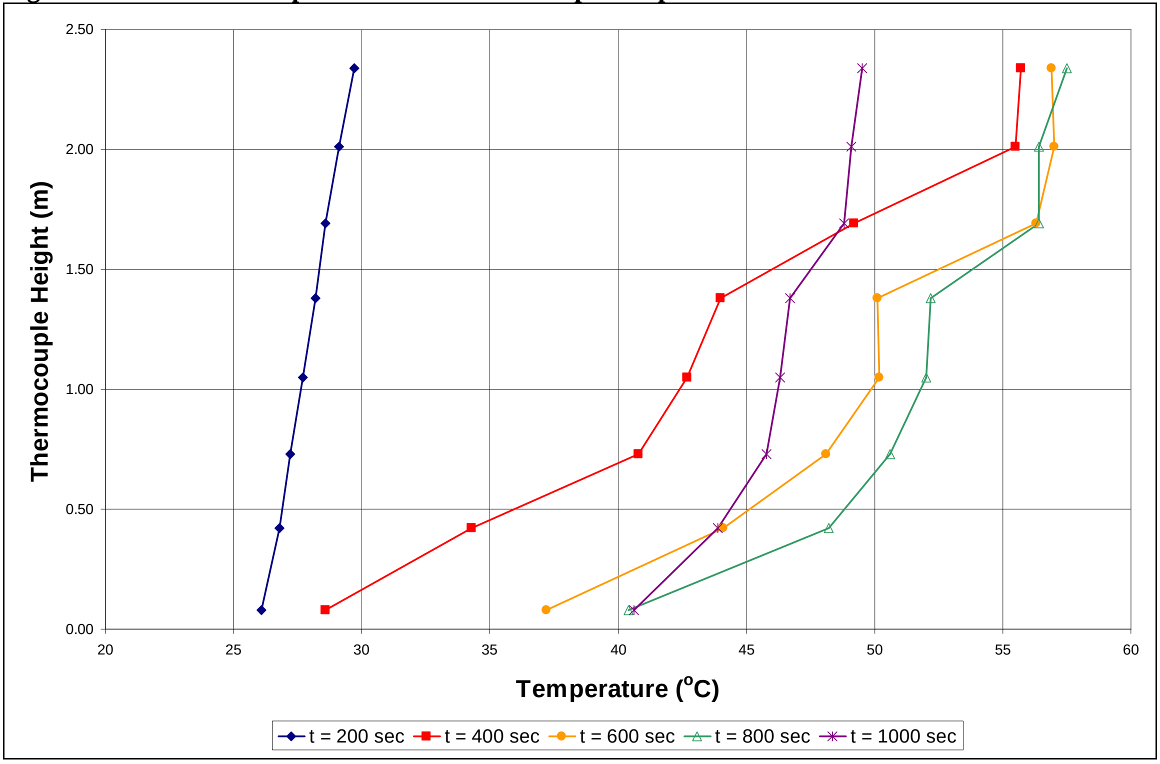
Figure 3.8 Test CDT17 Lounge thermocouple temperatures at time intervals



In Figure 3.8 the layer height is well defined at 400 seconds which corresponds to the first peak in the compartment temperatures. At 600 seconds during the trough between the two peak temperatures the layer is not as well defined in comparison to 400 seconds. At 200, 800 and 1000 seconds the height of the upper and lower layer interface is difficult to determine.

Figures 3.9 shows the temperatures recorded by the thermocouples in the open bedroom for test CDT17 which had the lounge door open at time intervals of 200, 400, 600, 800 and 1000 seconds.

Figure 3.9 Test CDT17 Open Bedroom thermocouple temperatures at time intervals



In Figure 3.9 it can be seen that during the first peak in the temperature readings at 400 seconds the layer interface height is well defined however it is difficult to determine the layer height at the other time steps.

Once the layer interface height was determined upper and lower layer temperatures were calculated using the spatially averaged temperature for the upper and lower zone. The method given by He (1997) and as shown in Equations 3.4 and 3.5 was used to determine the upper and lower layer temperature.

$$T_{av,u} = \frac{\int_{H_i}^{H_r} T dy}{H_r - H_i} \qquad \text{(Equation 3.4)}$$

$$T_{av,l} = \frac{\int_{0}^{H_i} T dy}{H_i} \qquad \text{(Equation 3.5)}$$

Where: $T_{av,u}$ = Average temperature of upper zone

$T_{av,l}$ = Average temperature of lower zone

H_r = Ceiling Height

H_i = Interface height

The integral in each formula is given by Equation 3.6 and 3.7.

$$\int_{H_i}^{H_r} T dy = \frac{1}{2}\left[\sum_{j=k+1}^{L}(T_{j+1} + T_j)(h_{j+1} - h_j) + (T_{k+1} + \Delta T_{ref})(h_{k+1} - H_i)\right] \qquad \text{(Equation 3.6)}$$

$$\int_{0}^{H_i} T dy = \frac{1}{2}\left[\sum_{j=0}^{k-1}(T_{j+1} + T_j)(h_{j+1} - h_j) + (T_k + \Delta T_{ref})(H_i - h_k)\right] \qquad \text{(Equation 3.7)}$$

Where: T_j = Temperature at point j, j = 0(floor), …..L+1(ceiling)

L = Number of thermocouples in the thermocouple tree

T_k = Temperature at the thermocouple which is right below the estimated interface height

T_{k+1} = Temperature at the thermocouple which is right above the estimated interface height

ΔT_{ref} = Upper layer reference height found from the N% rule

The upper and lower layer temperatures were also calculated using the equation of state methods given by He (1997) and as shown by Equations 3.8 and 3.9.

$$T_{av,u} = \frac{H_r - H_i}{\int_{H_i}^{H_r} \frac{1}{T} dy} \qquad \text{(Equation 3.8)}$$

$$T_{av,l} = \frac{H_i}{\int_0^{H_i} \frac{1}{T} dy} \qquad \text{(Equation 3.9)}$$

Where: $T_{av,u}$ = Average temperature of upper zone

$T_{av,l}$ = Average temperature of lower zone

H_r = Ceiling Height

H_i = Interface height

The two integrals are then given by Equations 3.10 and 3.11.

$$\int_{H_i}^{H_r} \frac{1}{T} dy = \int_{h_{k+1}}^{H_r} \frac{1}{T} dy + \sum_{j=k+1}^{L} \int_{h_j}^{h_{j+1}} \frac{1}{T} dy \qquad \text{(Equation 3.10)}$$

$$= \frac{h_{k+1} - H_i}{T_{k+1} - \Delta T_{ref}} \ln\left(1 + \frac{T_{k+1} - \Delta T_{ref}}{\Delta T_{ref}}\right) + \sum_{j=k+1}^{L} \frac{h_{j+1} - h_j}{T_{j+1} - T_j} \ln\left(1 + \frac{T_{j+1} - T_j}{T_j}\right)$$

$$\int_0^{H_i} \frac{1}{T} dy = \sum_{j=0}^{k-1} \int_{h_j}^{h_{j+1}} \frac{1}{T} dy + \int_{h_k}^{H_i} \frac{1}{T} dy \qquad \text{(Equation 3.11)}$$

$$= \sum_{j=0}^{k-1} \frac{h_{j+1} - h_j}{T_{j+1} - T_j} \ln\left(1 + \frac{T_{j+1} - T_j}{T_j}\right) + \frac{H_i - h_k}{\Delta T_{ref} - T_k} \ln\left(1 + \frac{\Delta T_{ref} - T_k}{T_k}\right)$$

Where: T_j = Temperature at point j, j = 0(floor), …..L+1(ceiling)

L = Number of thermocouples in the thermocouple tree

T_k = Temperature at the thermocouple which is right below the estimated interface height

T_{k+1} = Temperature at the thermocouple which is right above the estimated interface height

ΔT_{ref} = Upper layer reference height found from the N% rule

3.5 Fractional Effective Dose

Purser (2002) gives a range of formulae that were used to determine the fractional effective dose based on the results of the full scale rig testing. These are presented below.

The fractional effective concentration for smoke is given by Equation 3.12 for a small enclosure and Equation 3.13 for a large enclosure.

$$FEC_{smoke} = \left[\frac{OD}{m}\right] / 0.2 \qquad \text{(Equation 3.12)}$$

$$FEC_{smoke} = \left[\frac{OD}{m}\right] / 0.1 \qquad \text{(Equation 3.13)}$$

The fractional irritant concentration for gases is given by Equation 3.14.

$$FIC = FIC_{HCl} + FIC_{HBr} + FIC_{HF} + FIC_{SO_2} + FIC_{NO_2} + FIC_{CH_2CO} + FIC_{HCHO} + \sum FIC_x$$

(Equation 3.14)

Where: $\sum FIC_X$ = FICs for other irritants present.

The concentrations of the irritant gases deemed to be highly irritant by Purser et al (1998) are given in Table 3.6.

Table 3.6 Highly irritant doses of irritants gases

Gas	**Concentration predicted to impair escape in half the population (ppm)**	**Concentration predicted to cause incapacitation in half the population (ppm)**
HCl	200	900
HBr	200	900
HF	200	900
SO_2	24	120
NO_2	70	350
CH_2CHO (acrolein)	4	20
HCHO (formaldehyde)	6	30

In the report by Purser et al (1998) it was deemed that if the fractional irritant concentration reached a value of 1.0 then the smoke atmosphere would be highly irritant and would slow escape attempts. If the total exceeds a value of 1.0 by a factor of four or more it was deemed that escape would be prevented.

The other measure of the effect of irritant gases is the dose that causes a lethal effect in those exposed to the gas atmosphere. The fractional lethal dose for irritant gases is given by Equation 3.15.

$$FLD_{irr} = FLD_{HCl} + FLD_{HBr} + FLD_{HF} + FLD_{SO_2} + FLD_{NO_2} + FLD_{CH_2CHO} + FLD_{HCHO} + \sum FLD_x \quad \text{(Equation 3.15)}$$

Where: $\sum FLD_X =$ FLDs for other irritants present

The thirty minute exposure dose which is likely to be lethal used for each irritant gas are shown in Table 3.7.

Table 3.7 Thirty minute lethal exposure doses of irritants

Gas	**Exposure dose predicted to be lethal to half the population (ppm.min)**
HCl	114,000
HBr	114,000
HF	87,000
SO_2	12,000
NO_2	1,900
CH_2CHO (acrolein)	4,500
HCHO (formaldehyde)	22,500

The FLD_{irr} for short periods of time during the fire are summed until the value of FLD_{irr} reaches unity when it is predicted that a lethal dose has been inhaled.

The fractional effective incapacitating dose for all asphyxiant gases is given by Equation 3.16.

$$FED_{IN} = \left(FED_{Ico} + FED_{Icn} + FLD_{irr}\right) x VCO_2 + FED_{Io} \quad \text{(Equation 3.16)}$$

Where: $FED_{Ico} =$ fraction of an incapacitating dose of CO

$FED_{Icn} =$ fraction of an incapacitating dose of HCN

$FLD_{Irr} =$ fraction of an irritant dose contributing to hypoxia

$VCO_2 =$ multiplication factor for CO_2 induced hyperventilation

$FED_{Io} =$ fraction of an incapacitating dose of low oxygen hypoxia

$FED_{Ico_2} =$ fraction of an incapacitating dose of CO_2

Each of these variables are then calculated from Equations 3.17 to 3.20.

$$FED_{Ico} = \left(8.2925 \times 10^{-4} \times ppmCO^{1.036}\right) \times \frac{t}{30} \qquad \text{(Equation 3.17)}$$

$$FED_{Icn} = \left(\exp([CN]/43)\right) \times \frac{t}{220} \qquad \text{(Equation 3.18)}$$

Where: [CN] = [HCN] + [total organic nitriles] – [NO2]

$FLD_{Irr} =$ as calculated in Equation 3.15.

$$VCO_2 = \exp([CO_2]/4) \qquad \text{(Equation 3.19)}$$

$$FED_{Io} = t / \exp[8.13 - 0.54(20.9 - \%O_2)] \qquad \text{(Equation 3.20)}$$

A simplified look up table of fractional effective doses for incapacitation for each gas over a one minute time period was given by Purser et al (1998). The information is shown in Table 3.8.

Table 3.8 Simplified look up table for individual toxic gas FED

FED_{Ico} = CO ppm /25,000					
ppm HCN	**FED_{Icn}**	**$\%CO_2$**	**VCO_2**	**$\%O_2$**	**FED_{Io}**
0 – 50	0.00	0 – 2	1.0	21 – 13	0.00
50 – 100	0.05	2 – 3	1.5	13 – 12	0.02
100 – 125	0.10	3 – 4	2.0	12 – 11	0.05
125 – 150	0.15	4 – 5	2.5	11 – 10	0.08
150 – 200	0.50	5 – 6	3.0	10 – 9	0.15
200 +	1.00	6 – 7	3.5	9 – 8	0.20
		7 – 8	4.5	8 – 7	0.40
		8 – 10	4.8	7 – 6	0.70

A fractional effective dose of 1.0 due to toxic gases was deemed to cause incapacitation (loss of consciousness) with death predicted at approximately two to three times the incapacitating dose.

For the fractional effective dose due to radiation, a tenability limit of 2.5 kW/m^2 for radiant heat exposure for skin was adopted by Purser (2002). The time to incapacitation due to a radiant flux of q (W/m^2) is given by Equation 3.21.

$$t_{Irad} = \frac{80}{q^{1.33}} \qquad \text{(Equation 3.21)}$$

The time to incapacitation at a temperature T (°C) was calculated using Equation 3.22.

$$t_{Iconv} = 5 \times 10^{7} T^{-3.4} \qquad \text{(Equation 3.22)}$$

The fractional effective dose of heat is then calculated by summing the radiant and convected fractions using Equation 3.23.

$$FED = \sum_{t1}^{t2} \left(\frac{1}{t_{Irad}} + \frac{1}{t_{Iconv}} \right) \Delta t \qquad \text{(Equation 3.23)}$$

BRANZFIRE reports the concentrations of each gas in both the upper and lower layers, as well as calculating the fractional effective doses due to gases and from radiation. BRANZFIRE does not include the functionality to calculate a fractional irritant concentration. The fractional effective dose due to gases calculated in BRANZFIRE is given by Equation 3.24. The fractional effective dose takes account of an increased respiration rate due to exposure to carbon dioxide.

$$FED = FED_{O_2} + FED_{CO} + FED_{HCN} \qquad \text{(Equation 3.24)}$$

Each of the components of Equation 3.24 are given by Equations 3.25, 3.26 and 3.27.

$$FED_{O_2} = \int_0^t \frac{1}{\exp(8.13 - 0.54(20.9\% - \%O_2))} dt \qquad \text{(Equation 3.25)}$$

$$FED_{CO} = \frac{3.317 \times 10^{-5} \times RMV}{\%COHb} \int_0^t (ppmCO)^{1.036} dt \qquad \text{(Equation 3.26)}$$

Where: $\%COHb = (3.317 \times 10^{-5})(ppmCO)^{1.036}(RMV)t$

$RMV = \exp(0.2486\%CO_2 + 1.9086)$

BRANZFIRE allows the user to select a level of activity of the occupants in a compartment. The model uses values of RMV_0 and incapacitation doses of COHb applicable to a 70kg human as shown in Table 3.9.

Table 3.9 RMV_0 and COHb incapacitation dose for different activity levels

Activity	RMV_0 (l/min)	COHb Incapacitation dose (%)
At Rest	8.5	40
Light Work	25	30
Heavy Work	50	20

Comparison of Equation 3.26 which is taken from Wade (2004) and Equation 3.17 which is taken from Purser (1998) suggests that Purser (1998) used a value of RMV of 25 l/min. In the BRANZFIRE simulations a "light rest" activity level was selected so that the calculation of the fractional equivalent dose is carried out on the same basis.

The fractional effective dose due to hydrogen cyanide is then calculated using Equation 3.27.

$$FED_{HCN} = \int_0^t \frac{1}{\exp(5.396 - 0.012(ppmHCN))} dt \qquad \text{(Equation 3.27)}$$

Equation 3.27 applies where the HCN concentration is greater than 80ppm. A predicted fractional effective dose of one is deemed to cause incapacitation.

BRANZFIRE also predicts a fractional effective dose due to the combination of radiative effects which is calculated by Equation 3.28.

$$FED_{rad} = \int_0^t \frac{1}{55\left(\dot{q}_{rad} - 1.7\right)^{-0.8}} dt \qquad \text{(Equation 3.28)}$$

Where: $\dot{q}_{rad} = \Phi \varepsilon_u \sigma T_u^4$

$\varepsilon_u =$ emmisivity of the upper layer

$T_u =$ temperature of the upper layer (K)

$\sigma =$ Stefan Boltzmann constant = 5.66961 x 10^{-8} $Wm^{-2}K^{-4}$

$\Phi =$ Configuration factor (flat plate source and parallel differential element)

3.6 Smoke Alarms

In the full scale rig testing carried out by the BRE both optical and ionisation smoke alarms were installed in the lounge, hallway, landing and open bedroom. Spearpoint (1996) noted that the smoke alarms were readily available and were purchased from a local hardware store.

Optical and ionisation type smoke alarms detect smoke using a different process. Optical smoke alarms work on the principle of the obscuration of light or the scattering of light. For the obscuration of light type of smoke alarms the device contains a small light source which is detected by a receiver. The light signal in the smoke alarm is interrupted by the smoke particulate that fills the smoke alarm chamber. When the receiver can no longer detect a signal of adequate strength the alarm state is reached and the alarm sounds.

In the scattering of light type smoke alarms there is a light source which is positioned such that the photosensitive detector can not detect the source. When smoke particles enter the smoke alarm chamber they scatter the light from the source which can then be detected by the photosensitive receiver. Once the activation signal strength is reached the alarm sounds. Scattering light type smoke alarms were used in the full scale rig tests.

Ionisation smoke alarms work on a different process whereby a small radioactive source is placed in the smoke alarm which ionises the air in the chamber, making it conductive and allowing a current flow between two charged electrodes. When smoke enters the chamber of the smoke alarm the charged ions are attracted to the smoke particles, reducing the strength of the current. Once the current reduces below a specified level, the alarm sounds.

Spearpoint (1996) notes that optical type smoke alarms are more suited to situations where the smoke contains large particulate which typically occurs in a smouldering fire. Ionisation type smoke alarms are more suited to situations where the smoke contains smaller particles which are more commonly found in flaming fires.

BRANZFIRE allows the user to specify a single smoke alarm in a compartment which is triggered by the optical density of the ceiling jet. BRANZFIRE allows the user to specify whether the activation optical density is measured in the ceiling jet or in the smoke alarm chamber. The optical density in the smoke alarm chamber is calculated based on the optical density in the ceiling jet with an allowance for a delay time for smoke to enter the smoke alarm chamber based on the characteristic length of the smoke alarm.

The delay time to enter the chamber is a function of the velocity of the ceiling jet that the smoke alarm is exposed to. Because of this BRANZFIRE allows the user to input a radial distance from the fire plume to the smoke alarm so that the speed of the ceiling jet at the smoke alarm can be calculated. The greater the speed of the ceiling jet, the smaller the time of delay for smoke to enter the smoke alarm chamber.

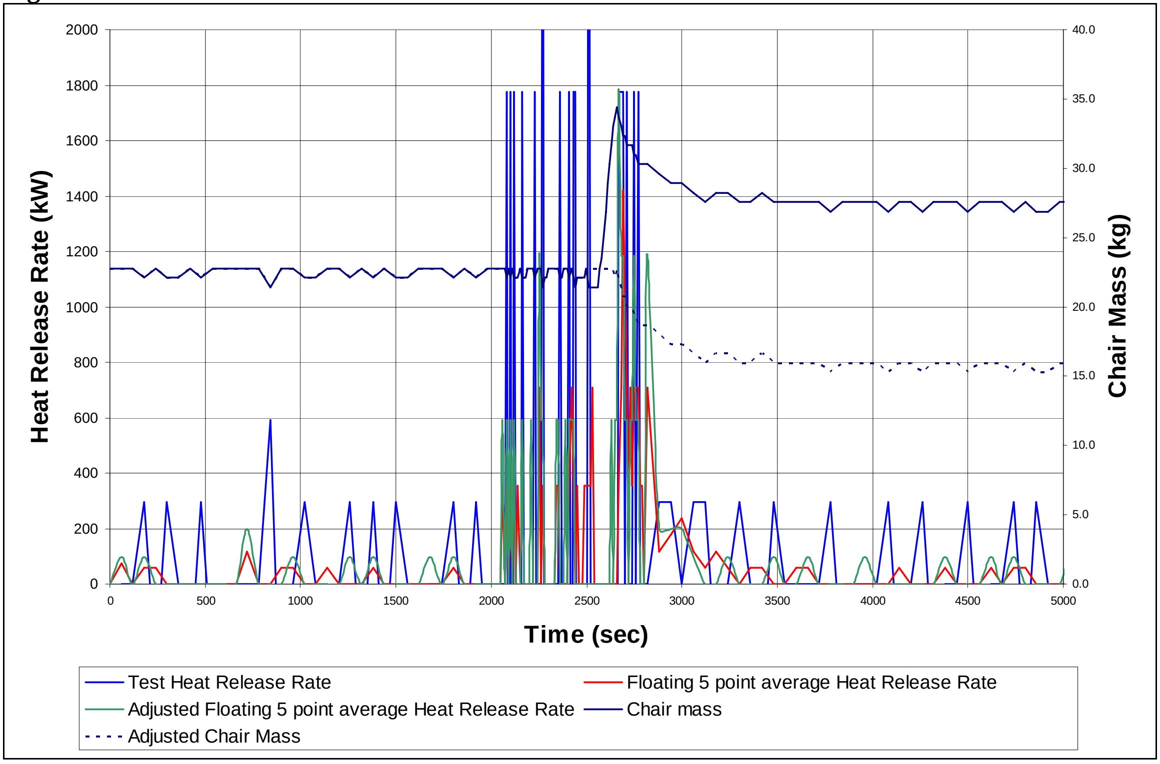
In the BRANZFIRE simulations the radial distance from the fire plume was set as the distance from the fire object to the smoke alarms in the lounge of the full scale rig testing based on the drawings on the BRE CD ROM. In the other compartments of the house the radial distance was defined as the distance from the point where smoke would enter the compartment to the location of the smoke alarm. For example, in the open bedroom the radial distance was defined as the distance from the door from the landing to the smoke alarm in the full scale rig testing.

For a detailed description of the calculation of the optical density in the smoke alarm the reader should refer to Wade (2004b).

4 Test CDT15 Simulation Results

The chair mass loss rates and the heat release rates derived from test CDT15 are shown in Figure 4.1.

Figure 4.1 Test CDT15 Heat Release Rate



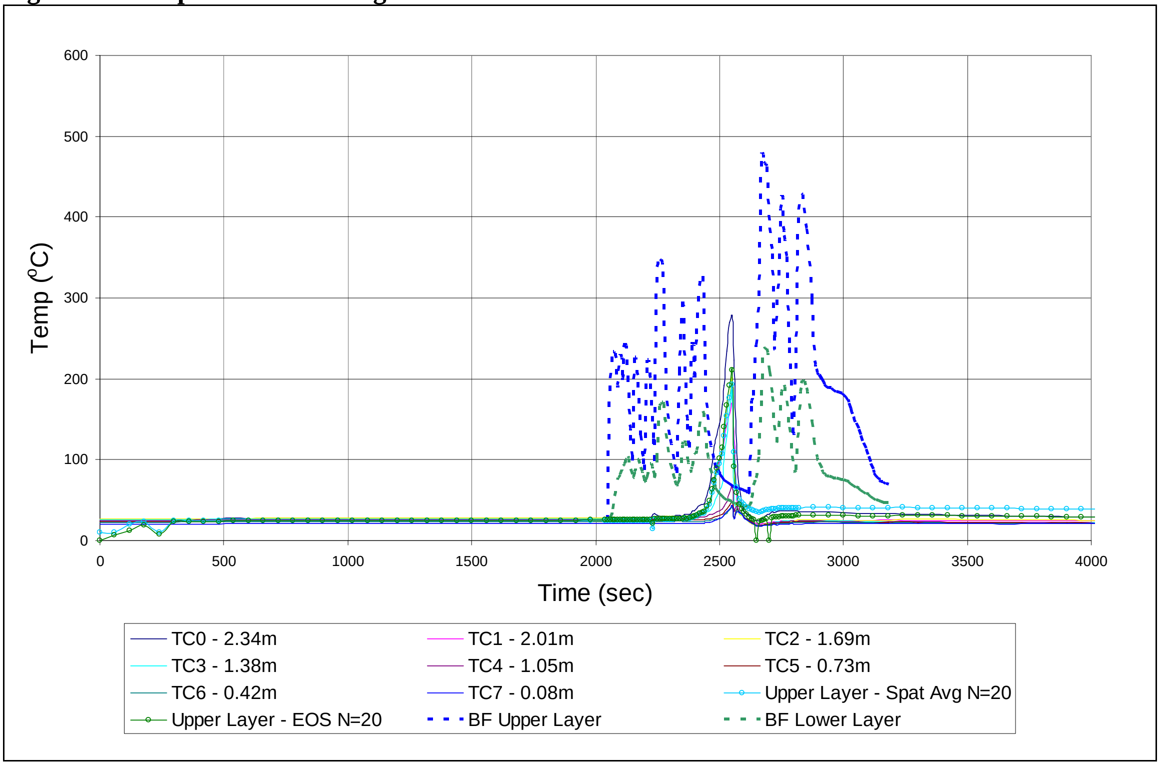
In Figure 4.1 it can be seen that the chair mass load cell signal was adjusted at approximately 2600 seconds. Spearpoint (1996) noted that flaming ignition of the smouldering fire was initiated at approximately 2220 seconds from the start of the test. Following this there is a decrease in the chair mass which generates a peak in the heat release rate. Other than the change in the chair mass load cell reading following the adjustment in the signal strength, the chair mass load cell reading is generally unchanged with small decreases in chair mass with the signal then increasing to the original signal value.

The dashed line in Figure 4.1 represents the adjusted mass of the chair to account for the increase in the signal value at 2600 seconds. It shows the gradual decrease in the chair mass following the signal adjustment with a total mass loss of approximately 7kg which is significant in comparison to the other tests. The heat release rate generated from the adjusted mass loss rate is also shown with a peak at 2600 seconds coinciding with the increase in the mass loss rate. The heat release rate predicted by the adjusted mass loss rate is very high in comparison to the heat release rates found for tests CDT16 – CDT18 presented in the following sections.

A simulation based on the two compartment arrangement for the hallway and landing rooms was run over a time period of 1200 seconds to simulate the test data from test CDT15 over the period of 1980 to 3180 seconds. The first 1980 seconds of the full rig test was not simulated due to the erratic but low heat release rate in this time period.

The temperature results for the lounge compared against the full scale rig test results are shown in Figure 4.2. Note that in the Figure 4.2 BRANZFIRE has been abbreviated to BF in the data series legend.

Figure 4.2 Temperatures in lounge



It can be seen from Figure 4.2 that the temperatures predicted by the BRANZFIRE simulation are approximately twice those recorded in the full scale rig tests and are very erratic.

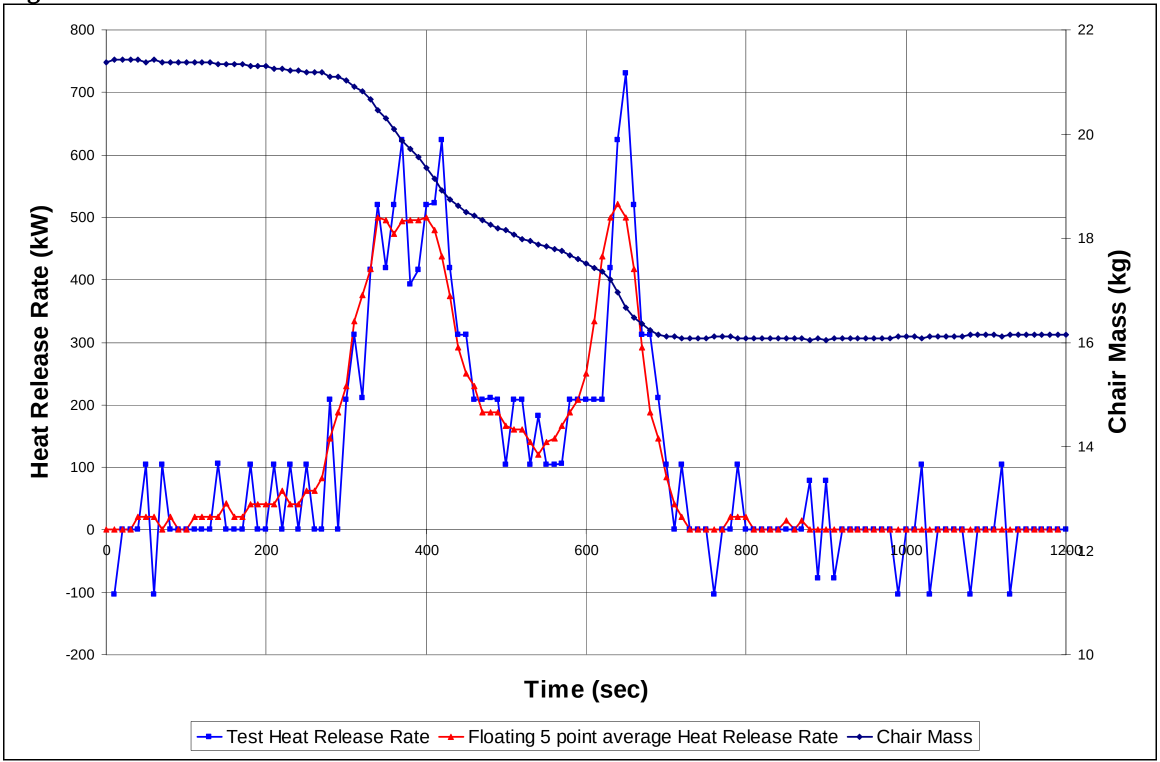
Because it is not possible to determine a realistic heat release rate to simulate the smouldering fire followed by the flaming fire and the poor quality of the results from the initial simulation it was decided not to simulate this test further.

5 Test CDT17 Simulation Results

Test CDT17 was the first of the tests carried out at Cardington with a fully flaming fire and the lounge door to the hallway open.

The heat release rate for the fire was determined from the mass loss rate given in the BRE testing data and is shown in Figure 5.1.

Figure 5.1 Test CDT17 Heat Release Rate



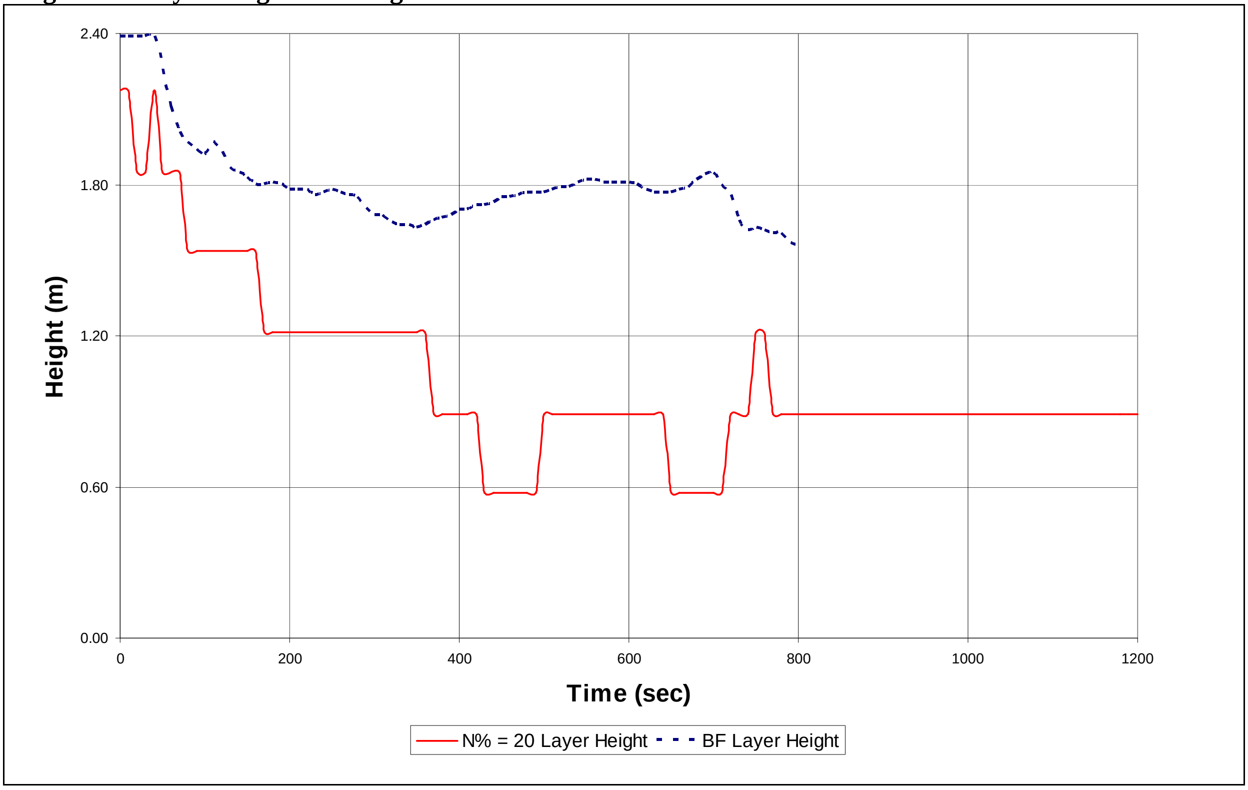
As noted in Section 3 of this report this test was simulated with two different configurations for the hallway, stair and landing. The results of the two simulations are discussed separately in Sections 5.1 and 5.2. Note that in the figures presented in this section BRANZFIRE has been abbreviated to BF in the data series legend.

5.1 Two Compartment Simulation

5.1.1 Layer Height

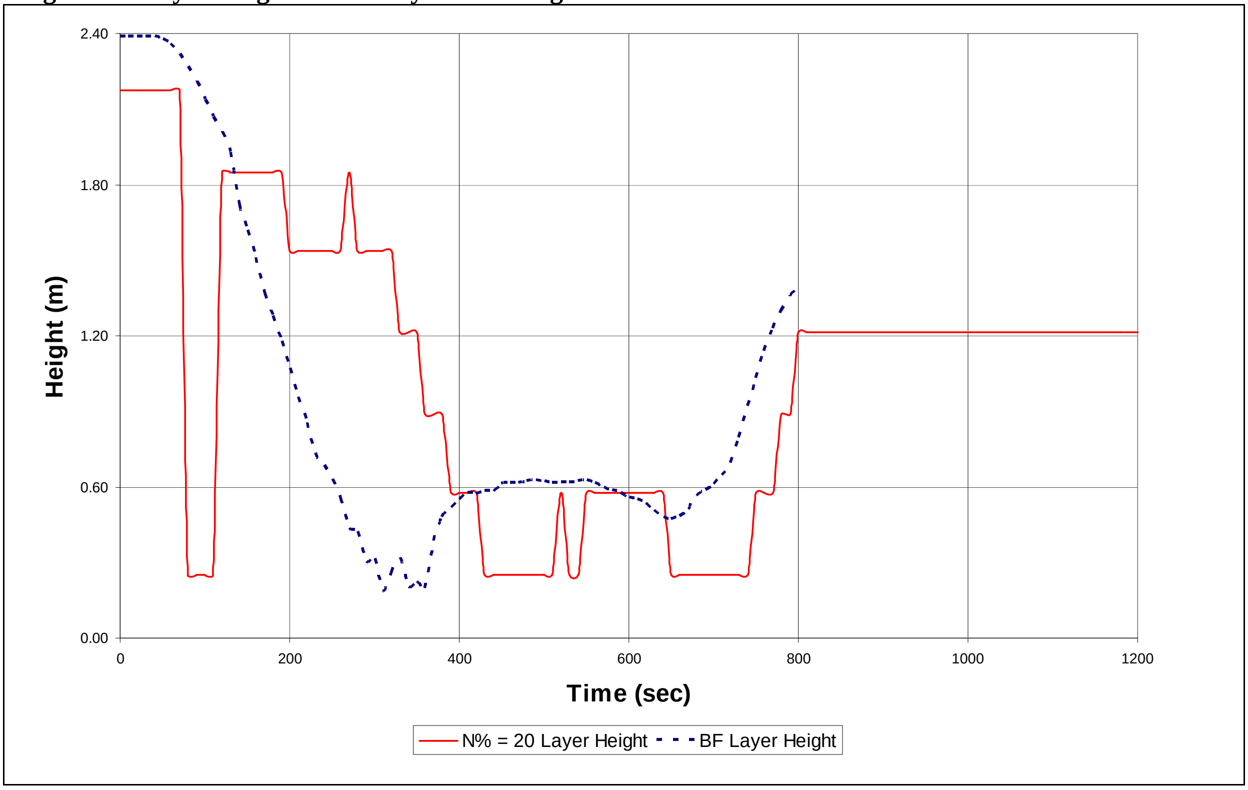
The layer heights predicted by the N% method using N = 20 and by the BRANZFIRE simulation for each of the compartments are presented in Figures 5.2 to 5.5.

Figure 5.2 Layer Height in Lounge



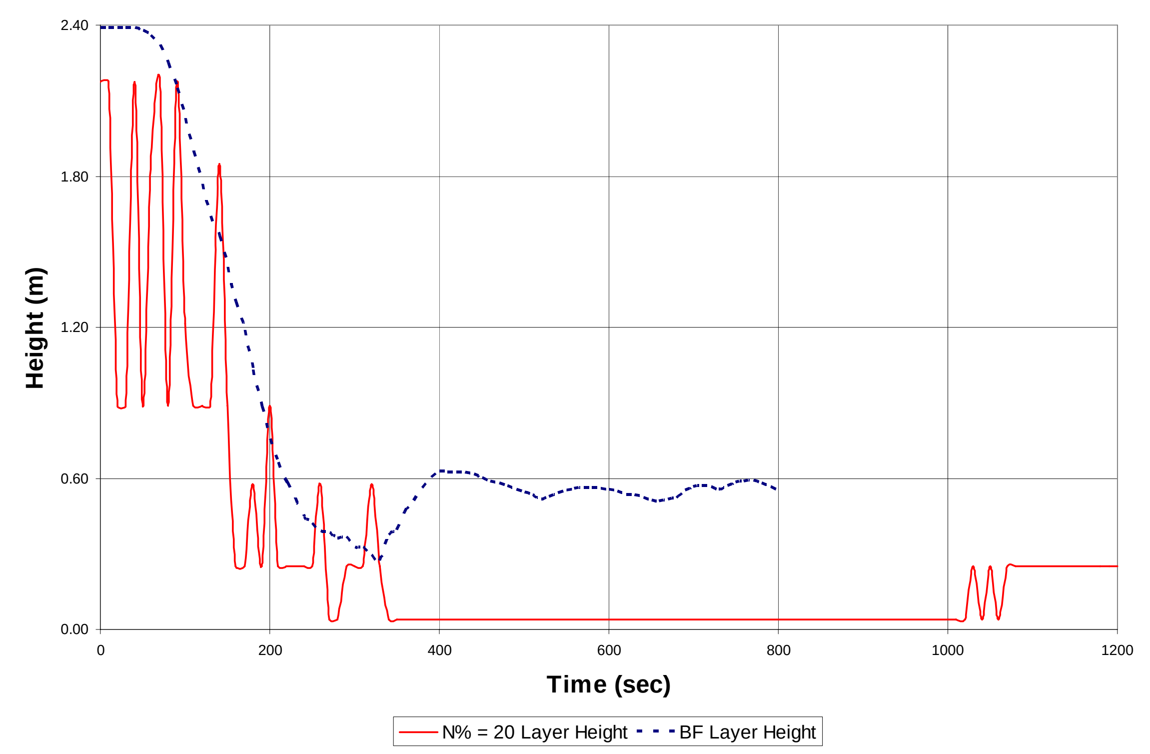
The decrease in the layer height is predicted to occur at approximately the right time by the BRANZFIRE simulation but the extent of the decrease in the layer height is under predicted. The N% method predicts the layer to lower to approximately 0.6m above floor level at approximately 500 seconds whereas the BRANZFIRE simulation predicts a decrease to a minimum value of 1.63m above floor level at 350 seconds.

Figure 5.3 Layer Height in Hallway near Lounge Door



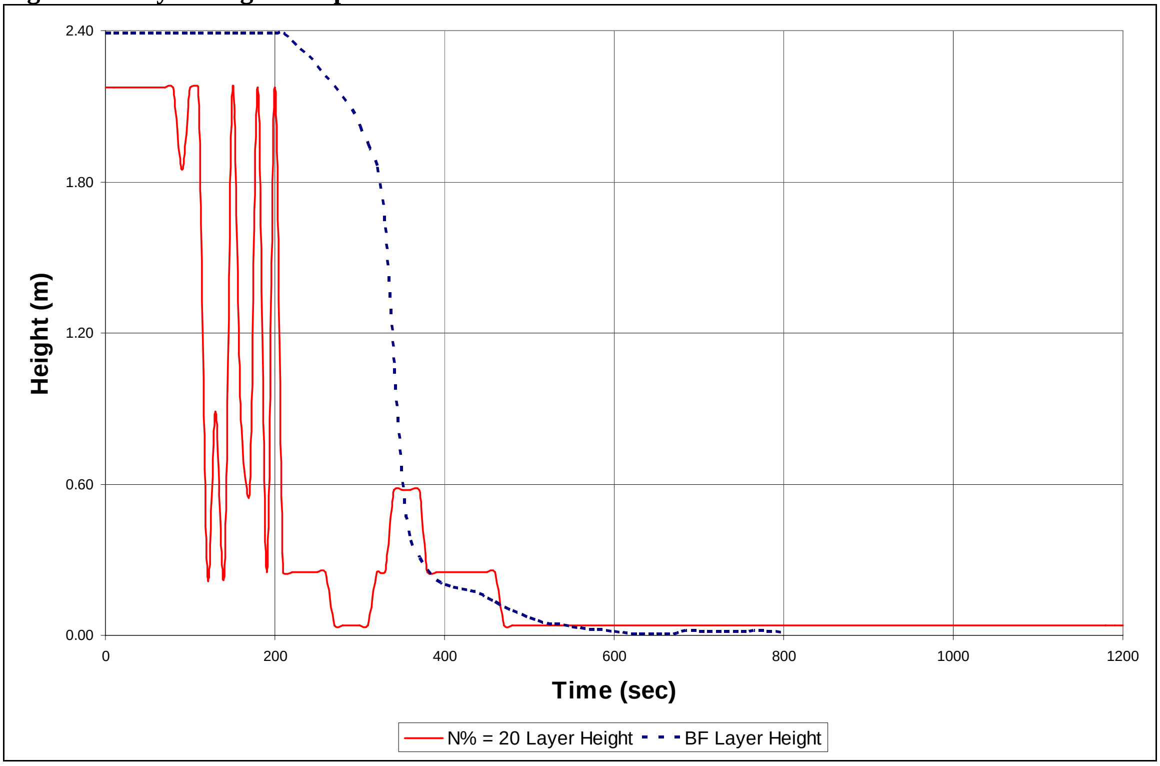
In the hallway the N% method predicts the layer height to lower and then rise abruptly at 100 seconds. This is likely to have been caused by small differences in the thermocouple readings. The BRANZFIRE simulation predicts the layer height to lower to its lowest value at approximately 200 seconds before the layer height predicted by the N% method. Both predict the layer height to decrease to a similar level of 0.3m above floor level after which it rises to approximately 0.6m before another small decrease and then rising to between 1.2m and 1.5m. The BRANZFIRE simulation under predicts the level of the layer interface in the second decrease in the layer height in comparison to the N% method.

Figure 5.4 Layer Height on Landing



On the landing the BRANZFIRE simulation makes a good prediction of the reduction in the layer height to a minimum level at approximately 300 seconds after the start of the simulation. The N% method predicts the layer height to decrease to the floor level whereas the BRANZFIRE simulation predicts the layer to reach a level of 0.3m above floor level and then rise to 0.6m above floor level.

Figure 5.5 Layer Height in Open Bedroom

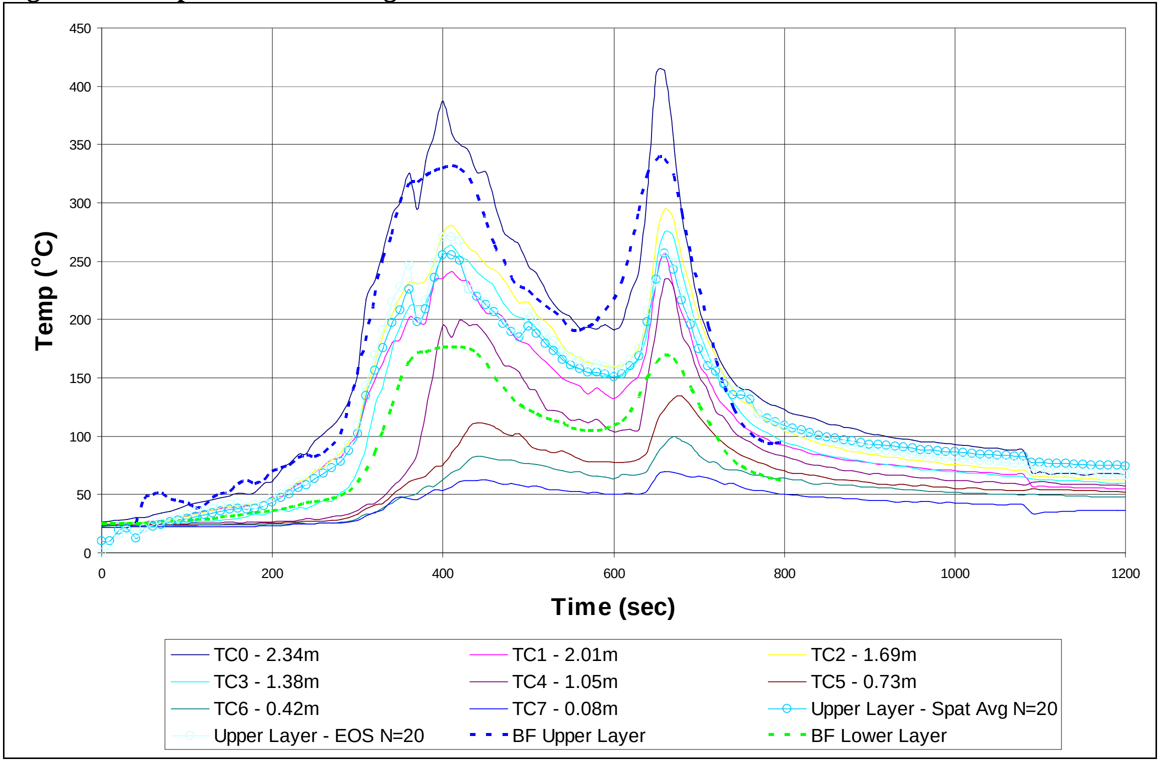


In the open bedroom the BRANZFIRE simulation predicts the layer to decrease to its minimum level approximately 175 seconds after the N% method. Both methods predict the layer height to decrease to floor level and then remain there for the rest of the simulation.

5.1.2 Temperatures

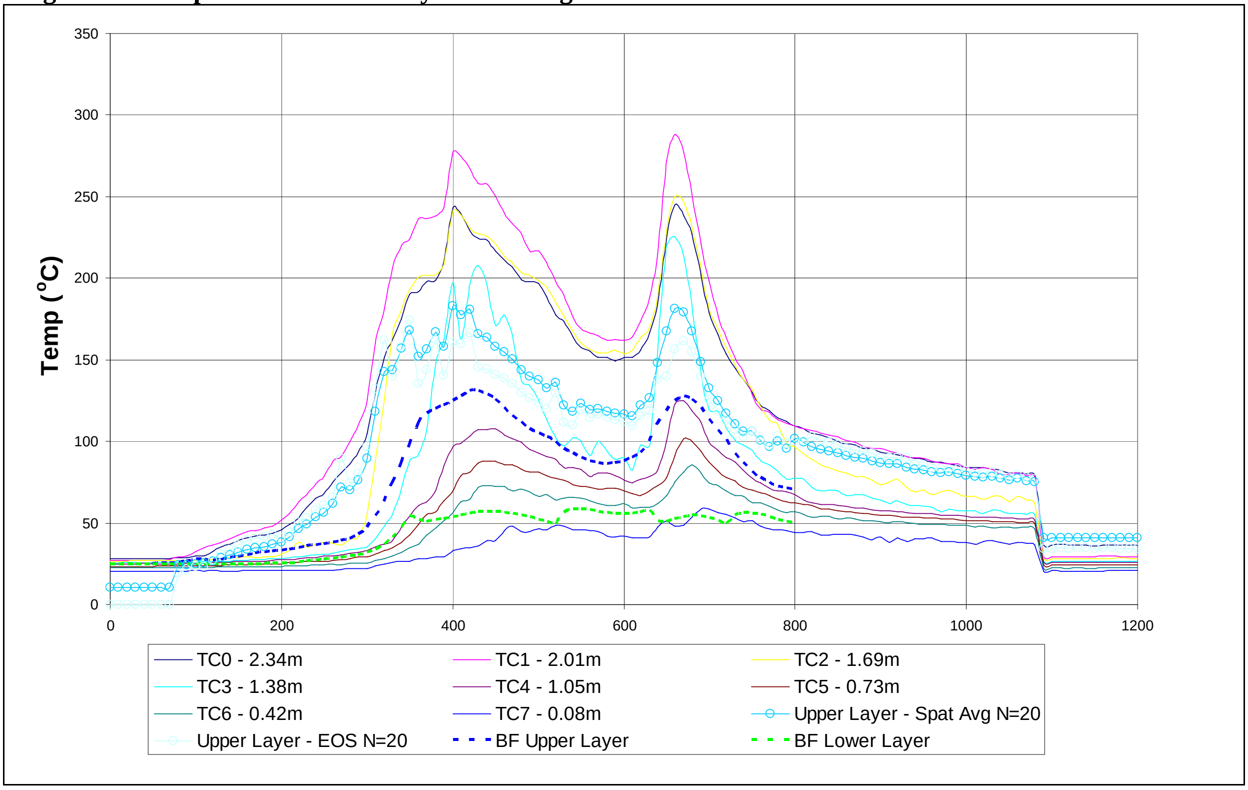
The compartment temperatures from the full scale rig testing and those generated by the BRANZFIRE simulations are shown in Figures 5.6 to 5.9. Also shown in Figures 5.6 to 5.9 are the upper layer temperatures predicted by the methods outlined in Section 3.

Figure 5.6 Temperatures in Lounge



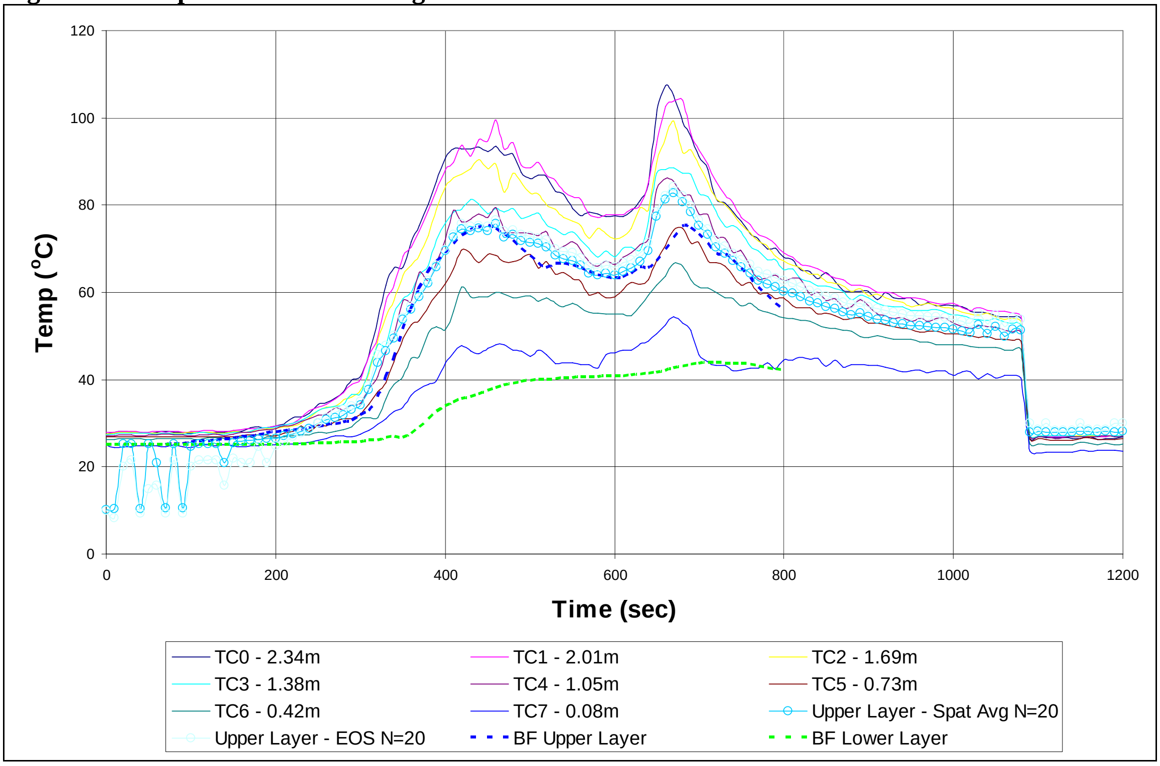
The BRANZFIRE simulation predicts a maximum upper layer temperature in the lounge of approximately 330°C in the first peak of the fire and a similar value in the second peak. The results of the full scale testing give maximum temperatures in the upper thermocouple of 390°C and 410°C respectively. A maximum upper layer temperature of 270°C in the first peak and 260°C in the second peak are predicted by the spatial average and the equation of state methods. The BRANZFIRE simulation over predicts the maximum temperature by approximately 20% in both of the peaks, in comparison to upper layer temperature based on the equation of state and spatial average methods.

Figure 5.7 Temperatures in Hallway near Lounge Door



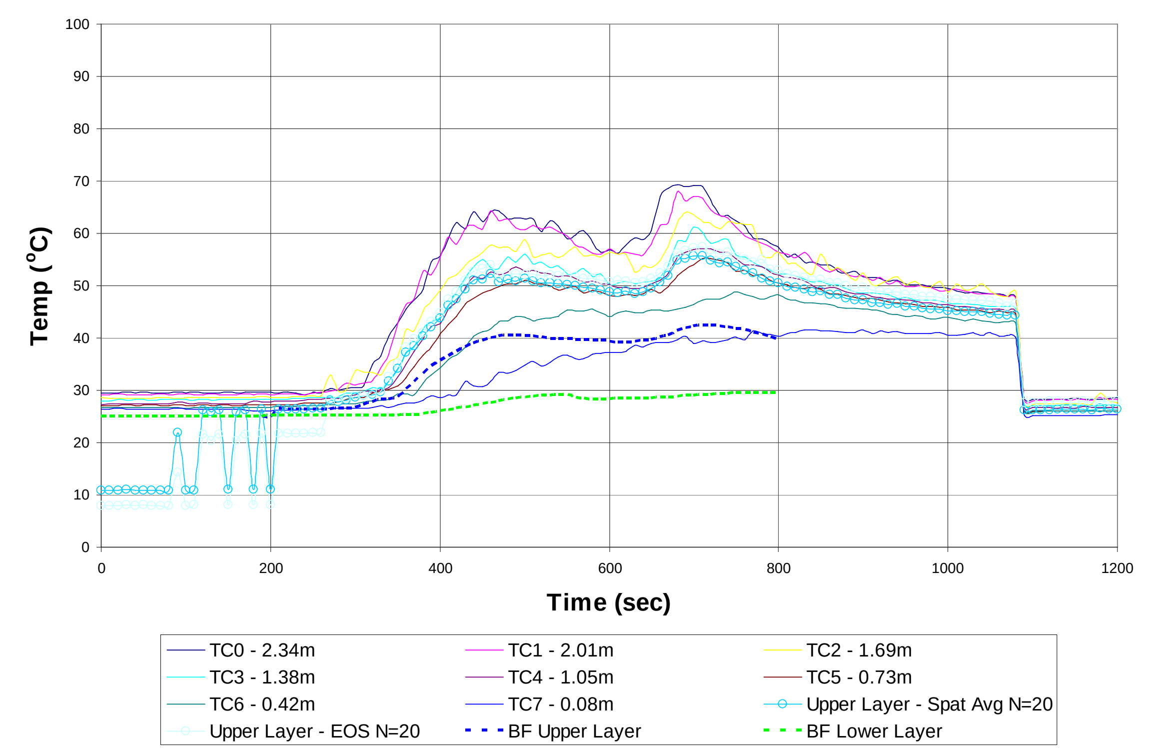
In the hallway the maximum temperature recorded during the full scale rig testing was recorded in the second thermocouple from the top of the thermocouple tree. The maximum upper layer temperature predicted by the spatial average and the equation of state methods in the first and second peak is approximately 180°C. The BRANZFIRE simulation predicts upper layer temperatures of approximately 130°C in both of the peaks which is approximately 30% below the temperatures predicted by the spatial average and the equation of state methods.

Figure 5.8 Temperatures on Landing



On the landing the BRANZFIRE simulation makes a very good prediction of the upper layer temperature. In the first peak the upper layer temperature predicted by the BRANZFIRE simulation is within approximately 2°C of the upper layer predicted by the equation of state and spatial average methods. In the second peak the difference between the two temperatures is approximately 10°C.

Figure 5.9 Temperatures in Open Bedroom

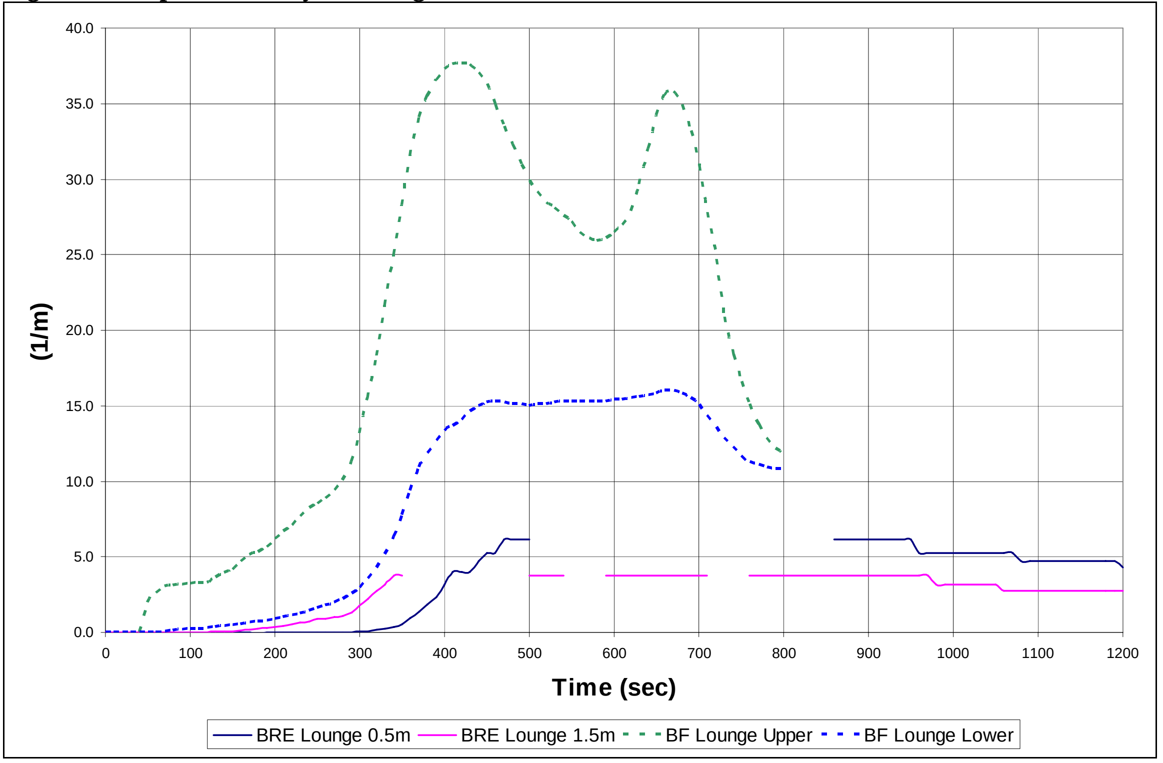


In the open bedroom the temperature increase in the upper thermocouple is approximately 40°C. In this compartment the BRANZFIRE simulation underestimates the upper layer temperature predicted by the equation of state and spatial average methods by approximately 10°C consistently from the first peak to the second peak in the compartment temperature.

5.1.3 Optical Density

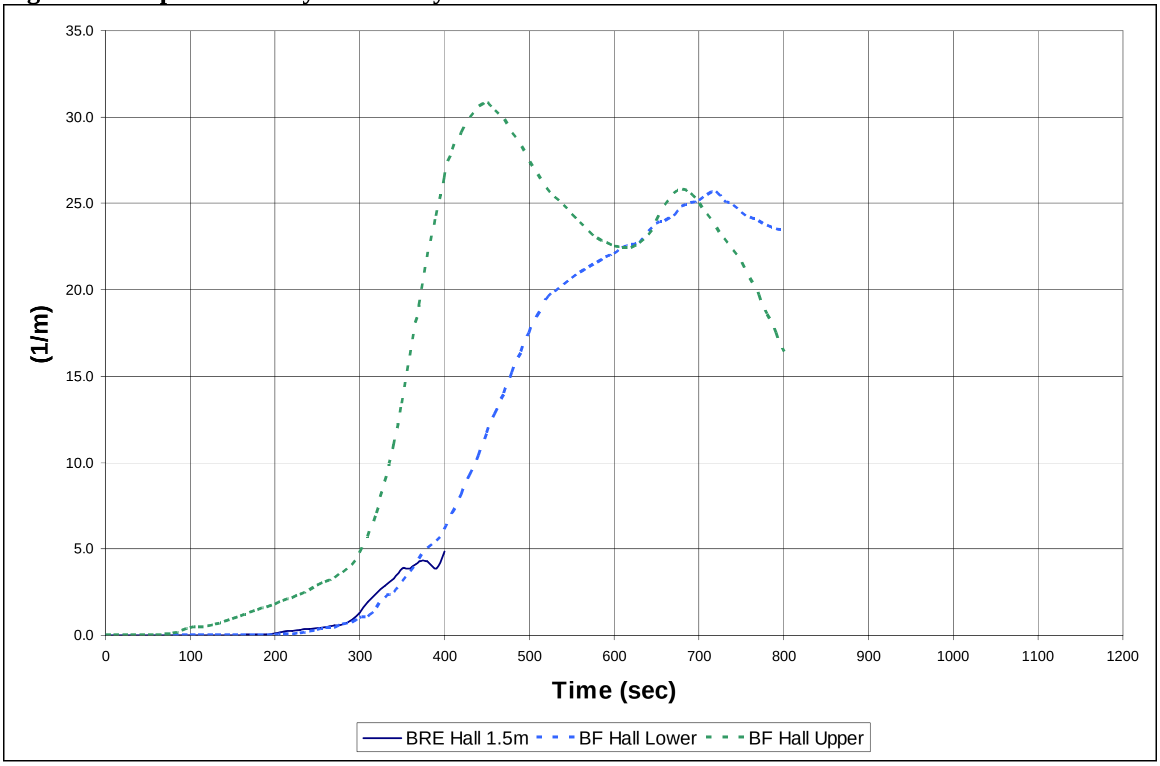
The optical density readings predicted by the BRANZFIRE simulation are compared against the data from the full scale rig tests for each of the compartments in Figures 5.10 to 5.13.

Figure 5.10 Optical Density in Lounge



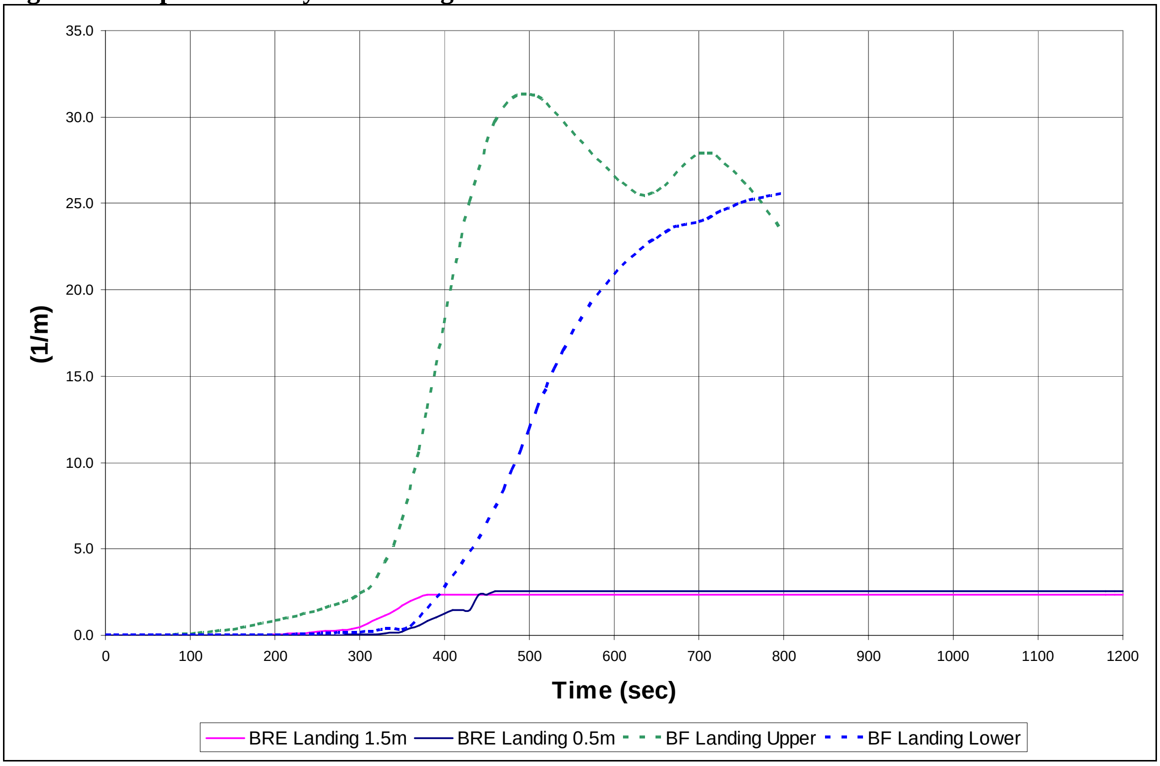
The BRANZFIRE simulation over predicts the optical density in the lounge by approximately 30m^{-1} in this simulation. A maximum value of 5m^{-1} was recorded by the sampling equipment in the full scale testing before the range on the instrumentation was exceeded. The BRANZFIRE simulation predicts a maximum upper layer optical density of approximately 38m^{-1}. It is not possible to compare the shape of the optical density curves because the range of the full scale rig instrumentation was exceeded.

Figure 5.11 Optical Density in Hallway



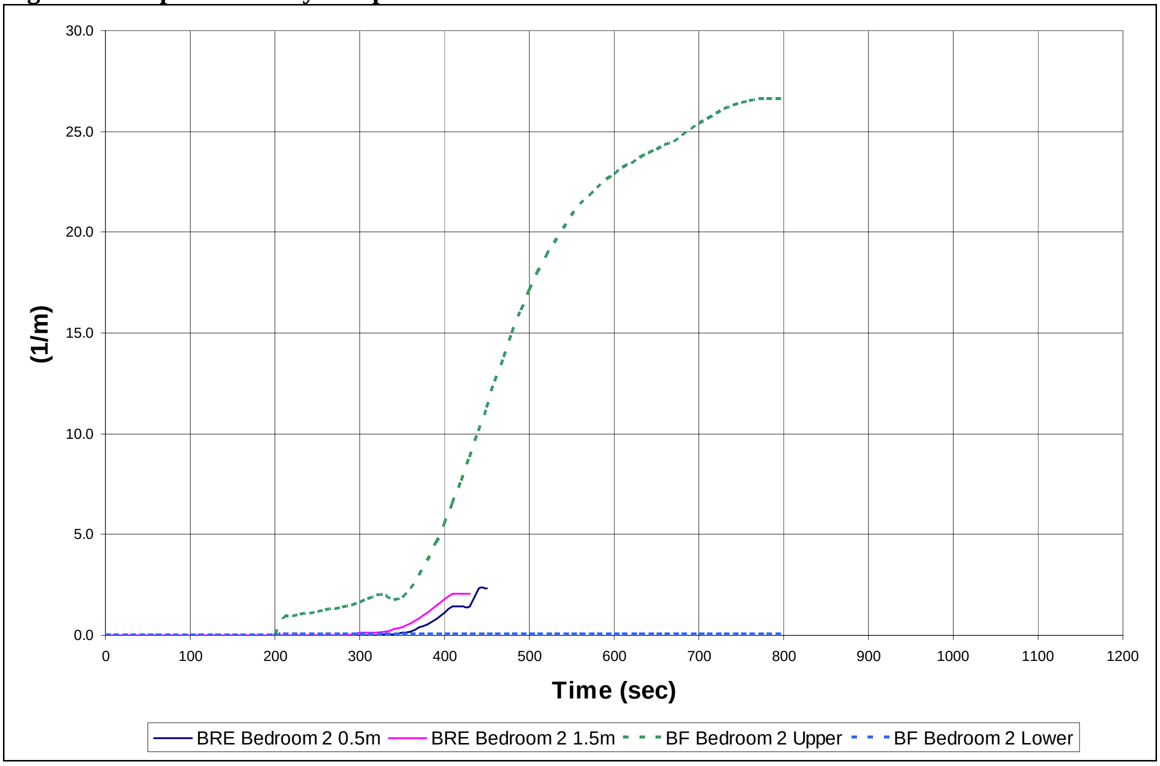
In the hallway the lower layer optical density predicted by the BRANZFIRE simulation closely follows the optical density recorded at 1.5m above floor level in the full scale rig testing up to 380 seconds. The range of 5.0m^{-1} of the instrumentation was exceeded after approximately 400 seconds and beyond this time there is no data available. At this time the BRANZFIRE simulation predicts an optical density of 30m^{-1} in the upper layer which is far in excess of the values recorded in the full scale testing.

Figure 5.12 Optical Density on Landing



On the landing the BRANZFIRE simulation also over predicts the optical density, reaching values of $30m^{-1}$ in comparison to recorded values of $2.4m^{-1}$ in the full scale testing. The BRANZFIRE simulation over predicts the start of the increase in the optical density predicting and increase approximately 200 seconds sooner that is seen in the full scale testing.

Figure 5.13 Optical Density in Open Bedroom

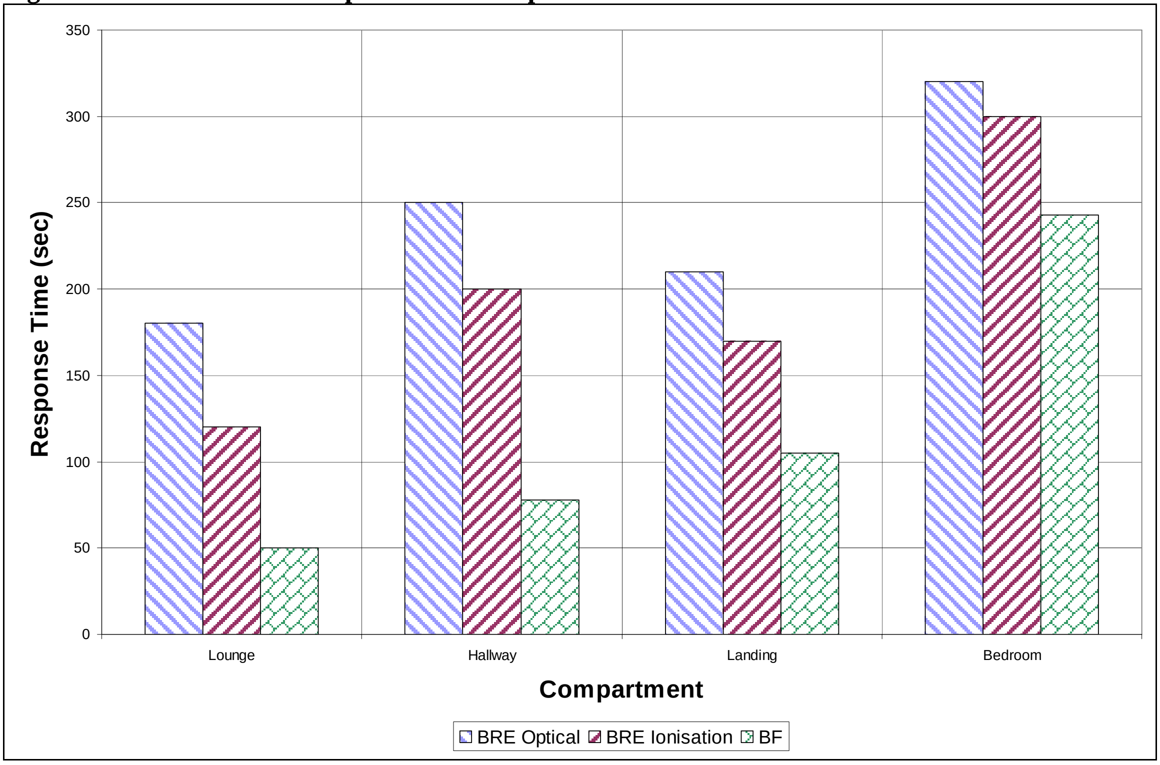


In the open bedroom the optical density recorded during the full scale testing reaches a value of approximately $2.3m^{-1}$ in the upper layer at around 400 seconds. Beyond this time no data is recorded because the range of the instrumentation was exceeded. The BRANZFIRE simulation predicts an increase to a value of approximately $1.5m^{-1}$ before remaining constant for approximately 200 seconds and then increasing steeply to a peak of $26m^{-1}$. This second increase can not be confirmed with the full scale testing as there was no data recorded at this time.

5.1.4 *Smoke Alarm Response*

The smoke alarm response times for the compartments where they were installed during the full scale testing are shown in Figure 5.14.

Figure 5.14 Smoke Alarm Response in all compartments



In the lounge the BRANZFIRE simulation predicts an activation time in the order of 50 seconds in comparison to 180 seconds for the optical smoke alarm and 120 seconds for the ionisation smoke alarm in the full scale testing. In the hallway the detection time for the optical smoke alarm and ionisation smoke alarm from the full scale testing are 250 and 200 seconds respectively. This is in comparison to 70 seconds predicted by the BRANZFIRE simulation.

On the landing the BRANZFIRE simulation predicts activation of the smoke alarm to occur at approximately 110 seconds while activation times of 210 seconds and 170 seconds are recorded for the optical and ionisation smoke alarms in the full scale testing. The full scale testing recorded activation times of 320 and 300 seconds for the optical and ionisation smoke alarms in the open bedroom. The BRANZFIRE simulation predicted an activation time of 240 seconds in this compartment.

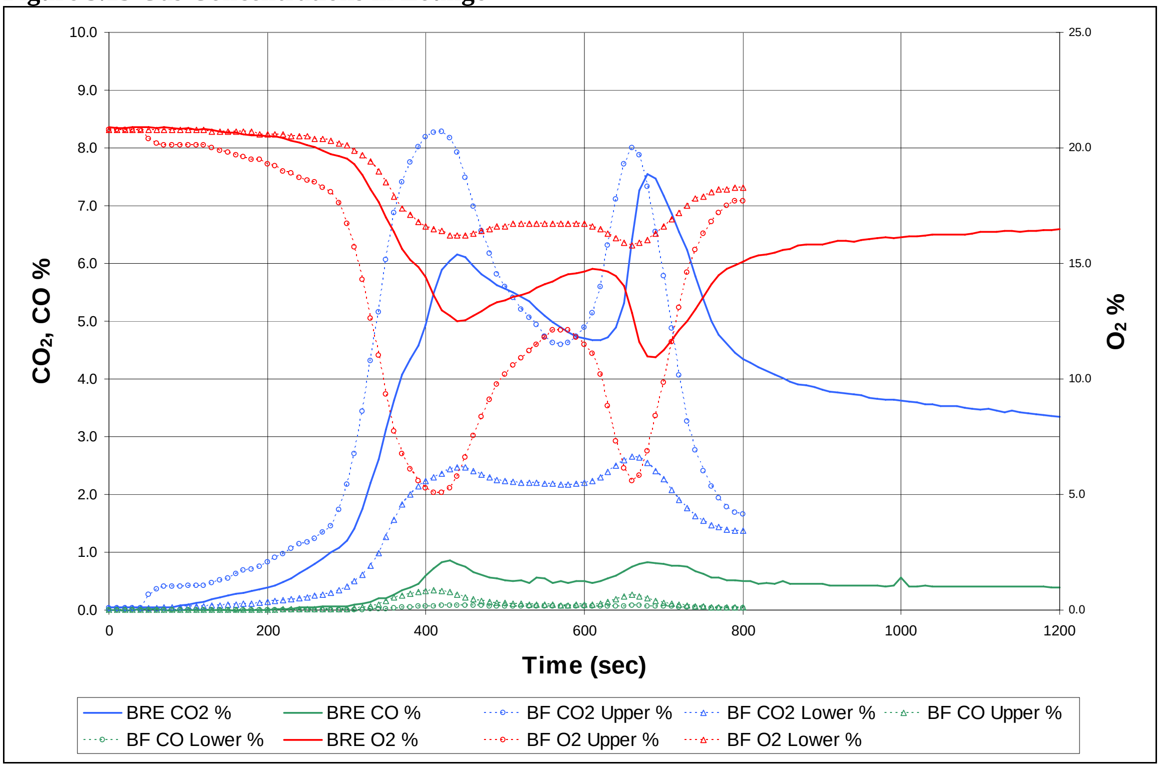
The activation times predicted by the BRANZFIRE simulation are much shorter than those recorded in the full scale testing and this can be attributed to an earlier increase in the optical densities in the BRANZFIRE simulations.

5.1.5 Gas Concentration

The oxygen, carbon dioxide and carbon monoxide gas concentrations predicted by the BRANZFIRE simulation are compared against the data recorded in the full scale testing in Figures 5.15 to 5.18.

Note that the hydrogen cyanide concentration from the full scale rig testing is not shown in the following figures as data was not recorded in the data files.

Figure 5.15 Gas Concentrations in Lounge

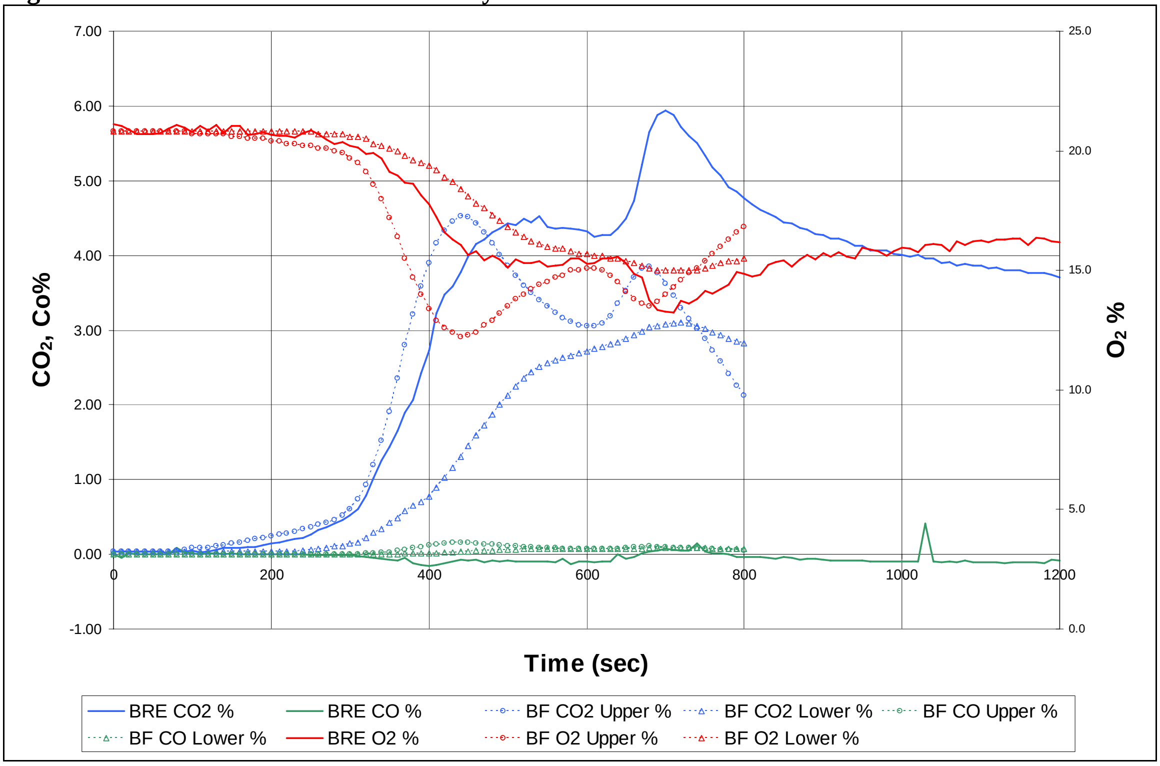


The oxygen concentration values predicted by the BRANZFIRE simulation closely follow the readings recorded during the full scale rig testing in the lounge. The two low points in the oxygen readings are predicted approximately 30 seconds earlier in the BRANZFIRE simulation than were seen in the full scale rig testing.

The increase in the carbon dioxide concentration recorded during the full scale rig testing is closely followed by the upper and lower layer concentrations predicted by the BRANZFIRE simulation in the lounge up to the first peak at approximately 400 seconds at which time the BRANZFIRE simulation predicted value peaks and decreases. The values recorded during the full scale testing decrease, but not to the same extent and the BRANZFIRE simulation under predicts the carbon dioxide concentration at the second peak.

The carbon monoxide concentration predicted by the BRANZFIRE simulation is very low and under predicts the values recorded in the full scale testing by a factor of 10.

Figure 5.16 Gas Concentrations in Hallway

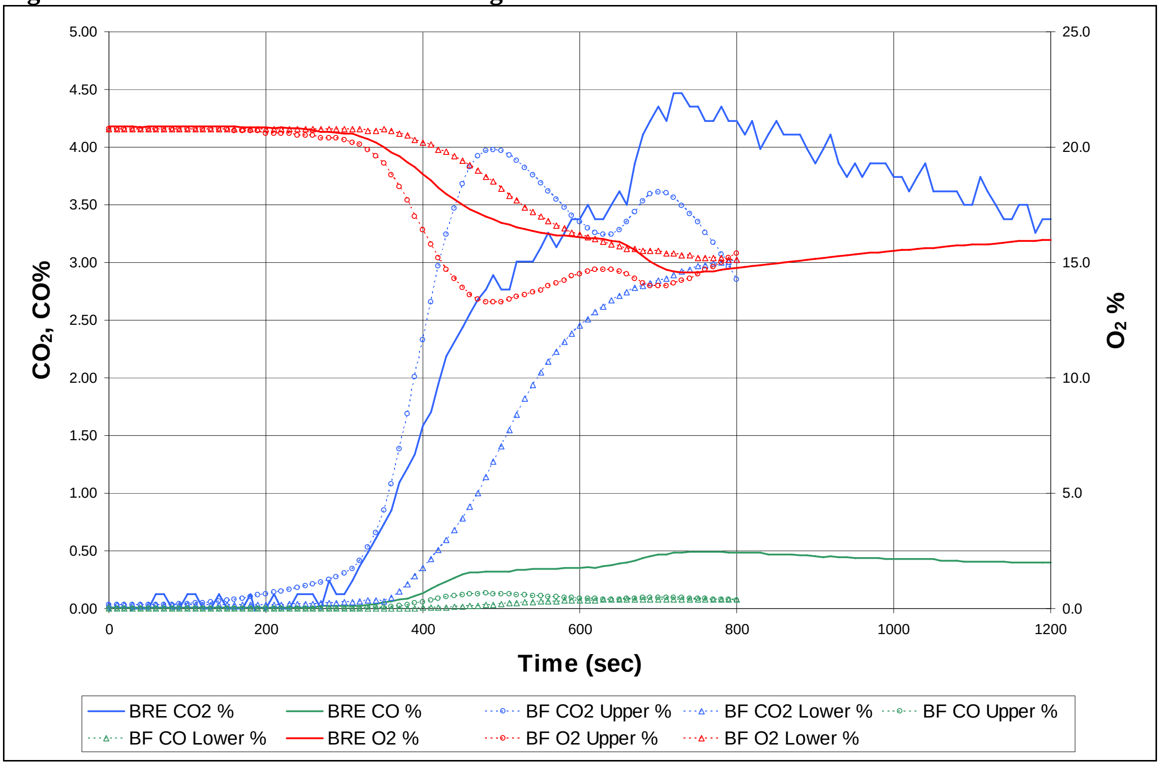


In the hallway the BRANZFIRE simulation predicts the timing of the decrease in the oxygen concentration reasonably well but over predicts the lower level that is reached in the first decrease of the oxygen concentration by approximately 3% oxygen. The oxygen concentration predicted by the BRANZFIRE simulation then increases a greater amount than was recorded during the full scale testing and the BRANZFIRE simulation predicts a similar value to the testing in the second decrease in the oxygen concentration.

The BRANZFIRE simulation predicts the carbon dioxide concentration in the hallway in a similar way to the lounge. The predicted increase in the carbon dioxide concentration is a good fit to the full scale rig test data up to the first peak, at which time the BRANZFIRE simulation concentration decreases more than is seen in the full scale testing and the BRANZFIRE simulation then under predicts the concentration in the second peak.

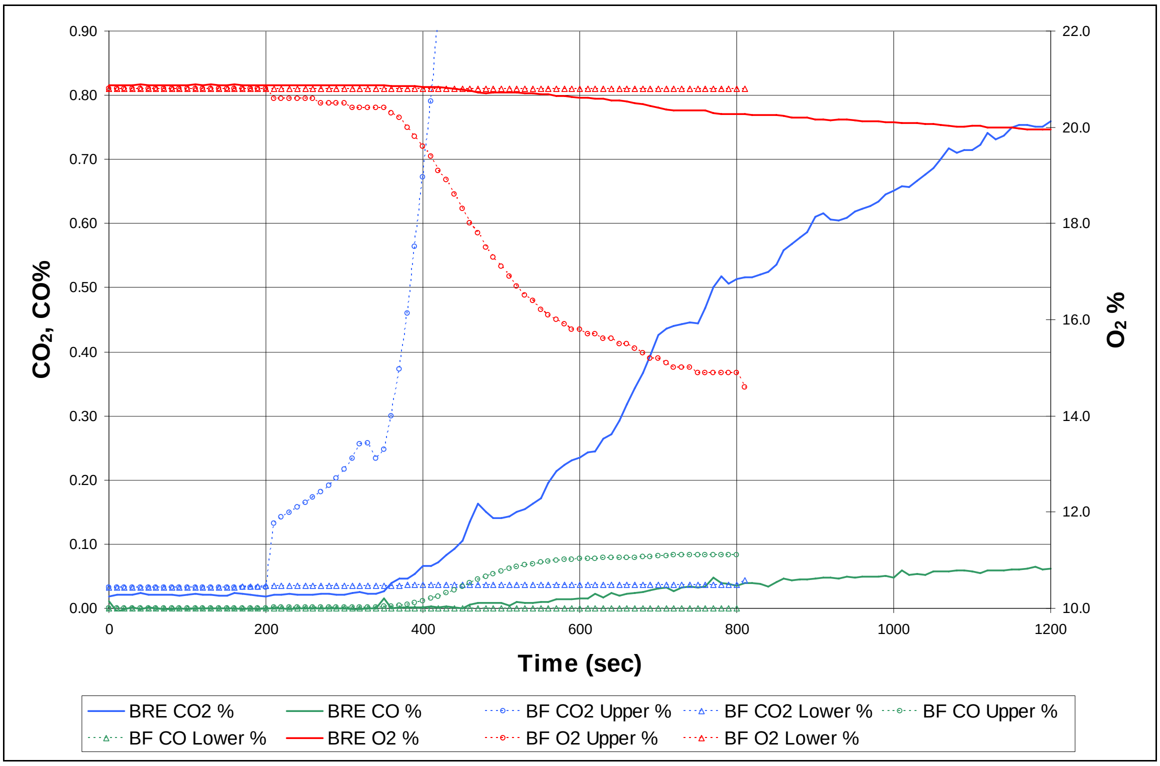
The carbon monoxide concentration data from the full scale testing is negative in some readings suggesting an error with the sampling equipment.

Figure 5.17 Gas Concentrations on Landing



On the landing the trends in the oxygen, carbon dioxide and carbon monoxide concentrations follow the same trends as was seen in the lounge and hallway. Larger carbon monoxide concentrations were recorded on the landing in comparison to the hallway in the full scale rig testing. This comparison may be affected by the negative values recorded in the hallway.

Figure 5.18 Gas Concentrations in Open Bedroom

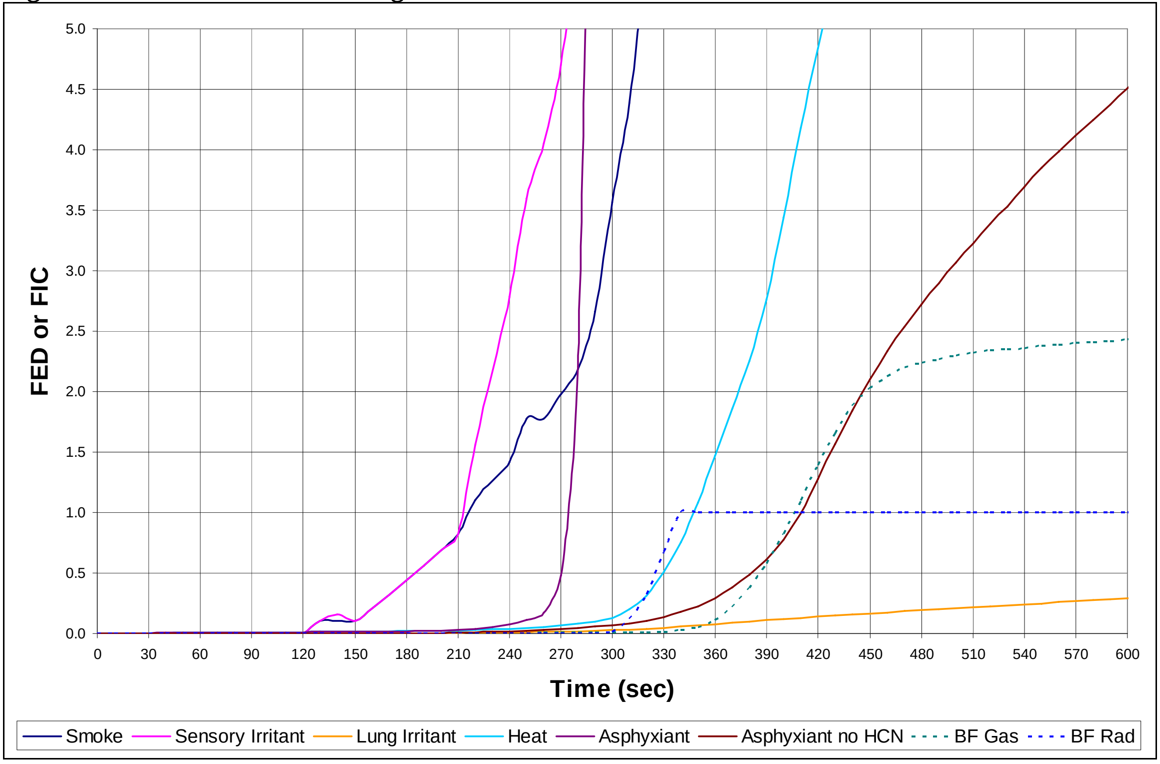


In the open bedroom there is a change in oxygen concentration of approximately 1% in the full scale rig test data. In this compartment the BRANZFIRE simulation predicts a decrease in oxygen concentration of approximately 6%, far in excess of the full scale rig test data. The carbon dioxide and carbon monoxide concentrations predicted by the BRANZFIRE simulation are significantly higher than those recorded during the full scale rig test data.

5.1.6 *Fractional Effective Dose*

The fractional effective dose and fractional irritant concentration determined in the full scale testing and those predicted by the BRANZFIRE simulation for the lounge are shown in Figure 5.19.

Figure 5.19 FIC and FED in Lounge

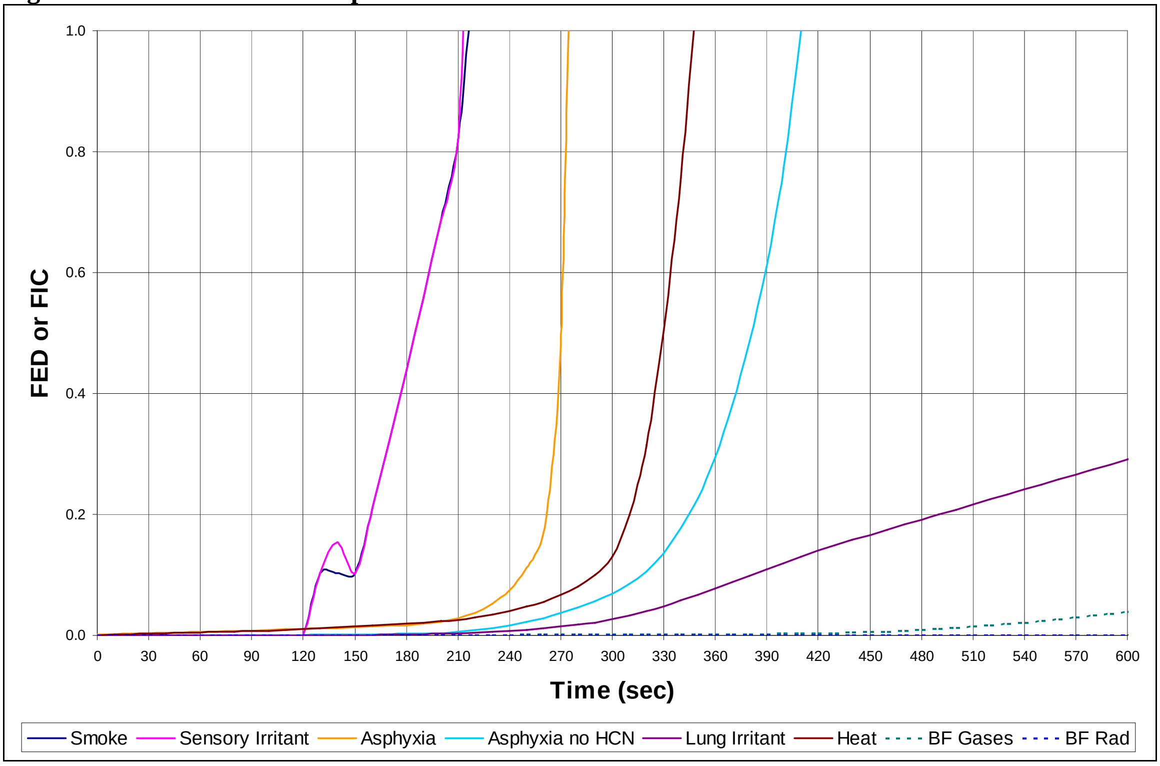


For this simulation with the lounge door open the BRANZFIRE simulation makes a good approximation of the fractional effective dose due to radiation reaching an incapacitating dose of 1.0 at the same time as was recorded during the full scale rig testing. Although the incapacitating dose is reached at the same time, the BRANZFIRE simulation predicted fractional effective dose begins to increase approximately 60 seconds later than was observed in the full scale rig tests.

The fractional effective dose due to gases predicted by the BRANZFIRE simulation closely matches the results from the full scale testing. A dose of 1.0 due to asphyxiant gases with no hydrogen cyanide was predicted by the BRANZFIRE simulation after 400 seconds with a lethal dose after approximately 450 to 500 seconds.

The fractional effective dose and fractional irritant concentration determined in the full scale testing and predicted by the BRANZFIRE simulation for the open bedroom are shown in Figure 5.20.

Figure 5.20 FIC and FED in Open Bedroom



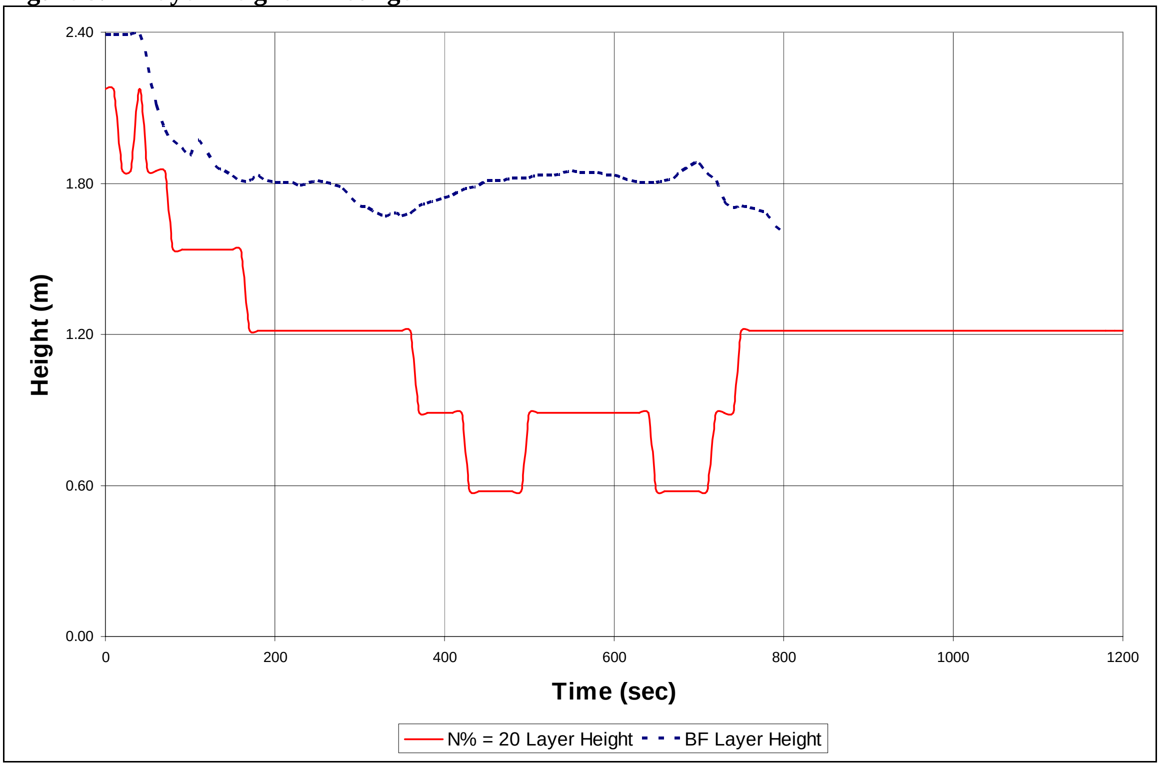
The BRANZFIRE simulation predicts a very low dose due to both heat and gases whereas an incapacitating dose was predicted after 340 seconds for heat and 400 seconds for asphyxiant gases with no hydrogen cyanide in the full scale testing.

5.2 *Three Compartment Simulation*

5.2.1 *Layer Height*

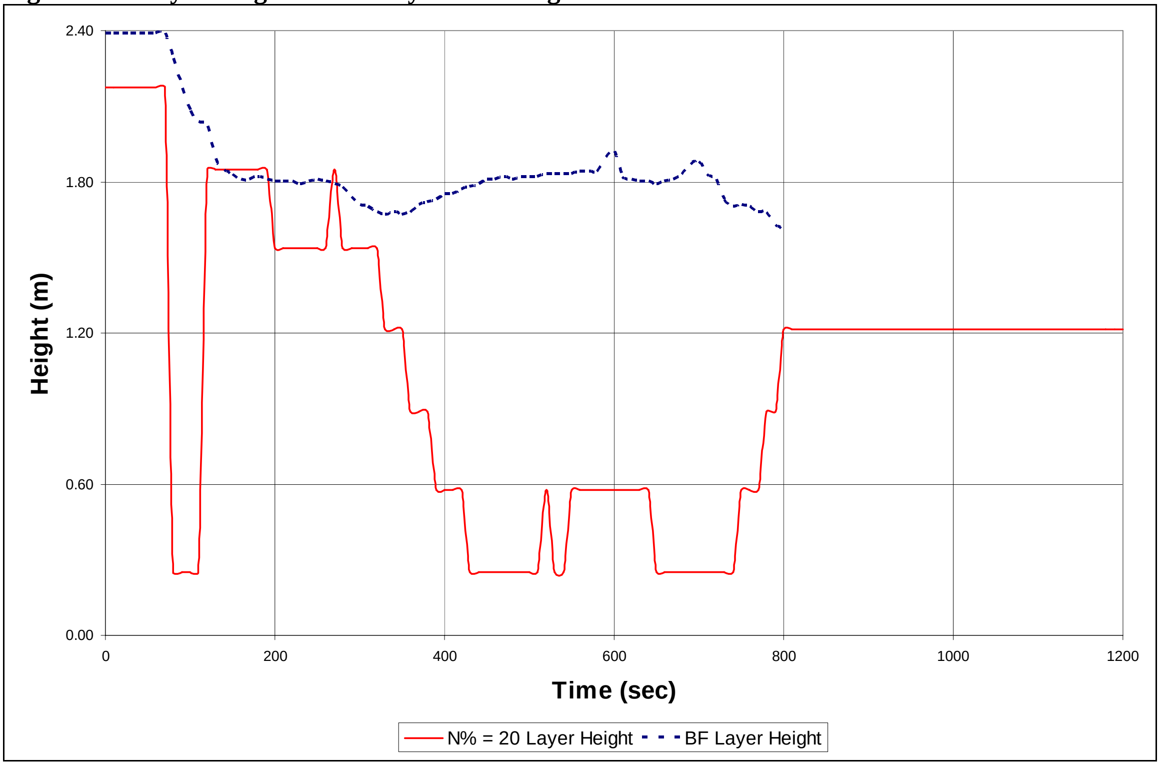
The layer heights predicted by the N% method using N = 20 and by the BRANZFIRE simulation for each of the compartments lounge are presented in Figures 5.21 to 5.25.

Figure 5.21 Layer Height in Lounge



In the lounge the three compartment simulation predicts the layer height to lower to a lesser extent than was predicted by the two compartment simulation but the general shape of the layer height curve is unchanged. The BRANZFIRE simulation predicts the layer height to lower to approximately 1.8m above floor level after approximately 160 seconds. The BRANZFIRE simulation under predicts the descent of the layer height in comparison to the N% method.

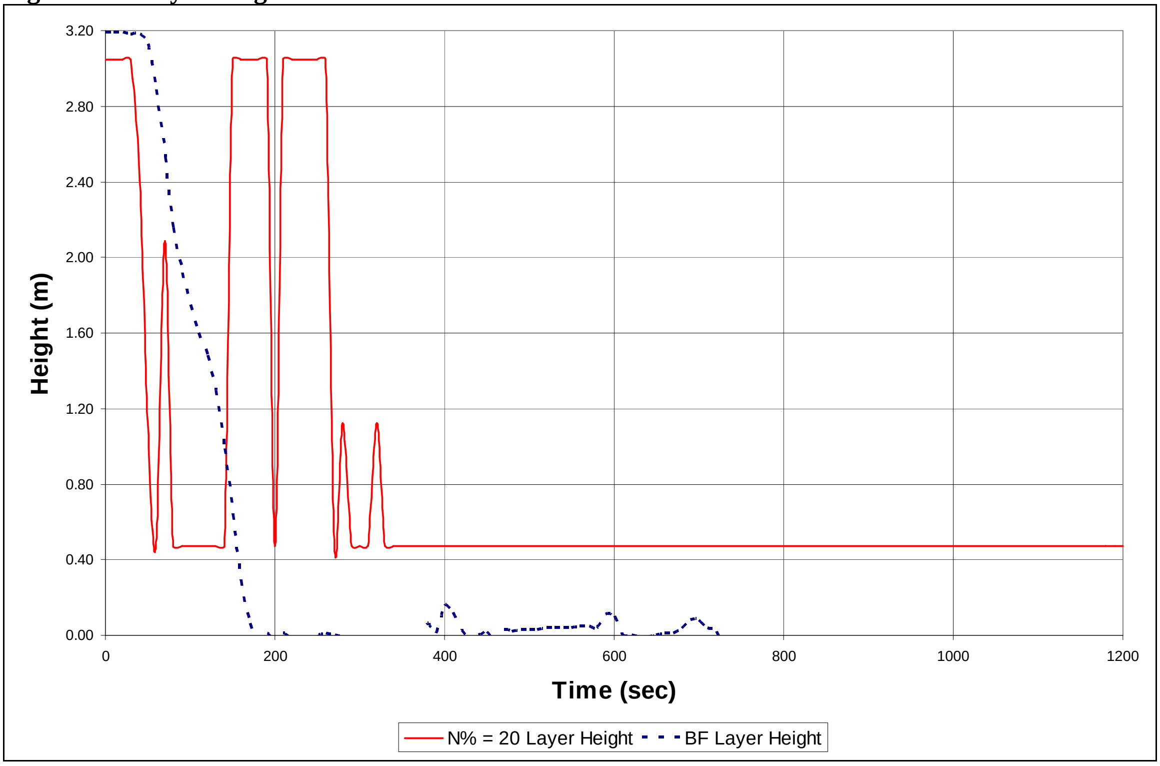
Figure 5.22 Layer Height in Hallway near Lounge Door



For the two compartment model the BRANZFIRE simulation made a reasonable prediction of the layer height in the hallway. The prediction of the layer height in the hallway is not as good for the three compartment simulation. There is a lesser degree of smoke filling with the BRANZFIRE simulation predicting the layer to decrease to approximately 1.8m above floor level whereas the N% method predicts the layer to lower to within 0.3m of the floor level.

The BRANZFIRE simulation makes a good prediction of the early lowering of the layer interface up to 300 seconds but then does not lower as far as the N% method following this.

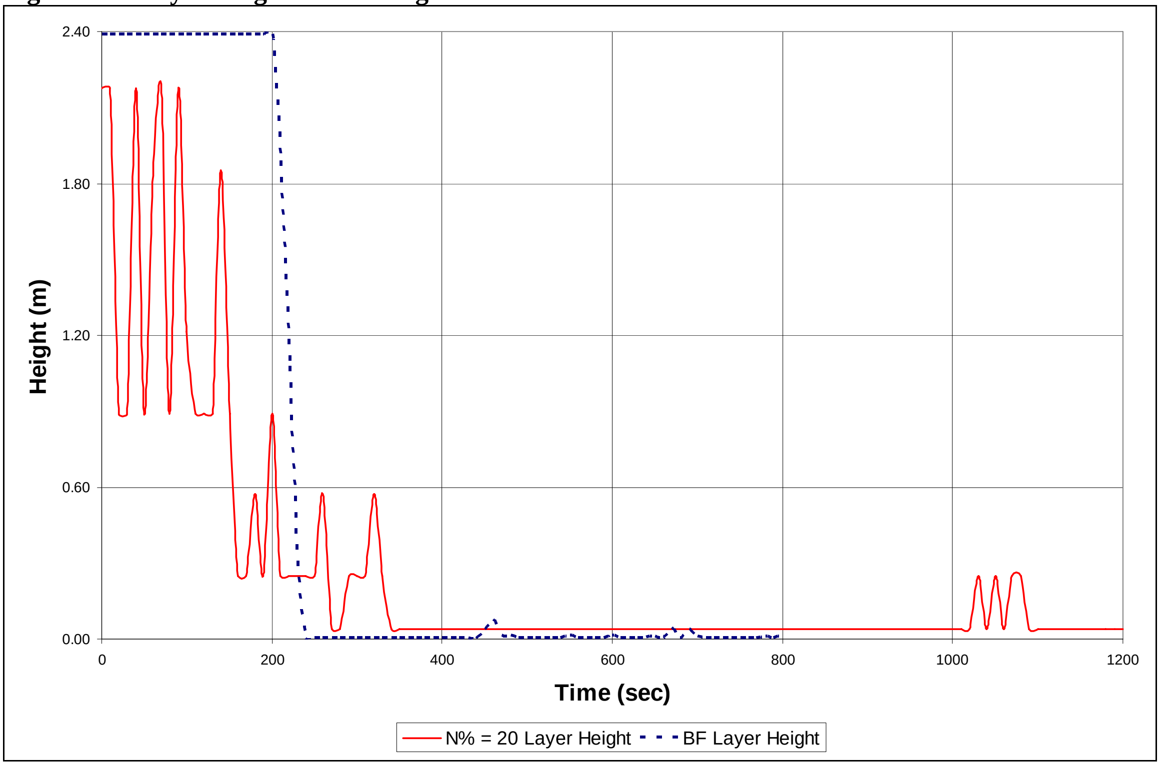
Figure 5.23 Layer Height on Stairs



The layer height predicted by the BRANZFIRE simulation has been reduced by 1.79m. This is the height from the ceiling in the landing to the top thermocouple on the thermocouple tree that has been used to determine the layer height using the N% method. This has been done so that the results can be compared equally.

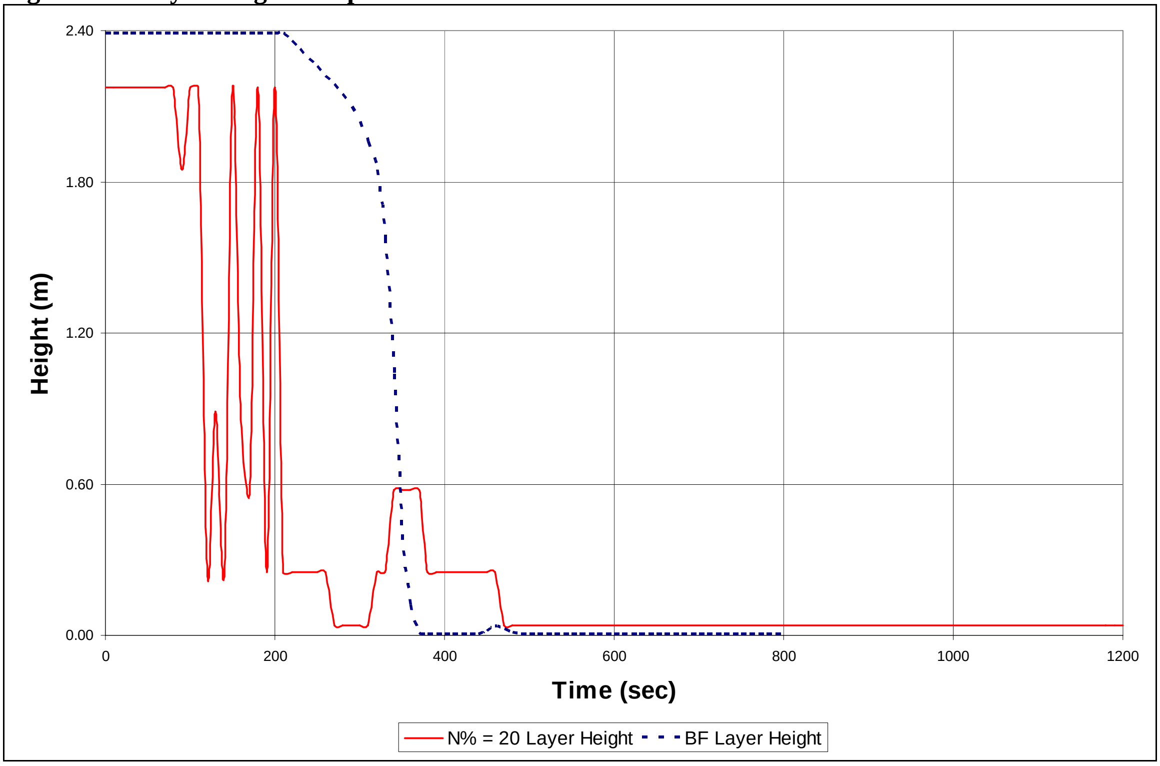
In this simulation the compartment that models the stairs becomes heavily smoke logged. The BRANZFIRE simulation makes a good prediction of the time of the layer height decreasing but over predicts the level to which it falls by approximately 0.6m.

Figure 5.24 Layer Height on Landing



On the landing the BRANZFIRE simulation makes a good prediction of the layer height with it decreasing to floor level at approximately 200 seconds and remaining there for the remainder of the simulation. The N% method predicts a slower rate of lowering of the layer interface height but also predicts the interface to lower to floor level and remain there after approximately 300 seconds.

Figure 5.25 Layer Height in Open Bedroom

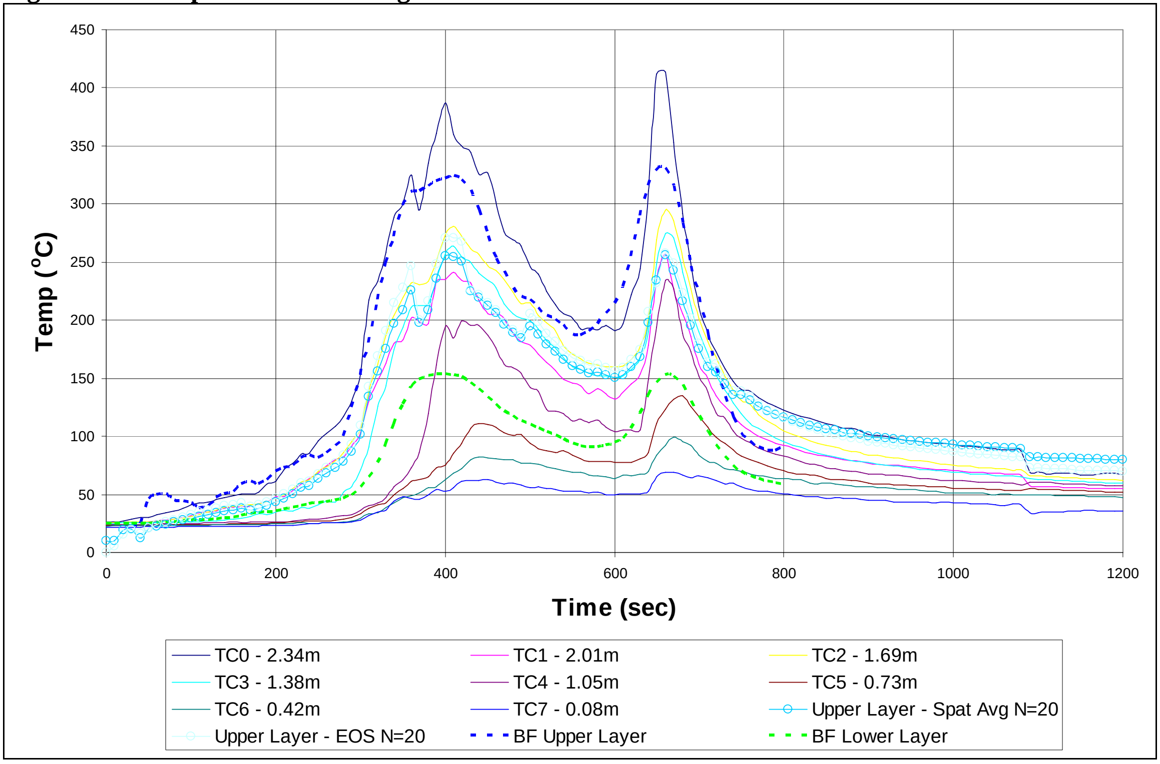


In the open bedroom the N% method predicts the layer height to lower to floor level at approximately 250 seconds and remain there for the rest of the simulation. The BRANZFIRE simulation predicts the lowering of the layer height to the same level but at approximately 375 seconds, some way behind the N% method.

5.2.2 Temperatures

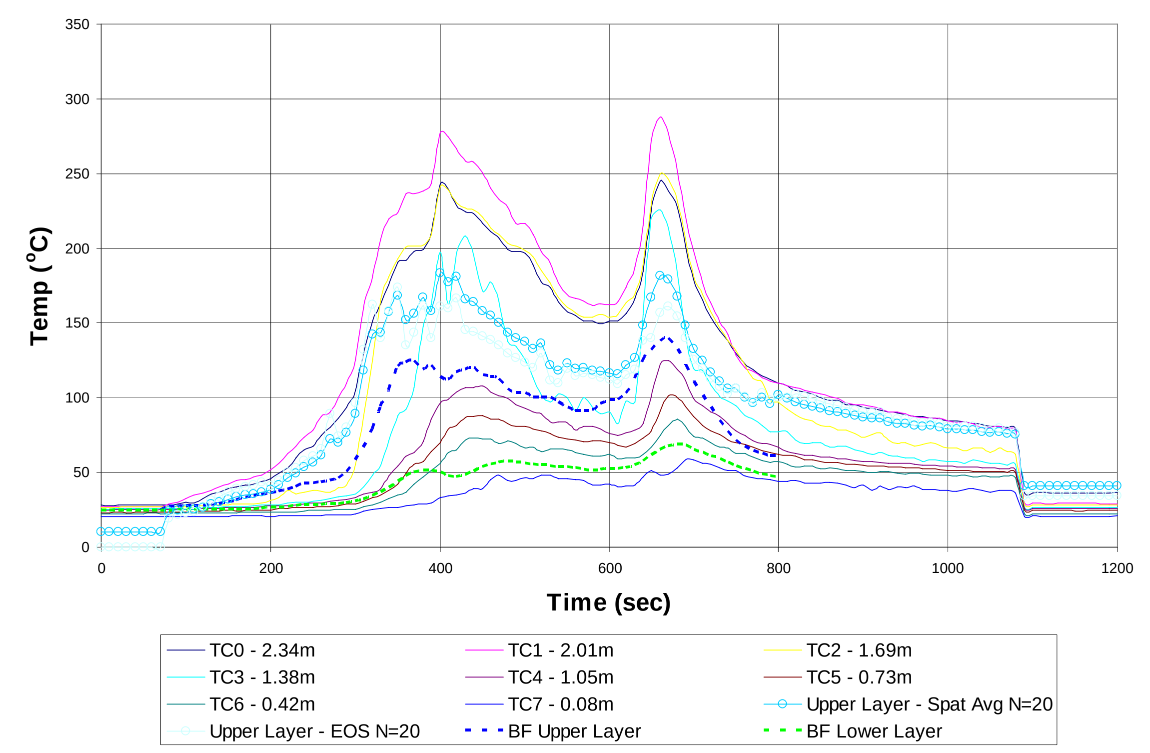
The compartment temperatures from the full scale rig testing and those generated by the BRANZFIRE simulation are shown in Figure 5.26 to 5.30. Also shown in Figures 5.26 to 5.30 are the upper layer temperatures predicted by the methods outlined in Section 3.

Figure 5.26 Temperatures in Lounge



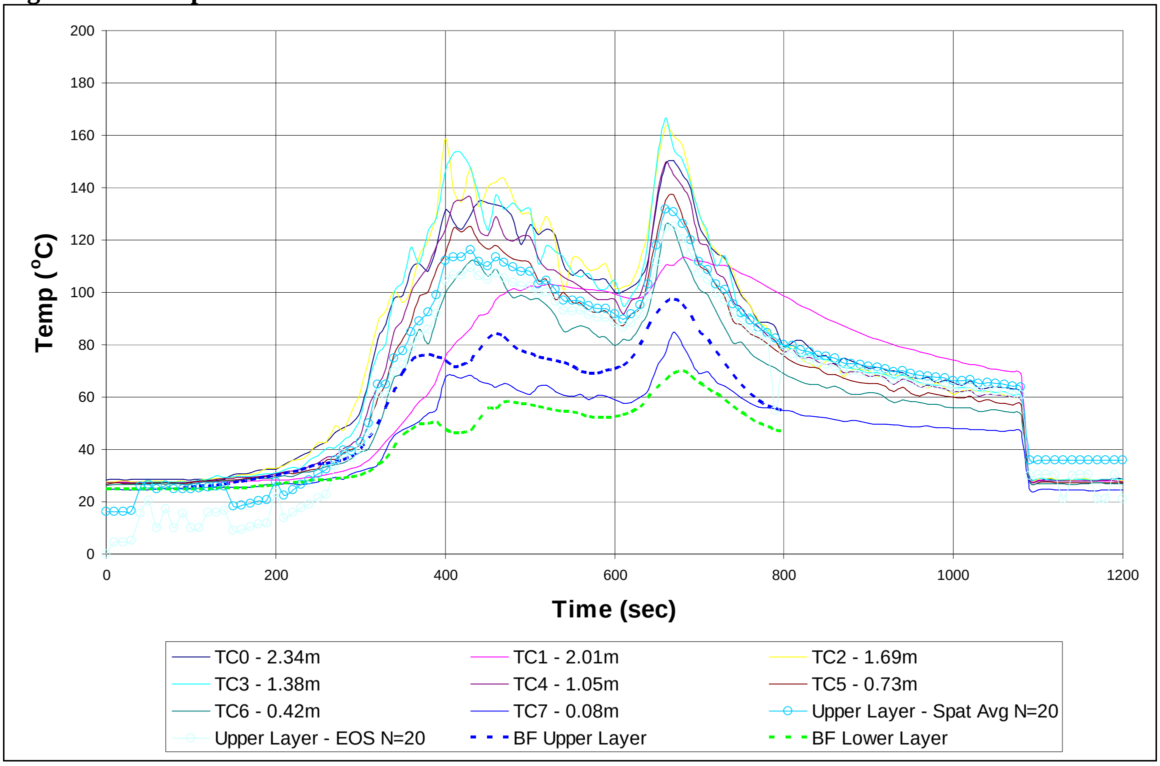
The temperatures predicted in the lounge by the three compartment simulations are slightly lower than was predicted in the lounge by the two compartment simulation. The BRANZFIRE simulation predicts a temperature of 324°C in the first peak and 331°C in the second peak. The first peak temperature is approximately 6°C lower than in the two compartment simulation and the second peak is unchanged. The equation of state and spatial average methods predicted temperatures of 270°C and 260°C in the first and second peaks respectively.

Figure 5.27 Temperatures in Hallway near Lounge Door



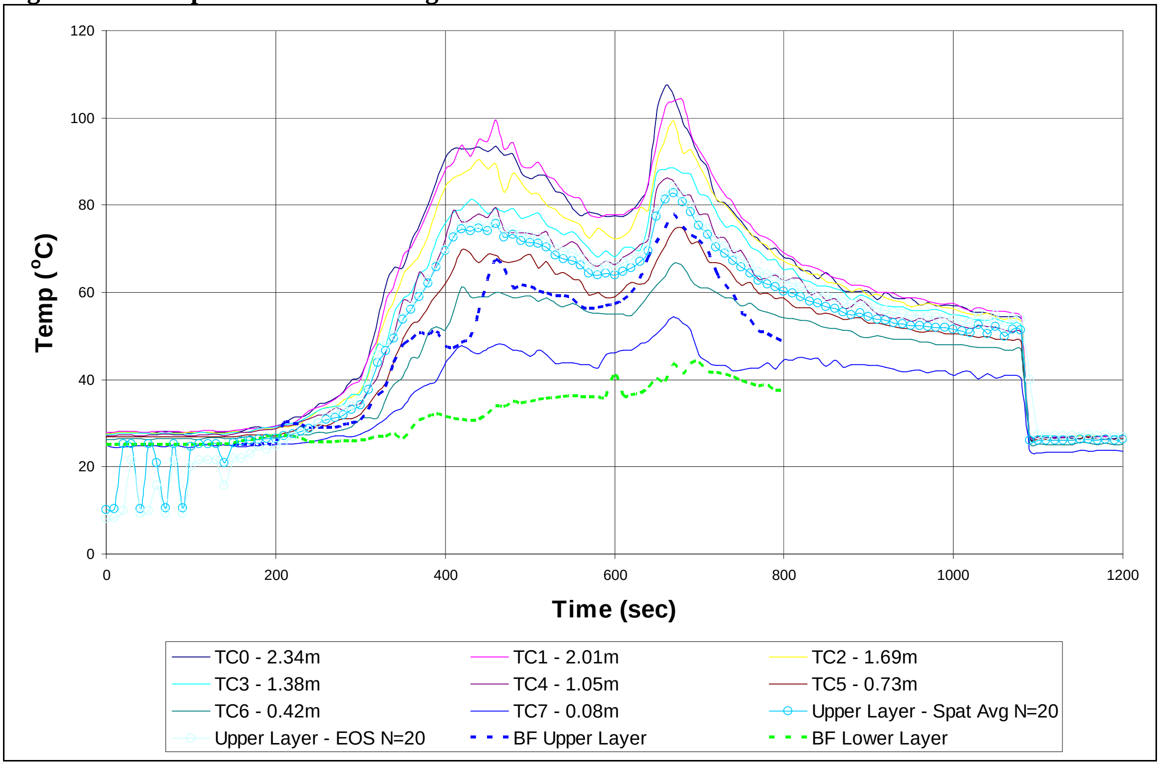
The temperatures predicted in the hallway for the two and three compartment simulations are very similar, with the three compartment simulation predicting a slightly lower temperature in the first peak and predicting the peak to occur slightly earlier than the two compartment simulation. The predicted temperature in the second peak is approximately 10°C higher in the three compartment simulation compared to the two compartment simulation.

Figure 5.28 Temperatures on Stair



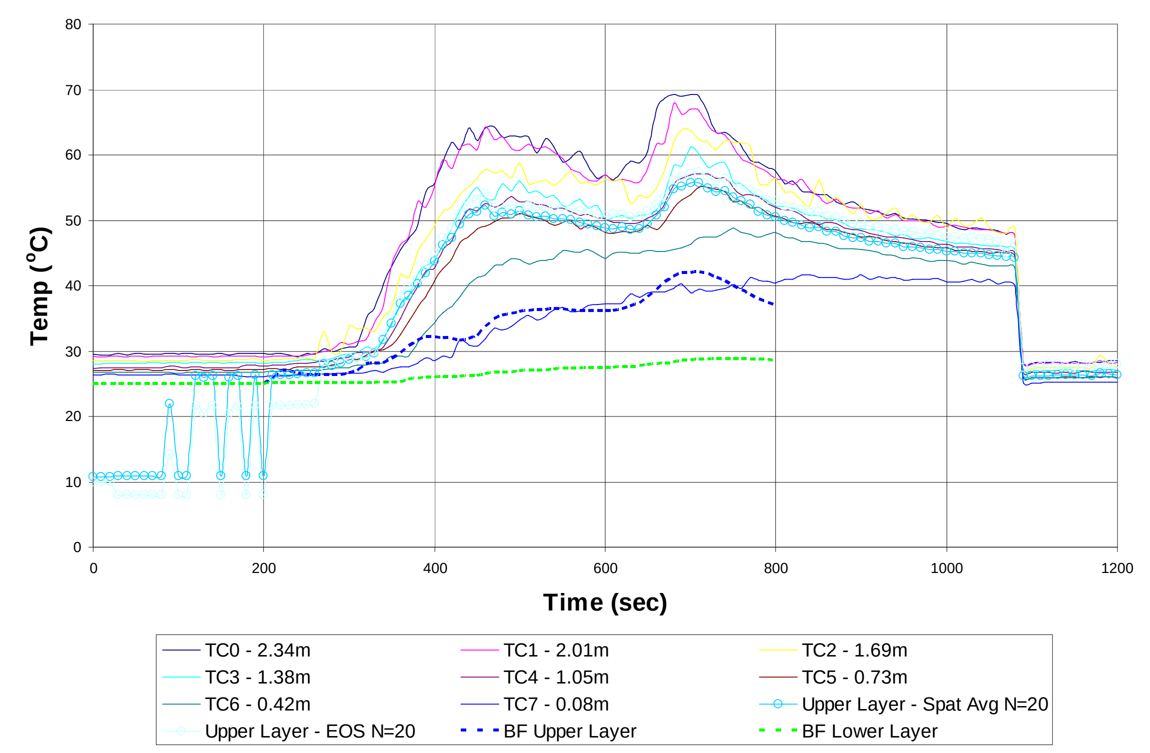
On the stairs the equation of state and spatial average methods predict a maximum upper layer temperature of approximately 115°C in the first peak and 130°C in the second peak. The BRANZFIRE simulation predicts maximum upper layer temperature values in the first and second peak of approximately 80°C and 100°C respectively, under estimating the values predicted by the equation of state and spatial average methods by 25%.

Figure 5.29 Temperatures on Landing



On the landing the BRANZFIRE simulation makes a very good prediction of the maximum upper layer temperatures, predicting temperatures within 10% at the first peak and 5% at the second peak of the temperatures predicted by the spatial average and equation of state methods.

Figure 5.30 Temperatures in Open Bedroom

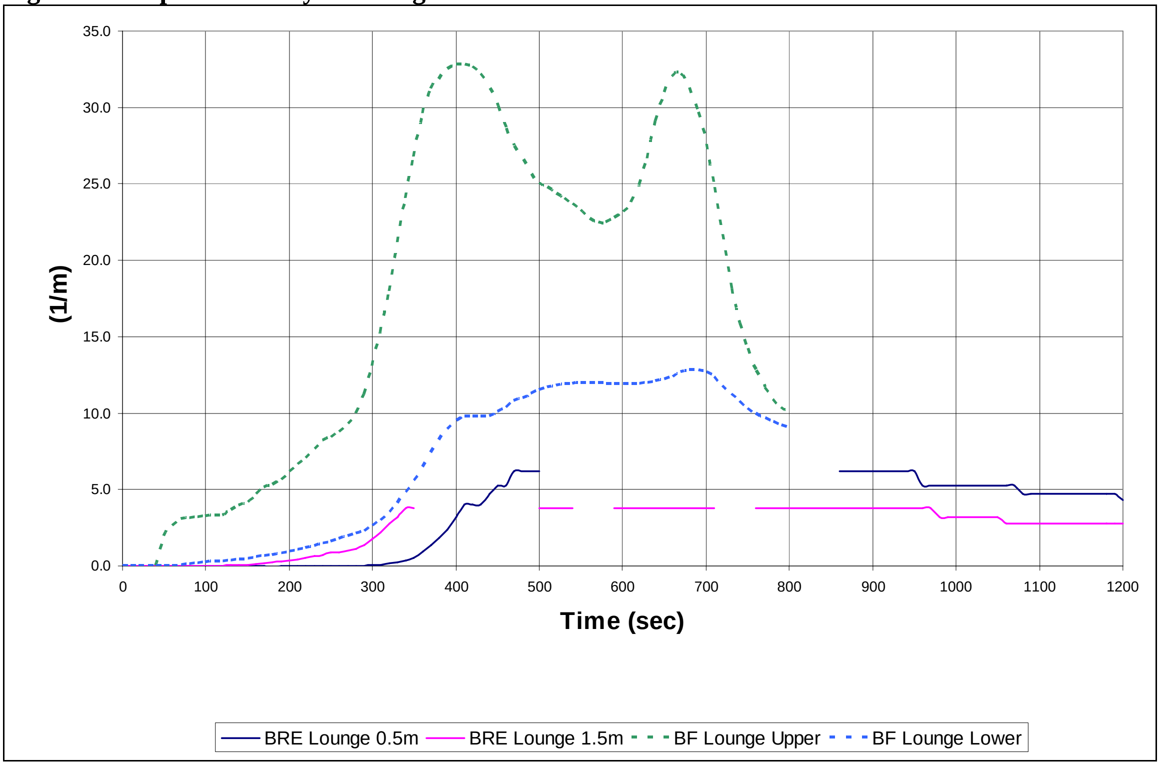


In the open bedroom the BRANZFIRE simulation under predicts the upper layer temperature at both the first and second peaks. The spatial average and equation of state methods predict maximum upper layer temperatures of 54°C and 60°C in the first and second peaks. The BRANZFIRE simulation predicts values of 35°C and 42°C in these peaks.

5.2.3 Optical Density

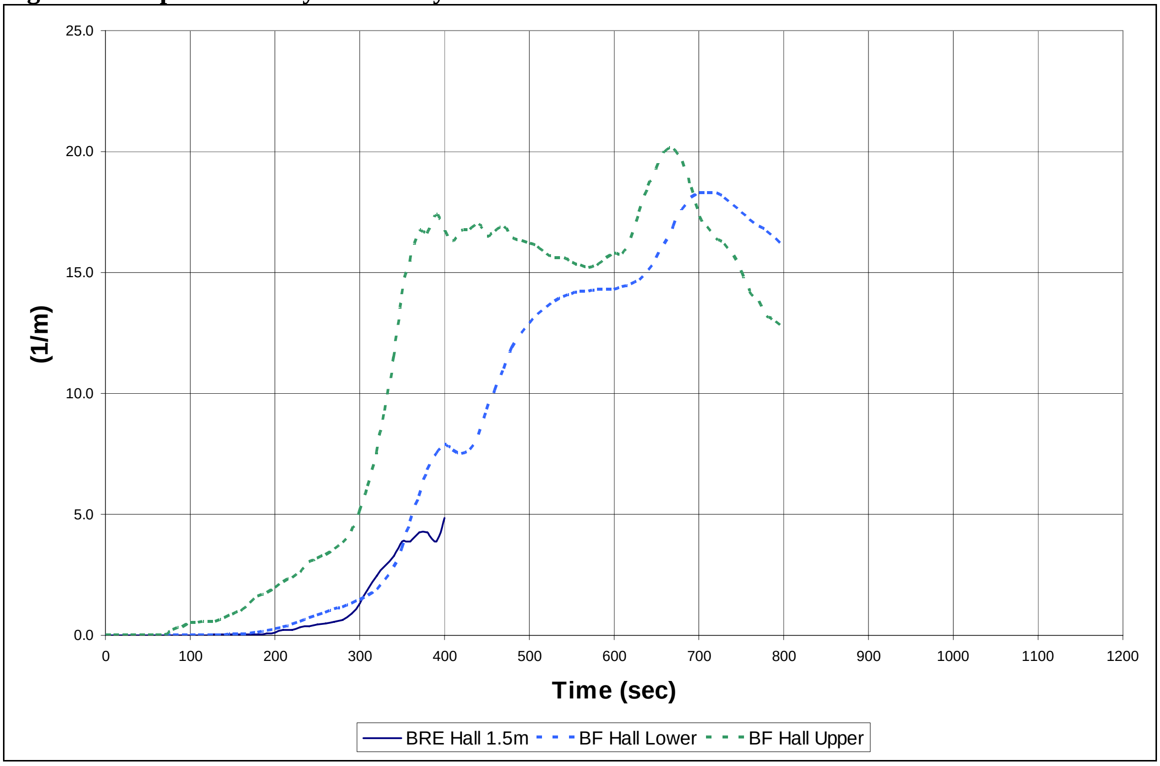
The optical density results generated by the BRANZFIRE simulation are compared against the readings recorded during the full scale rig testing in Figures 5.31 to 5.35.

Figure 5.31 Optical Density in Lounge



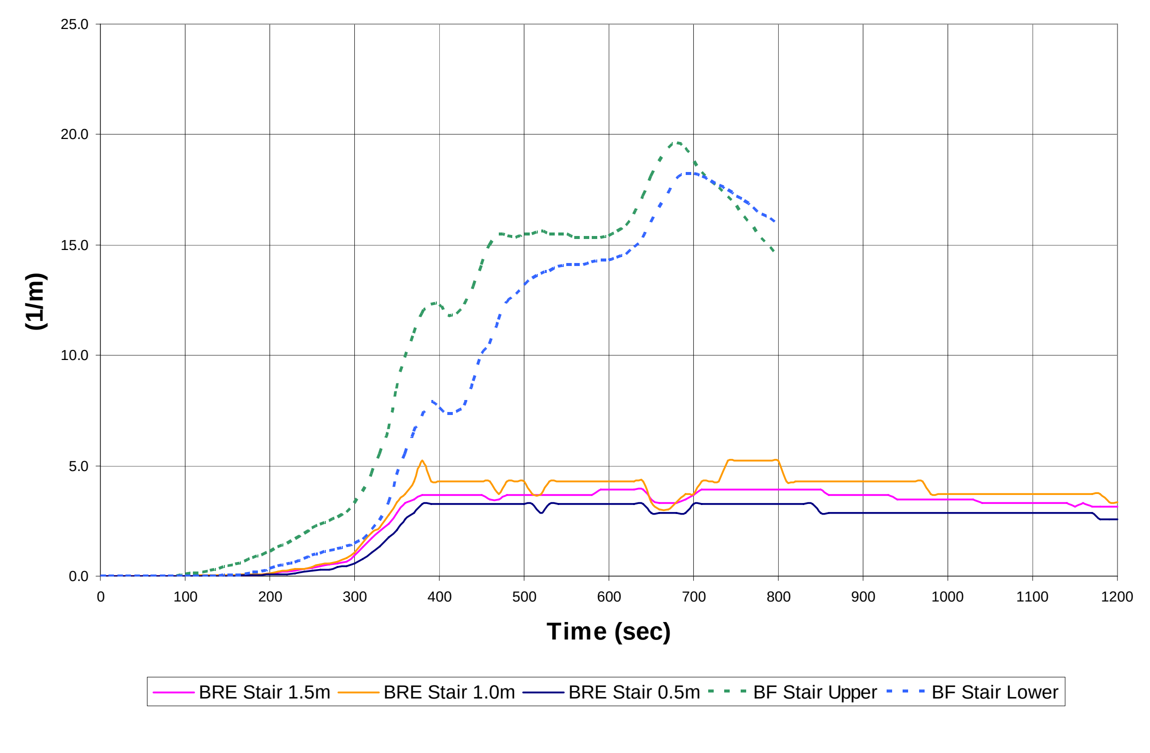
The full scale testing data predicts the upper layer optical density to increase to a maximum value of approximately 6m^{-1} at 500 seconds at which point the maximum range of the instrumentation is reached. The BRANZFIRE simulation predicts the upper layer optical density to reach a maximum value or 33m^{-1} at 400 seconds and then decrease to approximately 23m^{-1} before rising to a second peak of 32m^{-1} at 660 seconds. These values are less than were predicted in the lounge for the two compartment simulation by approximately 5m^{-1}.

Figure 5.32 Optical Density in Hallway



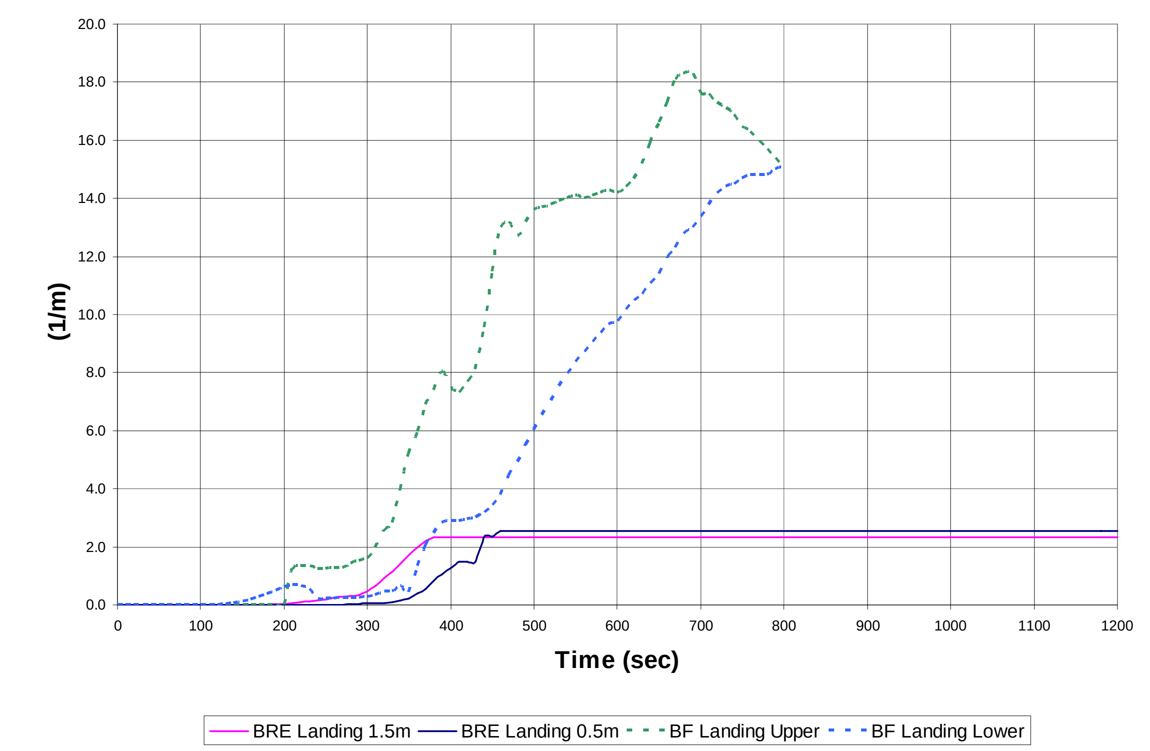
In the hallway the lower layer optical density provides a good estimate of the optical density recorded during the full scale rig testing up to a reading of $5m^{-1}$ at 400 seconds where the maximum range of the instrumentation is reached. The upper layer optical density predicted by the BRANZFIRE simulation reaches a first peak of $17m^{-1}$ at 400 seconds before rising to a second peak at 650 seconds of $20m^{-1}$. The upper layer optical density predicted by the BRANZFIRE simulation appears to be a poor approximation of the full scale rig test data from the amount of data collected during the full scale testing.

Figure 5.33 Optical Density on Stair



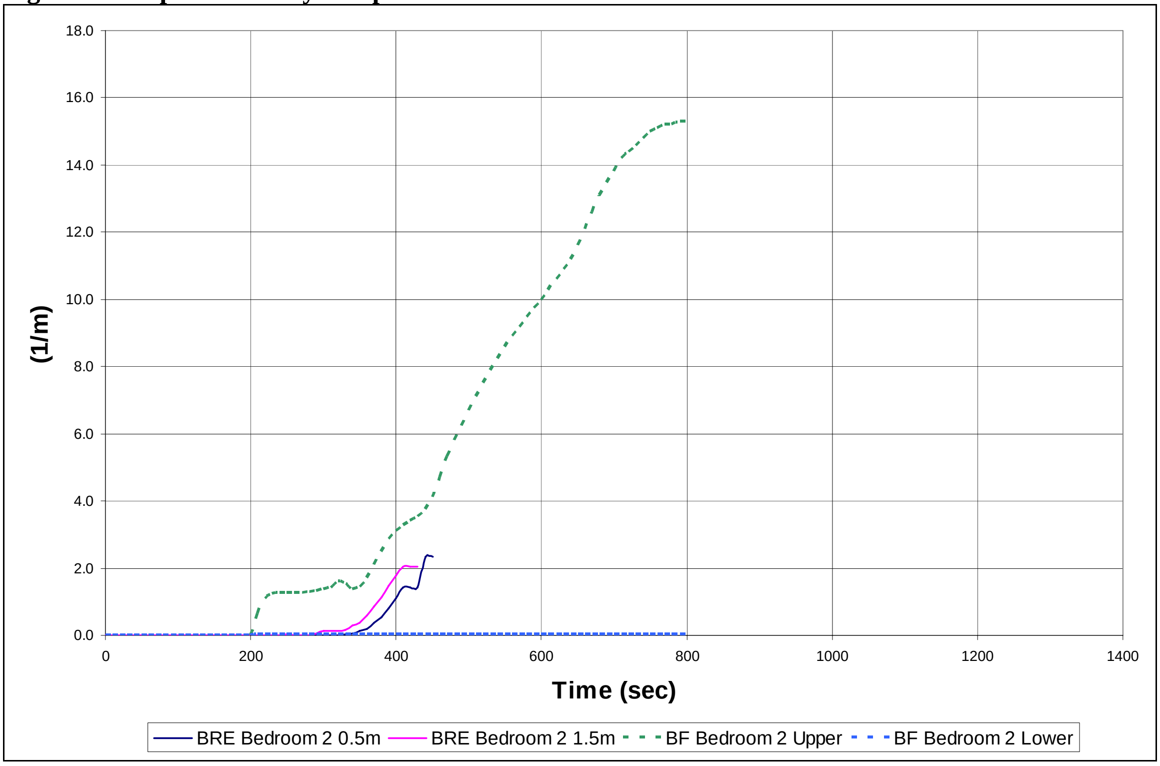
On the stairs the BRANZFIRE simulation predicts an increase in the optical density at a similar time to the full scale rig test data but continues up to a peak of approximately 19.5m^{-1}. This is far in excess of the value of approximately 4m^{-1} recorded during the full scale rig testing.

Figure 5.34 Optical Density on Landing



The upper layer optical density predicted by the BRANZFIRE simulation on the landing is also far in excess of the data recorded during the full scale rig testing. The BRANZFIRE simulation predicts a maximum upper layer optical density in the order of $18m^{-1}$ in comparison to the full scale rig test data which gives a maximum upper layer optical density of $2.5m^{-1}$.

Figure 5.35 Optical Density in Open Bedroom

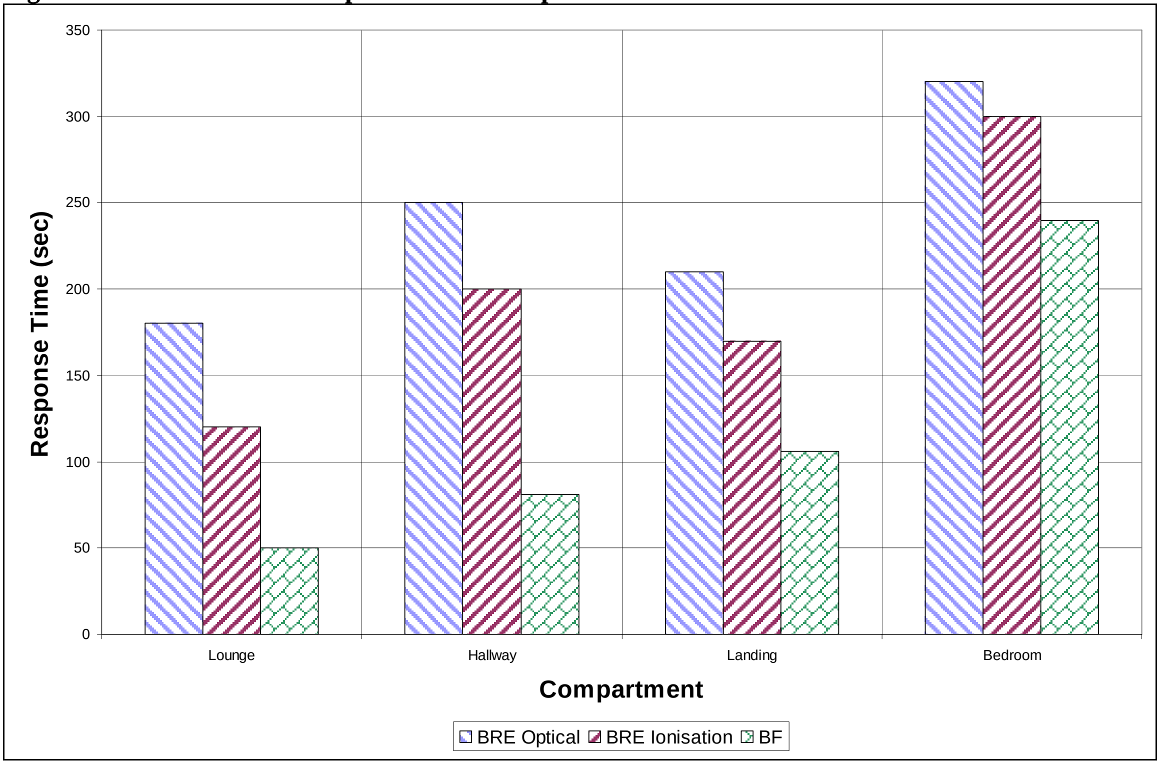


In the open bedroom the BRANZFIRE simulation predicts an upper layer optical density similar to the value predicted in the stairs and landing with a maximum upper layer optical density of $15m^{-1}$. This is far in excess of the maximum upper layer optical density of approximately $2m^{-1}$ recorded during the full scale rig testing.

5.2.4 Smoke Alarm Response

The smoke alarm response times from the full scale rig testing and the BRANZFIRE simulation for all of the compartments are shown in Figure 5.36.

Figure 5.36 Smoke Alarm Response in All Compartments



From Figure 5.36 it can be seen that the BRANZFIRE simulation predicts smoke alarm activation times significantly faster than for the full scale rig testing.

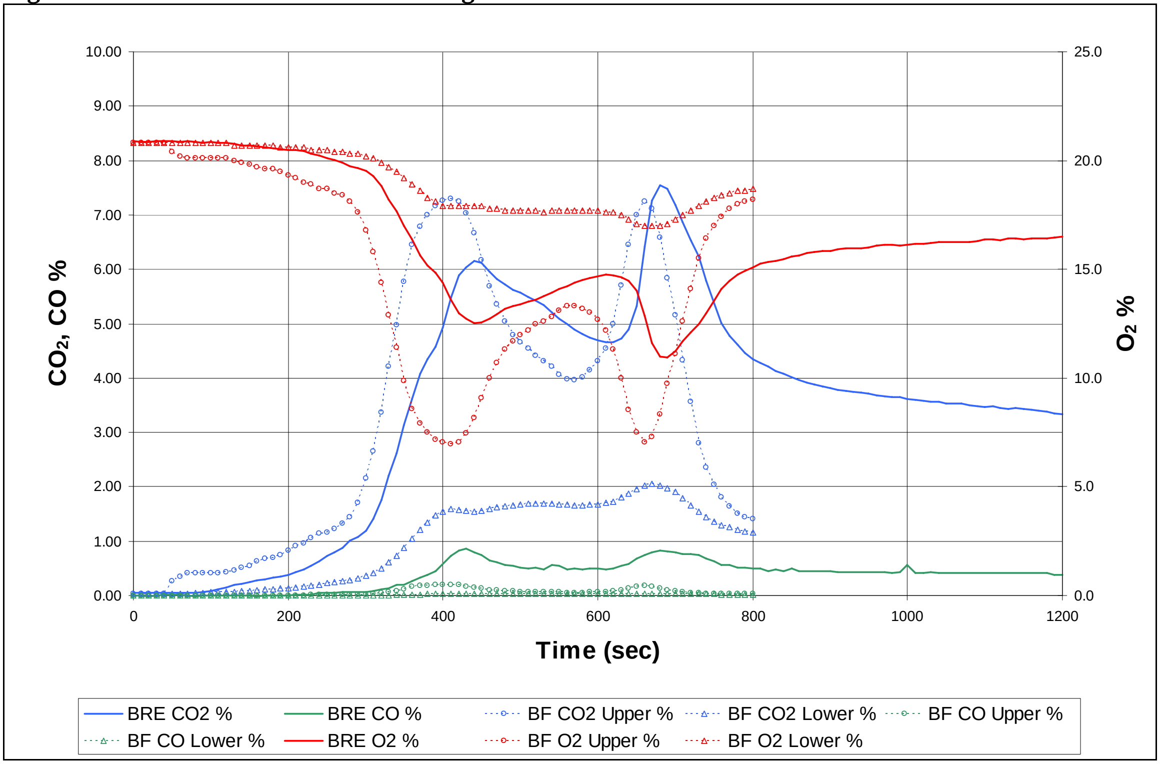
In the lounge the BRANZFIRE simulation predicts an activation time of approximately 50 seconds in comparison to the 180 and 120 seconds recorded for the optical and ionisation smoke alarms in the lounge. In the hallway the full scale rig test optical and ionisation smoke alarms activated in 250 and 200 seconds respectively in comparison to a predicted activation time of 70 seconds in the BRANZFIRE simulation.

On the landing the BRANZFIRE simulation predicts the smoke alarm activation at 110 seconds in comparison to the readings of 210 and 170 seconds for the optical and ionisation smoke alarms in the full scale testing. The margin between the full scale test results and the BRANZFIRE simulation are the closest in the open bedroom. The BRANZFIRE simulation predicts an activation time of 240 seconds in comparison to the activation times of 320 and 300 seconds for the optical and ionisation smoke alarms in the full scale rig tests.

5.2.5 *Gas Concentration*

The gas concentrations calculated in the BRANZFIRE simulations are compared against the data recorded during the full scale rig testing in Figures 5.37 to 5.40.

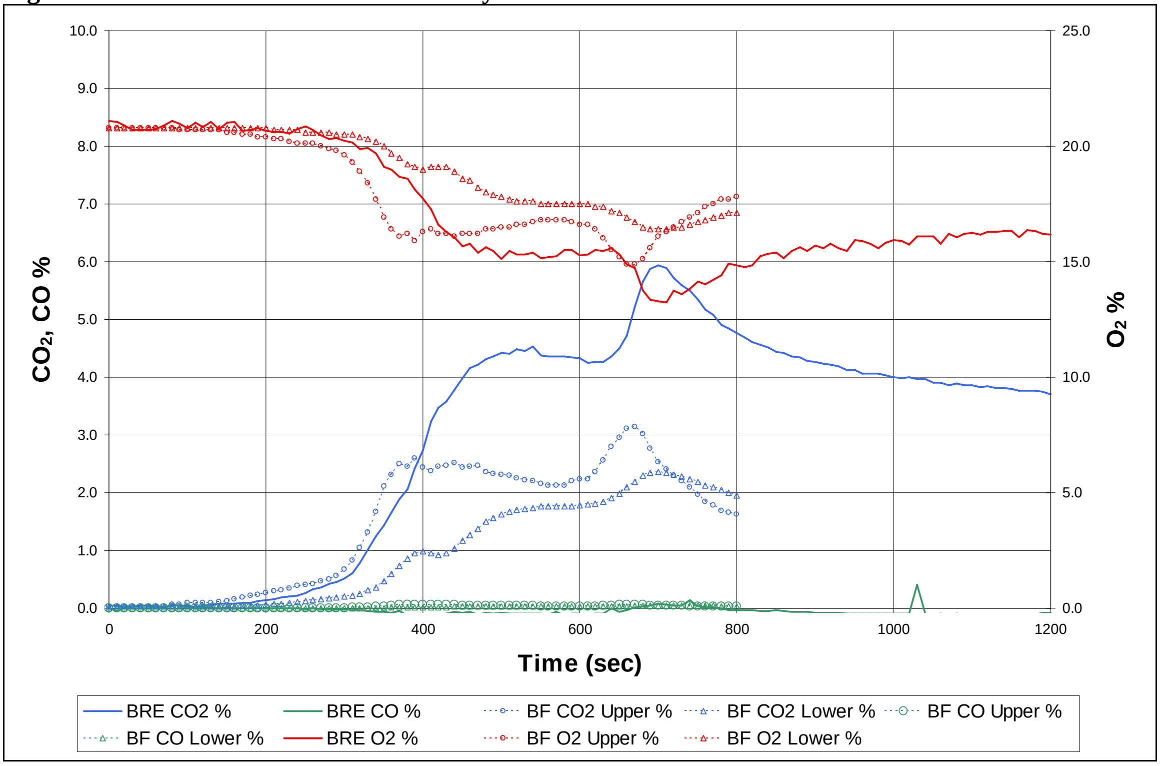
Figure 5.37 Gas Concentrations in Lounge



The results for the oxygen concentration in the lounge are different for the two and three compartment simulations. The oxygen concentration reduces to less than 7.5% in both peaks in the three compartment simulation, compared to 5% in the two compartment simulation. The carbon dioxide concentration predicted by the BRANZFIRE simulation increases at approximately the same rate as recorded in the full scale rig testing but reaches a peak at a higher value than the full scale rig test in the first peak. The second peak in the carbon dioxide concentration predicted by the BRANZFIRE simulation is a good approximation of the full scale rig test result.

The carbon monoxide concentration predicted by the BRANZFIRE simulation is significantly lower than the values recorded during the full scale testing.

Figure 5.38 Gas Concentrations in Hallway

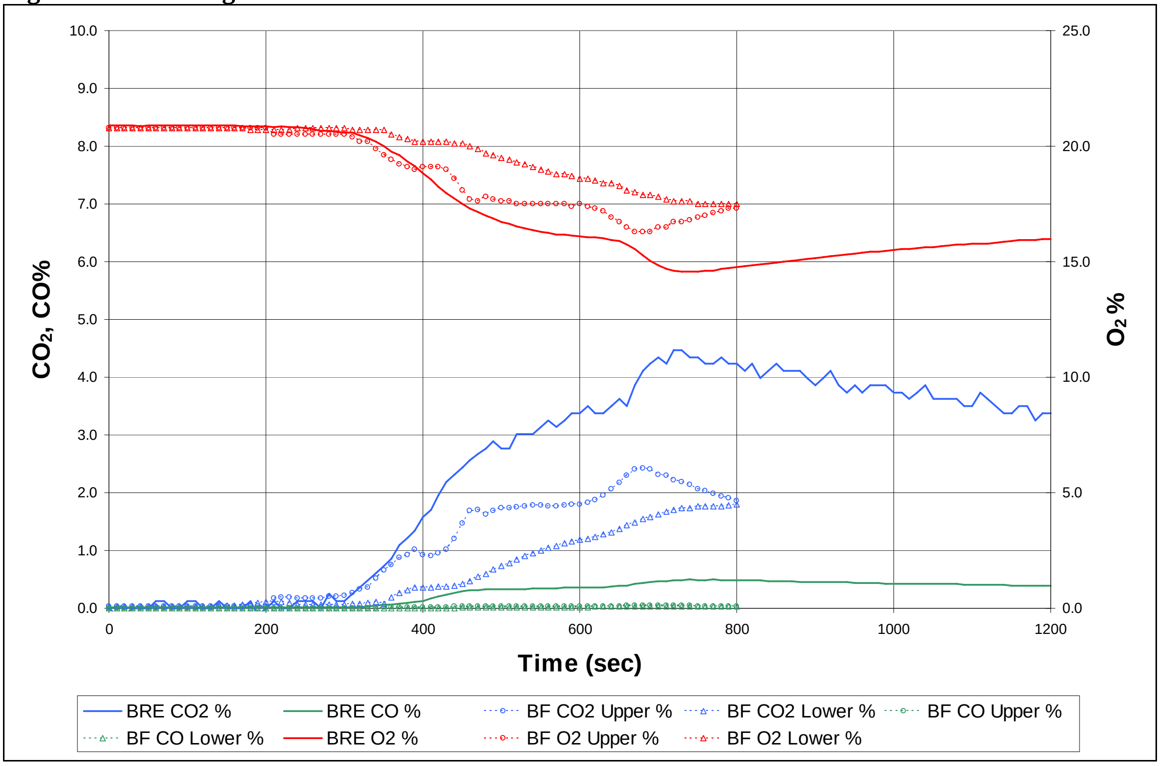


The oxygen concentration in the hallway is under predicted by the BRANZFIRE simulation in comparison to the full scale rig testing. The BRANZFIRE simulation predicts a minimum oxygen concentration of 14.7% at 670 seconds in comparison to the full scale rig testing which predicts a minimum value of 13.2% at 710 seconds.

In the hallway there are also differences in the carbon dioxide concentration between the two and three compartment models. The upper layer carbon dioxide concentration predicted by the BRANZFIRE simulation provides a good approximation of the full scale rig data until approximately 400 seconds, at which time the BRANZFIRE simulation reaches a constant value of approximately 2.5% while the full scale data continues to increase to 4.4% before rising to a second peak of 6%. The BRANZFIRE simulation makes only a small prediction of the second peak in the carbon dioxide concentration.

The carbon monoxide concentration is similar to the two compartment simulation results.

Figure 5.39 Landing Gas Concentrations



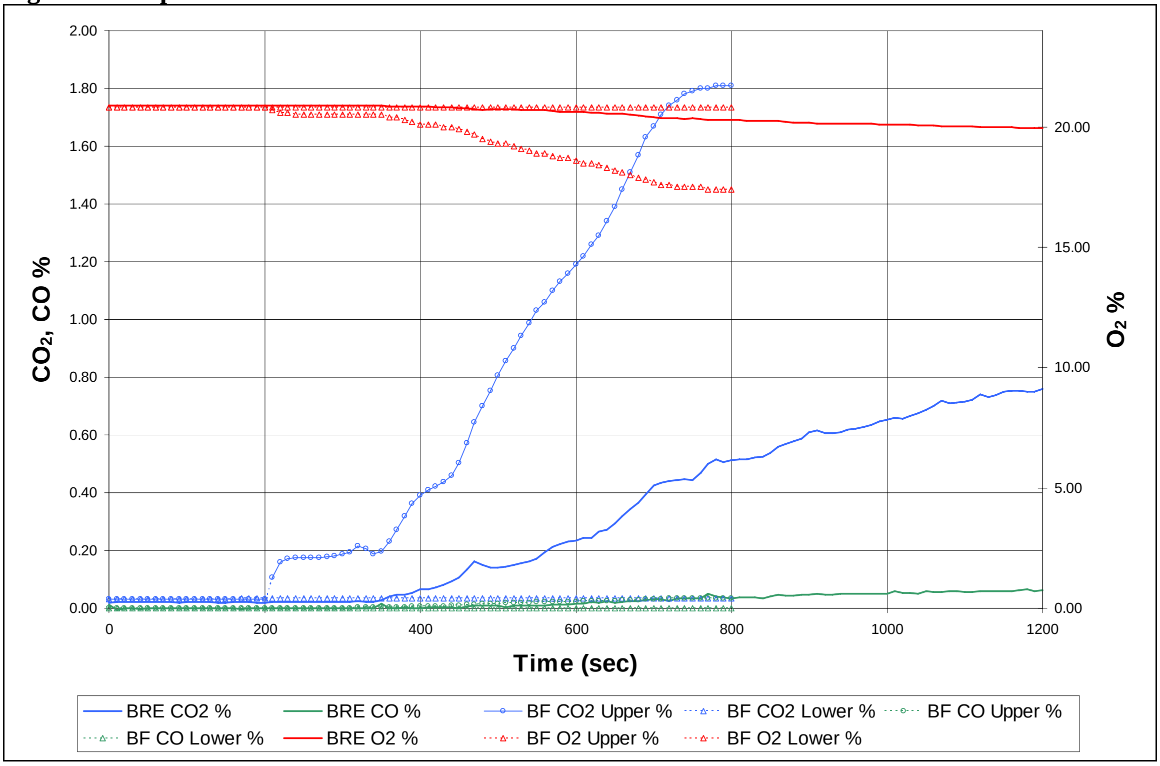
There are significant changes in the gas concentrations on the landing for the two and three compartment simulations.

For the three compartment simulation the BRANZFIRE simulation under predicts the decrease in the oxygen concentration predicting a lowest value of 15.8% while the full scale rig test reached a minimum value of 14.5%.

The carbon dioxide concentration predicted by the BRANZFIRE simulation provides a good approximation of the full scale test data up until approximately 400 seconds, before increasing at a slower rate than is seen in the hallway. The BRANZFIRE simulation predicts a maximum carbon dioxide concentration of 2.65% compared to the maximum of 4.5% recorded during the full scale rig test.

The carbon monoxide concentration is significantly under estimated by the BRANZFIRE simulation in this compartment also.

Figure 5.40 Open Bedroom Gas Concentrations



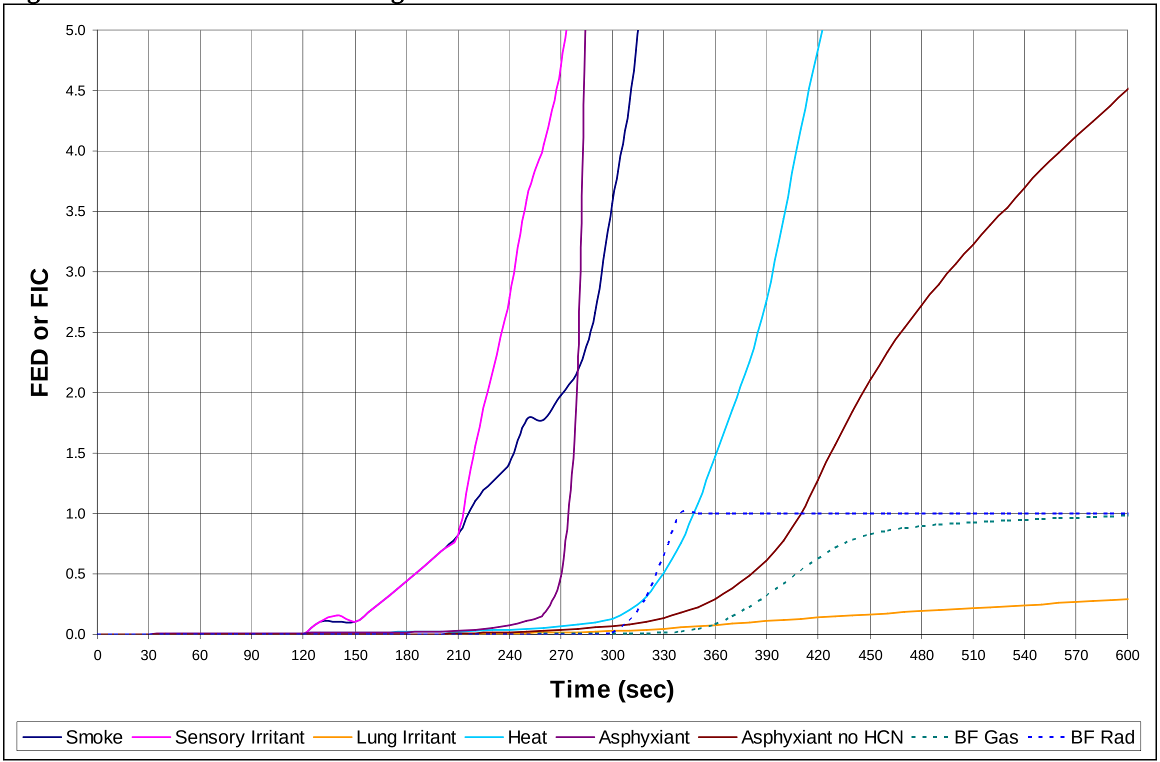
In the open bedroom there is only a very small decrease in the oxygen concentration during the full scale rig testing whereas the BRANZFIRE simulation predicts a decrease in oxygen concentration from 20.8% to approximately 17%.

The BRANZFIRE simulation greatly over predicts the increase in the carbon dioxide concentration but makes a more reasonable approximation of the carbon monoxide concentration than in the other compartments.

5.2.6 *Fractional Effective Dose*

The fractional effective dose and fractional irritant concentration determined in the full scale testing and predicted by the BRANZFIRE simulations for the lounge are shown in Figure 5.41.

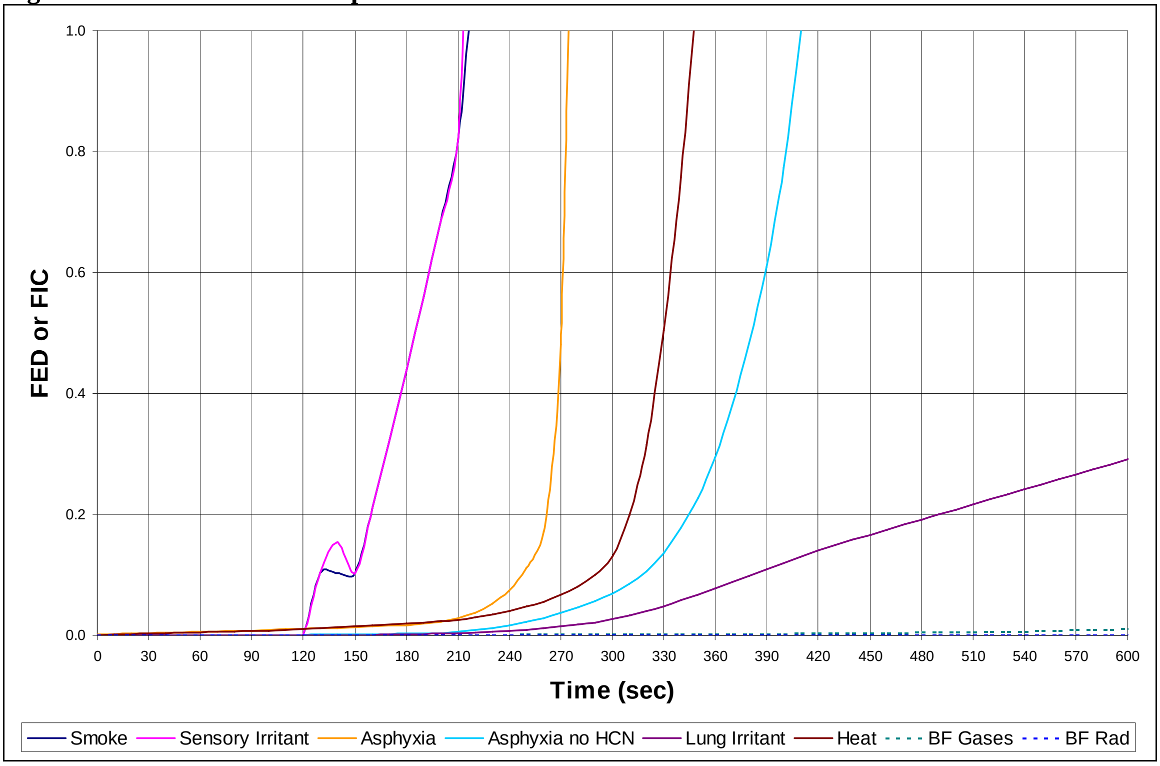
Figure 5.41 FIC and FED in Lounge



In the three compartment setup the BRANZFIRE simulation makes a good approximation of the fractional effective dose due to heat, as seen in the two compartment model. The predicted increase in the fractional effective dose due to gases is slower in the three compartment model compared to the two compartment model and an effective dose of 1.0 due to gases is predicted approximately 210 seconds later in the BRANZFIRE simulation in comparison to the full scale rig testing.

The fractional effective dose and fractional irritant concentration determined in the full scale testing and predicted by the BRANZFIRE simulations for the open bedroom are shown in Figure 5.42.

Figure 5.42 FIC and FED in Open Bedroom



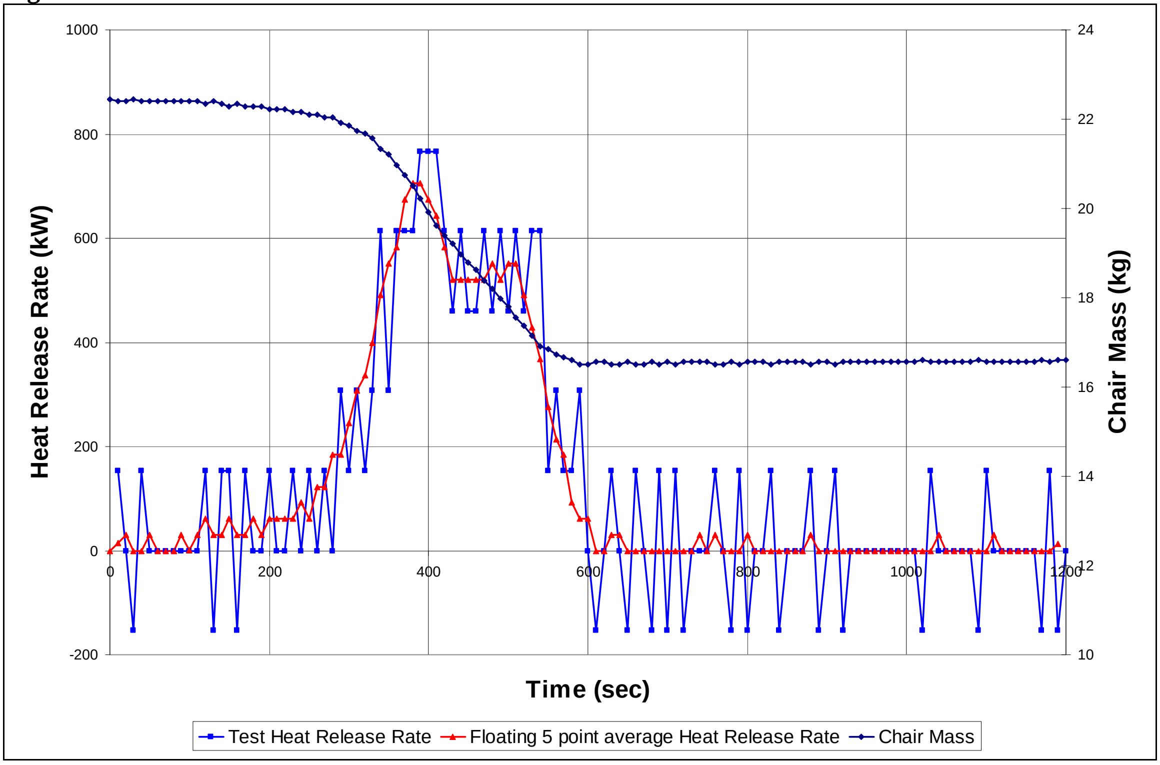
In the open bedroom of the three compartment model the fractional effective doses predicted by the BRANZFIRE simulation are lower than for the two compartment model and are again a poor estimate of the doses observed during the full scale testing.

6 Test CDT18 Simulation Results

Test CDT18 was the third of the tests carried out at Cardington with a fully flaming fire and was conducted with the lounge door open.

The heat release rate determined for the simulation which was calculated from the mass loss rate given in the BRE testing data is shown in Figure 6.1.

Figure 6.1 Test CDT18 Heat Release Rate



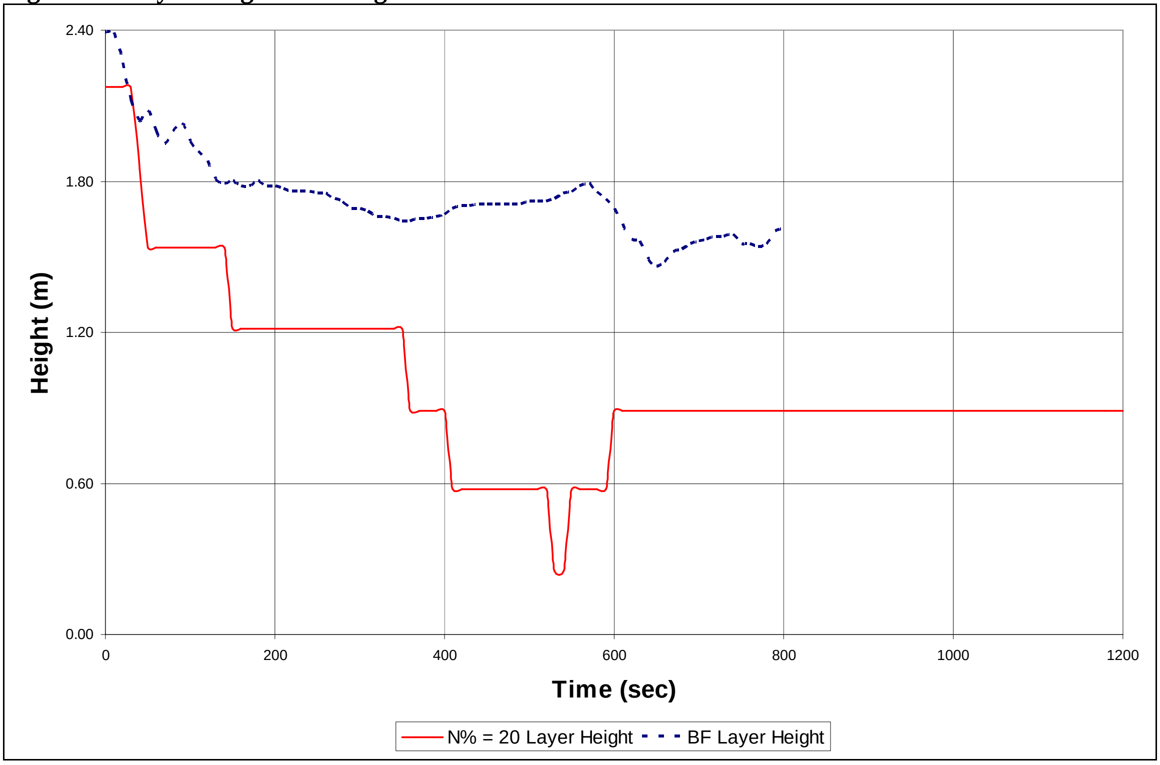
As for test CDT17, this test was simulated using both the two and three compartment simulations of the hallway, stair and landing. The results of the two simulations are presented in Sections 6.1 and 6.2. Note that in the figures presented in this section BRANZFIRE has been abbreviated to BF in the data series legend.

6.1 Two Compartment Simulation

6.1.1 Layer Height

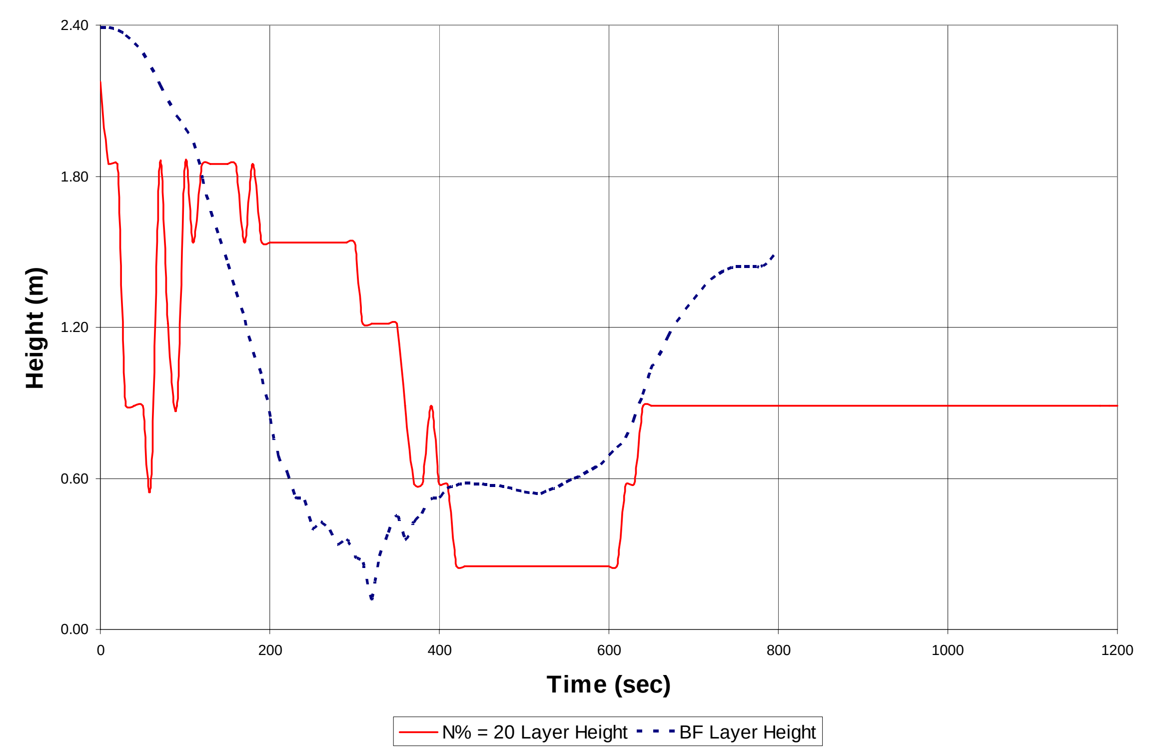
The layer height predicted in the lounge, hallway, landing and open bedroom by the N% method with N = 20 and the BRANZFIRE simulations are presented in Figures 6.2 to 6.5.

Figure 6.2 Layer Height in Lounge



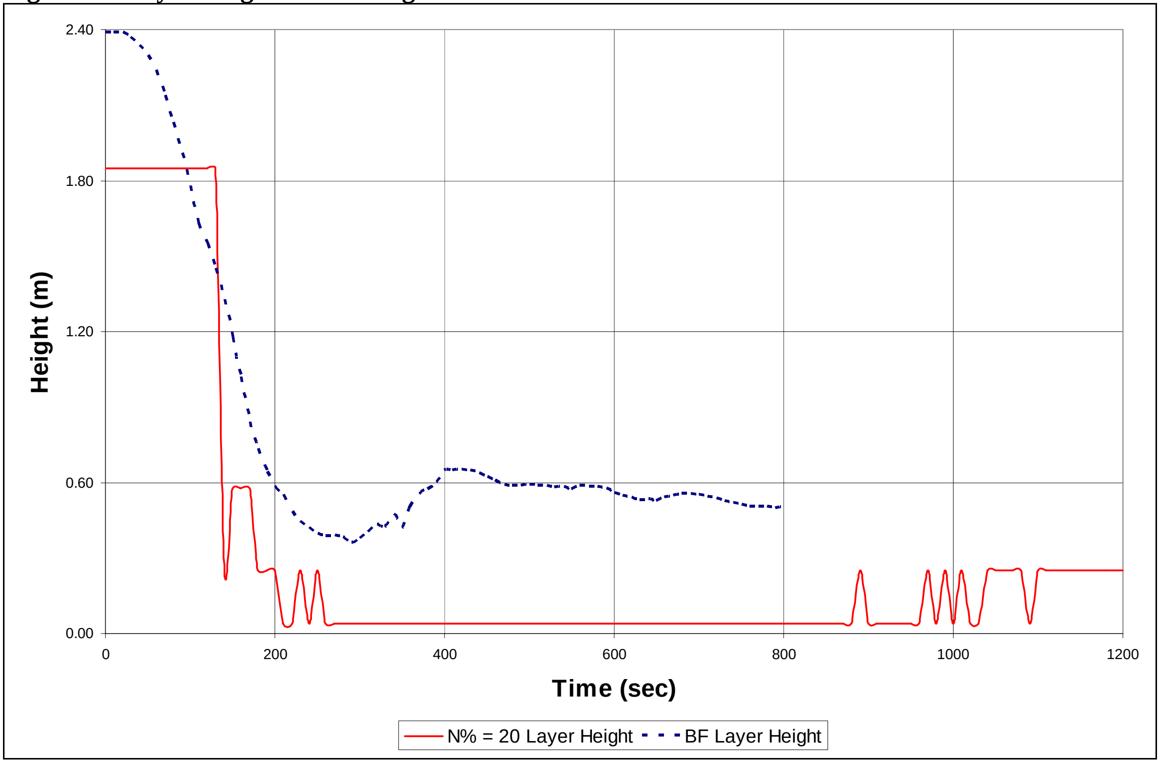
The N% method predicts the layer height to steadily lower to a height of 0.25m above floor level after 540 seconds and remain there briefly before rising to a steady level of 0.89m above floor level for the remainder of the test. The BRANZFIRE simulation predicts the very early lowering of the layer height well but does not make a good prediction of the extent of the lowering of the layer. The BRANZFIRE simulation predicts the layer interface to reach a level of 1.46m above floor level at its lowest point which occurs at 650 seconds.

Figure 6.3 Layer Height in Hallway



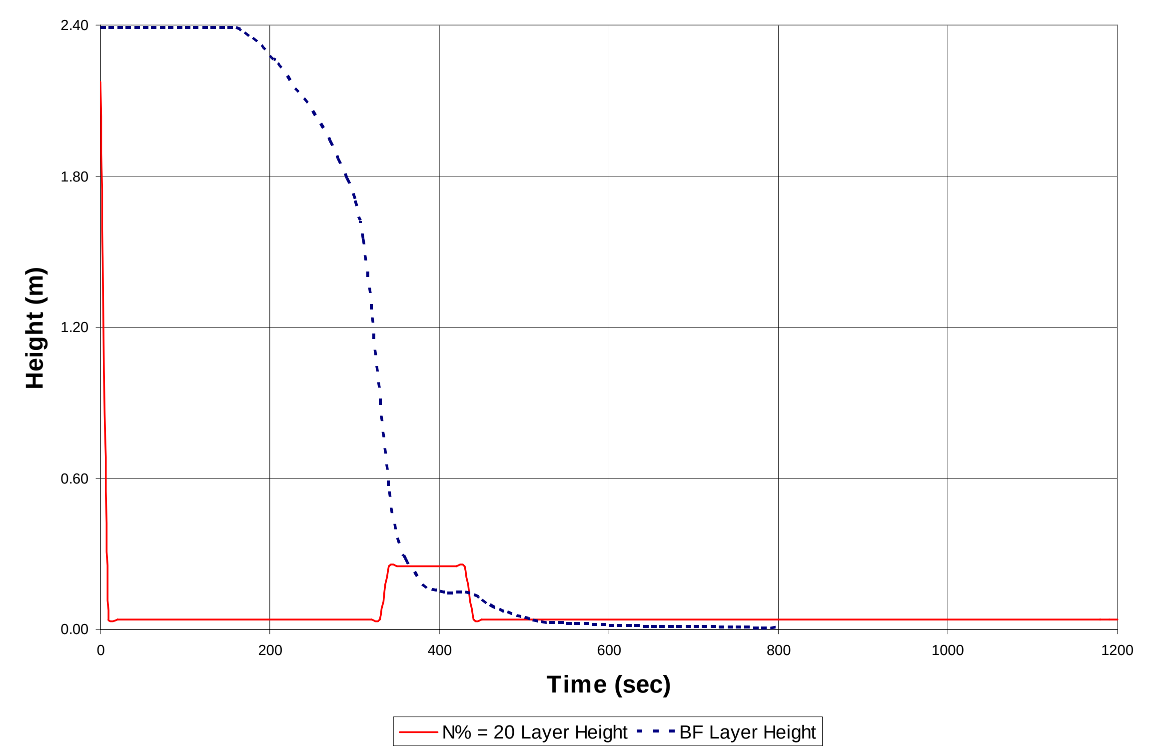
In the hallway both the BRANZFIRE simulation and the N% method predict the layer height to lower to approximately the same level of 0.12m and 0.25m above floor level respectively. The BRANZFIRE simulation predicts this lowest point to occur at 320 seconds in comparison to the N% method which predicts the lowest point at 420 seconds. Both the BRANZFIRE simulation and the N% method predict the layer height to rise after remaining at its lowest point briefly, but the BRANZFIRE simulation predicts the layer to rise to a higher level than is predicted by the N% method. As noted in Section 3, once temperatures begin to return to ambient levels it becomes much more difficult to determine the layer height using the N% method.

Figure 6.4 Layer Height on Landing



On the landing the BRANZFIRE simulation makes a very good prediction of the time of the lowering of the layer height but under predicts the extent of the lowering of the layer. The N% method predicts the layer to reach floor level at 220 seconds and remain there for the remainder of the test. The BRANZFIRE simulation predicts the layer to descend to 0.36m above floor level and then rise to a more constant layer height of approximately 0.56m after 400 seconds. The layer is predicted to be at its lowest level at 290 seconds by the BRANZFIRE simulation.

Figure 6.5 Layer Height in Open Bedroom

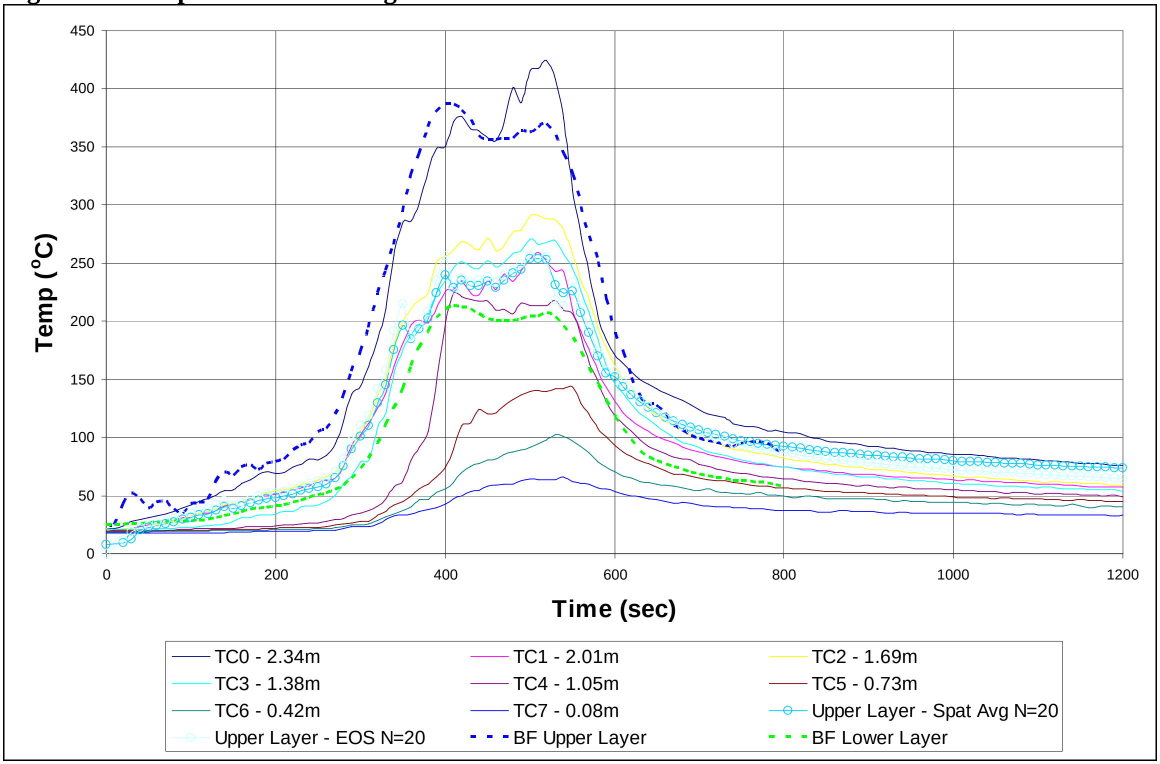


In the open bedroom the BRANZFIRE simulation predicts the layer height to descend to 0.15m above floor level at 400 seconds and then lower to floor level at 500 seconds and remain there for the rest of the simulation. The N% method predicts the layer to lower to floor level immediately after the test is started and remain there for the rest of the test other than a slight rising at approximately 400 seconds. As noted in Section 3 with the relatively low temperature changes in the open bedroom the N% method has difficulty predicting the layer height.

6.1.2 Temperatures

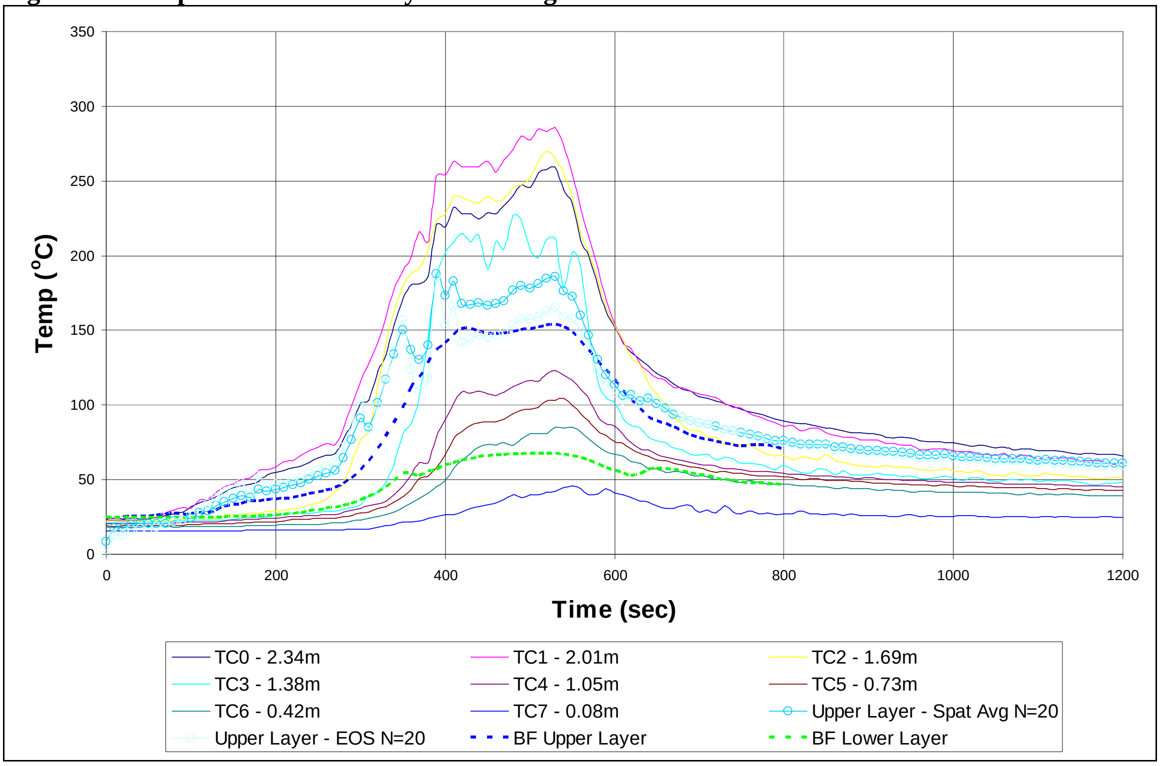
The compartment temperatures from the full scale rig testing and those generated by the BRANZFIRE simulation are shown in Figures 6.6 to 6.9. Also shown in Figures 6.6 to 6.9 are the upper layer temperatures predicted by the methods outlined in Section 3.

Figure 6.6 Temperatures in Lounge



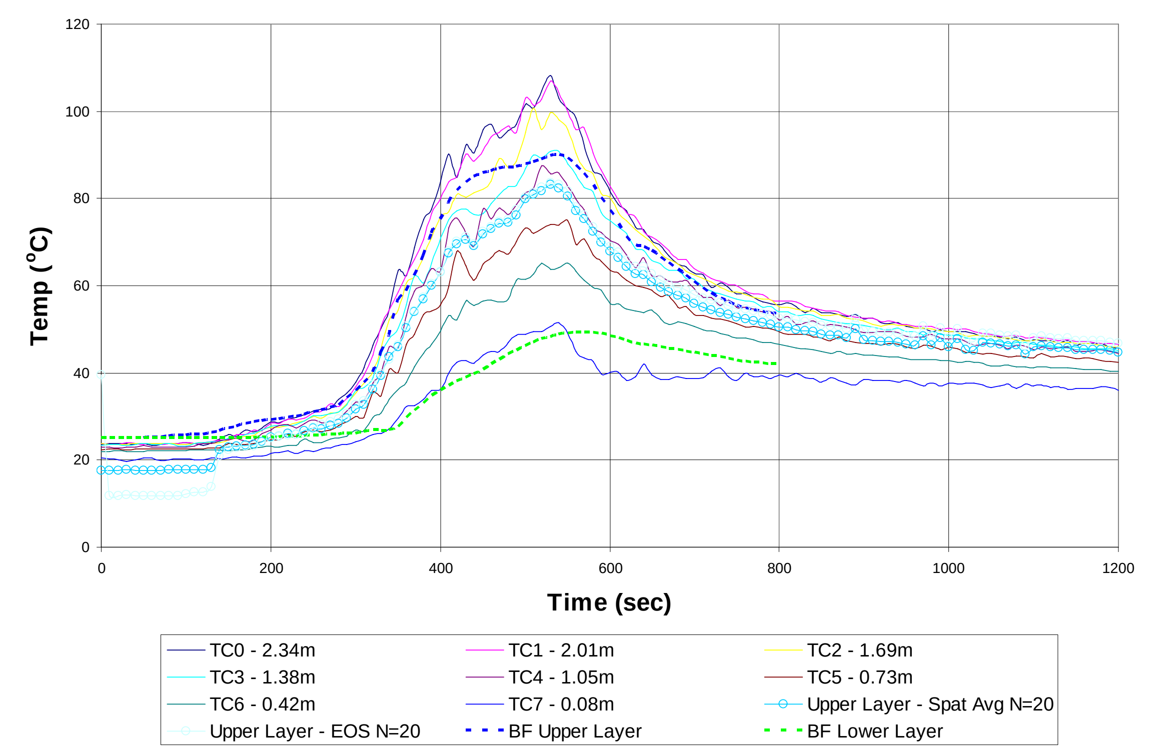
In this simulation the spatial average and equation of state methods predict a peak upper layer temperature of approximately 250°C. The BRANZFIRE simulation predicts a maximum upper layer temperature of 385°C which is of similar magnitude to the maximum temperature recorded in the highest thermocouple.

Figure 6.7 Temperatures in Hallway near Lounge Door



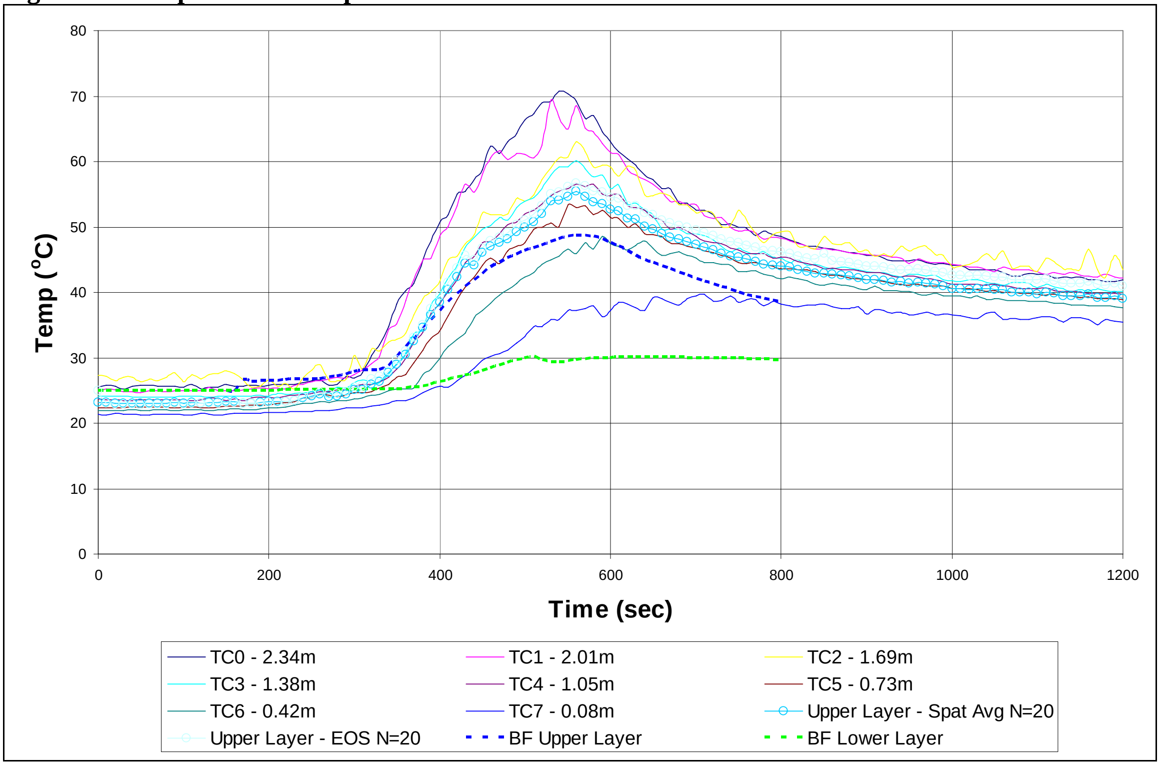
In the hallway near the lounge door the BRANZFIRE simulation predicts a peak upper layer temperature of 155°C at 530 seconds in comparison to the spatial average and equation of state methods which predicts maximum upper layer temperatures of 185°C and 165°C respectively at approximately 530 seconds. The BRANZFIRE simulation under predicts the spatial average and equation of state methods by approximately 5% to 15% at the peak temperature.

Figure 6.8 Temperatures on Landing



On the landing the BRANZFIRE simulation makes a very good approximation of the peak upper layer temperature, predicting a maximum value of 90°C in comparison to the spatial average and equation of state methods which predict a maximum upper layer temperature of 83°C. The BRANZFIRE simulation predicts a higher early increase in the upper layer temperature than is predicted by the spatial average and equation of state methods with the temperature rising to approximately 82°C at 420 seconds and then increasing gradually to the peak temperature at 540 seconds. At 420 seconds the equation of state and spatial average methods predict a temperature of 70°C which then increases more rapidly to the peak temperature at 540 seconds.

Figure 6.9 Temperatures in Open Bedroom

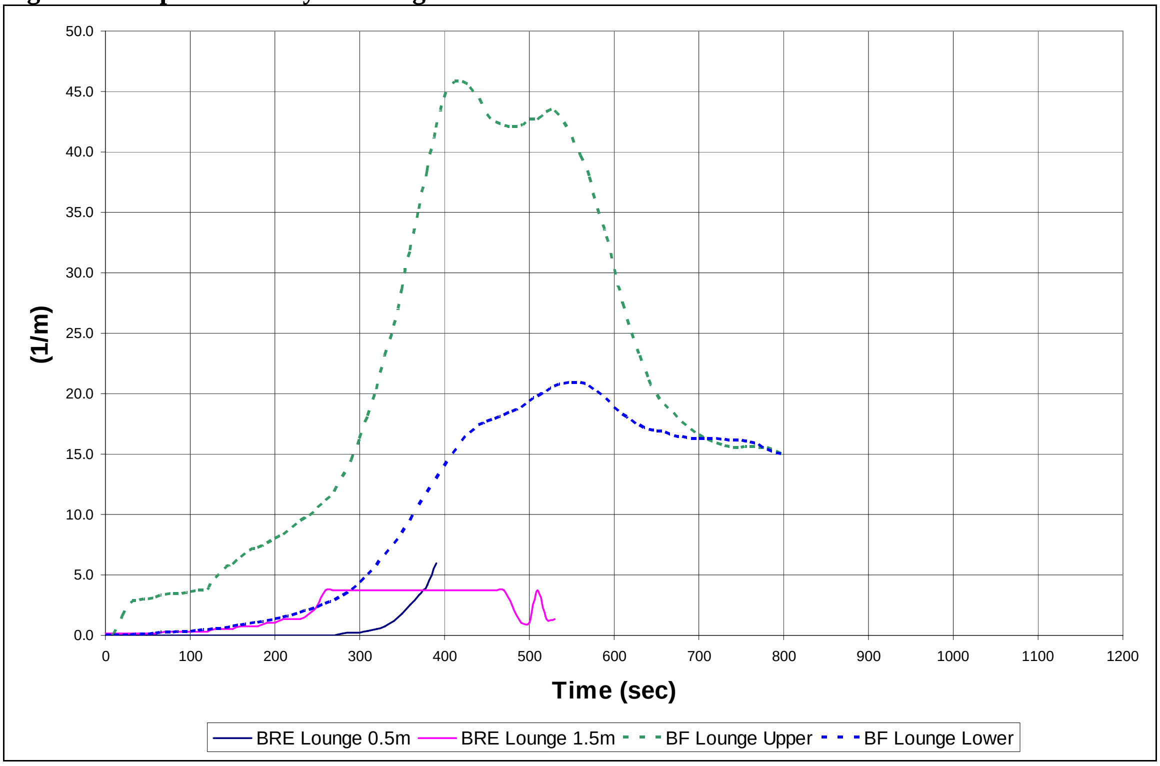


In the open bedroom a temperature increase of approximately 50°C was observed in the two highest thermocouples during the full scale rig testing. The equation of state and spatial average methods predict a maximum upper layer temperature of 55°C at 540 seconds. The BRANZFIRE simulation makes a reasonable approximation of the upper layer temperature predicting a maximum upper layer temperature of 49°C at 540 seconds, approximately 10% lower than the two data reduction methods.

6.1.3 *Optical Density*

The optical density results generated by the BRANZFIRE simulation are compared against the readings recorded during the full scale rig testing in Figures 6.10 to 6.13.

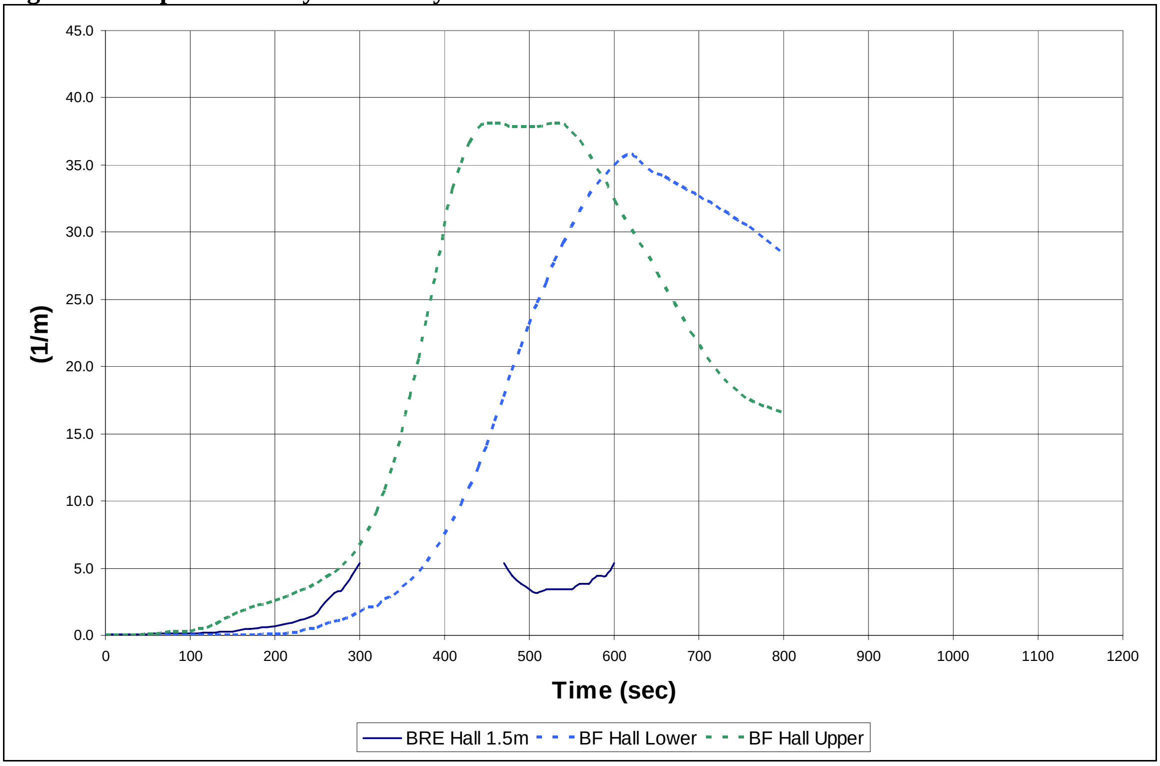
Figure 6.10 Optical Density in Lounge



As in the simulation of test CDT17 the optical density in the lounge is greatly over predicted. The BRANZFIRE simulation predicts a maximum upper layer optical density of greater than $45m^{-1}$ at its peak with an optical density of greater than $20m^{-1}$ in the lower layer. In the full scale rig testing the optical density at the lower sampling point exceeded the range of the sampling equipment at 380 seconds with a reading of 6 m^{-1}. In the upper layer during the full scale rig testing the optical density reached a maximum value of $4m^{-1}$. It is unclear whether the range of the upper layer sampling equipment was exceeded during this test.

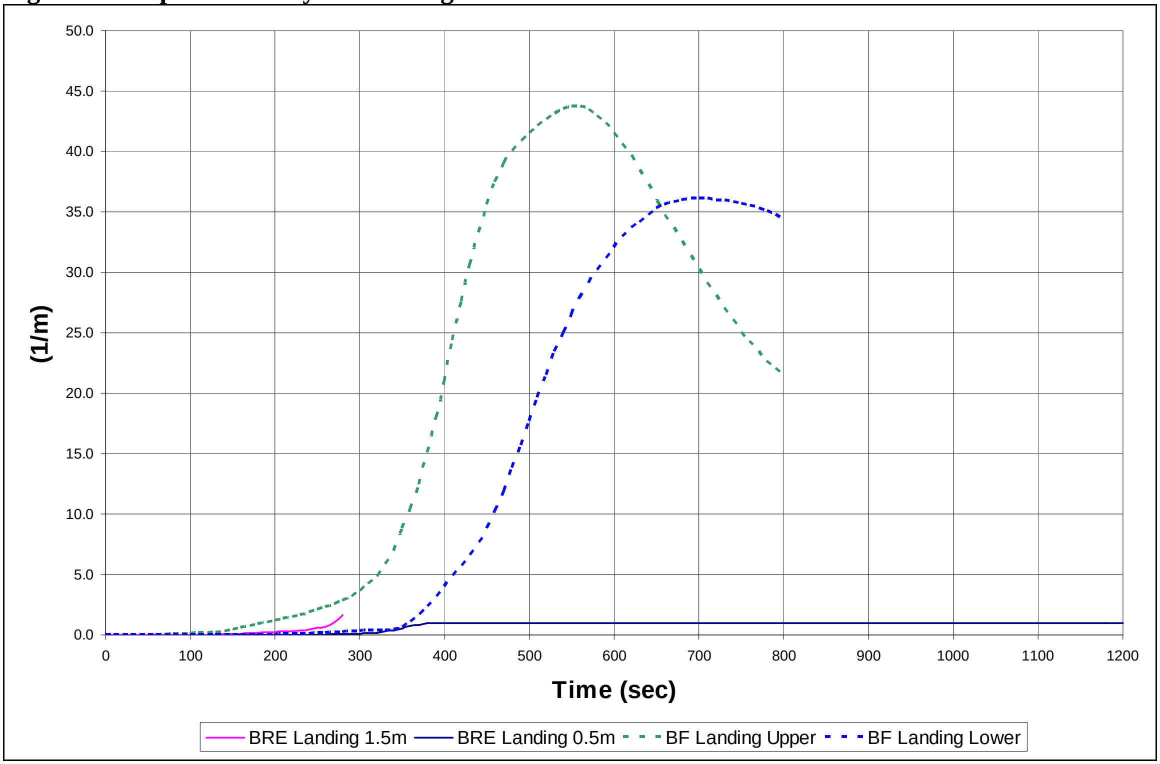
The BRANZFIRE simulation predicts the optical density in both layers to begin increasing approximately 200 seconds earlier than the full scale rig tests.

Figure 6.11 Optical Density in Hallway



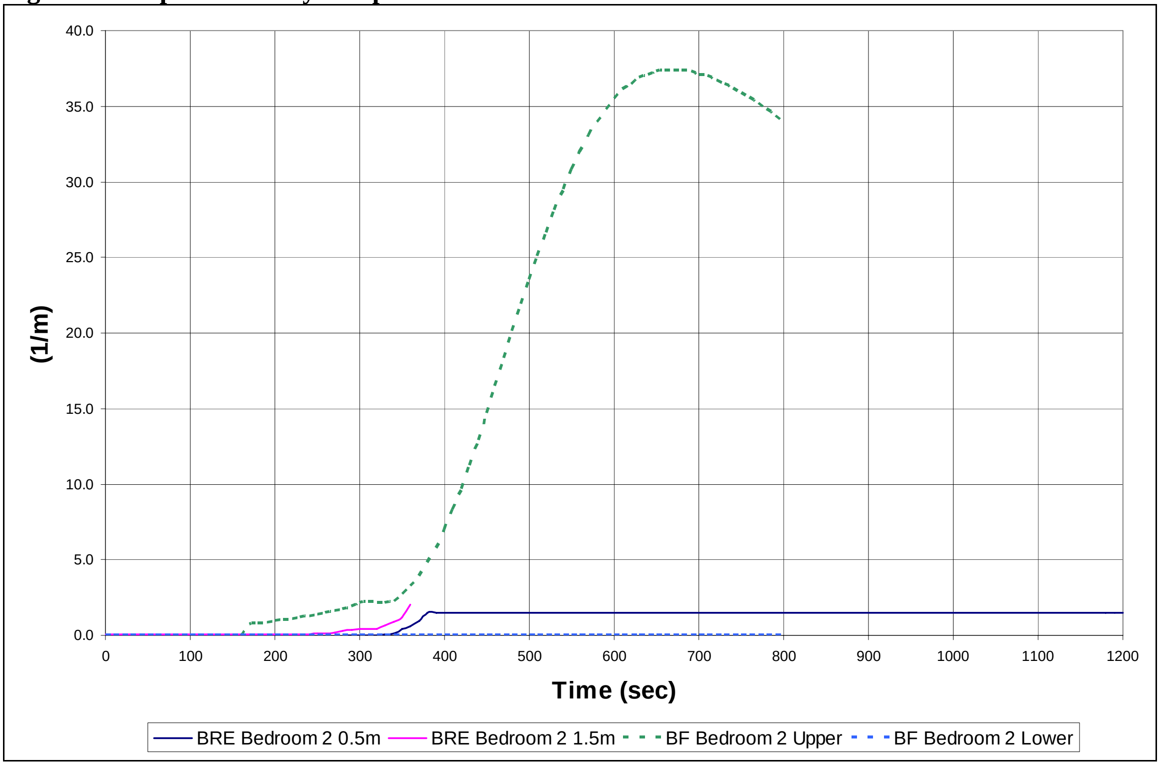
In the hallway the upper and lower layer optical density values predicted by the BRANZFIRE simulation are both a good approximation of the values recorded during the full scale rig testing up to approximately 300 seconds. The peak optical density predicted by the BRANZFIRE simulation in both the upper and lower layer is approximately 36 – 37m^{-1}. The sampling equipment in the BRE testing recorded a maximum value of 5.5 m^{-1} before the maximum range of the equipment was exceeded.

Figure 6.12 Optical Density on Landing



On the landing very low optical densities were observed during the full scale rig testing with a maximum value of $1m^{-1}$ in the lower layer and $1.6m^{-1}$ in the upper layer before no further readings were taken in the upper layer. The BRANZFIRE simulation predicts a peak optical density of $44m^{-1}$ in the upper layer and $36m^{-1}$ in the lower layer. The start of the increase in the optical densities in both layers is approximated well by the BRANZFIRE simulation.

Figure 6.13 Optical Density in Open Bedroom

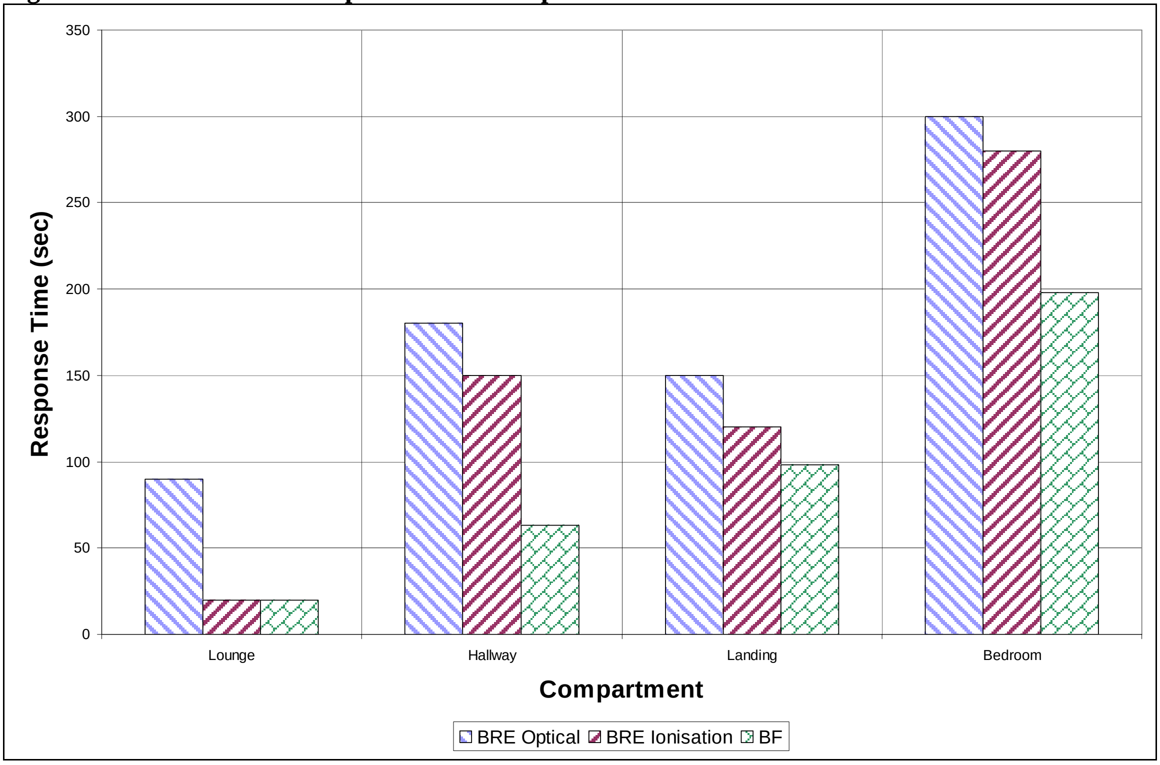


In the open bedroom the BRANZFIRE simulation predicts a maximum upper layer optical density of $37m^{-1}$ but predicts no increase of the optical density in the lower layer. In the BRE testing a maximum optical density of $1.5m^{-1}$ was recorded in the lower layer and $2m^{-1}$ in the upper layer before the range of the equipment recording the upper layer optical density was exceeded.

6.1.4 *Smoke Alarm Response*

The smoke alarm activation times for the BRANZFIRE simulation are compared against the activation times recorded during the full scale rig testing in Figure 6.14.

Figure 6.14 Smoke Alarm Response in All Compartments



In the lounge the BRANZFIRE simulation predicts an activation time of 20 seconds which is a more rapid activation time than was observed for the optical smoke alarm in the full scale testing which had an activation time of 90 seconds. The ionisation smoke alarm activated in 20 seconds in the lounge during the full scale testing.

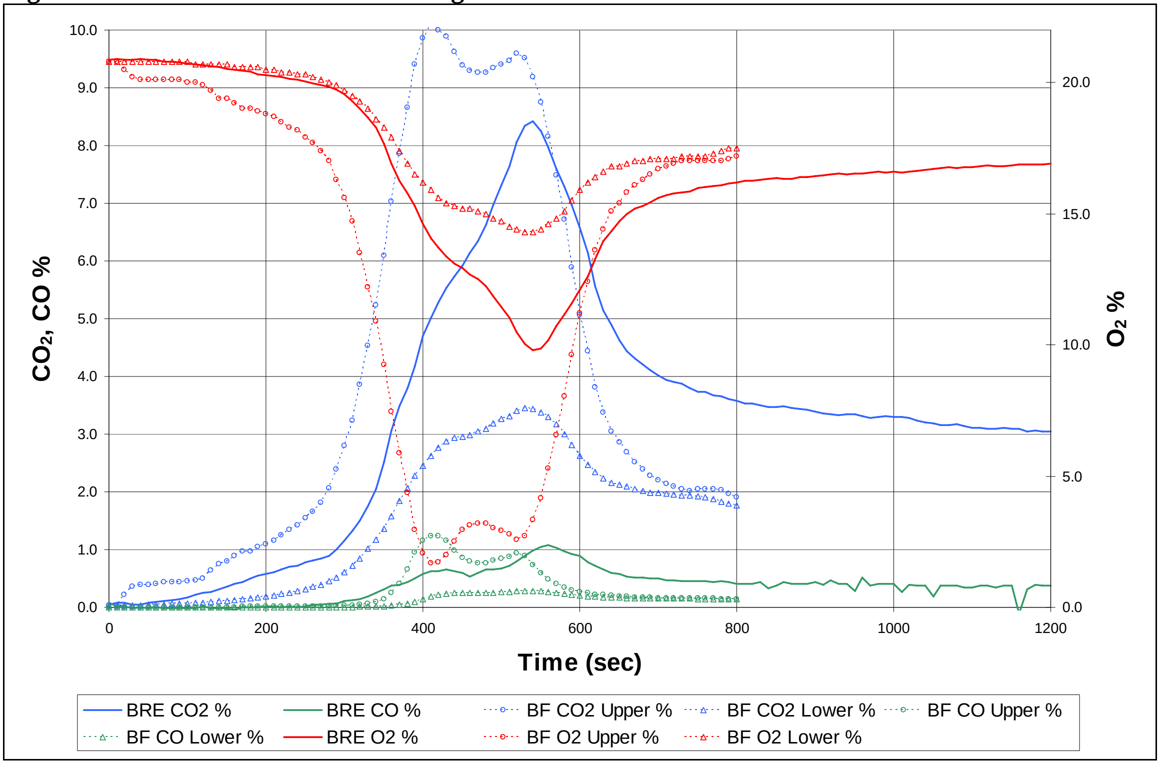
Activation times of 180 and 150 seconds were recorded for the optical and ionisation smoke alarms respectively on the landing during the full scale testing. The BRANZFIRE simulation predicted an activation time of 63 seconds in this compartment. On the landing the activation time is better predicted by the BRANZFIRE simulation which predicts activation at 98 seconds compared to the full scale rig testing where activation times of 150 and 120 seconds were observed for the optical and ionisation smoke alarms respectively.

In the open bedroom the BRANZFIRE simulation predicted an activation time of 198 seconds for the smoke alarm. The optical smoke alarm activated at 300 seconds and the ionisation smoke alarm activated in 280 seconds during the full scale rig testing.

6.1.5 Gas Concentration

The gas concentrations observed in each of the compartments during the BRE testing are compared against the BRANZFIRE simulation output in Figures 6.15 to 6.18.

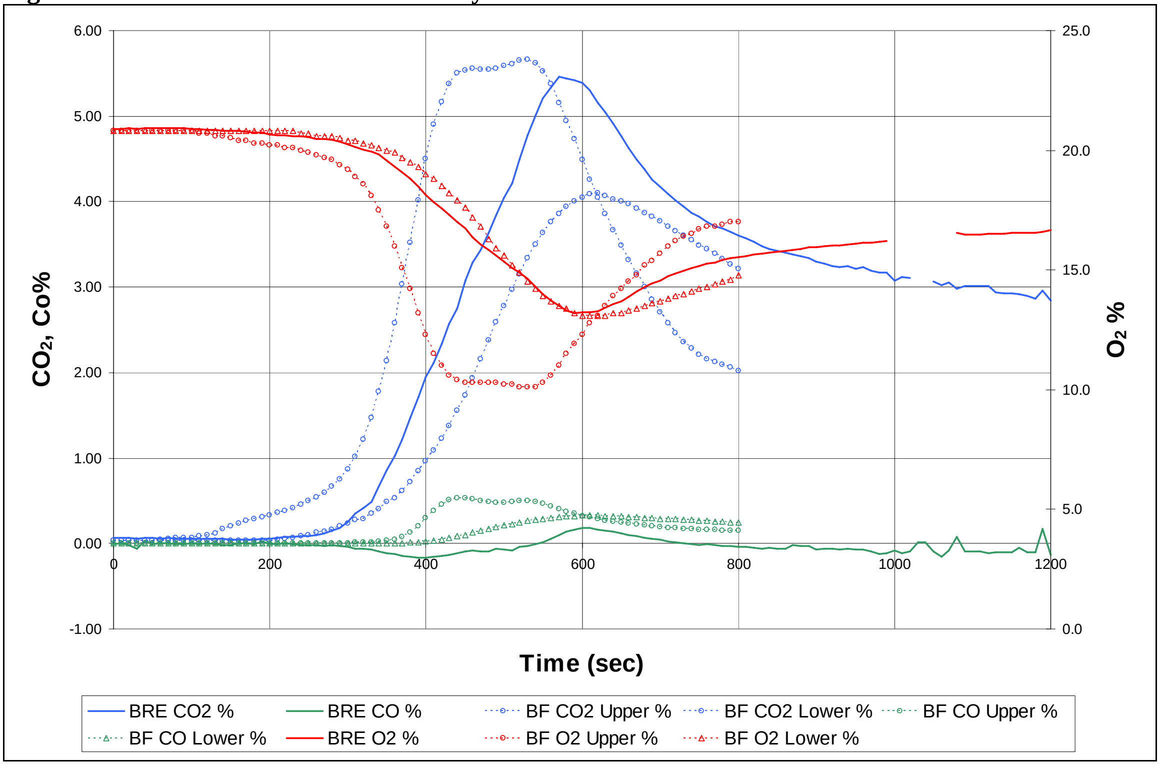
Figure 6.15 Gas Concentration in Lounge



In the lounge the oxygen concentration was observed to lower to approximately 10% in the BRE testing. The BRANZFIRE simulation predicted the oxygen concentration to lower to 1.7% in the upper layer which is significantly lower than the observed value. The BRANZFIRE simulation predicted the carbon dioxide concentration to increase to 10% in the upper layer in comparison to a peak value of 8.4% observed during the full scale rig testing.

The carbon monoxide level was predicted to increase to a peak value of 1.2% at 400 seconds by the BRANZFIRE simulation and was observed to reach a peak value of 1.1% at 560 seconds in the full scale testing.

Figure 6.16 Gas Concentration in Hallway

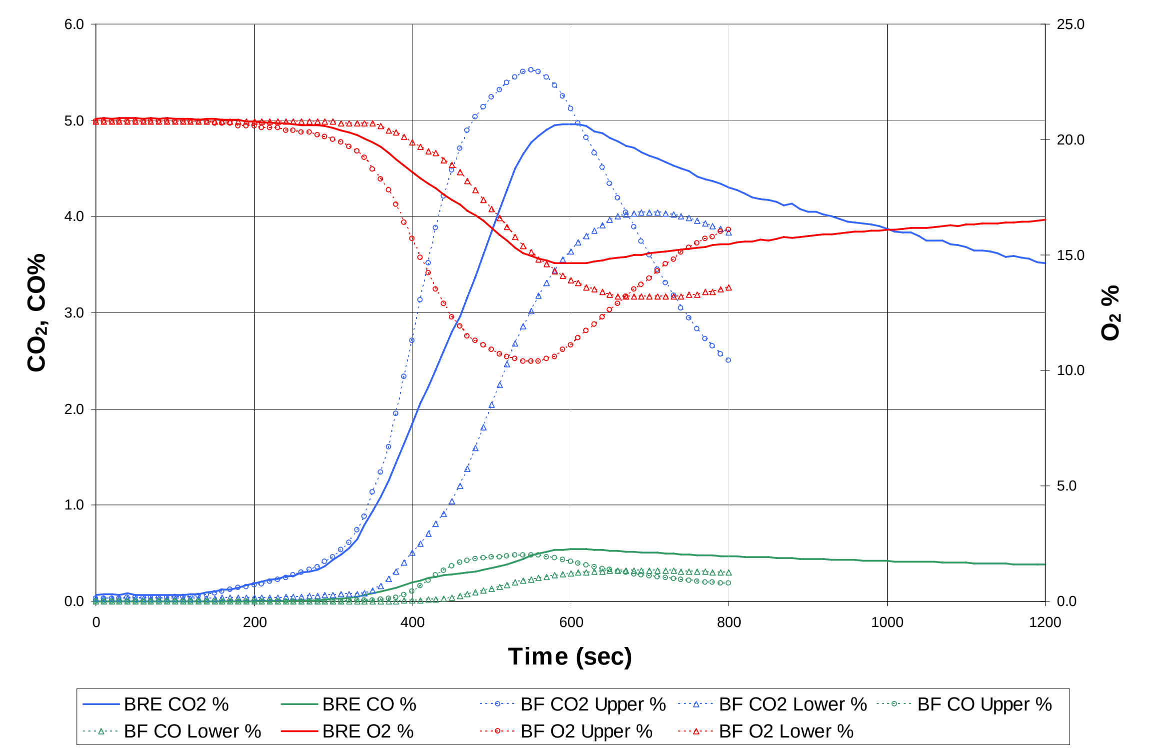


In the hallway the BRANZFIRE simulation predicts the oxygen concentration to decrease to 10% compared to a decrease to 13% observed during the full scale testing. The BRANZFIRE simulation prediction of the lower layer oxygen concentration is a very good approximation of the oxygen concentration.

The BRANZFIRE simulation predicts a peak carbon dioxide concentration of 5.6% which is very close to the observed peak carbon dioxide concentration of 5.4%. However the BRANZFIRE simulation predicts the peak temperature to occur approximately 50 seconds sooner than was observed during the full scale testing.

The BRE testing predicts a peak carbon monoxide concentration of 0.18% at 600 seconds in comparison to the BRANZFIRE simulation which predicts a peak concentration of 0.53% at 440 seconds. Negative values for the carbon monoxide concentration were recorded during the full scale testing which may have reduced the peak value observed.

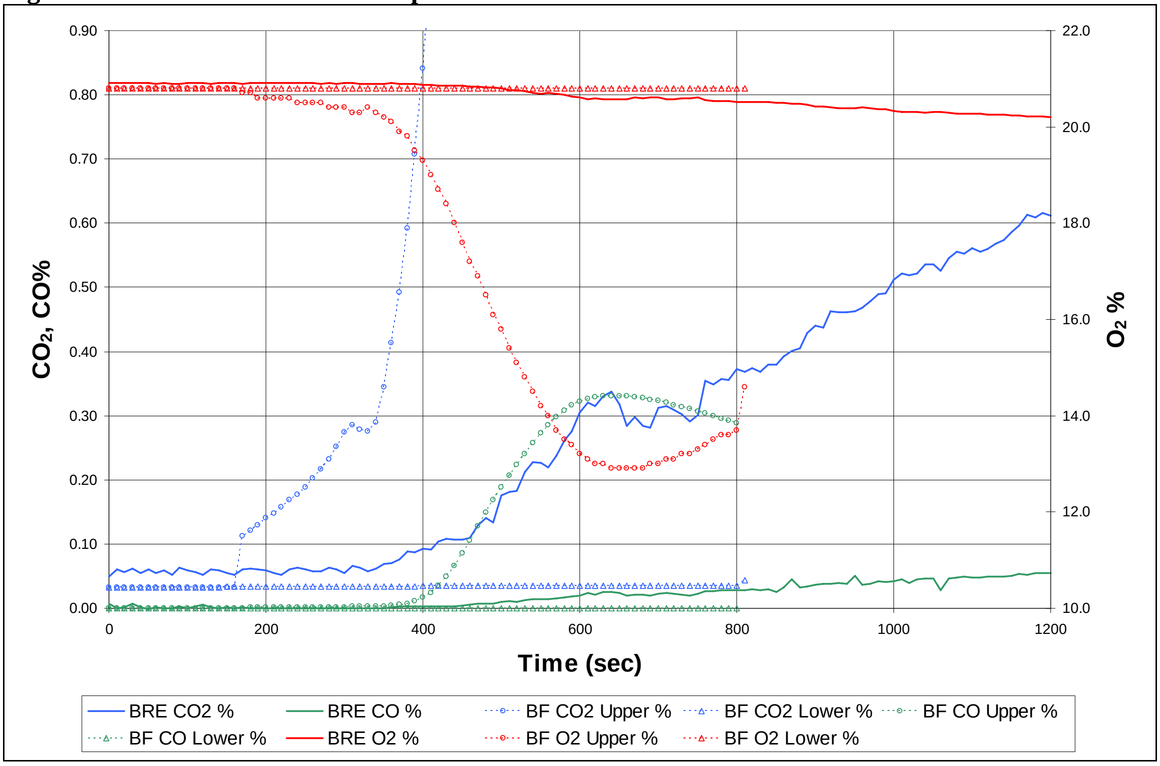
Figure 6.17 Gas Concentration on Landing



On the landing the BRANZFIRE simulation predicts the oxygen concentration to lower to 10.4% compared to 14.6% observed during the full scale testing. The BRANZFIRE simulation makes a good approximation of the carbon dioxide concentration in the landing, predicting a peak value of 5.5% at 550 seconds compared to a peak of 5.0% at 600 seconds in the full scale testing.

A maximum carbon monoxide concentration of 0.54% was observed at 600 seconds in the full scale rig testing. The BRANZFIRE simulation predicts a maximum value of 0.48% at 550 seconds.

Figure 6.18 Gas Concentration in Open Bedroom



In the open bedroom only a 0.7% decrease in the oxygen concentration was observed in the full scale testing with the oxygen concentration lowering to 20.2%, the BRANZFIRE simulation predicts the oxygen concentration to lower to 12.9% at its lowest concentration.

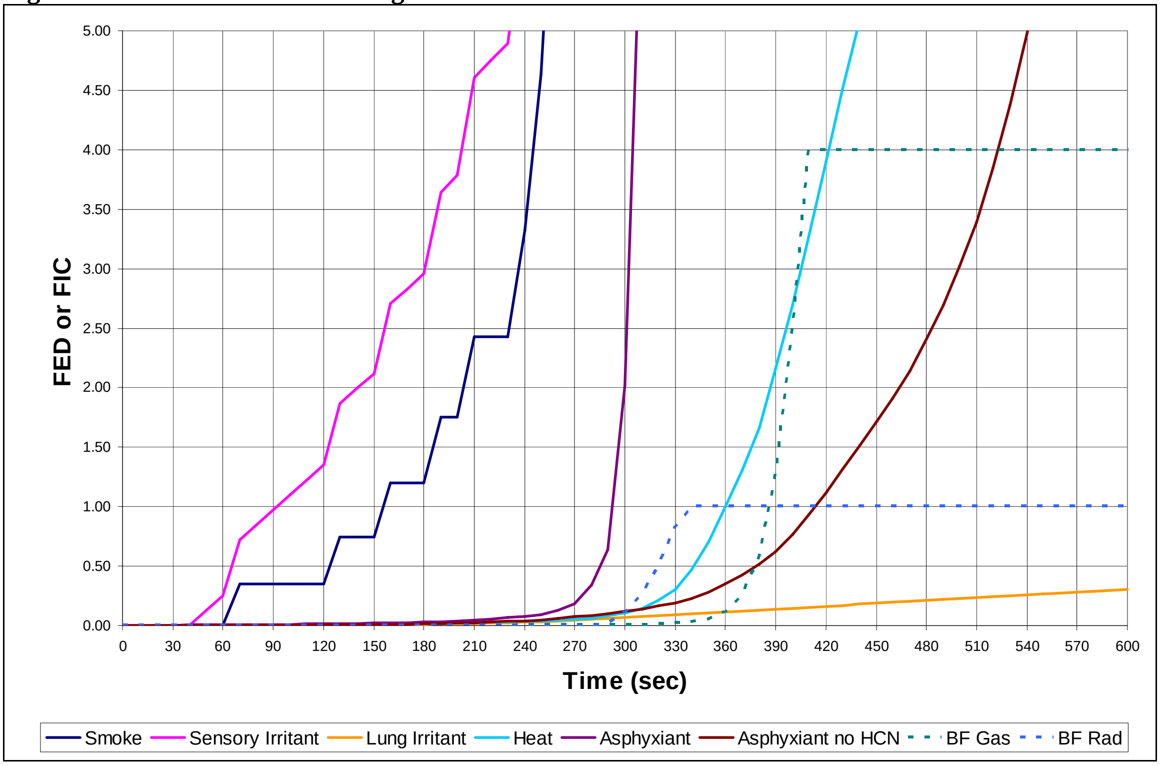
A peak carbon dioxide concentration of 0.61% was observed at the end of the full scale rig testing in comparison to the BRANZFIRE simulation, which predicted a peak carbon dioxide concentration of 4.2%.

A very small increase in the carbon monoxide concentration to 0.05% was observed in the full scale testing in comparison to a predicted peak value of 0.33% by the BRANZFIRE simulation.

6.1.6 *Fractional Effective Dose*

The BRANZFIRE simulation prediction of the fractional effective dose in the lounge and the open bedroom are presented alongside the values determined from the full scale testing in Figures 6.19 and 6.20.

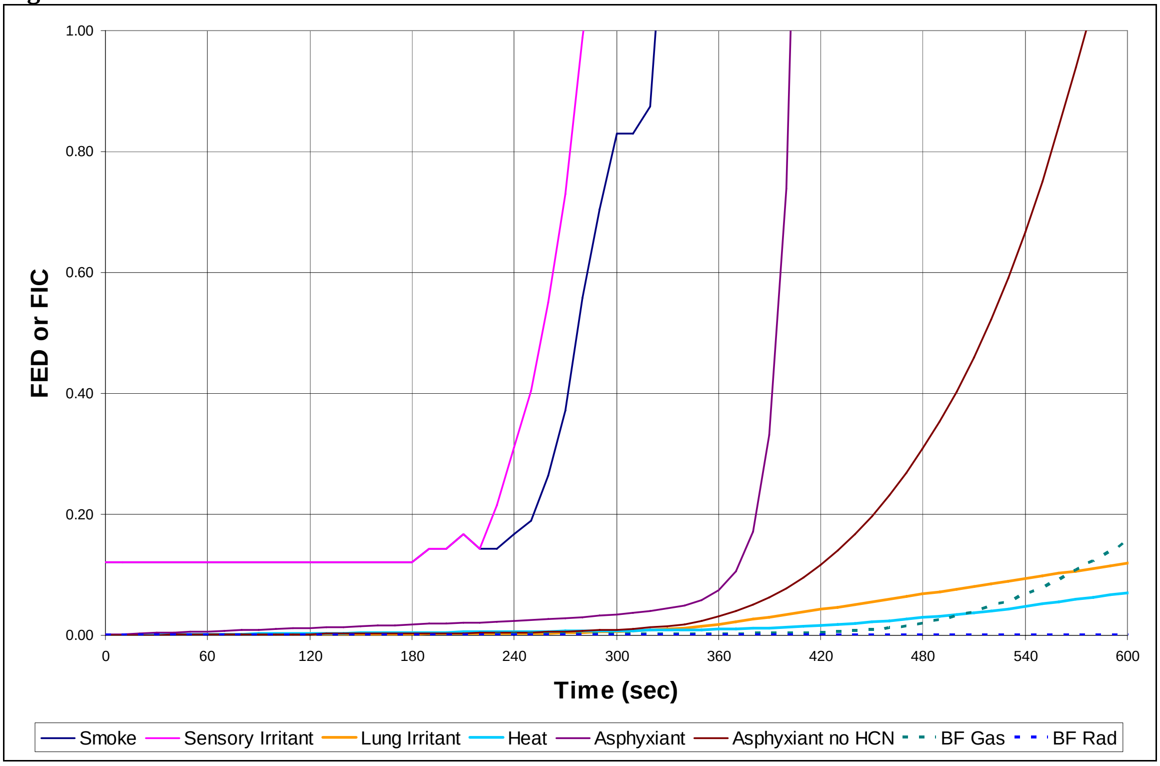
Figure 6.19 FED and FIC in Lounge



In the lounge the BRANZFIRE simulation predicts the fractional effective dose due to radiation to reach an incapacitating value of 1.0 after 340 seconds. This is in comparison to the full scale testing where a value of 1.0 was reached after 360 seconds. The BRANZFIRE simulation makes a very good approximation of the fractional effective dose due to radiation.

In the full scale testing, a fractional effective dose due to asphyxiant gases not including hydrogen cyanide of 1.0 was reached after 415 seconds in the lounge. The BRANZFIRE simulation predicted a value of 1.0 to be reached after approximately 390 seconds.

Figure 6.20 FED and FIC in Bedroom



In the open bedroom the full scale testing recorded a value of 1.0 for the fractional effective dose due to asphyxiant gases not including hydrogen cyanide after 580 seconds. The BRANZFIRE simulation predicted a maximum value of 0.16 after 600 seconds.

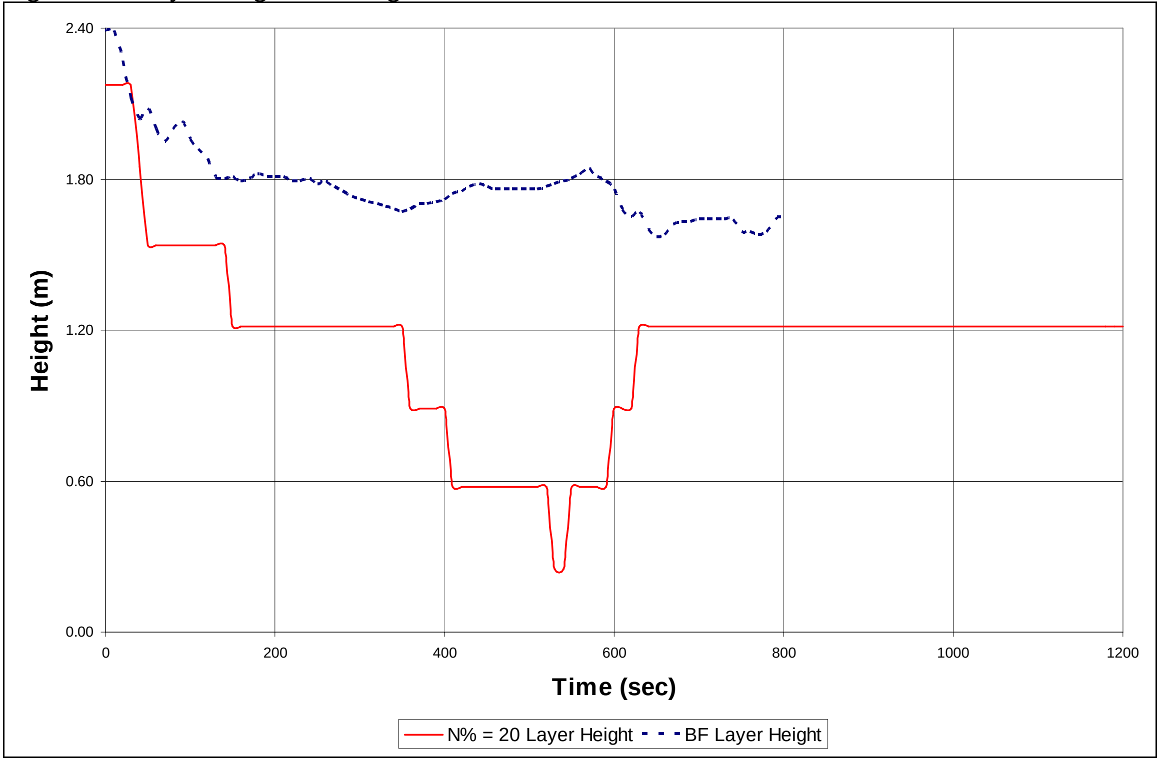
Due to the low upper layer temperatures predicted in the open bedroom by the BRANZFIRE simulation the predicted fractional effective dose due to radiation did not increase above zero. A maximum value of 0.07 was observed after 600 seconds in the full scale rig testing.

6.2 *Three Compartment Simulation*

6.2.1 *Layer Height*

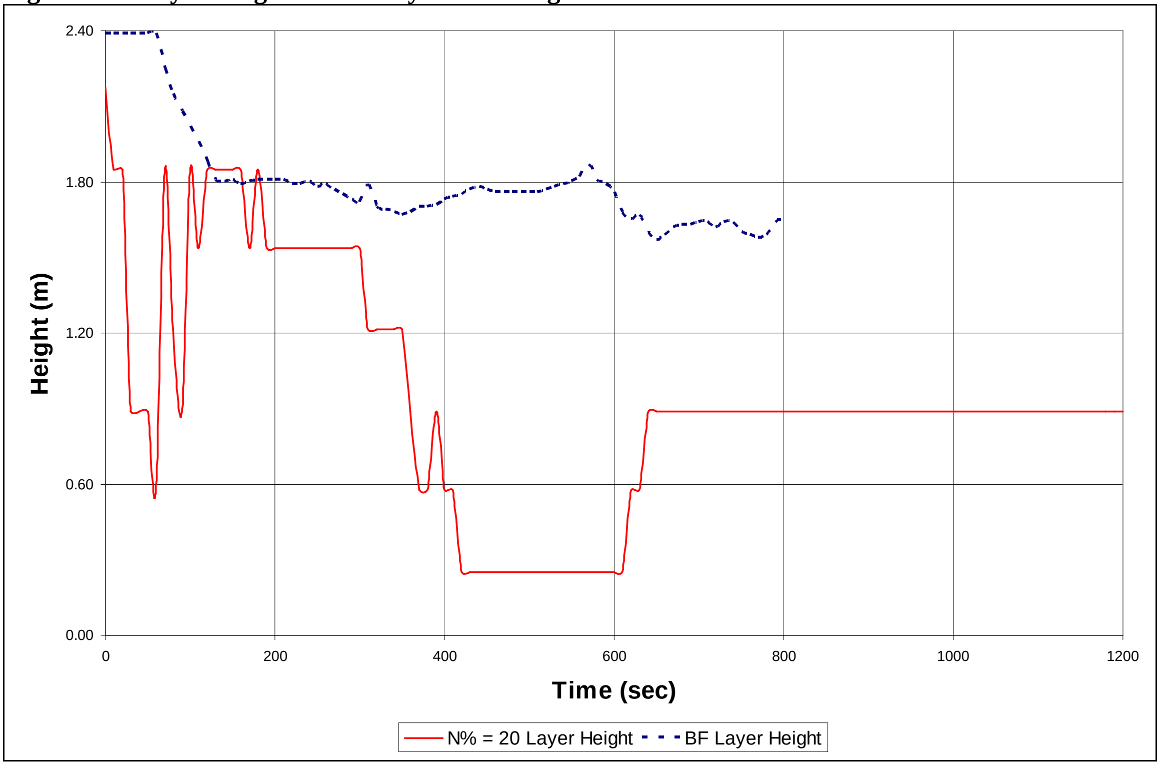
The layer heights in each of the compartments predicted by the BRANZFIRE simulation and by the N% method with N = 20 are shown in Figures 6.21 to 6.25.

Figure 6.21 Layer Height in Lounge



The layer height in the lounge in the three compartment simulation is predicted to lower to a lesser extent than was predicted by the two compartment simulation but the general shape of the layer height curve is unchanged. The BRANZFIRE simulation predicts the layer height to lower to approximately 1.8m above floor level after approximately 160 seconds. The BRANZFIRE simulation under predicts the descent of the layer height in comparison to the N% method.

Figure 6.22 Layer Height in Hallway near Lounge Door

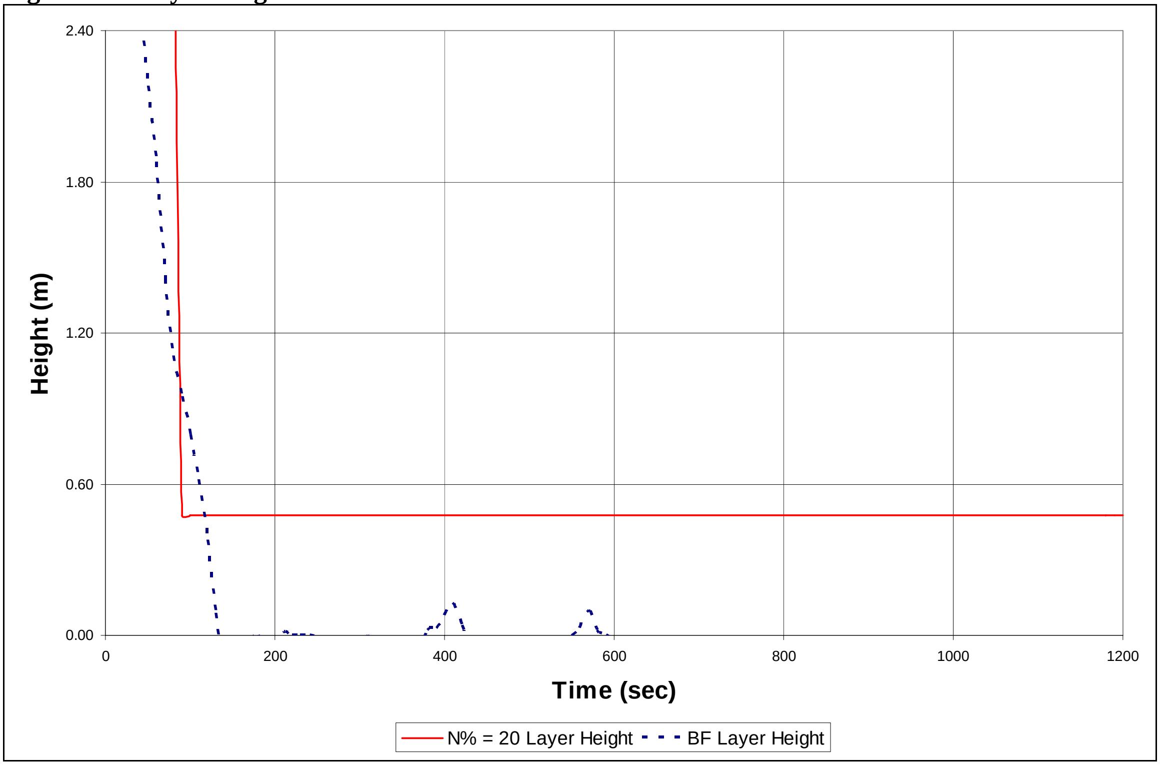


In the hallway the BRANZFIRE simulation predicts the layer height to lower to 1.8m above floor level after approximately 130 seconds before lowering to its lowest value of 1.6m above floor level after 650 seconds.

The N% method predicts the layer to drop below 0.6m above floor level rapidly before rising to 1.5m above floor level for approximately 150 seconds and then lowering to 0.25m above floor level after 420 seconds.

The BRANZFIRE simulation predicts the initial lowering of the layer interface reasonably well but under predicts the extent of the initial lowering by approximately 0.3m and does not predict the second lowering of the layer. The lowering of the layer height predicted by BRANZFIRE is significantly less than for the two compartment simulation.

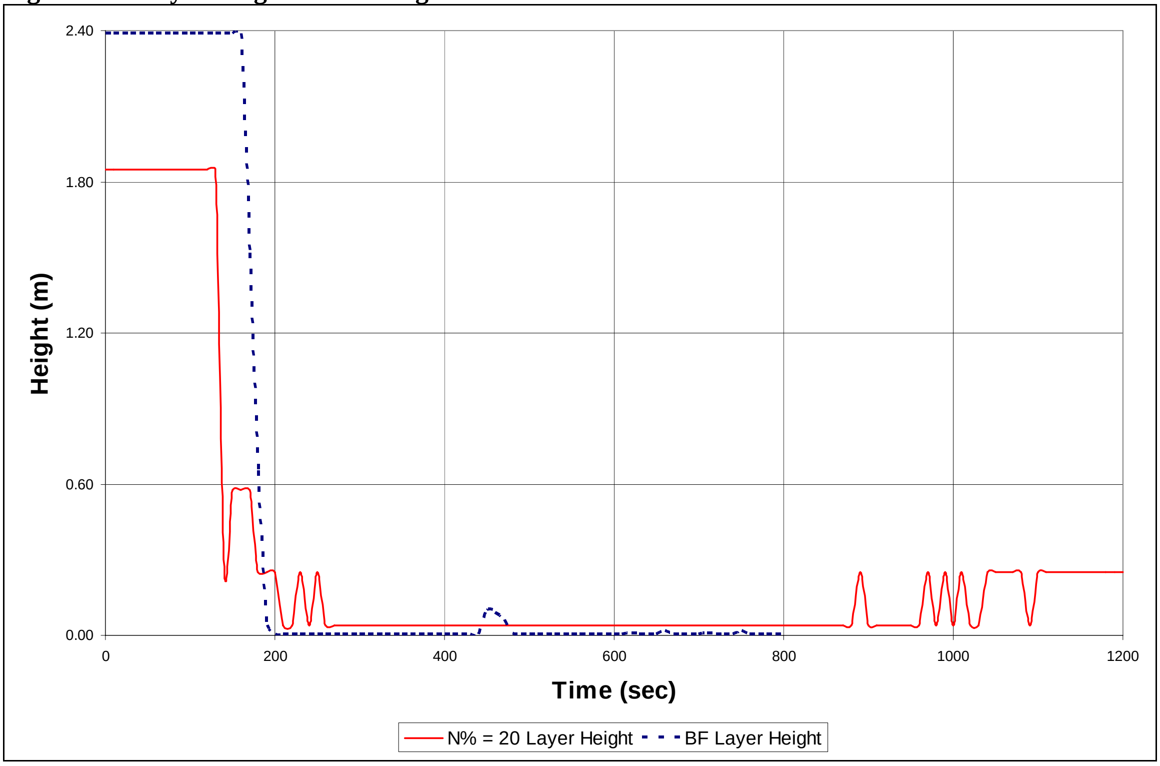
Figure 6.23 Layer Height on Stairs



On the stairs the N% method predicts the layer height to lower to 0.48m above floor level after 90 seconds and remain at that level. The BRANZFIRE simulation predicts the layer height to lower to floor level after 140 seconds and remain there for the remainder of the test.

The BRANZFIRE simulation makes a good estimate of the timing of the lowering of the layer height but over predicts the height that it lowers to.

Figure 6.24 Layer Height on Landing

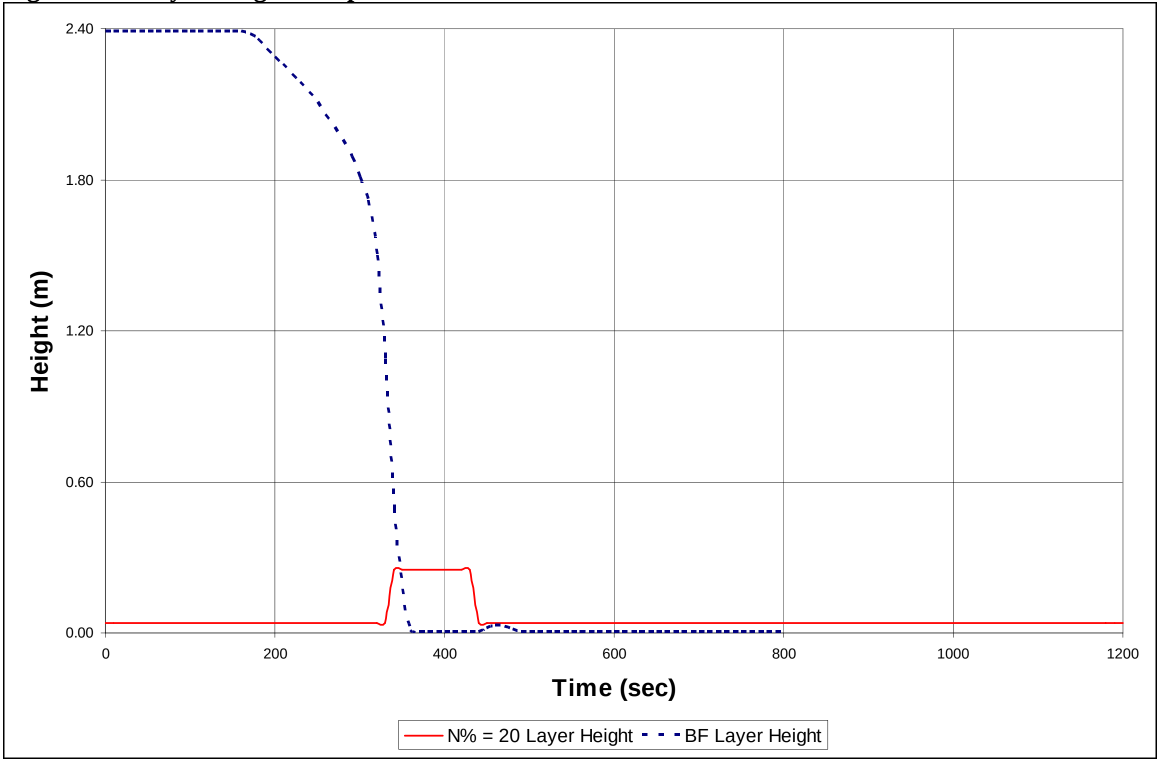


On the landing the N% method predicts the layer interface to lower to floor level after 200 seconds and to remain there until approximately 960 seconds, after which the layer height oscillates between floor level and 0.25m above floor level. The layer is predicted to start lowering at 130 seconds by the N% method.

The BRANZFIRE simulation predicts the layer height to begin lowering after 160 seconds and to reach floor level after 190 seconds. The layer height is then predicted to remain at floor level for the rest of the simulation.

The layer height in the landing for the three compartment simulation is predicted by the BRANZFIRE simulation to descend lower than the two compartment simulation.

Figure 6.25 Layer Height in Open Bedroom



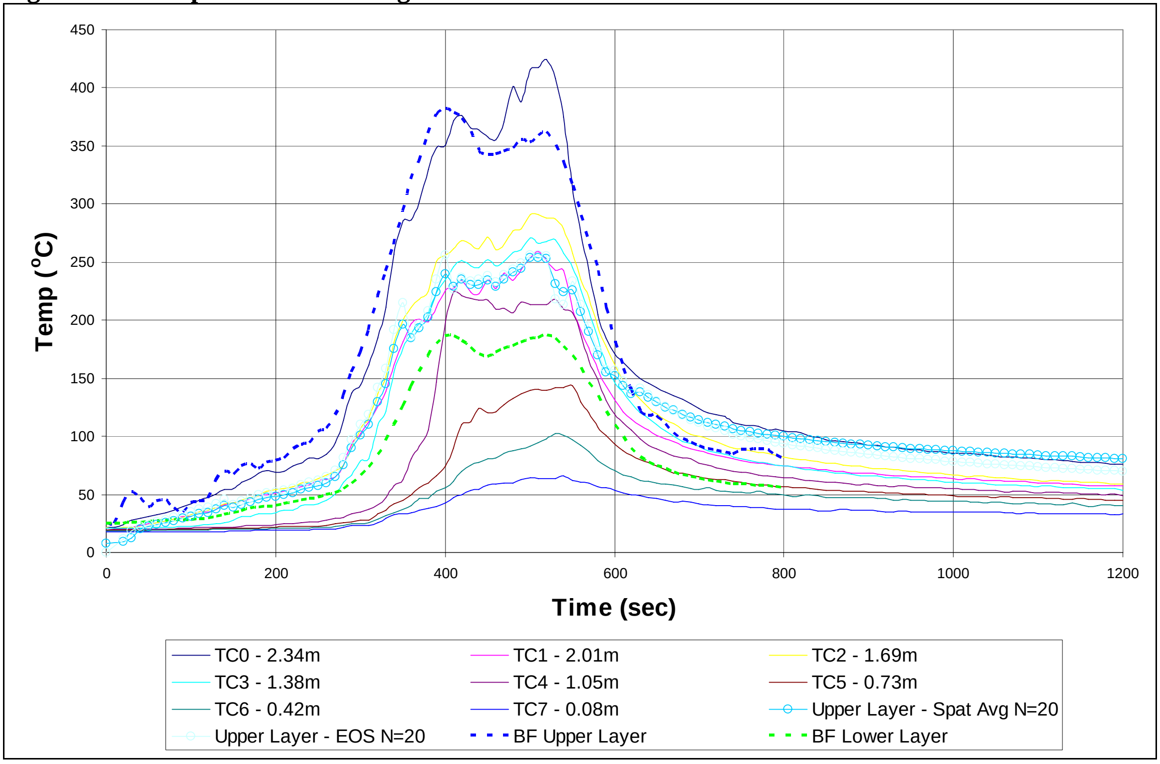
In the open bedroom the N% method predicts the layer height to be at floor level for the entire test other than one small increase to 0.25m above floor level for 90 seconds, beginning at 340 seconds. The layer height is not clearly defined in this compartment due to the small temperature increases and the N% method can not accurately define the location of the layer height.

The BRANZFIRE simulation predicts the layer height to begin lowering at 170 seconds reaching floor level at 360 seconds and remaining at floor level for the remainder of the simulation. This is very similar to the two compartment simulation layer height prediction.

6.2.2 *Temperatures*

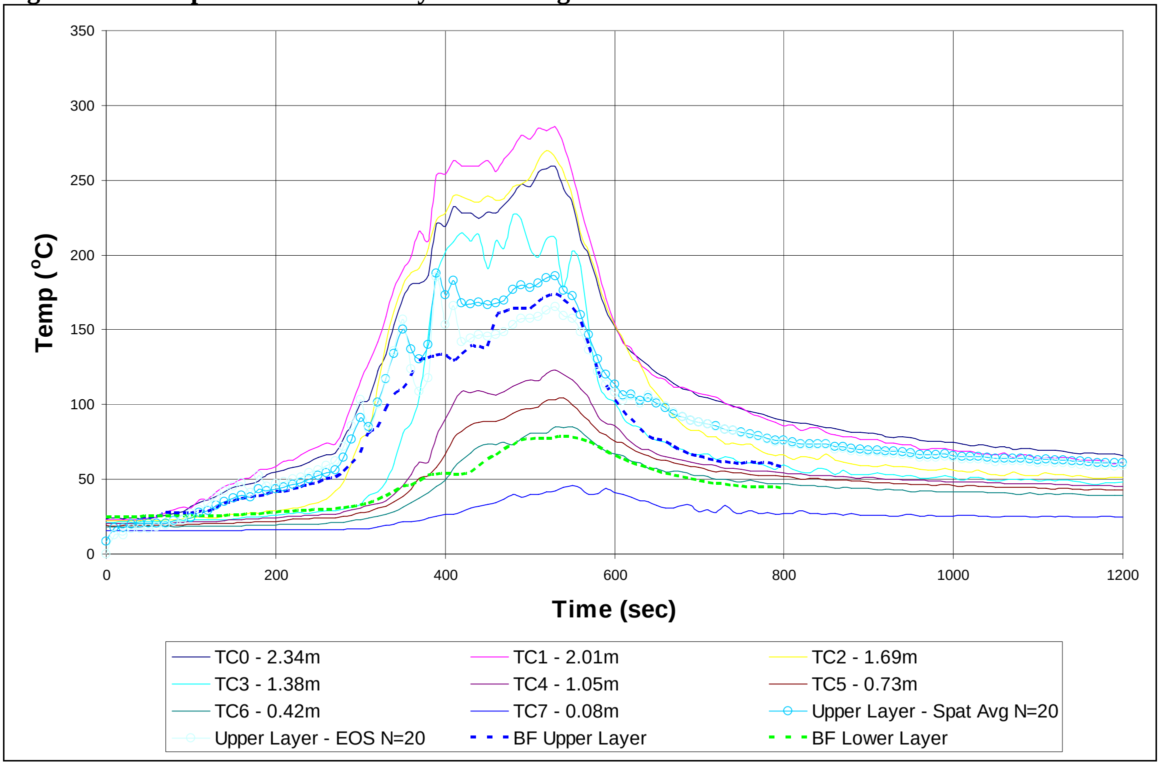
The compartment temperatures from the full scale rig testing and those generated by the BRANZFIRE simulation are shown in Figures 6.26 to 6.30 below. Also shown in Figures 6.26 to 6.30 are the upper layer temperatures predicted by the methods outlined in Section 3.

Figure 6.26 Temperatures in Lounge



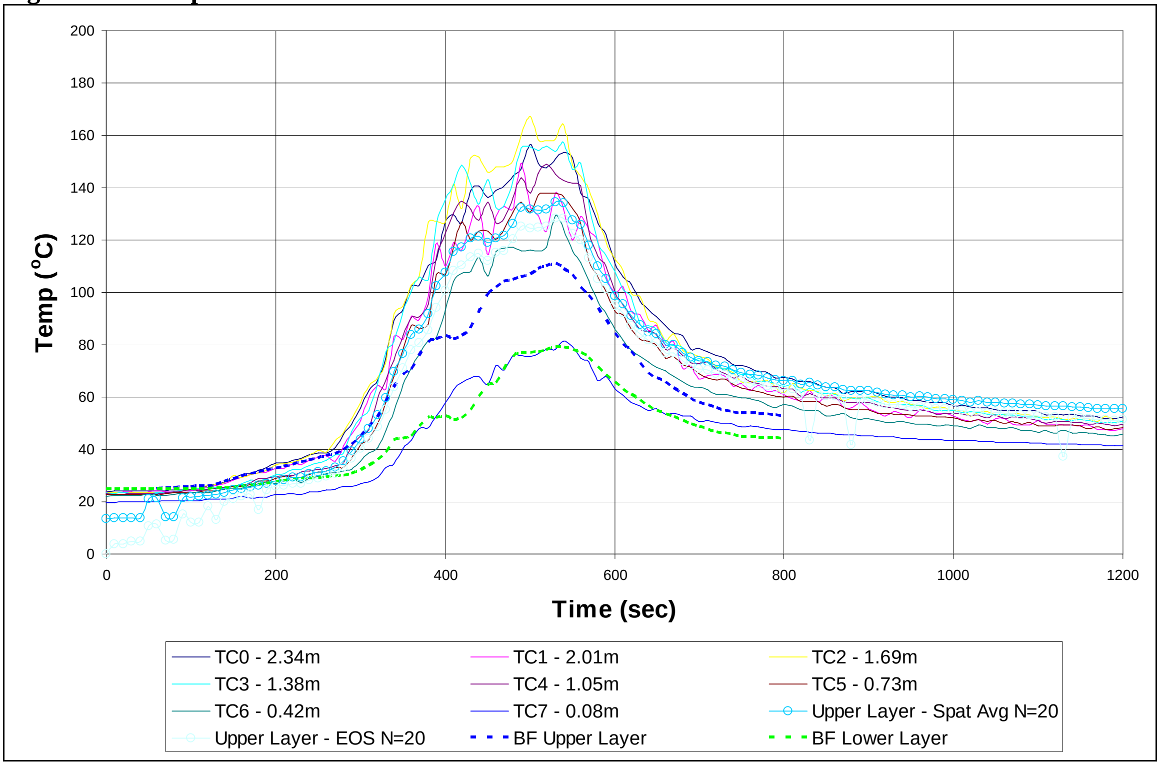
The BRANZFIRE simulation predicts a maximum upper layer temperature of 382°C in the first peak at 400 seconds and 362°C in the second peak at 520 seconds. The peak values are approximately 5°C less than in the two compartment simulation. The BRANZFIRE predicted values are significantly higher than those predicted by the equation of state and spatial average methods.

Figure 6.27 Temperatures in Hallway near Lounge Door



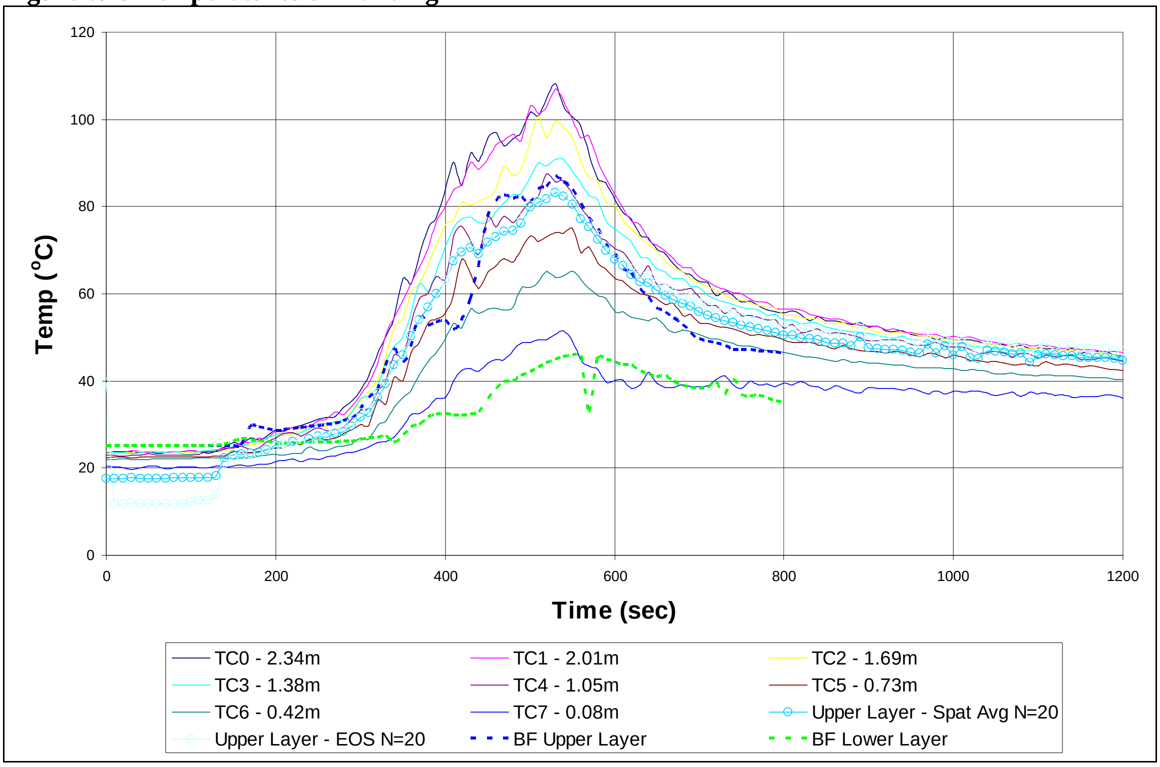
The spatial average and equation of state methods predict a maximum upper layer temperature in the hallway of 185°C after 400 seconds followed by a small decrease and a second peak temperature of 185°C after 530 seconds. The BRANZFIRE simulation predicts a temperature of 133°C after 400 seconds and a peak temperature of 174°C at 530 seconds. These temperatures are approximately 50°C less than the two compartment simulation in the first peak and 9°C higher in the second peak.

Figure 6.28 Temperatures on Stairs



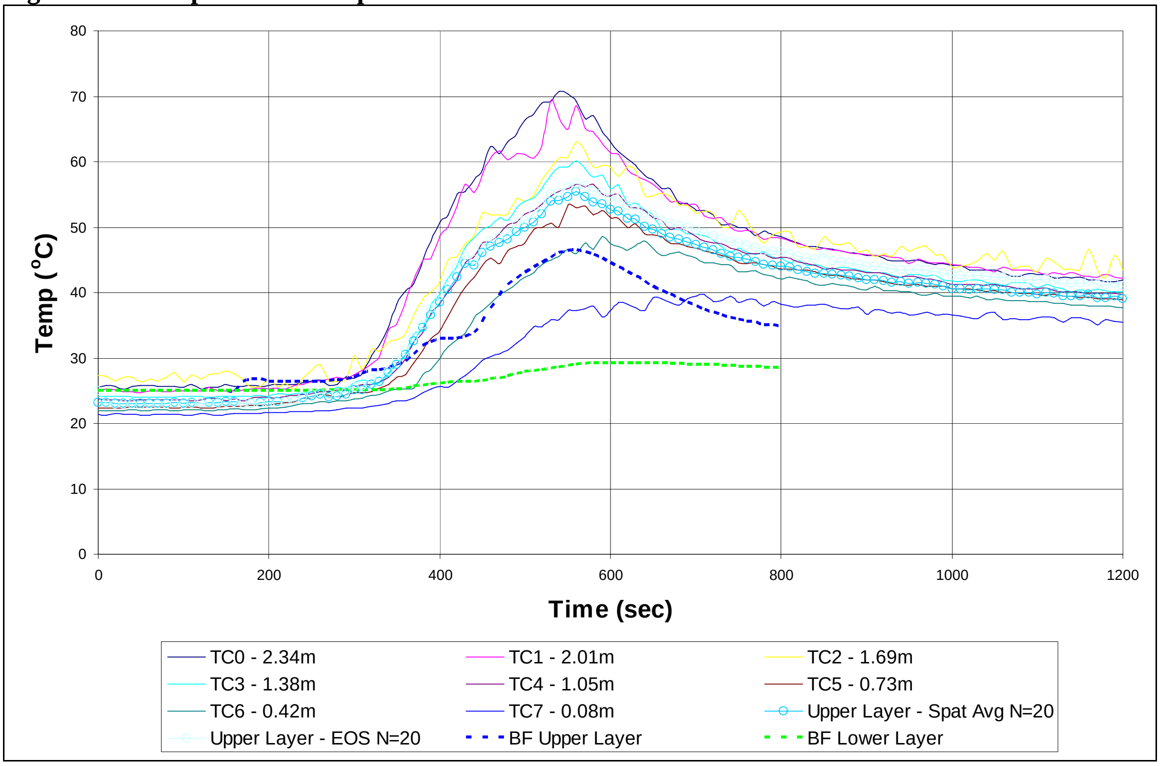
On the stairs the spatial average and equation of state methods predict a maximum upper layer temperature of approximately 130°C after 540 seconds. The BRANZFIRE simulation predicts a maximum temperature of 111°C at 540 seconds.

Figure 6.29 Temperatures on Landing



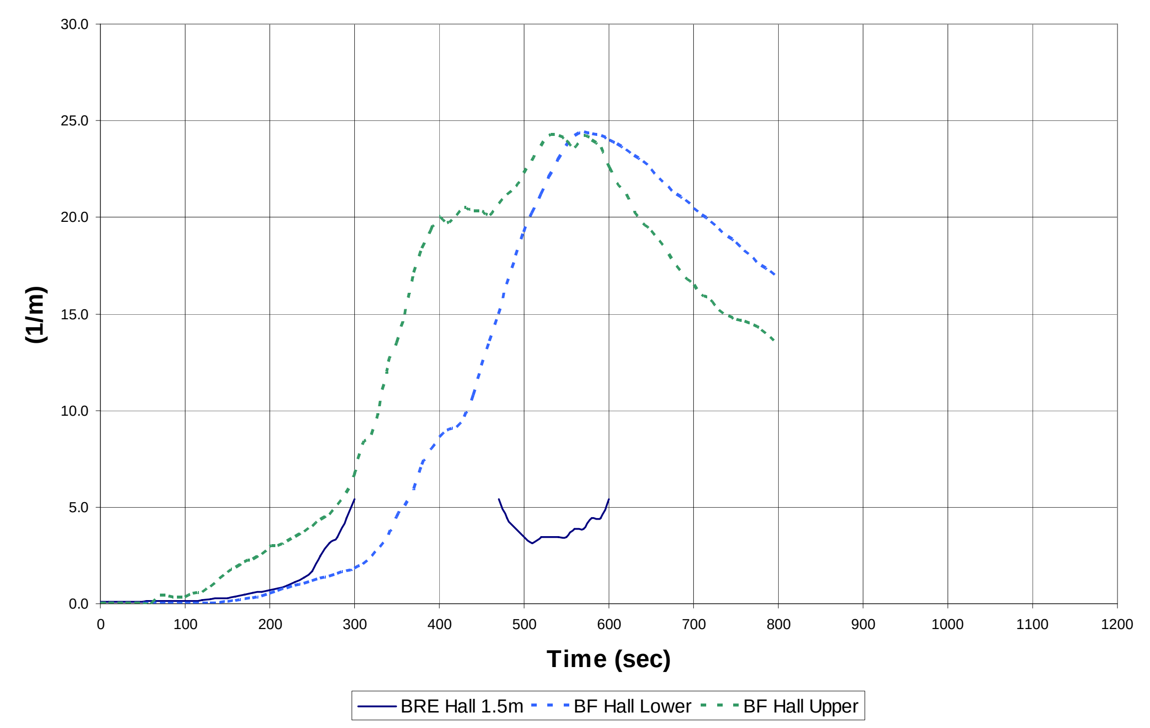
On the landing the BRANZFIRE simulation makes a very good approximation of the upper layer temperature predicting a maximum value of 87°C at 530 seconds in comparison to the spatial average and equation of state methods which predict a maximum value of 83°C at 530 seconds. The BRANZFIRE simulation maximum upper layer temperature is approximately 5% higher than the spatial average and equation of state method values. The BRANZFIRE predicted values are of a similar magnitude to the two compartment simulation but the shape of the temperature curve is different.

Figure 6.30 Temperatures in Open Bedroom



In the open bedroom the equation of state and spatial average methods predict a maximum upper layer temperature of 57°C after 560 seconds in comparison to the BRANZFIRE simulation which predicts a maximum upper layer temperature of 46°C after 560 seconds. The values predicted by BRANZFIRE for the three compartment simulation are 3°C less than for the two compartment simulation.

Figure 6.32 Optical Density in Hallway

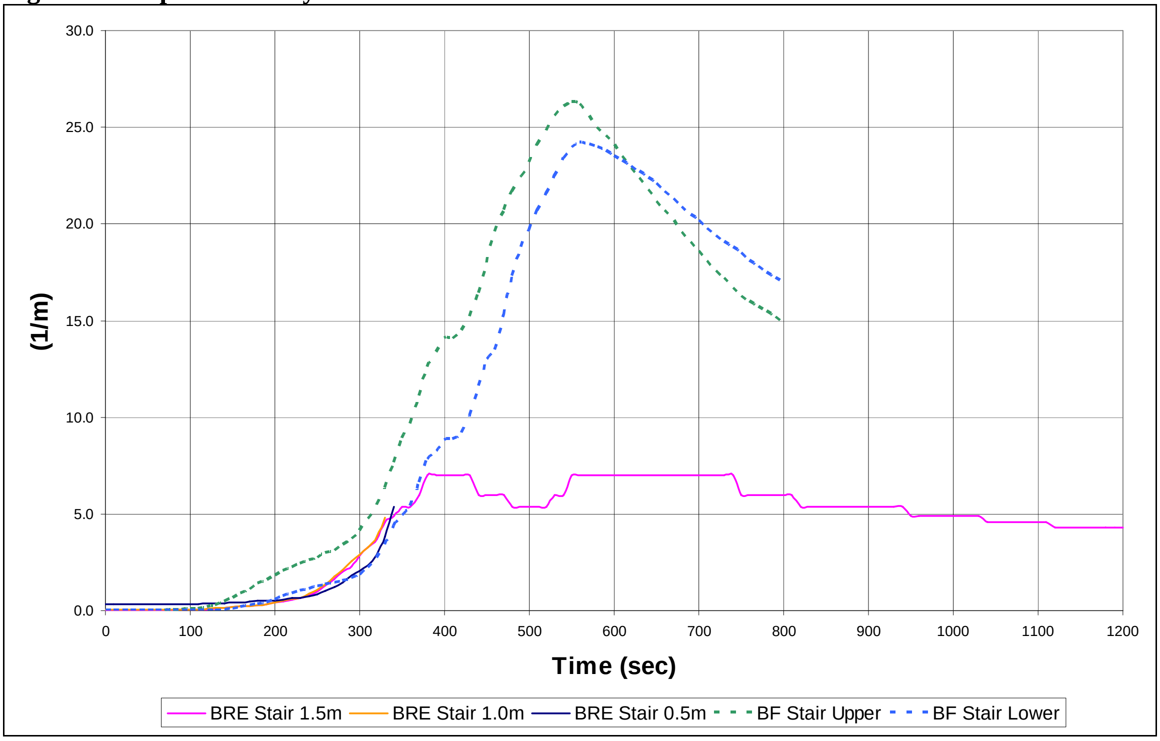


In the hallway the BRANZFIRE simulation predicts both the upper and lower layer optical densities to reach a peak value of $24m^{-1}$ after approximately 550 seconds. During the full scale rig testing the optical density recorded at 1.5m above floor level reached a value of $5.4m^{-1}$ after 300 seconds which was the maximum reading recordable by the sampling equipment. Between 470 and 600 seconds the reading dropped below $5.4m^{-1}$ reaching a minimum value of $3.1m^{-1}$ before increasing to $5.4m^{-1}$ again.

The BRANZFIRE simulation makes a good prediction of the increase in the optical density in the compartment but appears to over predict the maximum optical density, although this can not be confirmed as the sampling equipment in the full scale testing was overwhelmed.

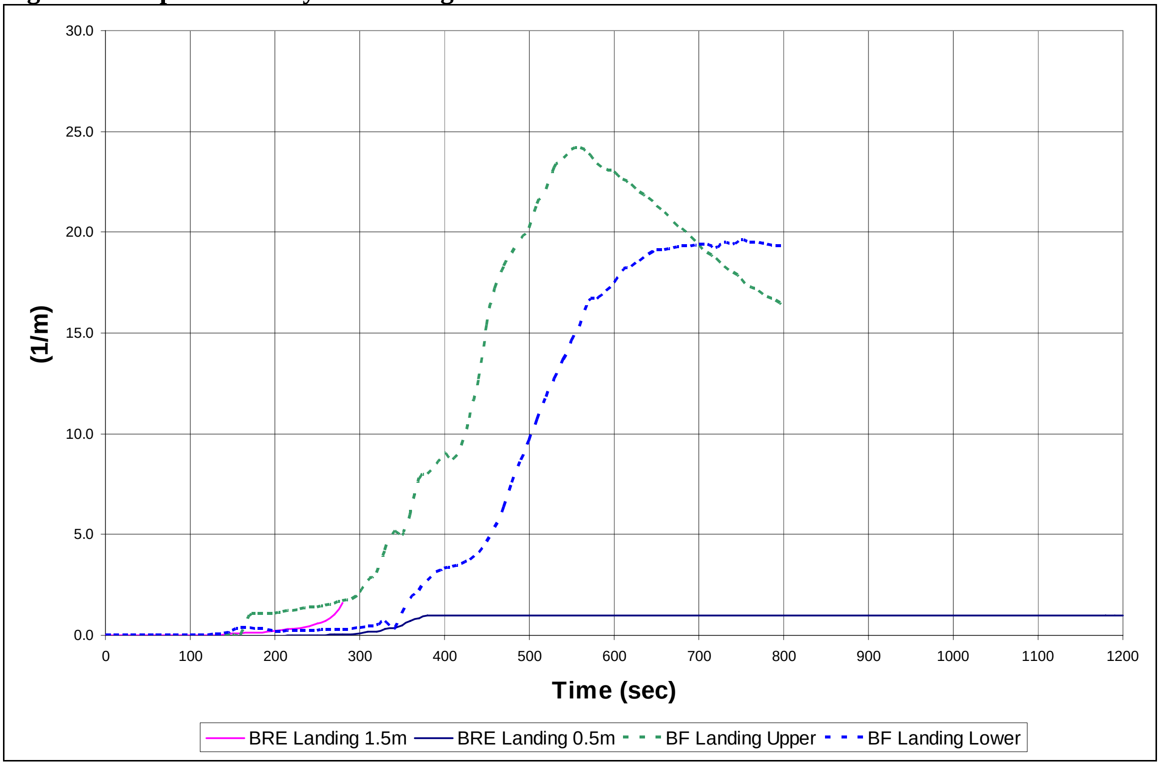
The peak optical densities are approximately $13m^{-1}$ less than the two compartment simulation.

Figure 6.33 Optical Density on Stairs



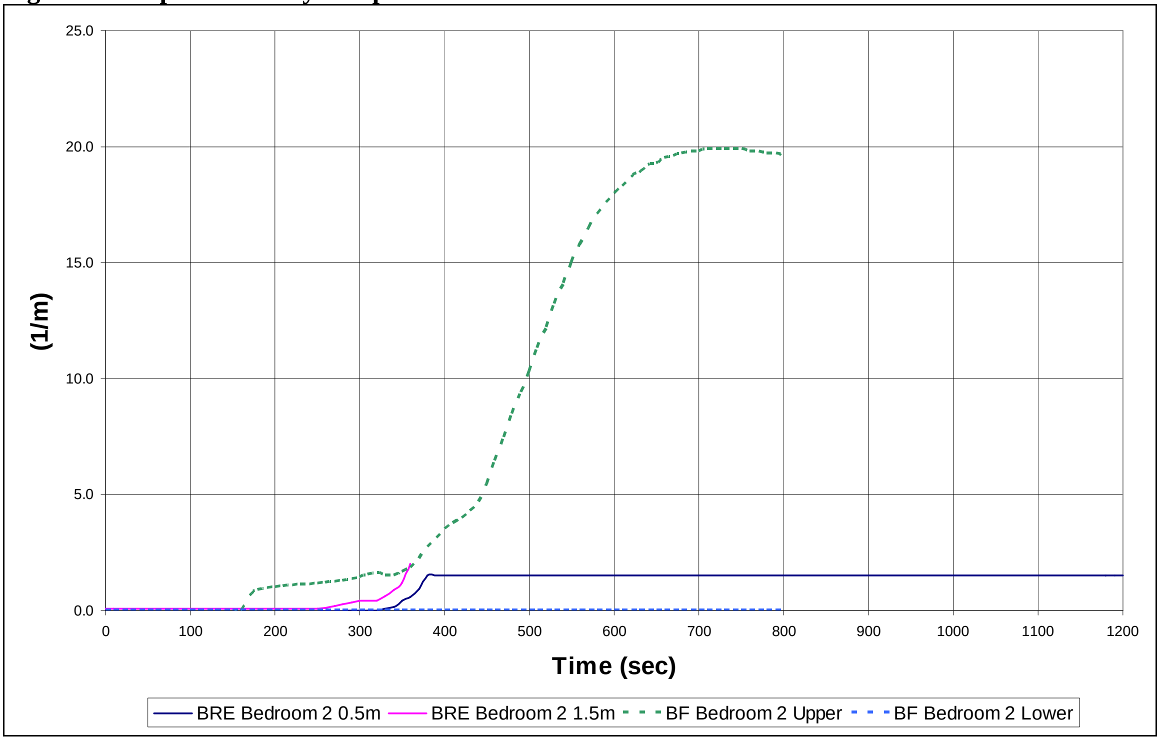
On the stair the BRANZFIRE simulation also makes a very good prediction of the increase in the optical density but again appears to over predict the maximum optical density. The BRANZFIRE simulation predicts a maximum value of $26m^{-1}$ after 550 seconds in the upper layer. During the full scale rig testing the sampling equipment at 1.0 and 1.5m above floor level reached their maximum readings of $5.4m^{-1}$ at 340 seconds.

Figure 6.34 Optical Density on Landing



On the landing the BRANZFIRE simulation predicts the optical density in the upper layer to reach a maximum value of $24m^{-1}$ after 550 seconds. The upper layer optical density in the full scale rig tests reached the maximum reading in the instrumentation at 280 seconds with a reading of $1.7m^{-1}$. The BRANZFIRE predicted optical densities are approximately $20m^{-1}$ less than the two compartment simulation.

Figure 6.35 Optical Density in Open Bedroom

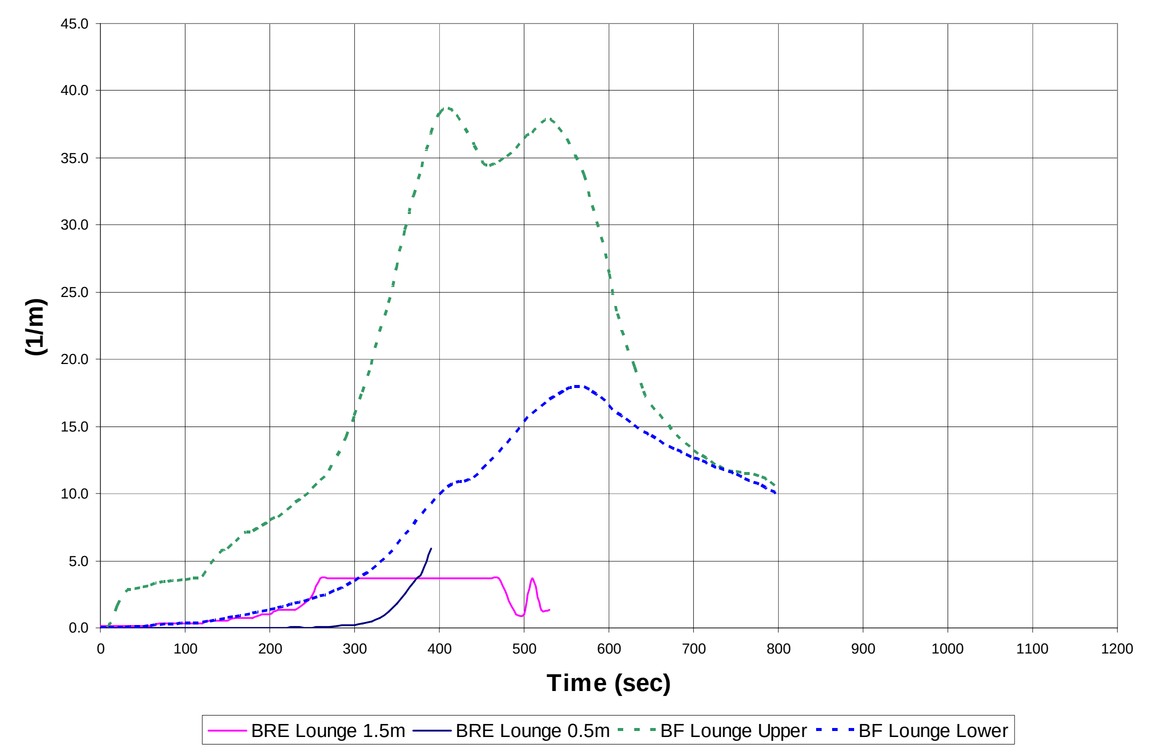


In the open bedroom the BRANZFIRE simulation predicts no increase in the optical density in the lower layer but predicts the upper layer optical density to reach a peak value of $20m^{-1}$ at 730 seconds. This appears to be far in excess of the readings recorded during the full scale testing although this can not be confirmed because the maximum reaching of the instrumentation of $1.9m^{-1}$was reached at 360 seconds. The predicted upper layer optical density is approximately $17m^{-1}$ less than the two compartment simulation.

6.2.3 Optical Density

The optical density results generated by the BRANZFIRE simulation are compared against the readings recorded during the full scale rig testing in Figures 6.31 to 6.35.

Figure 6.31 Optical Density in Lounge



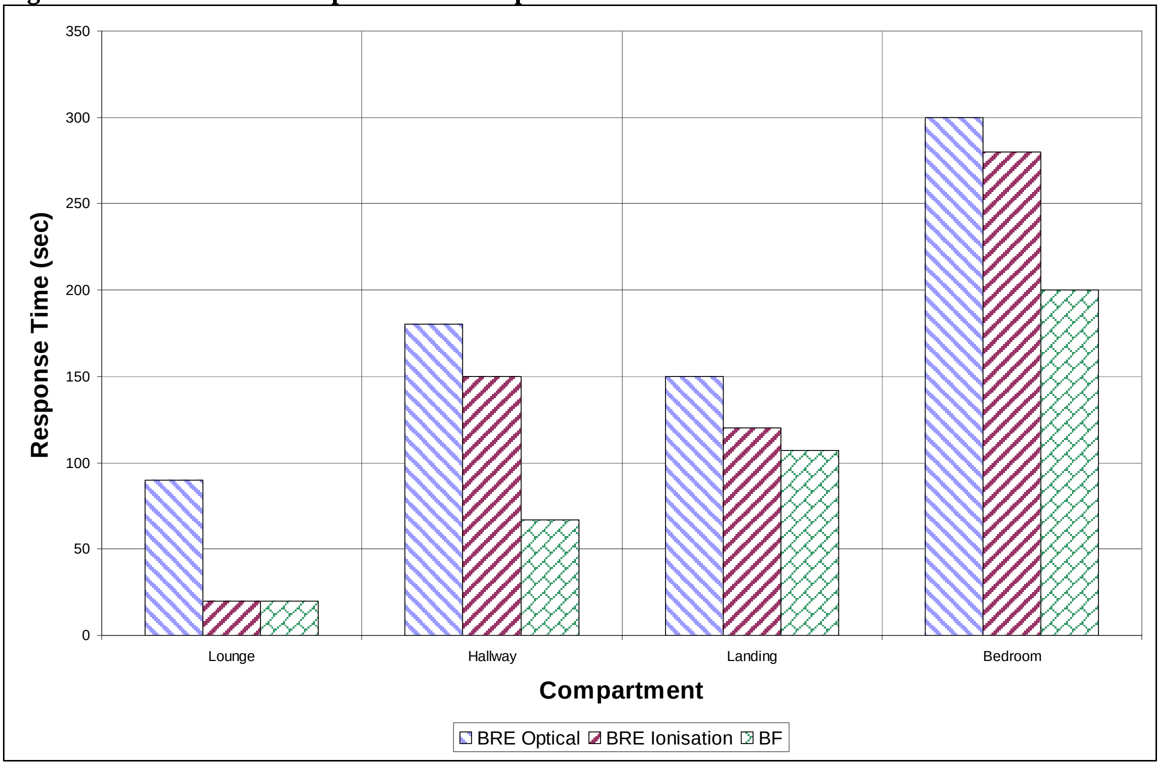
The BRANZFIRE simulation predicts the upper layer optical density to reach a maximum value or $39m^{-1}$ at 410 seconds and then decrease to approximately $34m^{-1}$ before rising to a second peak of $38m^{-1}$. The range of the full scale rig sampling equipment was exceeded after 390 seconds at $6m^{-1}$ in the upper layer.

The peak optical density predicted by the BRANZFIRE simulation is approximately 6 m^{-1} less than in the two compartment simulation.

6.2.4 *Smoke Alarm Response*

The smoke alarm response times from the full scale rig testing and the BRANZFIRE simulation for all of the compartments are shown in Figure 6.36.

Figure 6.36 Smoke alarm response in all compartments



In the lounge the smoke alarm response times are unchanged from the two compartment configuration simulation.

The BRANZFIRE simulation predicts an activation time of 67 seconds for the optical smoke alarm in the hallway in comparison to a recorded activation time of 180 seconds for the optical smoke alarm in the full scale testing. The ionisation smoke alarm in the hallway during full scale testing activated at approximately 150 seconds.

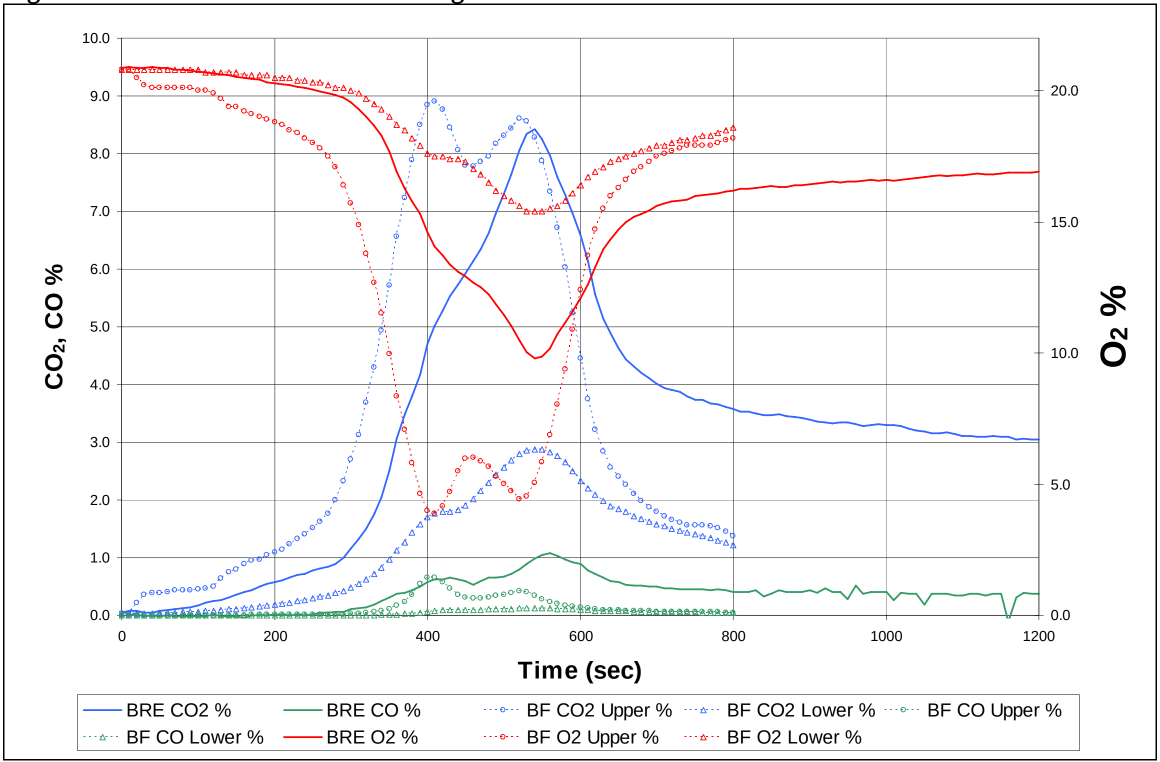
On the landing smoke alarm activation times of 150 and 120 seconds were recorded during the full scale testing for the optical and ionisation alarms respectively. The BRANZFIRE simulation predicted the activation time for the optical smoke alarm to be 107 seconds.

In the open bedroom the BRANZFIRE simulation predicted the smoke alarm activation time to be 200 seconds in comparison to the optical and ionisation smoke alarms in the full scale testing, which activated in 300 and 280 seconds respectively.

6.2.5 *Gas Concentration*

The gas concentrations calculated in the BRANZFIRE simulations are compared against the data recorded during the full scale rig testing in Figures 6.37 to 6.40.

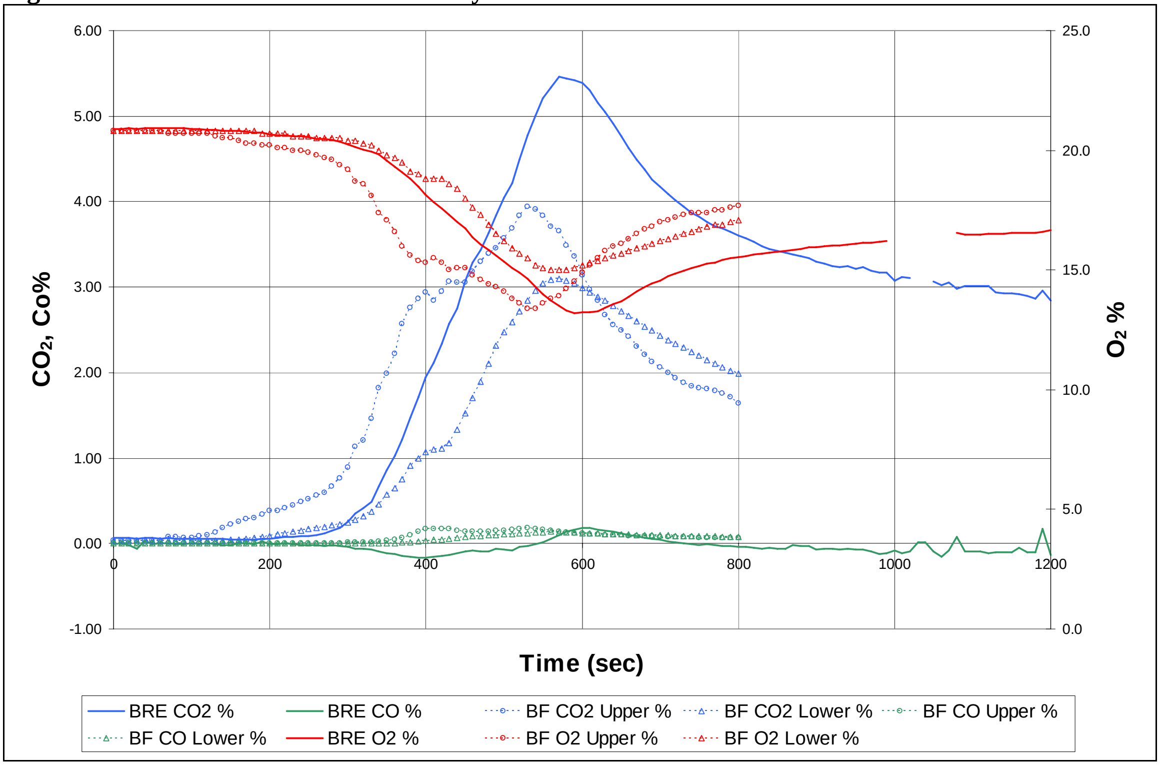
Figure 6.37 Gas Concentration in Lounge



The oxygen concentration predicted by BRANZFIRE reduces to less than 4.5% in both peaks in the three compartment simulation compared to 2% in the two compartment simulation. The carbon dioxide concentration predicted by the BRANZFIRE simulation increases at approximately the same rate as recorded in the full scale rig testing but reaches a slightly higher peak than the full scale rig test. The second peak in the carbon dioxide concentration predicted by the BRANZFIRE simulation is a very good approximation of the full scale rig testing.

The carbon monoxide concentration predicted by the BRANZFIRE simulation is approximately half the values recorded during the full scale testing.

Figure 6.38 Gas Concentration in Hallway

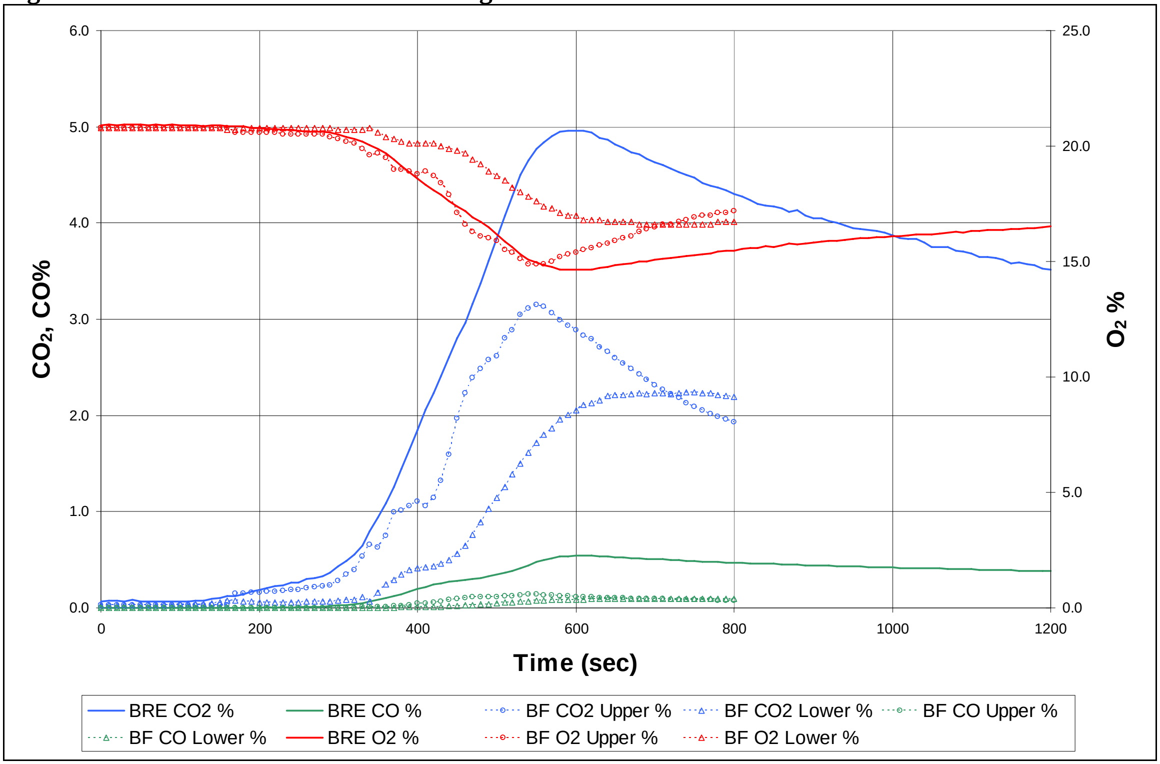


In the hallway the BRANZFIRE simulation makes a very good prediction of the oxygen concentration. The BRANZFIRE simulation predicts the upper layer oxygen concentration to lower to approximately 13.4% after 540 seconds in comparison to the full scale rig testing where the oxygen concentration was observed to lower to 13.2% after 600 seconds. The shape of the oxygen concentration curve for the BRANZFIRE simulation and the full scale rig testing are very similar. The oxygen concentration does not lower to the same extent in the three compartment simulation as it does in the two compartment simulation.

The BRANZFIRE simulation does not make as good a prediction of the carbon dioxide concentration predicting a maximum concentration of 3.94% after 530 seconds. A maximum reading of 5.5% was observed after 570 seconds in the full scale rig testing. The BRANZFIRE simulation makes a good approximation of the beginning of the increase in the carbon dioxide concentration but underestimates the peak carbon dioxide concentration. This is in comparison to the two compartment simulations where the carbon dioxide concentration is over predicted.

A maximum concentration of 0.17% is predicted after 400 seconds by the BRANZFIRE simulation in comparison to the full scale rig testing where a maximum value of 0.18% was recorded after 600 seconds.

Figure 6.39 Gas Concentration on Landing

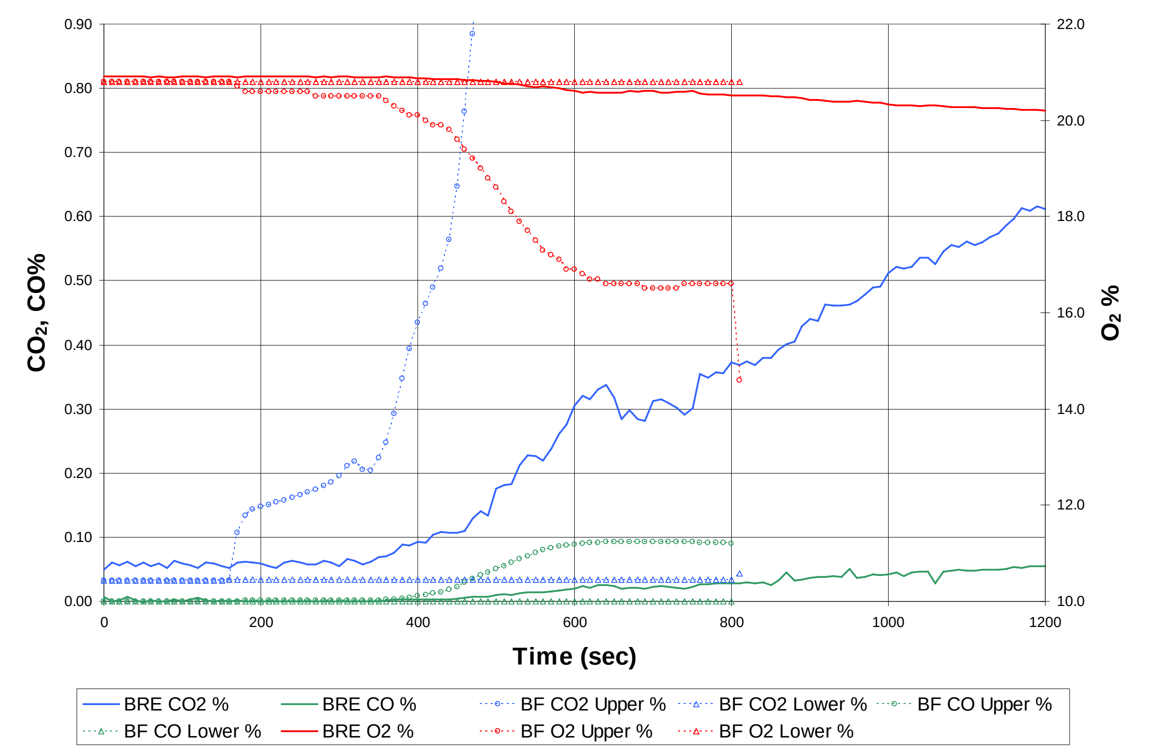


On the landing the BRANZFIRE simulation makes a very good approximation of the oxygen concentration predicting a minimum concentration of 14.9% after 550 seconds whereas a minimum value of 14.6% at 580 seconds was recorded during the full scale testing. The change in the oxygen concentration recorded during the full scale testing is predicted very well by the BRANZFIRE simulation. The two compartment simulation over predicted the decrease in the oxygen concentration.

The beginning of the increase in the carbon dioxide concentration is predicted well by the BRANZFIRE simulation but in this compartment it also under predicts the maximum carbon dioxide concentration in comparison to the two compartment simulation where it over predicted the carbon dioxide concentration. A maximum value of 4.96% at 600 seconds was recorded in the full scale rig testing in comparison to a maximum value of 3.13% in the upper layer at 560 seconds predicted by the BRANZFIRE simulation.

In the full scale rig testing a maximum carbon monoxide concentration of 0.54% was recorded at 600 seconds in comparison to a maximum value of 0.14% at 540 seconds predicted by the BRANZFIRE simulation.

Figure 6.40 Gas Concentration in Open Bedroom



In the open bedroom the BRANZFIRE simulation over predicts the lowering of the oxygen concentration, predicting a minimum concentration of 16.6% after 800 seconds in comparison to a minimum value 20.2% recorded after 1200 seconds in the full scale rig testing. The over prediction of the lowering of the oxygen concentration is less for the three compartment simulation compared to the two compartment simulation.

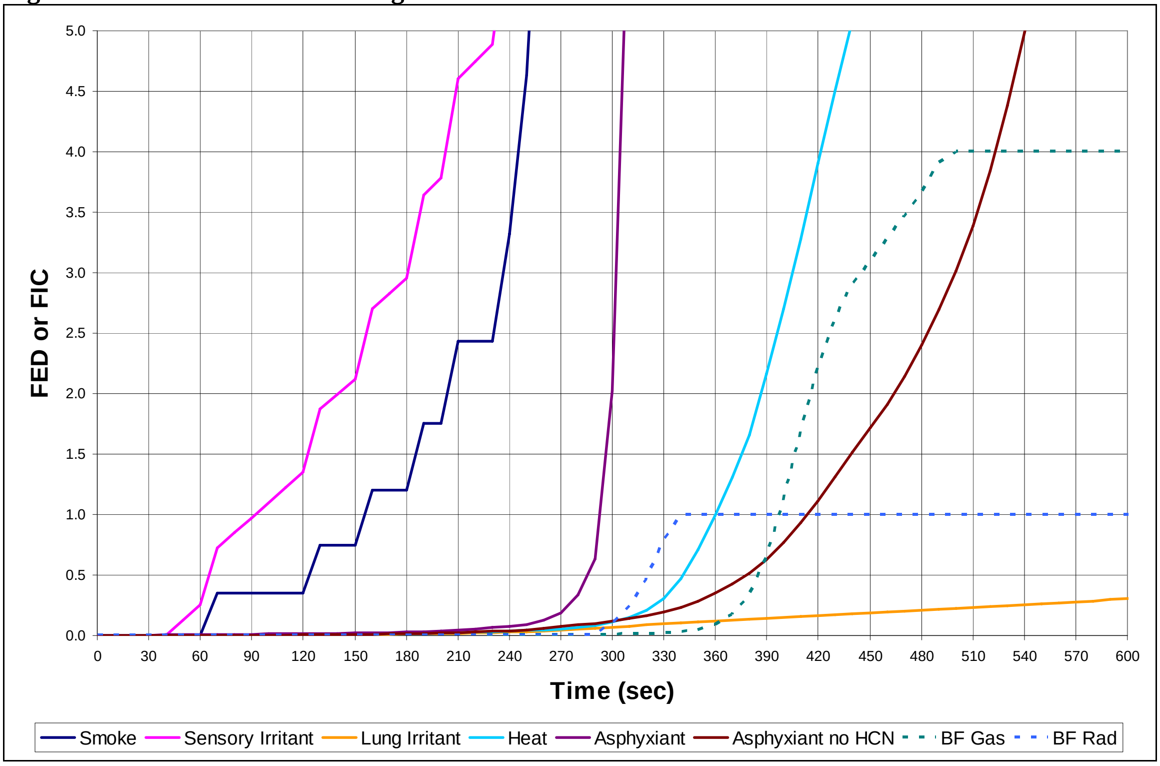
The carbon dioxide concentration is also over predicted with a maximum value of 2.27% predicted at 680 seconds by the BRANZFIRE simulation in comparison to the full scale rig testing where a maximum value of 0.61% was recorded at 1200 seconds.

The BRANZFIRE simulation predicts a maximum carbon monoxide concentration of 0.09% at 620 seconds in comparison to the full scale testing where a maximum value of 0.05% was recorded at 1200 seconds.

6.2.6 Fractional Effective Dose

The fractional effective dose predicted by the BRANZFIRE simulation and those determined from the recorded readings in the full scale rig testing for the lounge and open bedroom are compared in Figures 6.41 and 6.42.

Figure 6.41 FED and FIC in Lounge

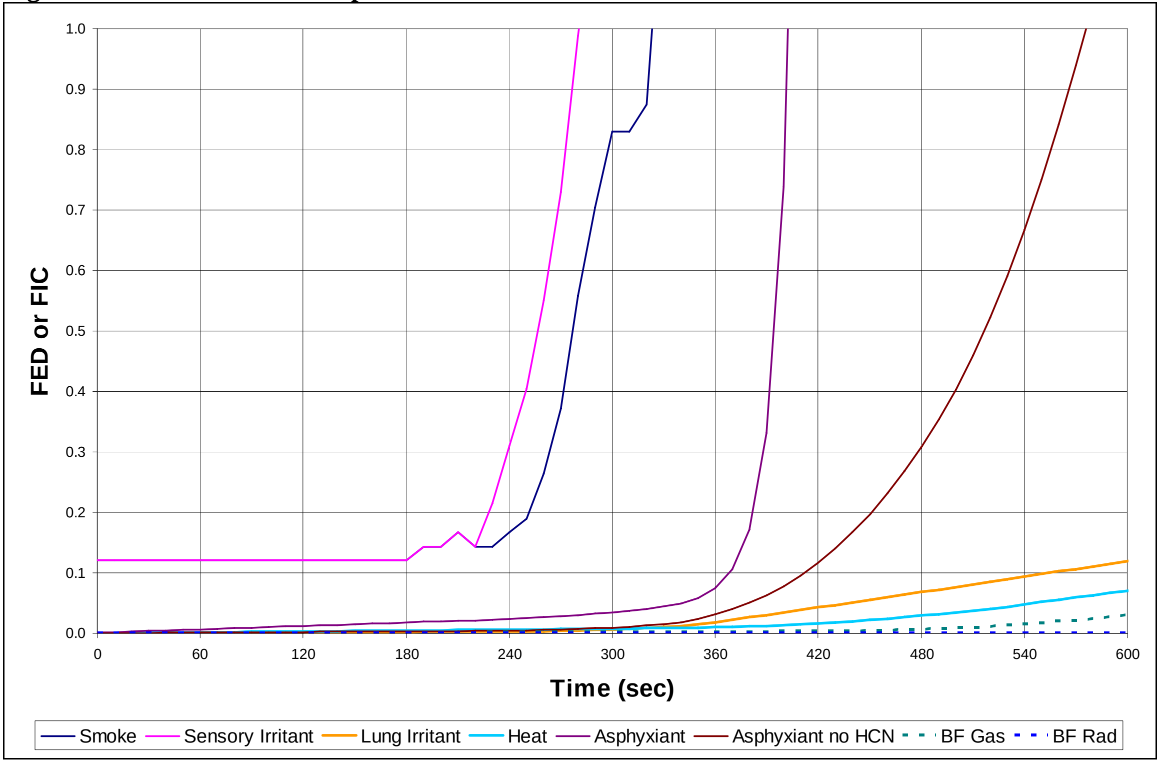


The BRANZFIRE simulation predicts the fractional effective dose due to heat to reach a value of 1.0 at 340 in comparison to the calculations based on the full scale testing where a value of 1.0 is reached at 360 seconds.

The fractional effective dose due to asphyxiant gases not including hydrogen cyanide was calculated to reach a value of 1.0 after 420 seconds in the full scale testing. The BRANZFIRE simulation predicts the fractional effective dose to reach a value of 1.0 after 400 seconds.

These results are largely unchanged from the two compartment simulation.

Figure 6.42 FED and FIC in Open Bedroom



In the open bedroom the calculations based on the observations during the full scale testing predict the fractional equivalent dose due to asphyxiant gases not including hydrogen cyanide to reach a value of 1.0 after 580 seconds. The BRANZFIRE simulation predicts a maximum value of 0.03 to occur after 600 seconds.

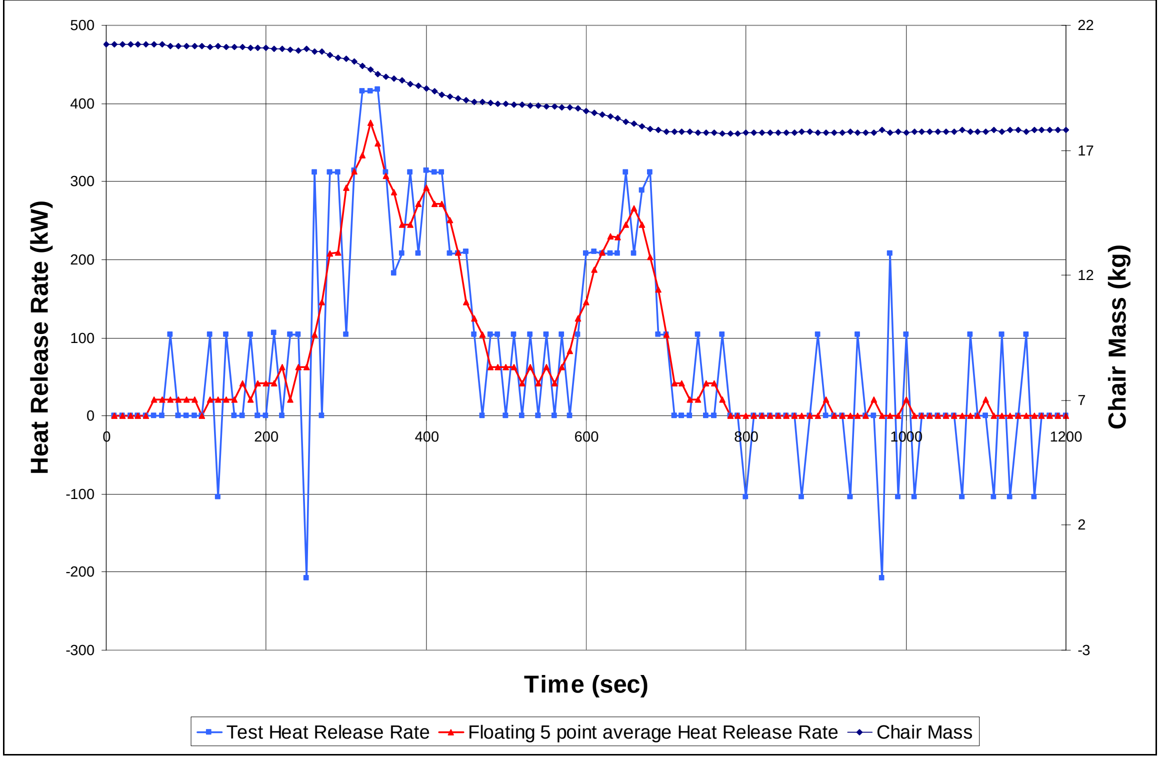
The BRANZFIRE simulation predicts the fractional effective dose due to radiation to not increase above zero during the simulation due to the low compartment temperatures. The fractional effective dose calculated from the full scale rig testing observations reaches a maximum value of 0.07 after 600 seconds.

7 Test CDT16 Simulation Results

Test CDT16 was the first of the tests carried out at Cardington with a fully flaming fire and was conducted with the lounge door closed. This test was the simulated in BRANZFIRE after tests CDT17 and CDT18 because it presents a challenge to the abilities of the BRANZFIRE model due to the lounge door being closed.

The heat release rate determined for the fire which was determined from the mass loss rate given in the BRE testing data is shown in Figure 7.1.

Figure 7.1 Test CDT16 Heat Release Rate



As noted in Section 3 this scenario was modelled with two different configurations of the vent around the door from the lounge to the hallway. One simulation used a vent 0.01m high and the full width of the door located at the base of the door, and the other used a vent 0.01m wide for the full height of the door.

Because the downstream effects of the fire with the lounge door closed were expected to be significantly less than in the simulations with the lounge door open, it was decided that the comparison of a two compartment and three compartment simulation of the hallway, stair and landing arrangement would not be as meaningful as for the simulations with the lounge door open. Based on the results of the simulations for tests CDT17 and CDT18 it was unclear whether the two or three compartment simulation produced better results in comparison to the full scale rig testing.

It was decided that the three compartment simulations produced marginally better results than the two compartment simulations and both of the lounge door vent configurations for test CDT16 were simulated using the three compartment model for the hallway, stair and landing rooms. The results of the two simulations are discussed separately in Sections 7.1 and 7.2.

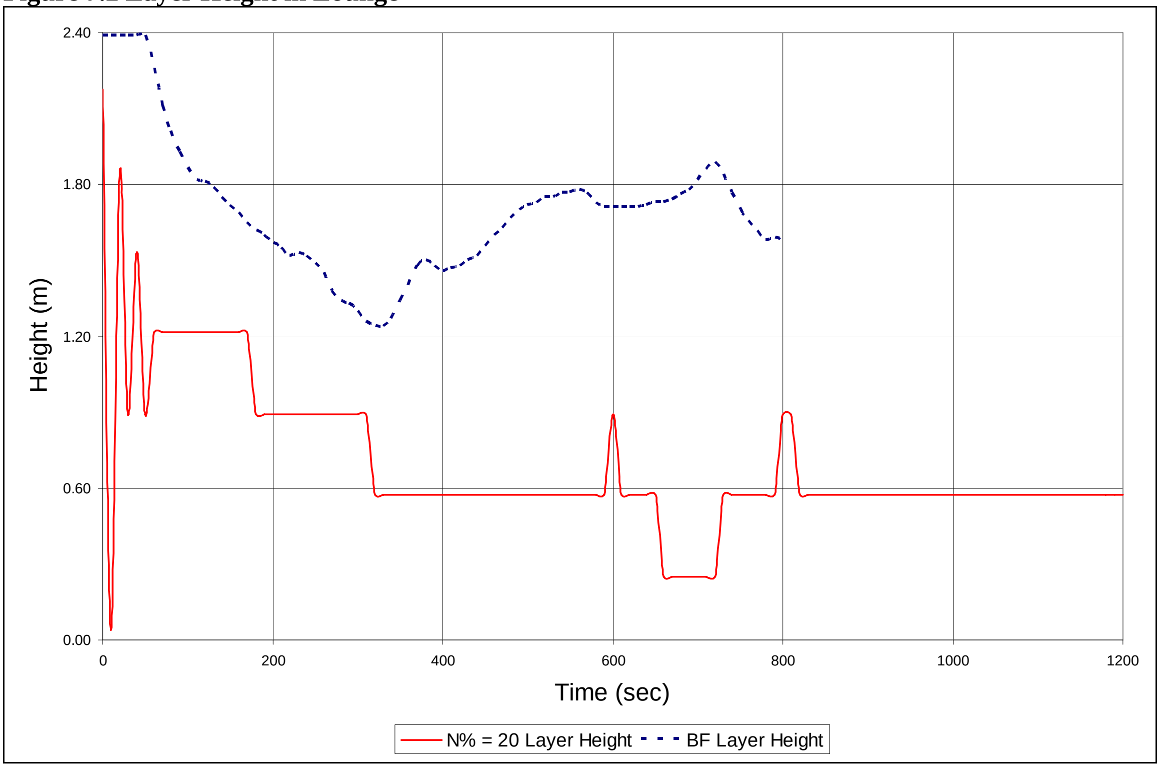
Note that in the figures presented in this section BRANZFIRE has been abbreviated to BF in the data series legend.

7.1 Horizontal Vent Simulation

7.1.1 Layer Height

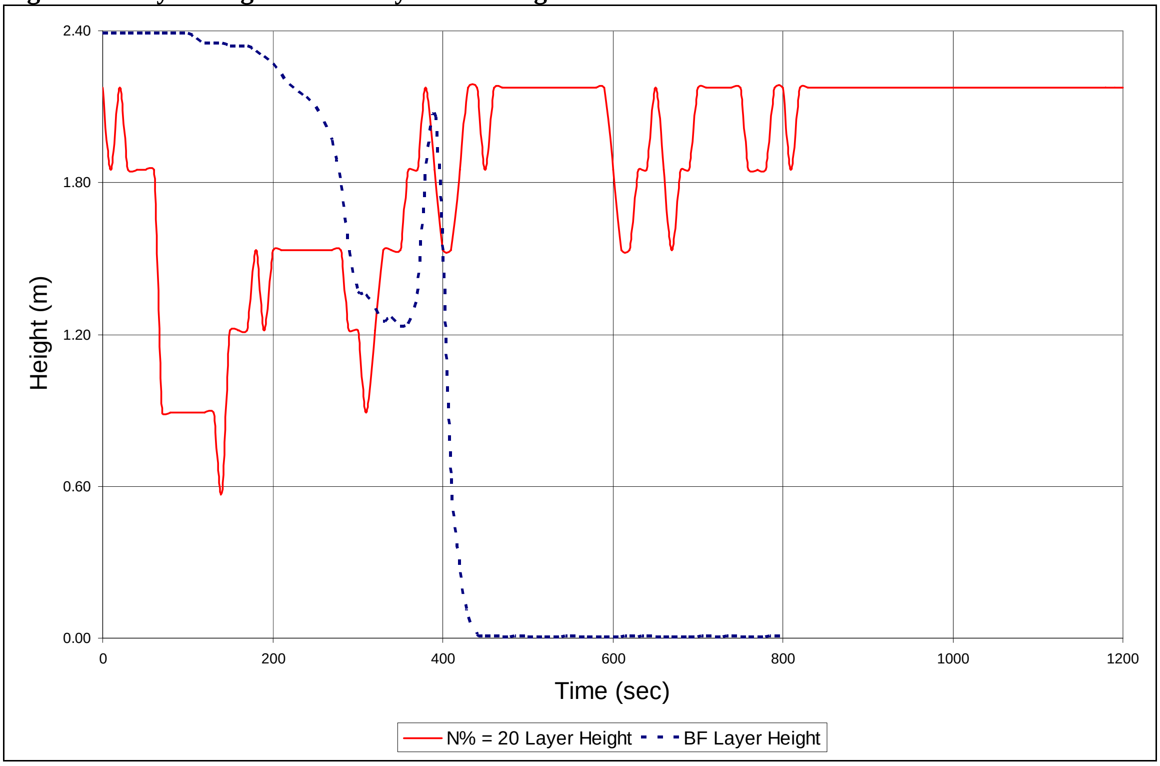
The layer heights in the lounge predicted by the N% method using N = 20 and from the BRANZFIRE simulation are shown for each compartment in Figures 7.2 to 7.6.

Figure 7.2 Layer Height in Lounge



The N% method predicts a general decrease in the layer height over the first 300 seconds of the test with the layer height decreasing to approximately 0.6m from the floor. The BRANZFIRE simulation predicts a similar decrease in the layer height through to approximately 300 seconds but predicts the layer interface height to be at approximately 1.2m from floor level. The BRANZFIRE simulation then predicts the layer height to increase after approximately 400 seconds as the heat release rate in the main compartment starts to decrease. This increase in layer height is not predicted by the N% method. As the temperatures in the compartment decrease and the differences between the temperatures recorded at each thermocouple decrease the N% method less accurately predicts the layer height.

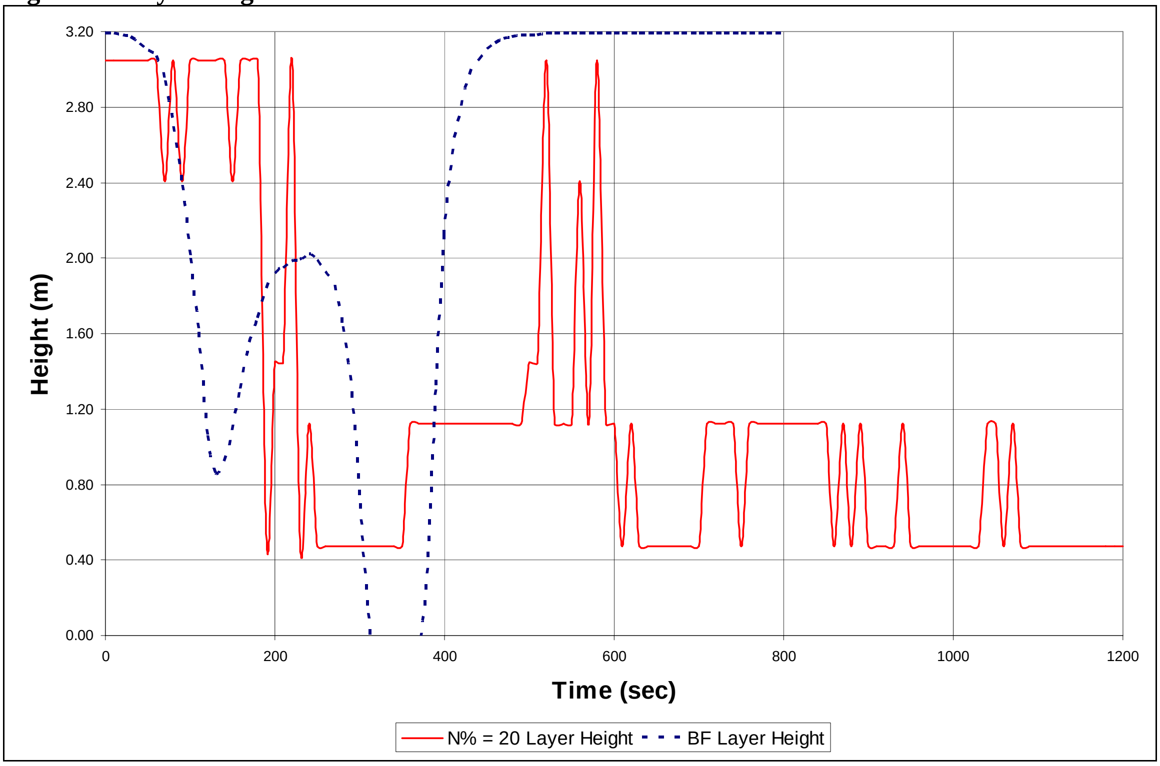
Figure 7.3 Layer Height in Hallway near Lounge Door



In the hallway the BRANZFIRE simulation makes a relatively poor prediction of the layer height. The BRANZFIRE simulation predicts the layer height to decrease to 1.2m above floor level after 360 seconds before rising to 2.0m above floor level and then rapidly lowering to floor level at 440 seconds and remaining there for the rest of the simulation.

The N% method predicts the layer to lower to 0.6m above floor level after 140 seconds before increasing to 2.1m above floor level at 400 seconds and remaining at approximately that level for the remainder of the test.

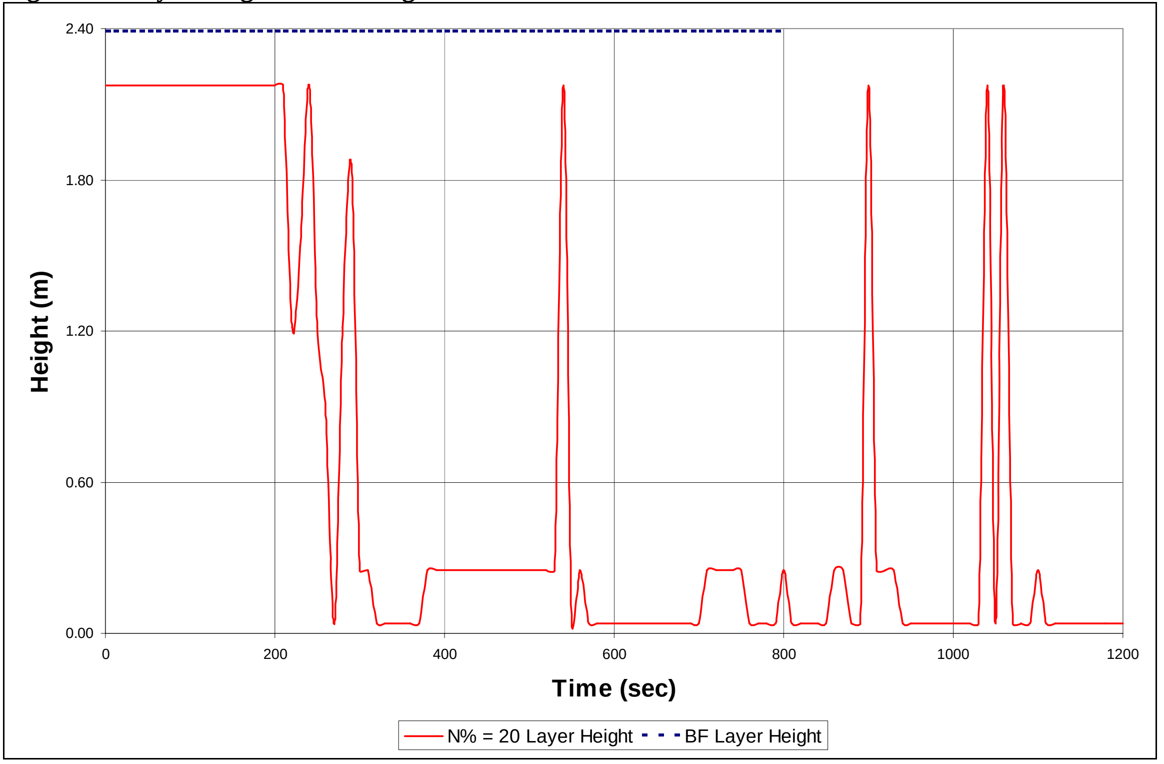
Figure 7.4 Layer Height on Stairs



On the stairs the N% method predicts the layer height to lower to 0.4m above floor level after approximately 200 seconds. It then predicts the layer to oscillate between this level and 1.1m above floor level for the remainder of the test with brief increases to 3.05m above floor level.

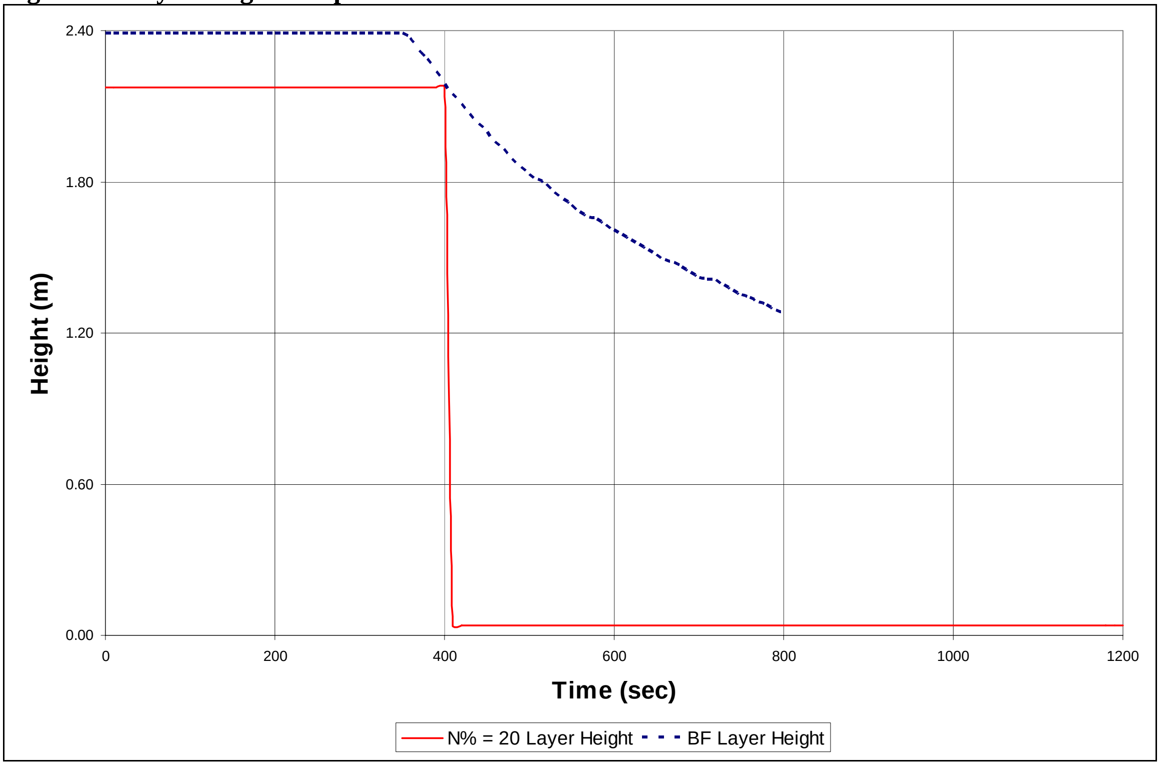
The BRANZFIRE simulation predicts an initial lowering of the layer to 0.85m above floor level after 130 seconds before rising to 2.0m above floor level at 240 seconds and then lowering to floor level at 320 seconds. The layer then rises to ceiling level again after 540 seconds. The BRANZFIRE simulation makes a poor prediction of the layer height in this compartment in comparison to the N% method.

Figure 7.5 Layer Height on Landing



On the landing the BRANZFIRE simulation predicts the layer height to remain unchanged during the simulation whereas the N% method predicts the layer to lower to floor level after 270 seconds and remain there for the remainder of the test with some brief increases to 2.2m above floor level. With the very low temperature increases recorded during the full scale rig test the N% method prediction of the layer height does not have a high level of accuracy.

Figure 7.6 Layer Height in Open Bedroom

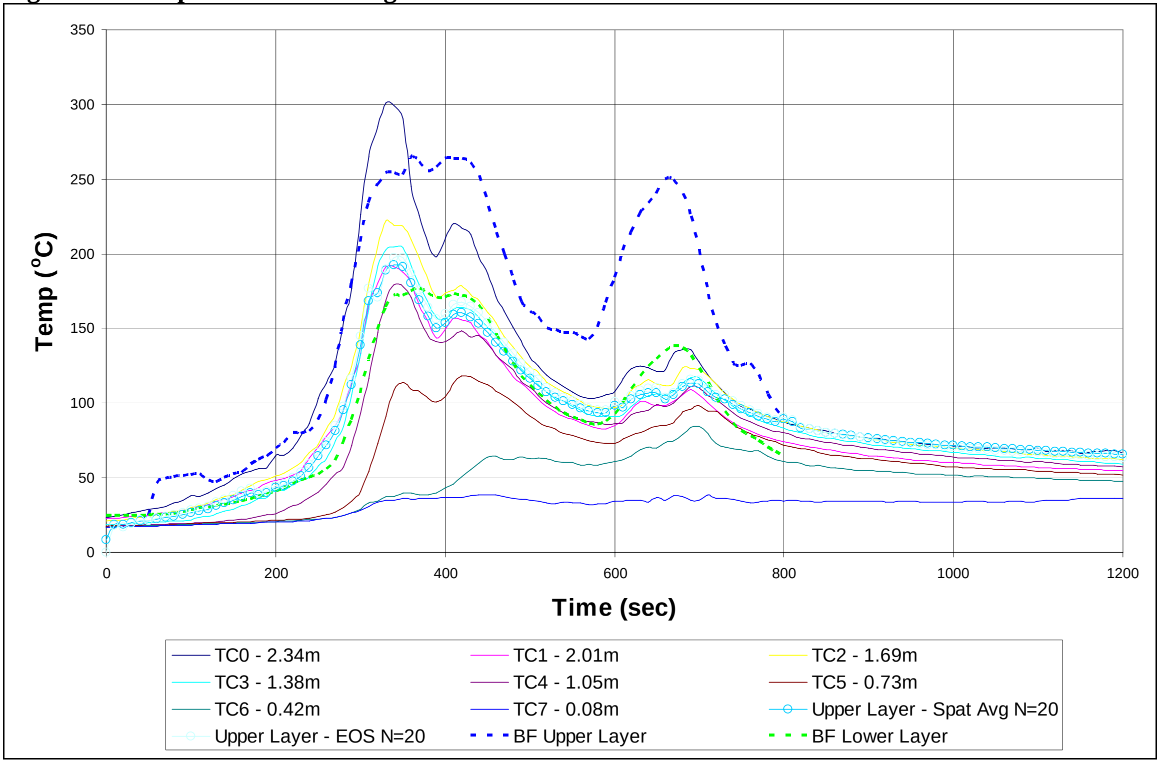


In the open bedroom compartment the layer height predicted by the N% method is affected by the very small temperature change in the compartment with layer heights either at floor level or at ceiling level predicted by the N% method. The BRANZFIRE simulation predicts the layer height to decrease at approximately the same time as the N% method but predicts a minimum level of 1.3m at the completion of the simulation at 800 seconds. It is of interest to note that the layer height decreases to this level in the open bedroom but does not lower on the landing.

7.1.2 Temperatures

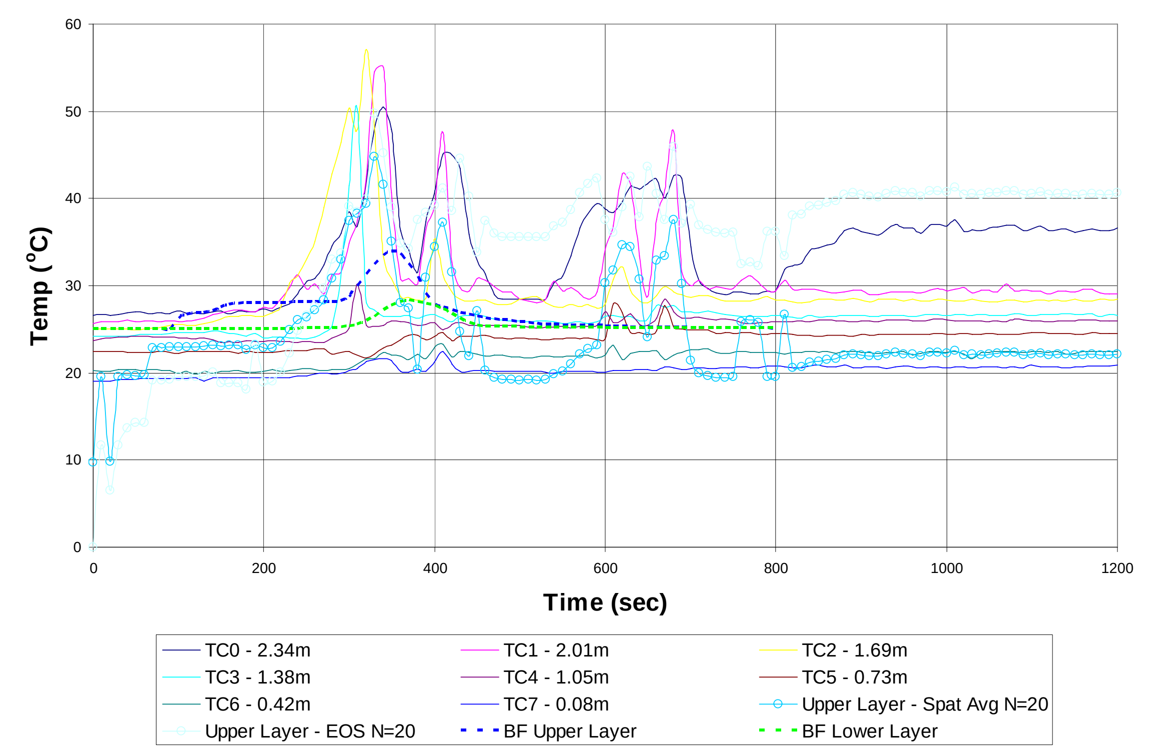
The compartment temperatures from the BRE testing and those generated by the BRANZFIRE simulation are shown in Figures 7.7 to 7.11. Also shown in Figures 7.7 to 7.11 are the upper layer temperatures predicted by the methods outlined in Section 3.

Figure 7.7 Temperatures in Lounge



The maximum upper layer temperature predicted by BRANZFIRE in the first peak of the fire is approximately 35°C less than the temperature recorded at the highest thermocouple in the centre of the lounge in the BRE testing. The maximum upper layer temperature predicted by the BRANZFIRE simulation is approximately 35% higher than the upper layer temperature predicted by the spatial average and equation of state methods. Both the spatial average and the equation of state methods predict similar results which compare well with the upper layer temperatures from the BRE testing.

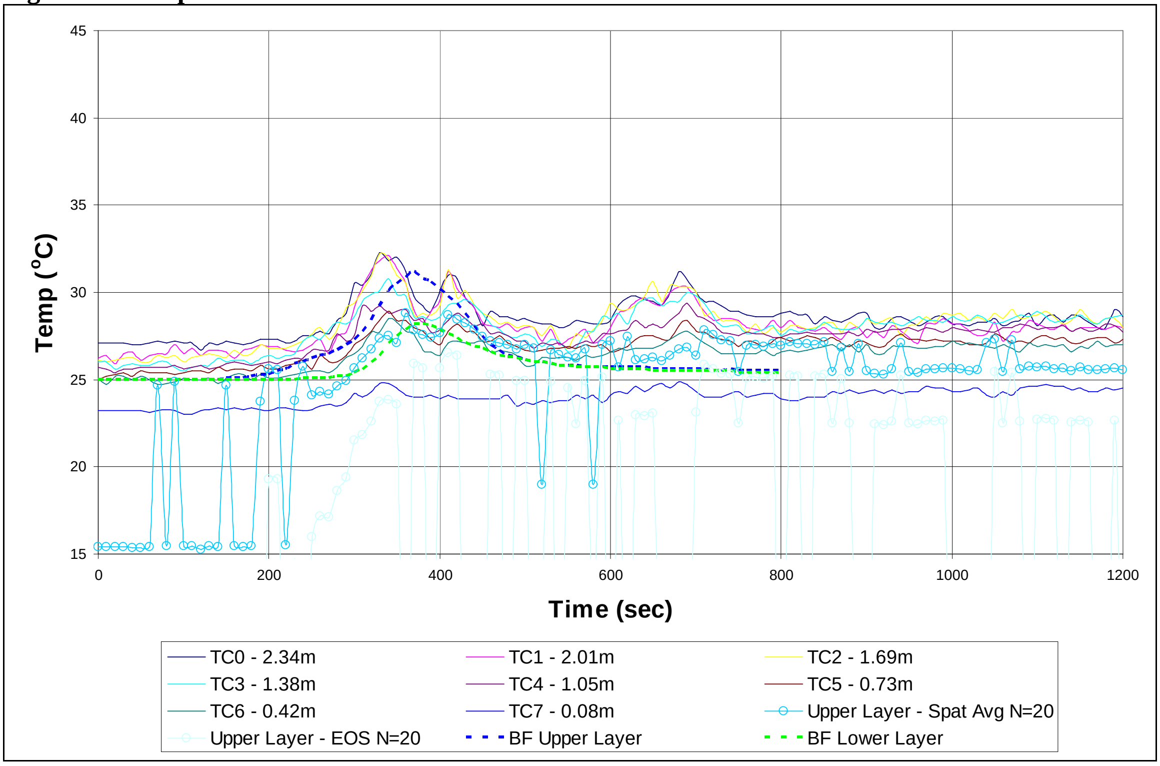
Figure 7.8 Temperatures in Hallway near Lounge Door



The third thermocouple from the top of the thermocouple tree records the highest peak temperature in the hallway. The peak temperature is approximately twice the ambient temperature. Because of the small temperature rise recorded in this testing and the fact that the highest temperatures are not necessarily recorded in the highest thermocouples the spatial average and equation of state formulas do not make good predictions of the upper layer temperatures.

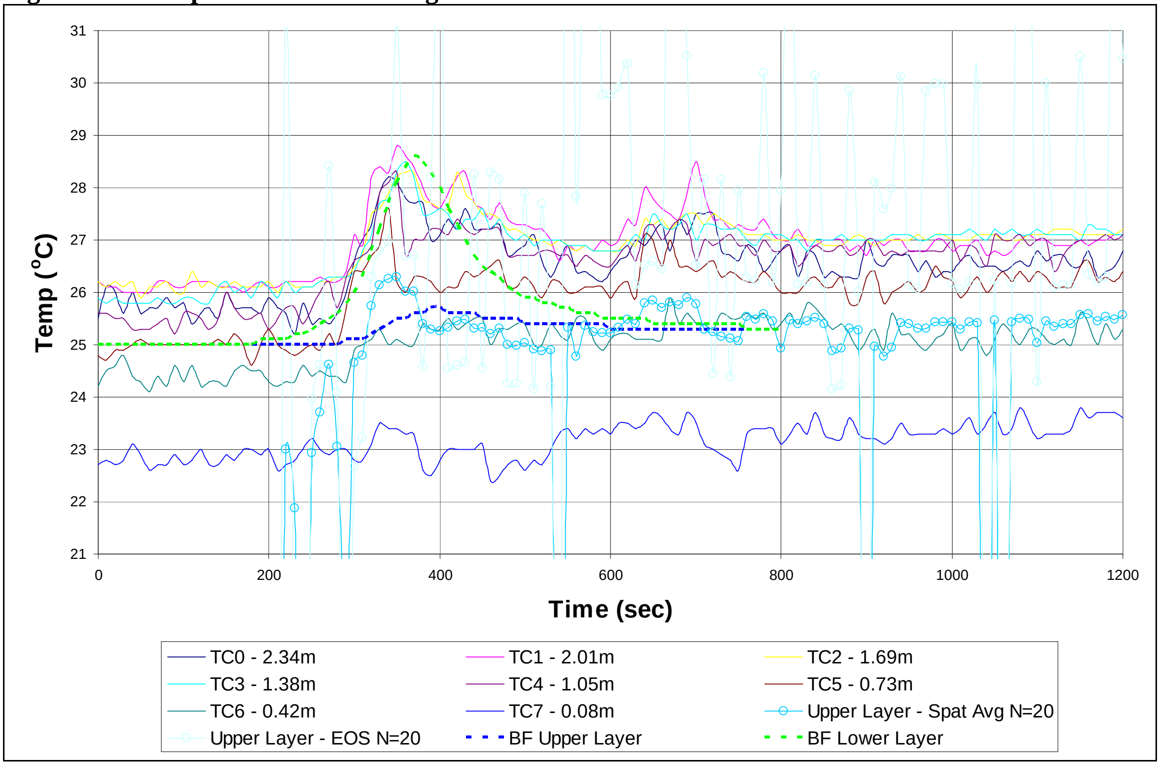
When compared against the spatial average and equation of state methods the BRANZFIRE simulation under predicts the maximum upper layer temperature. The BRANZFIRE simulation predicts a maximum upper layer temperature of 34°C in comparison to a maximum value of 50°C predicted by the equation of state and spatial average methods.

Figure 7.9 Temperatures on Stairs



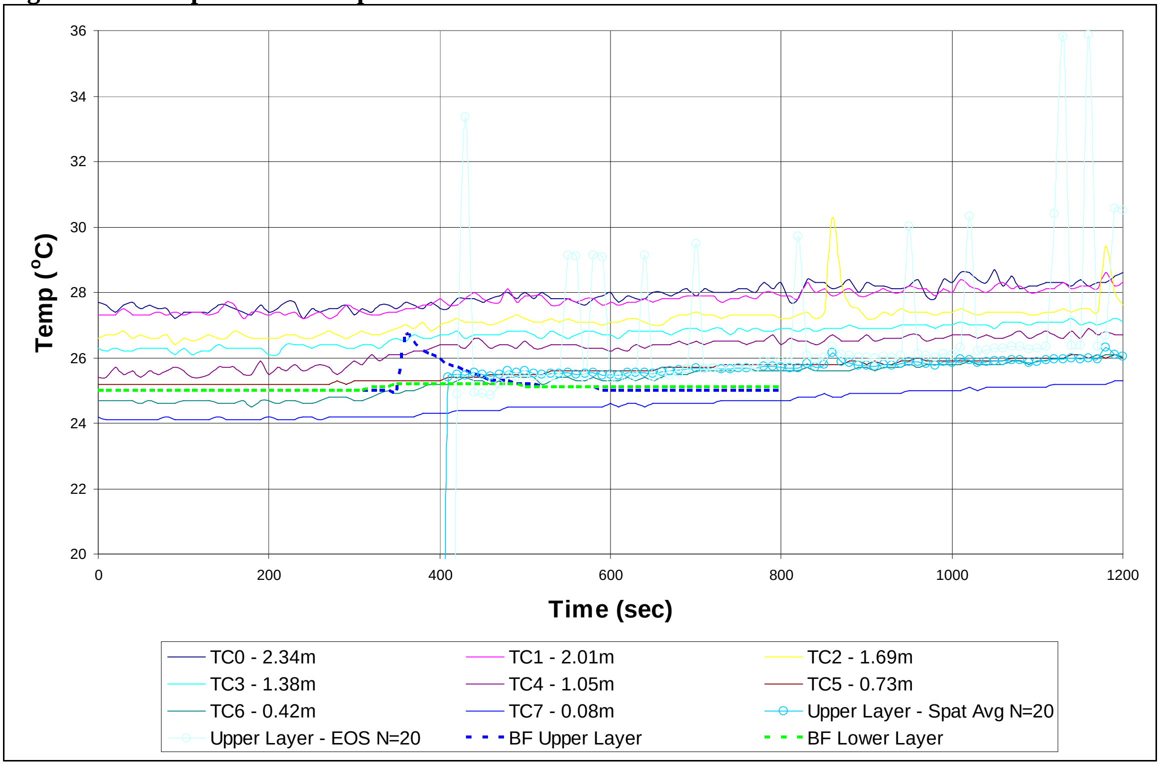
A very low temperature increase was recorded on the stairs during the full scale rig testing with a maximum increase of 5°C recorded in the upper thermocouples with a maximum temperature of 32°C. The equation of state and spatial average methods predict an increase to a maximum of 29°C and the BRANZFIRE simulation predicts the upper layer temperature to increase to a maximum value of 31°C.

Figure 7.10 Temperatures on Landing



The spatial average and equation of state methods provide a poor approximation of the upper layer temperature due to the very small temperature changes in these layers. The BRANZFIRE simulation predicts an increase in the upper layer temperature of less than 1°C but predicts an increase of greater than 3°C in the lower layer. The temperature rise in the upper thermocouple during the BRE testing is in the order of 3.5°C.

Figure 7.11 Temperatures in Open Bedroom

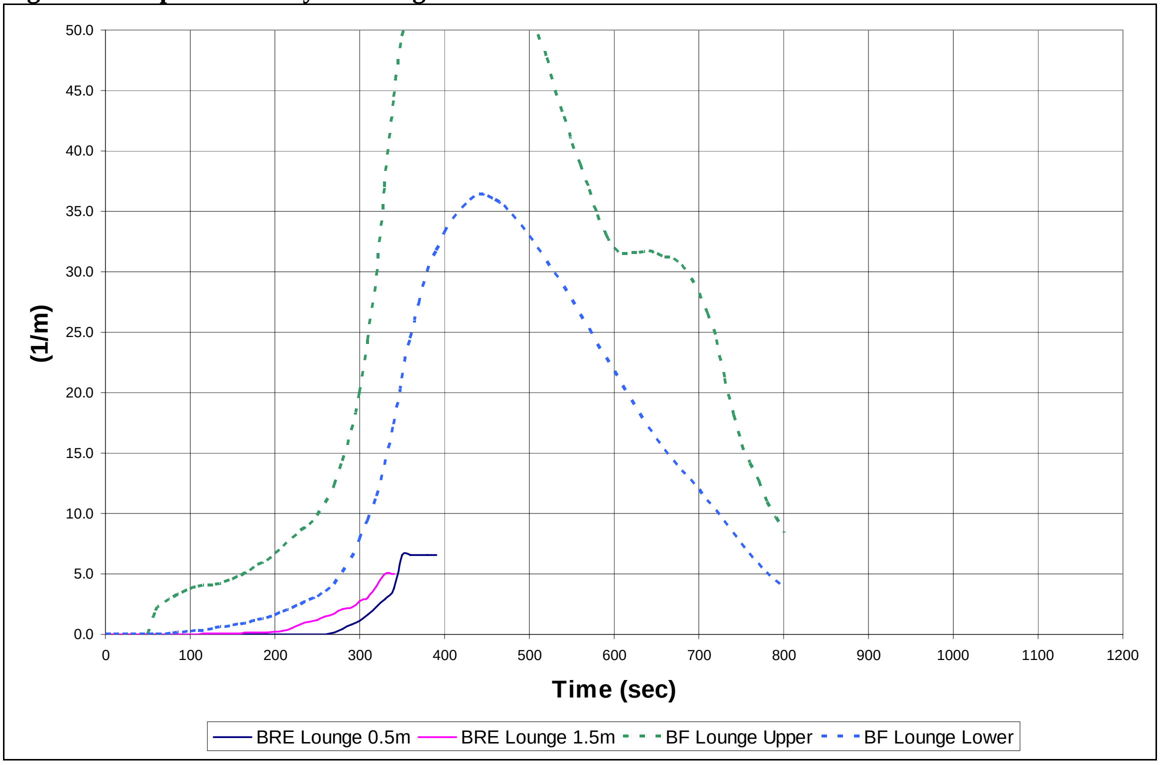


Very small changes in the open bedroom temperatures were recorded during the BRE testing and the BRANZFIRE simulation over predicts the upper layer temperature rise by predicting a increase of approximately 1°C. The spatial average and equation of state methods give poor predictions of the compartment temperatures due to the small temperature increases and subsequent poorly defined layer interface.

7.1.3 Optical Density

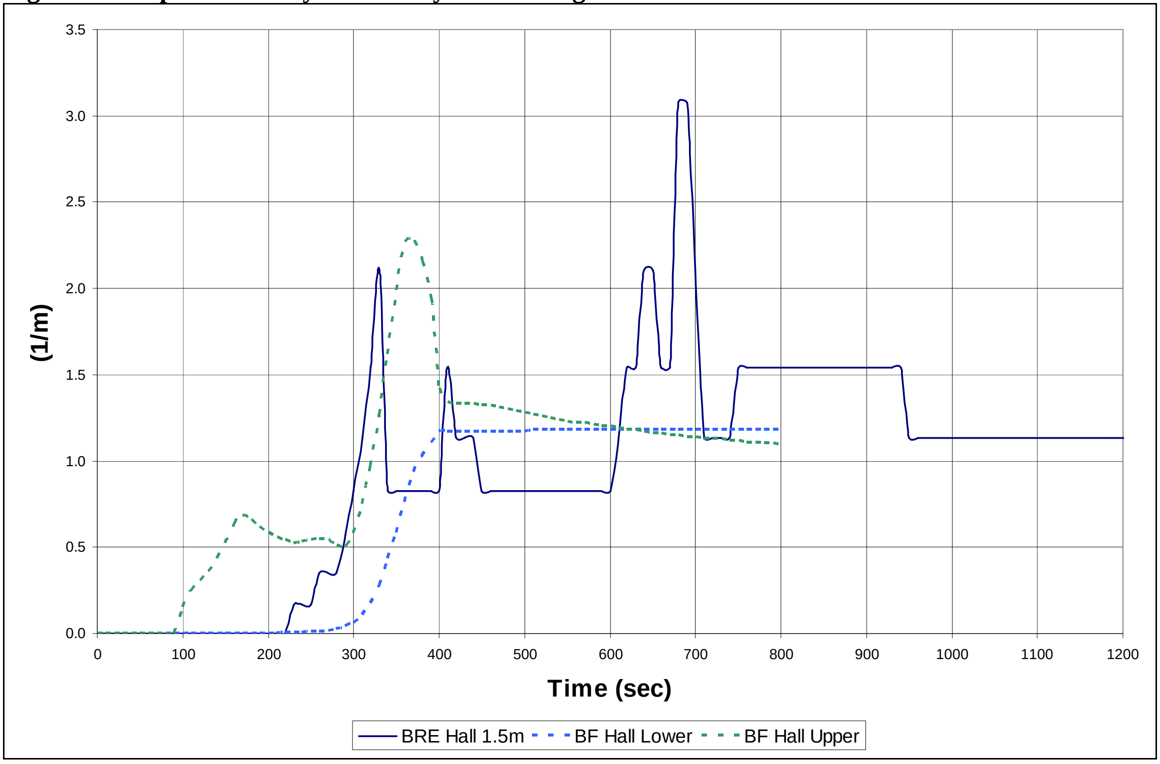
The optical density readings predicted by the BRANZFIRE simulation are compared against the data from the full scale rig tests for each of the compartments in Figures 7.12 to 7.16.

Figure 7.12 Optical Density in Lounge



The BRANZFIRE simulation greatly over predicts the optical density in the lounge for this test. A maximum value of approximately $6m^{-1}$ was recorded during the full scale rig testing before the maximum reading of the instruments was reached. The BRANZFIRE simulation predicts a maximum optical density of approximately $60m^{-1}$ in the upper layer that correlates to a visibility of approximately 0.016m which is very dense smoke. The BRANZFIRE simulation predicts the optical density to rise faster than in the full scale rig tests. It is not possible to compare the predicted optical density after the peak reading because it was beyond the range of the instrumentation used in the full scale rig testing.

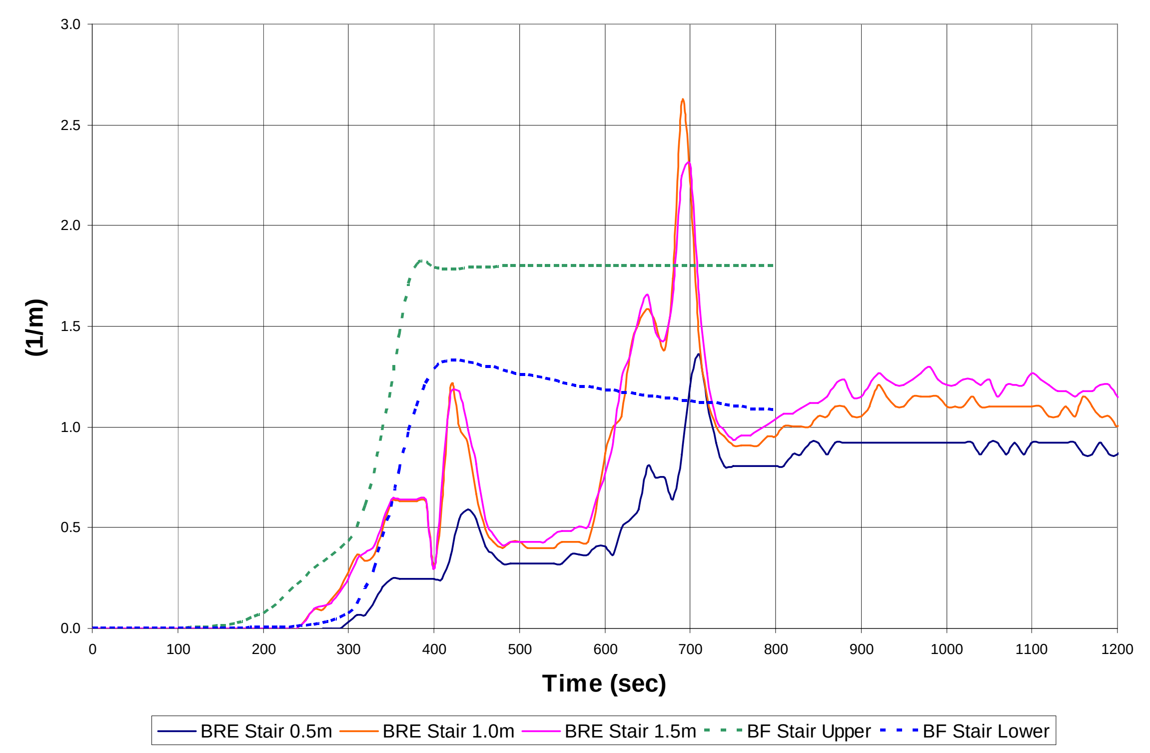
Figure 7.13 Optical Density in Hallway near Lounge Door



In the hallway optical densities were only recorded at 1.5m above floor level in the full scale rig testing. These readings are compared against the upper and lower layer optical densities predicted by the BRANZFIRE simulation in Figure 7.13. The increase in the optical density is predicted reasonably well by the BRANZFIRE simulation with the upper layer increasing ahead of the values from the full scale rig testing and the lower layer increasing after the full scale rig results. The peak optical density predicted by the BRANZFIRE simulation is approximately $2.3m^{-1}$ whereas the maximum reading recorded in the full scale tests at the same time is approximately $2.1m^{-1}$. The BRANZFIRE simulation predicts a decrease in the optical density following the decrease in the heat release rate but does not predict an increase in the optical density during the second peak in the heat release rate, as seen in the readings from the full scale rig testing.

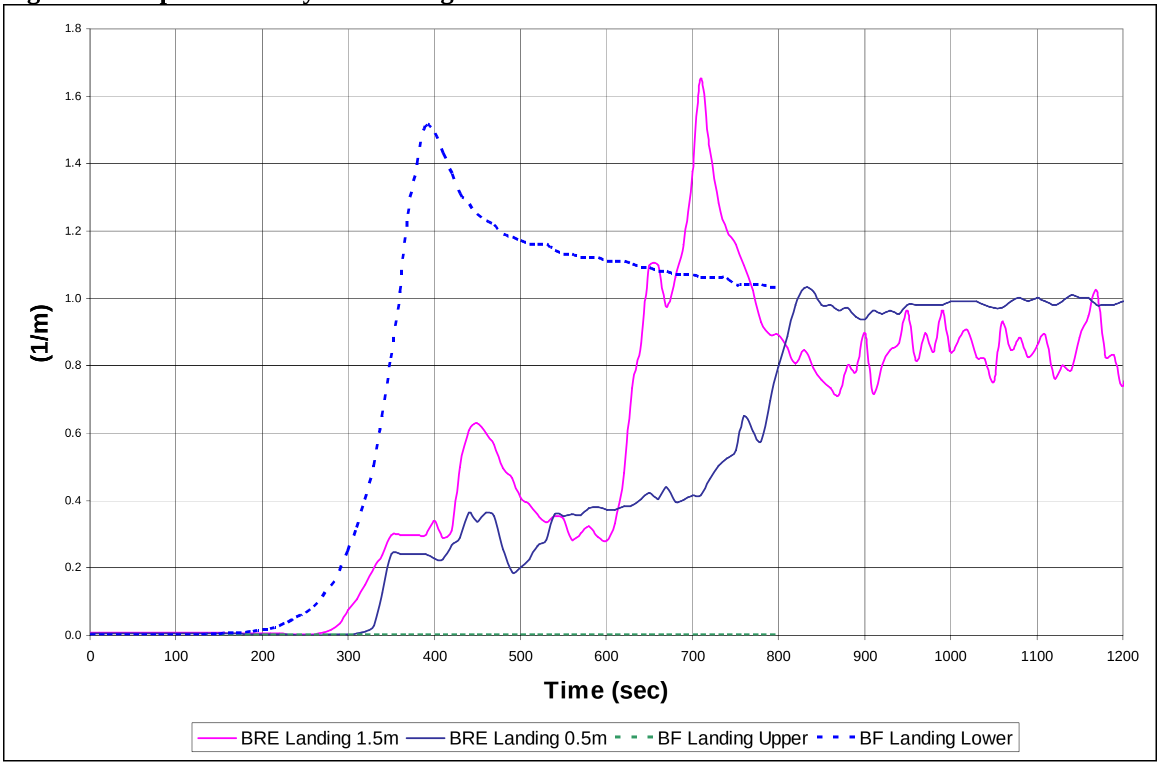
The magnitude of the optical density predicted by the BRANZFIRE simulation is unexpected given that the lounge door is closed in this simulation with only a 0.01m gap at the base of the door. A high optical density at the level of the door sill is required to generate such a large increase in the hallway.

Figure 7.14 Optical Density on Stair



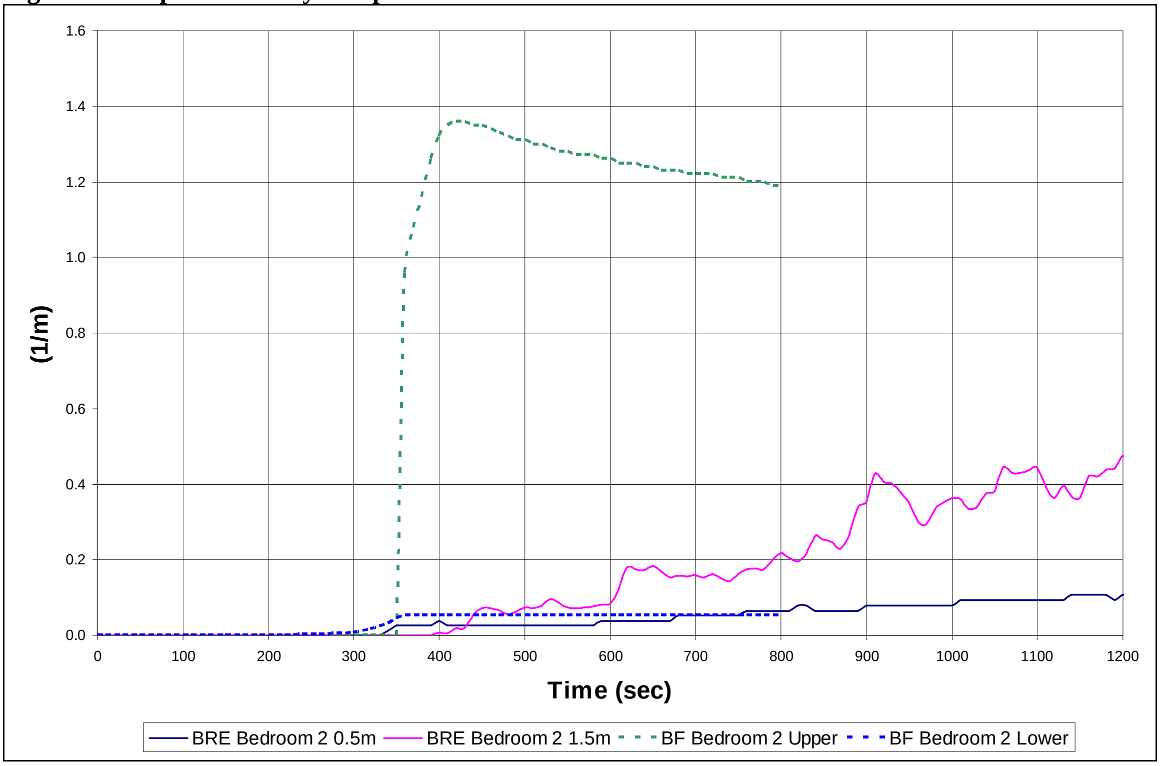
On the stairs the BRANZFIRE simulation makes a reasonable prediction of the optical density, predicting a peak optical density of 1.8m^{-1} after 390 seconds. A value of 1.2m^{-1} was recorded in the full scale rig testing at 420 seconds which was followed by a second higher peak of 2.6m^{-1} after 700 seconds. The second peak in the optical density was not predicted by the BRANZFIRE simulation.

Figure 7.15 Optical Density on Landing



On the landing the upper layer optical density predicted by the BRANZFIRE simulation increases earlier than the upper sampling point in the full scale rig testing and predicts a peak optical density of approximately 1.51m^{-1} compared to a recorded optical density of 0.34m^{-1} in the full scale rig at this time. The optical density recorded during the full scale rig testing then increases to a peak value of 1.65m^{-1} after 710 seconds which is not predicted by the BRANZFIRE simulation.

Figure 7.16 Optical Density in Open Bedroom

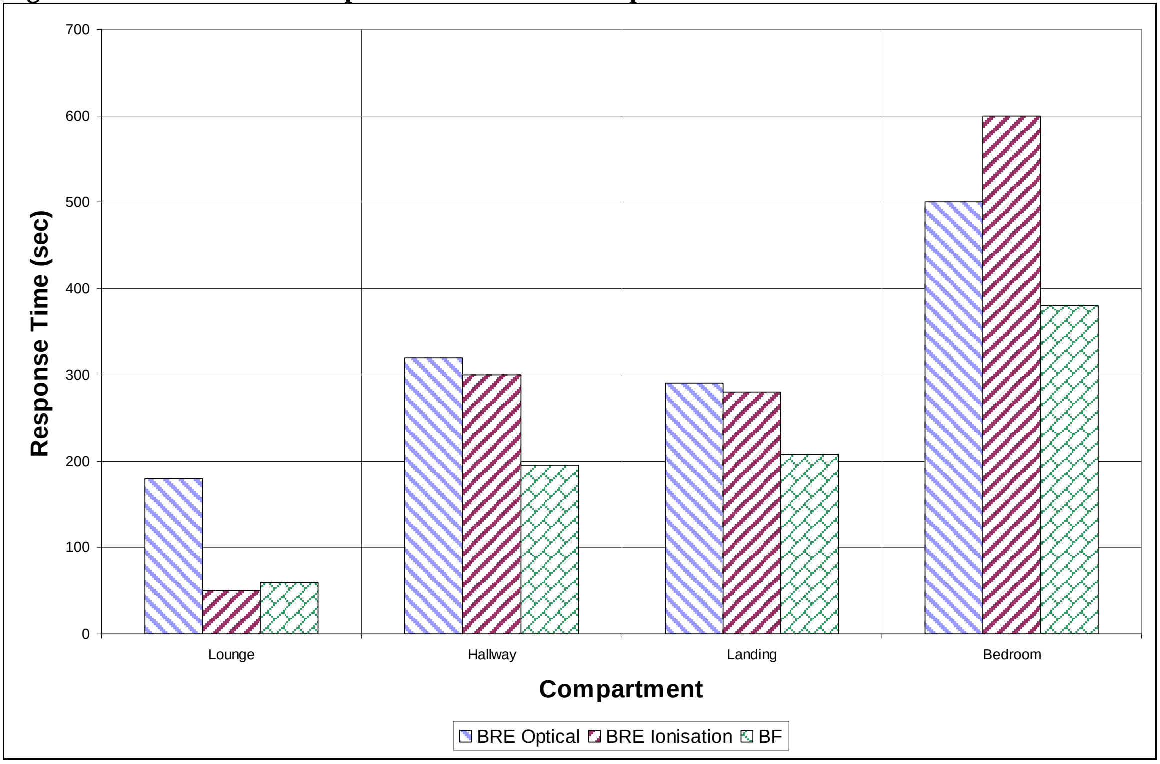


In the open bedroom BRANZFIRE predicts the upper layer optical density to increase to a maximum value of $1.36m^{-1}$ after 420 seconds. The full scale rig testing recorded a maximum value of $0.45m^{-1}$ at the end of the test at 1200 seconds.

7.1.4 Smoke Alarm Response

The smoke alarm activation times observed during the full scale rig testing are compared against the predicted smoke alarm response times from the BRANZFIRE simulation in Figure 7.17.

Figure 7.17 Smoke Alarm Response Times for All Compartments



In the lounge the BRANZFIRE simulation predicts a much faster activation time compared against the optical smoke alarm but a slightly slower activation time compared to the ionisation smoke alarm from the full scale rig testing. In the hallway the BRANZFIRE simulation predicts activation times approximately 100 seconds faster than both the optical and ionisation smoke alarms in the full scale rig testing.

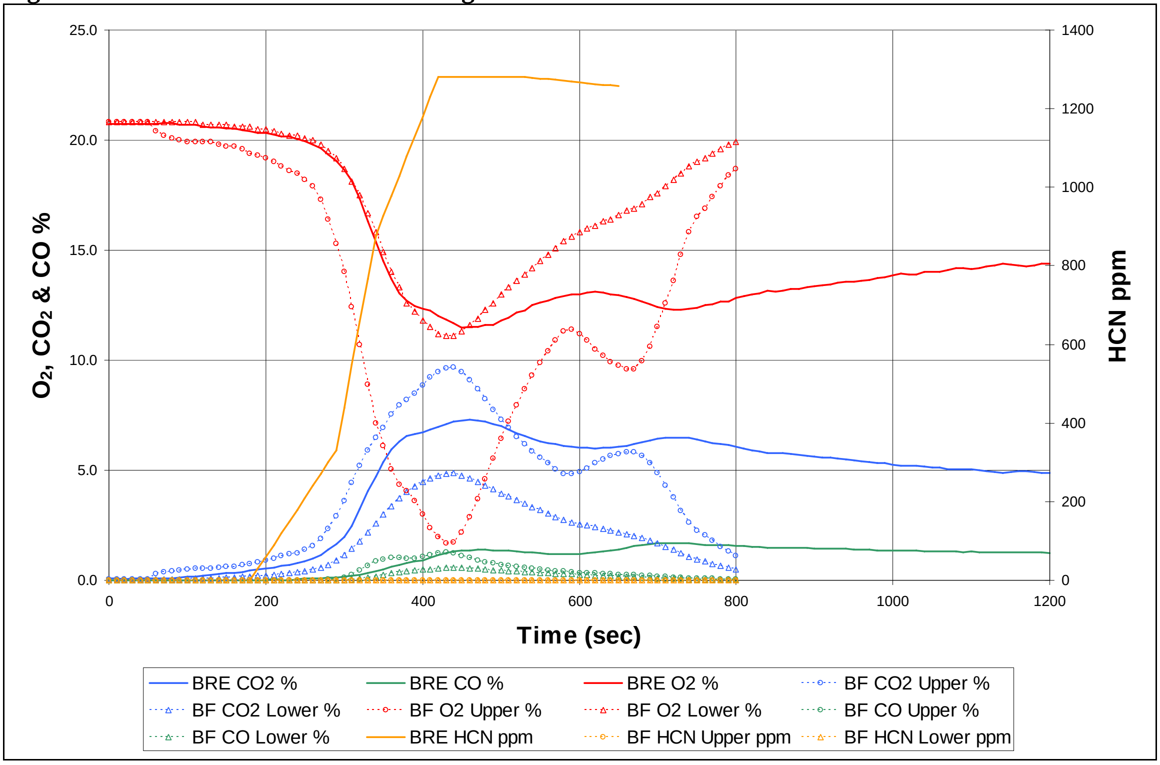
A similar result is obtained on the landing with the BRANZFIRE simulation predicting activation times approximately 90 seconds faster than the full scale rig testing. In the open bedroom the full scale rig testing gave an activation of 600 seconds for the ionisation smoke alarm and 500 seconds for the optical smoke alarm. The BRANZFIRE simulation predicted an activation time of approximately 380 seconds.

The faster activation times predicted by BRANZFIRE are likely to be caused by the more rapid increase in the optical density recordings shown in Figures 7.12 to 7.16.

7.1.5 Gas Concentration

Gas concentrations for the compartments of the full scale rig and the BRANZFIRE simulation are shown in Figures 7.18 to 7.21.

Figure 7.18 Gas Concentrations in Lounge



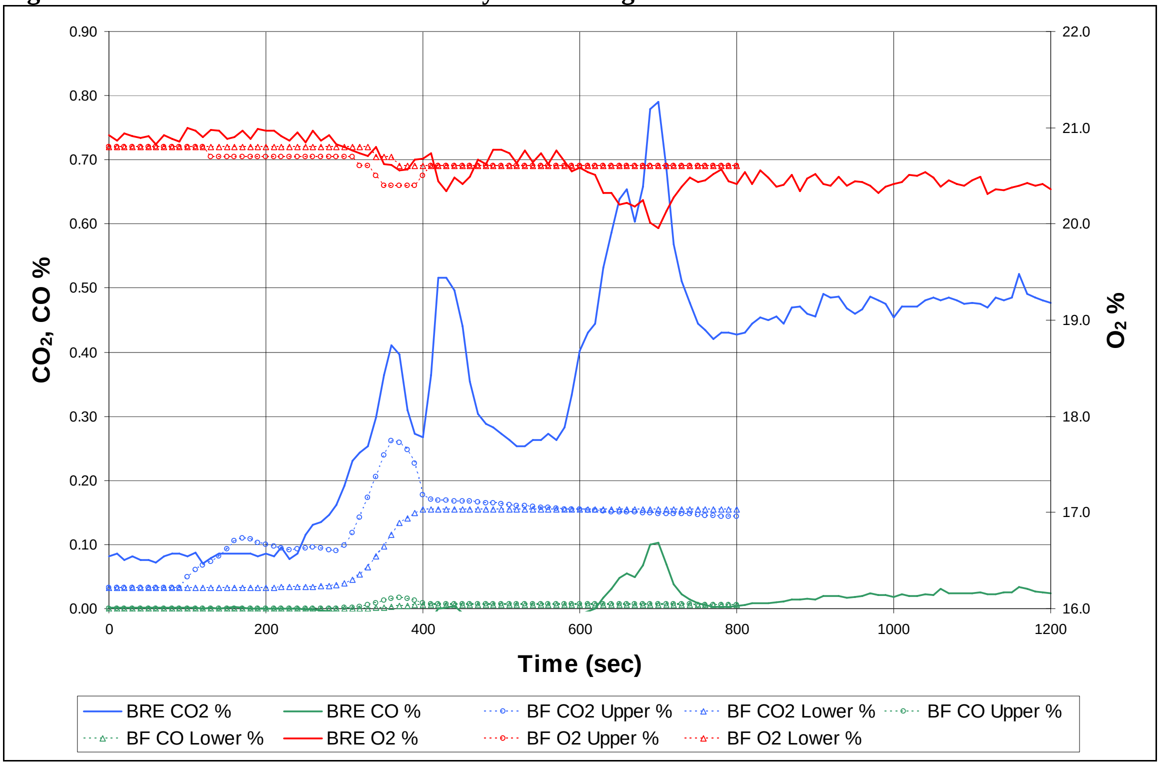
The decrease of the oxygen concentration of the upper layer predicted by the BRANZFIRE simulation greatly exceeds the decrease recorded during the full scale rig testing. The shape of the oxygen concentration curve predicted by the BRANZFIRE simulation is correct but the BRANZFIRE simulation predicts the oxygen concentration to lower to 1.7% at 430 seconds. The full scale rig testing recorded a minimum value of 11.5% at 470.

The carbon dioxide concentration predicted by the BRANZFIRE simulation is a very good approximation of the full scale rig testing with the upper and lower layer predicted values bracketing the recorded values from the full scale rig testing. The maximum carbon dioxide concentration predicted by the BRANZFIRE simulation is 9.7% at 440 seconds in comparison to a peak value of 7.3% recorded at 460 seconds during the full scale rig testing.

The carbon monoxide concentration predicted by the BRANZFIRE simulation is a good approximation of the full scale rig testing during the early part of the simulation. A maximum value of approximately 1.3% is predicted by the BRANZFIRE simulation at 430 seconds in comparison to 1.68% at 740 seconds recorded during the full scale testing.

The hydrogen cyanide concentration predicted by the BRANZFIRE simulation is not discernible on the graph and is almost constant at 0.1ppm. A maximum reading of 1300ppm was recorded during the full scale rig testing.

Figure 7.19 Gas Concentrations in Hallway near Lounge Door

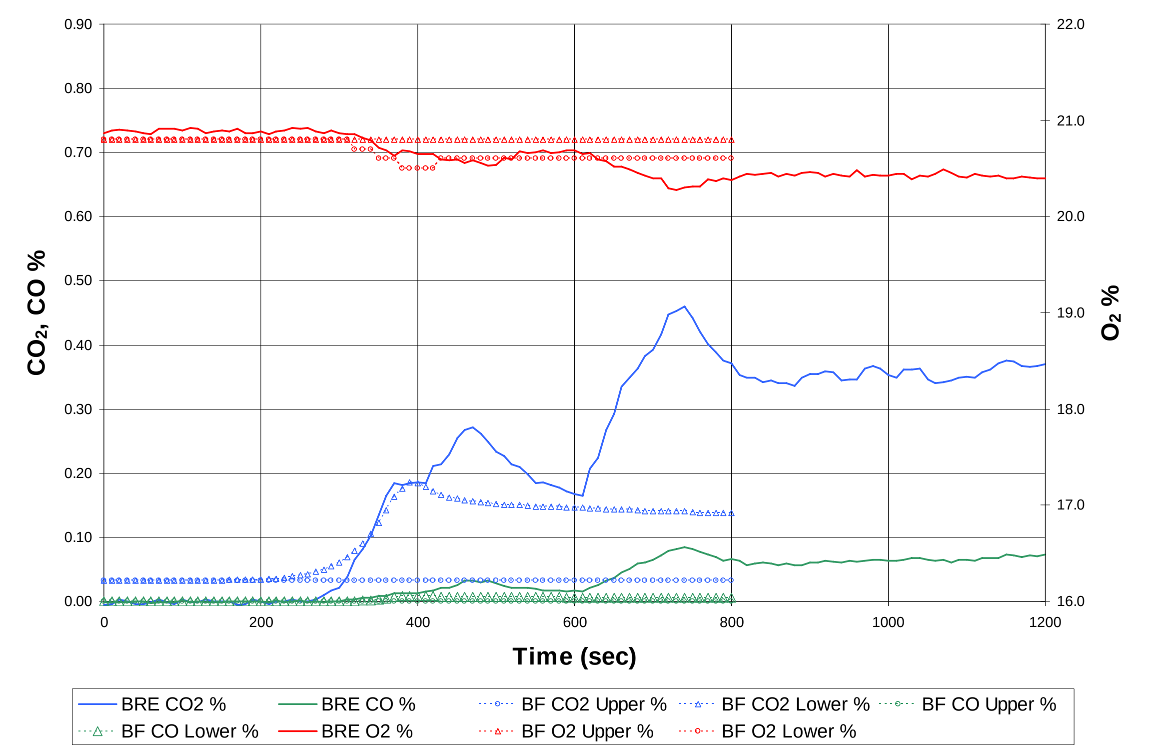


In the hallway the oxygen concentration recorded during the full scale testing reduced by less than 1% to a minimum value of 19.95% at 700 seconds. The BRANZFIRE simulation predicts a minimum value of 20.4% at 340 seconds before increasing to 20.6% and remaining at that level for the rest of the simulation.

The carbon dioxide concentration predicted by the BRANZFIRE simulation under predicts the values recorded during the full scale rig testing. The BRANZFIRE simulation predicts a maximum value of 0.26% at 360 seconds before decreasing to approximately 0.15% for the remainder of the test. At 360 seconds a value of 0.41% was recorded during the full scale rig testing and the maximum value of 0.79% was recorded at 700 seconds.

In the hallway the BRANZFIRE simulation predicts only a very small increase in the carbon monoxide concentration to 0.02% compared to an increase to 0.1% in the full scale rig testing.

Figure 7.20 Gas Concentrations on Landing

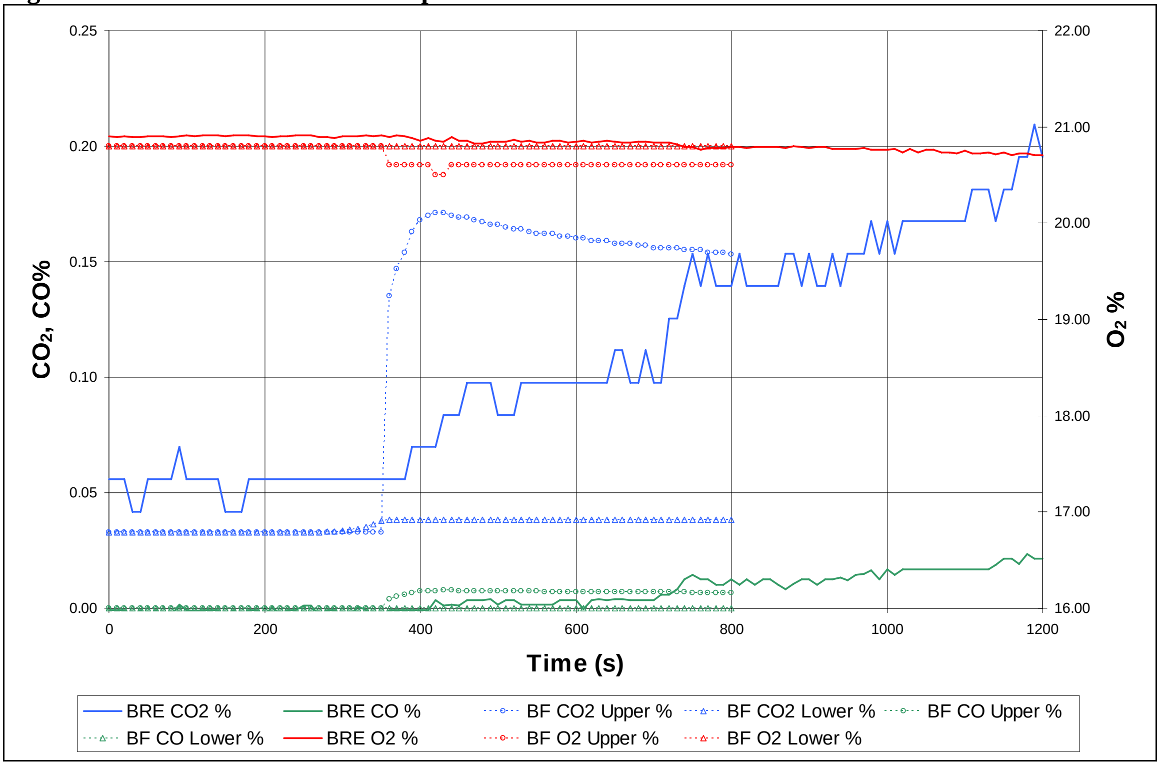


On the landing the oxygen concentration predicted by the BRANZFIRE simulation is a reasonable approximation of the full scale testing results with oxygen concentrations decreasing approximately 1 – 2% from ambient conditions.

The BRANZFIRE simulation makes a reasonable prediction of the carbon dioxide concentration up to the first peak in the heat release rate. After the first peak in heat release rate the BRANZFIRE simulation predicts the carbon dioxide level to decrease to a value of approximately 0.14%. The full scale rig testing recorded a second peak in the heat release rate of 0.46% at 760 seconds.

The carbon monoxide concentration is poorly predicted in this compartment by the BRANZFIRE simulation which predicts almost no increase in the carbon monoxide concentration. The full scale rig testing recorded an increase in the carbon monoxide concentration to peak value of 0.08%

Figure 7.21 Gas Concentrations in Open Bedroom



A very small change in the oxygen concentration was recorded in the open bedroom in the full scale testing and the BRANZFIRE simulation also predicts a very small change in the oxygen concentration.

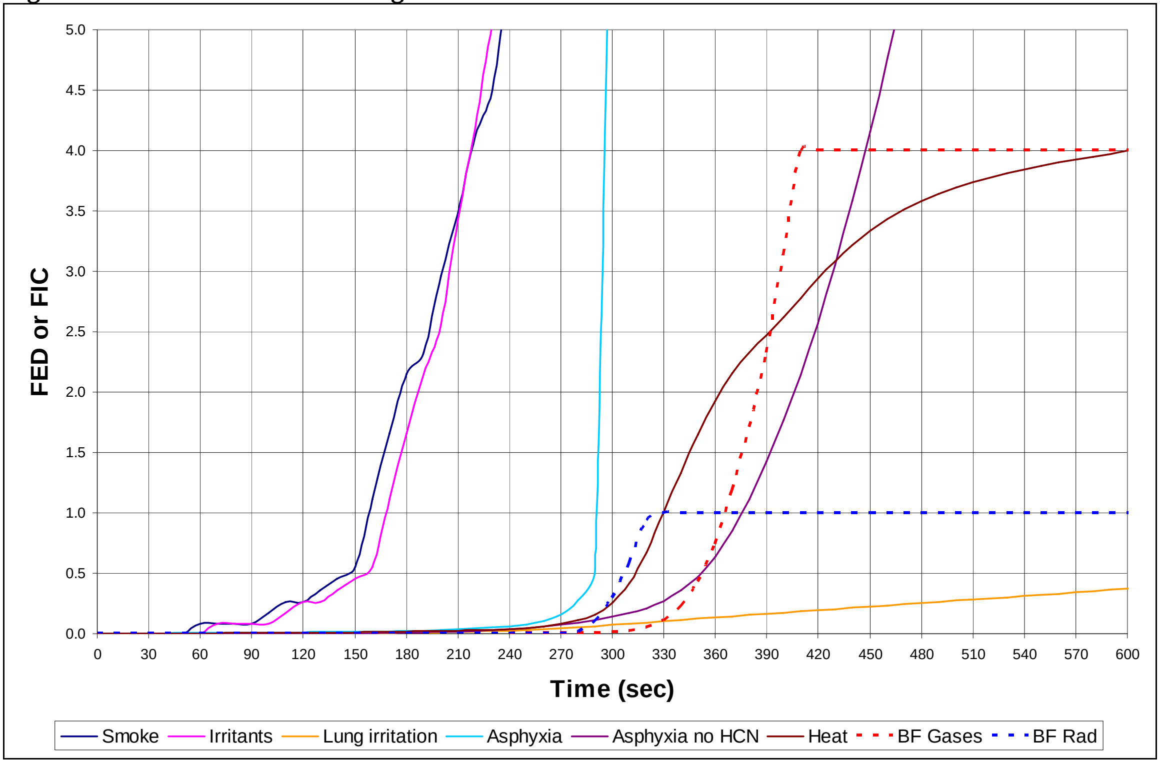
The BRANZFIRE simulation predicts a rapid increase in the carbon dioxide concentration at the same time as the decrease in the oxygen concentration which is not seen in the full scale testing where a gradual increase in the carbon dioxide concentration is seen. The BRANZFIRE simulation predicts a maximum carbon dioxide concentration of 0.17% whereas the full scale rig testing recorded a peak value of 0.21% at 1200 seconds.

A negligible change in the carbon monoxide concentration was seen in the full scale testing and this was under predicted by the BRANZFIRE simulation which predicted an increase to 0.01%. The maximum carbon monoxide concentration recorded during the full scale testing was 0.02%.

7.1.6 Fractional Effective Dose

The results of the fractional irritant concentration and fractional effective dose determined from the full scale testing and the fractional effective dose predicted by the BRANZFIRE simulation for the lounge are shown in Figure 7.22.

Figure 7.22 FIC and FED in Lounge



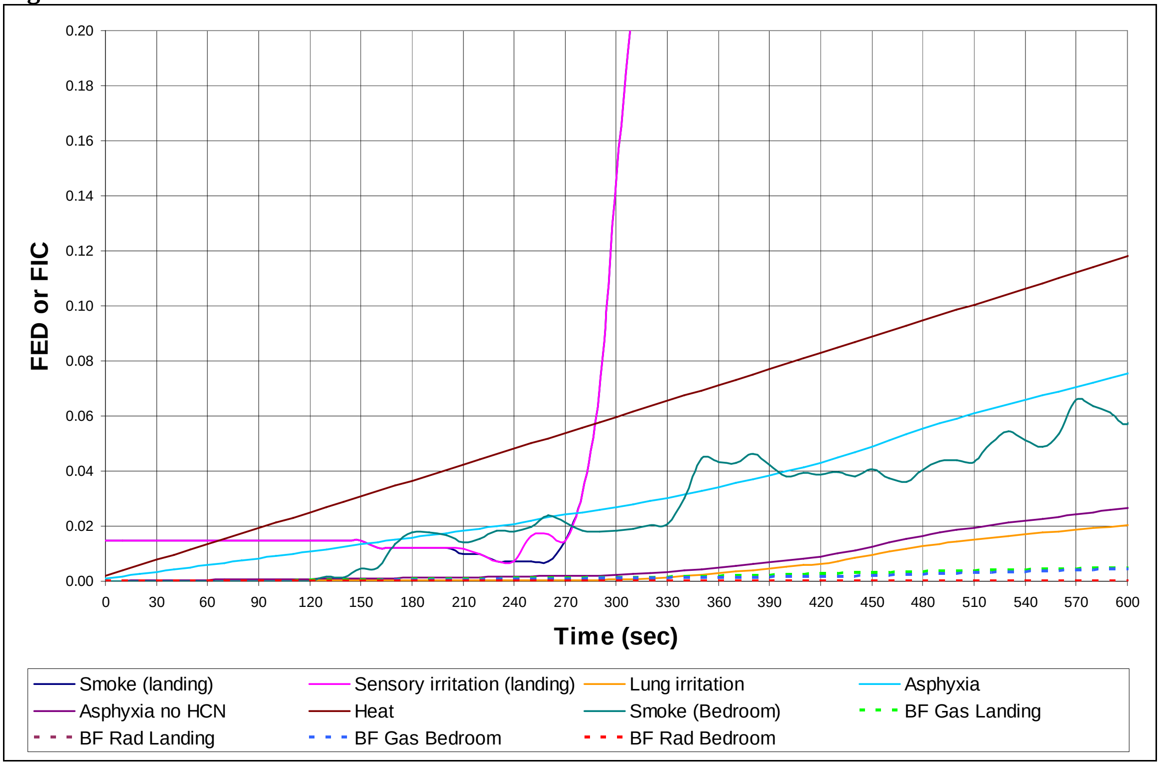
The BRANZFIRE simulation makes a very good approximation of the fractional effective dose due to radiation, predicting an incapacitating dose to be received after approximately 320 seconds. The results calculated from the observations during the full scale testing give a fractional effective dose of 1.0 after 330 seconds.

The fractional effective dose calculated from the observations during the full scale testing reaches a value of 1.0 at 380 seconds. The BRANZFIRE simulation predicts a value of 1.0 due to gases at 370 seconds. The BRANZFIRE simulation predicted the fractional effective dose due to gases to begin increasing later than the full scale testing, but to increase more rapidly.

The BRANZFIRE simulation does not predict the fractional irritant dose due to irritant gases.

The FIC and FED predicted for the bedroom are shown in Figure 7.23.

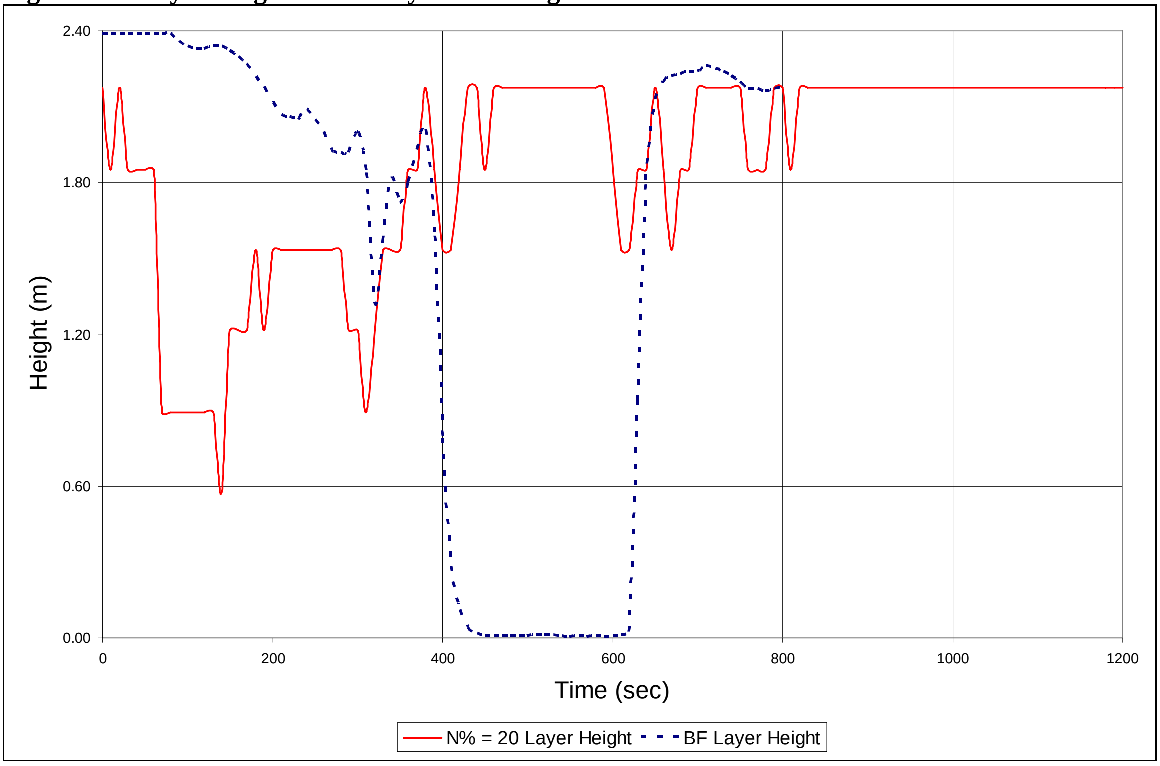
Figure 7.23 FIC and FED in Bedroom



The BRANZFIRE simulation predicts no increase in the fractional effective dose due to radiation in the open bedroom because of the very low temperature increase in this compartment. The full scale rig test data gives a maximum value of the fractional equivalent dose due to radiation of 0.12 at 600 seconds.

A maximum value of 0.027 for the fractional equivalent dose due to asphyxiant gases not including hydrogen cyanide is calculated from the full scale rig testing at 600 seconds. The BRANZFIRE simulation predicts a maximum value of 0.004 at 600 seconds.

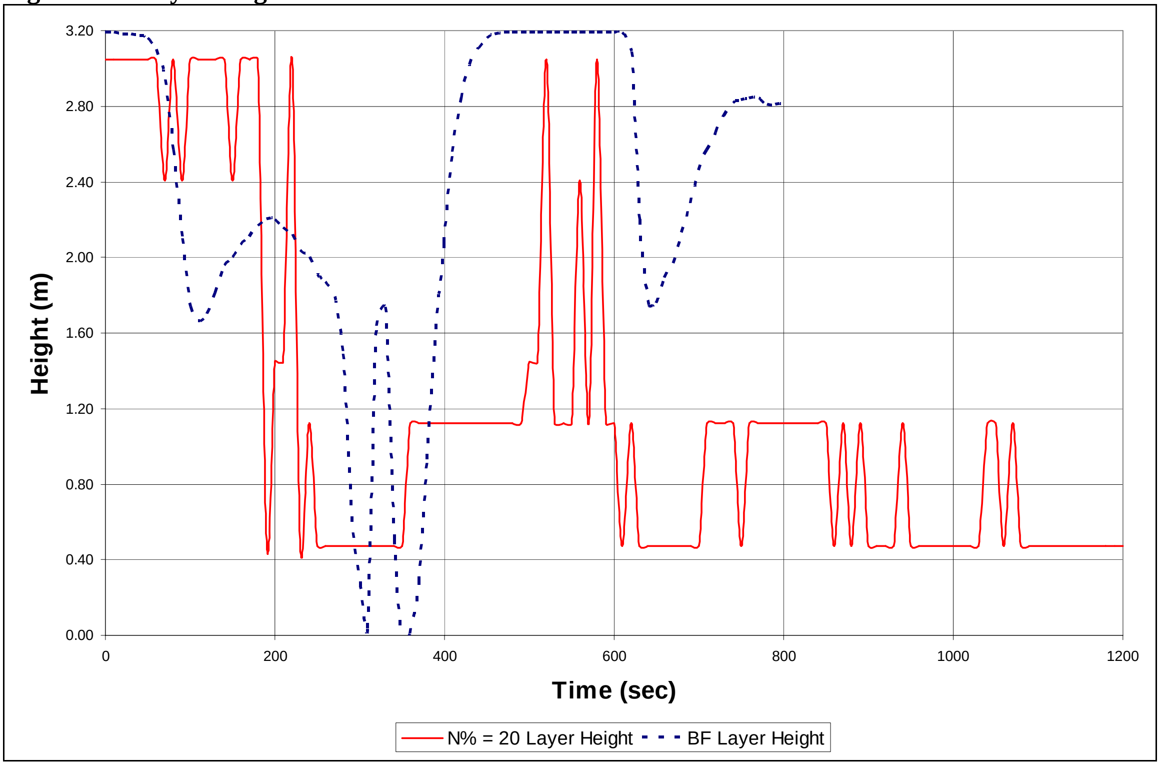
Figure 7.25 Layer Height in Hallway near Lounge Door



The layer height predicted by the BRANZFIRE simulation in the hallway for the vertical vent simulation is similar to the height predicted by the horizontal vent simulation except that the vertical vent simulation predicts the layer height to rise to 2.3m above floor level at 620 seconds after being at floor level for approximately 180 seconds. This increase in the layer height was not predicted by the horizontal vent simulation.

The N% method predicts the layer height to lower to 0.6m above floor level after 140 seconds and then increase to 2.2m above floor level at 430 seconds, at which time the layer height predicted by the BRANZFIRE simulation is starting to lower.

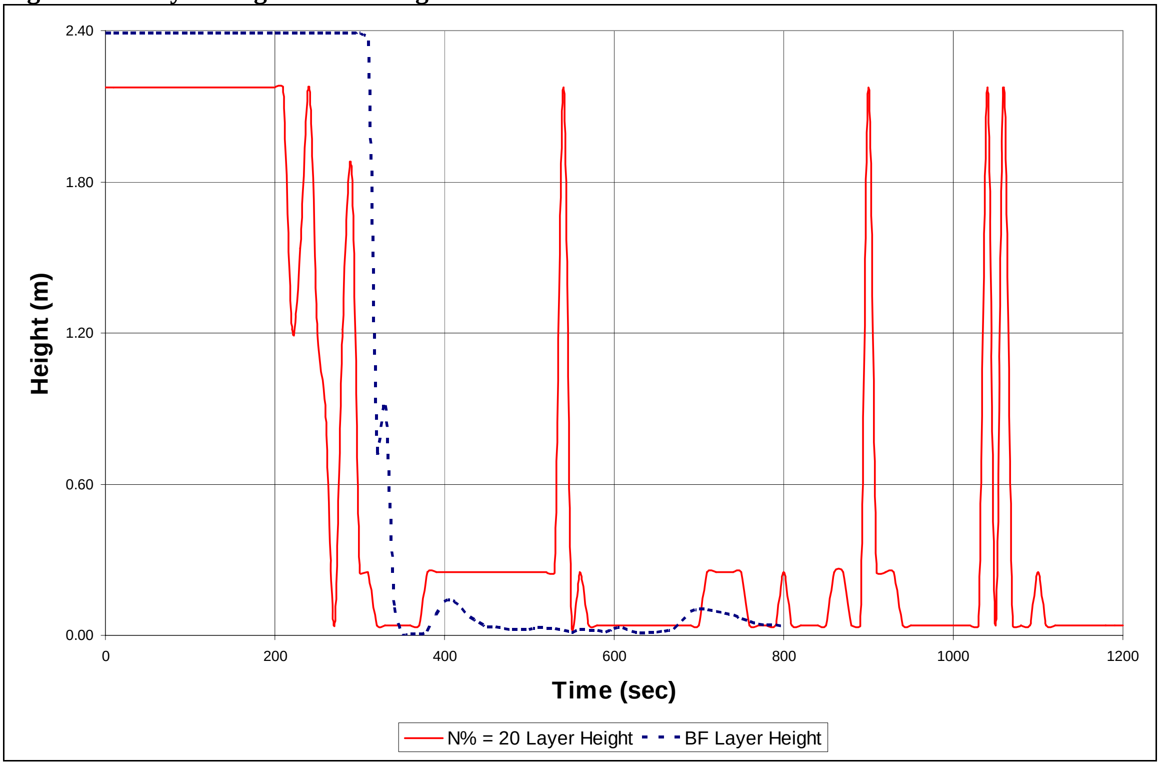
Figure 7.26 Layer Height on Stairs



On the stairs the layer height predicted by the vertical vent simulation predicts the layer height to initially lower to 1.65m above floor level after 110 seconds. Following this it rises to 2.2m above floor level. The layer height is then predicted to lower to floor level before rising back to ceiling level and then lowering to 1.65m above floor level again. This prediction of the layer height is very similar to the horizontal vent simulation which does not predict the lowering of the layer after 600 seconds as shown in Figure 7.26.

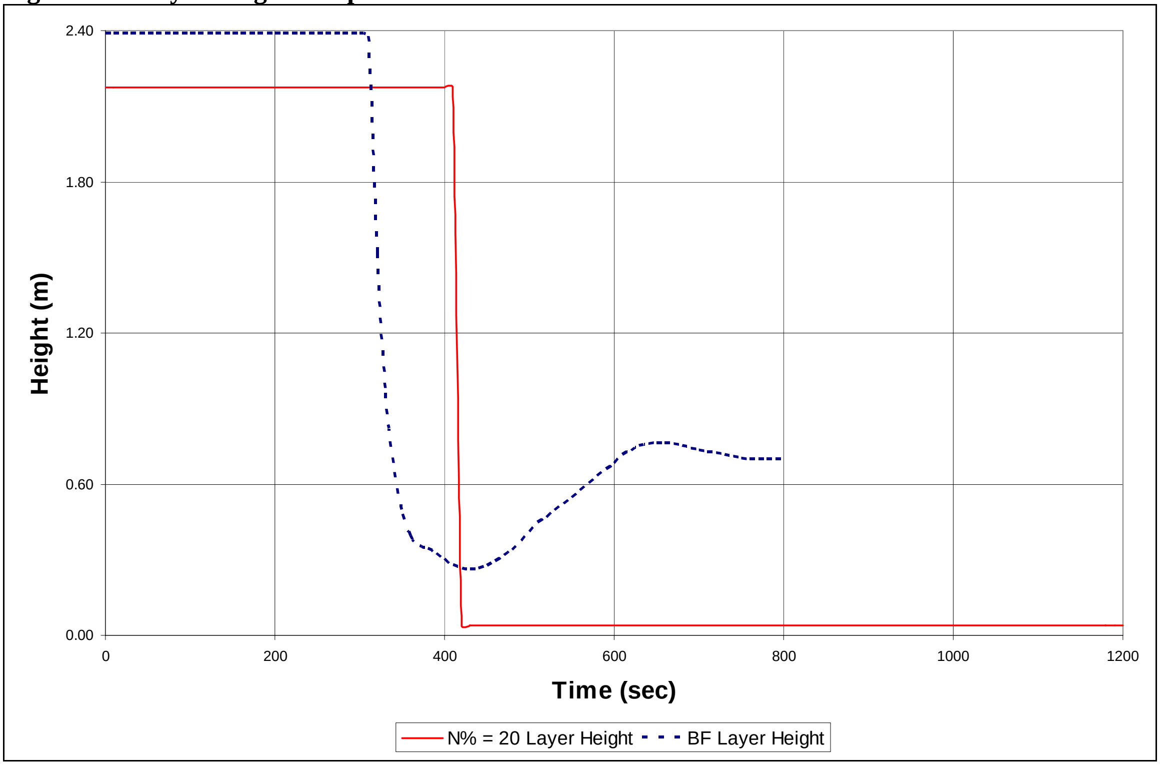
A similar pattern is predicted by the N% method although the maximum and minimum layer heights are not as large. The layer height predictions will not have a high level of accuracy due to the relatively small temperature increases in this compartment.

Figure 7.27 Layer Height on Landing



On the landing the BRANZFIRE simulation makes a good prediction of the layer height, with the layer lowering to floor level at a similar time to that predicted by the N% method and the layer interface staying at that level for the remainder of the simulation. Again, the layer height prediction by the N% method is affected by the low temperature increases in the compartment. This is in contrast to the horizontal vent simulation where the layer height was predicted to not lower at all.

Figure 7.28 Layer Height in Open Bedroom



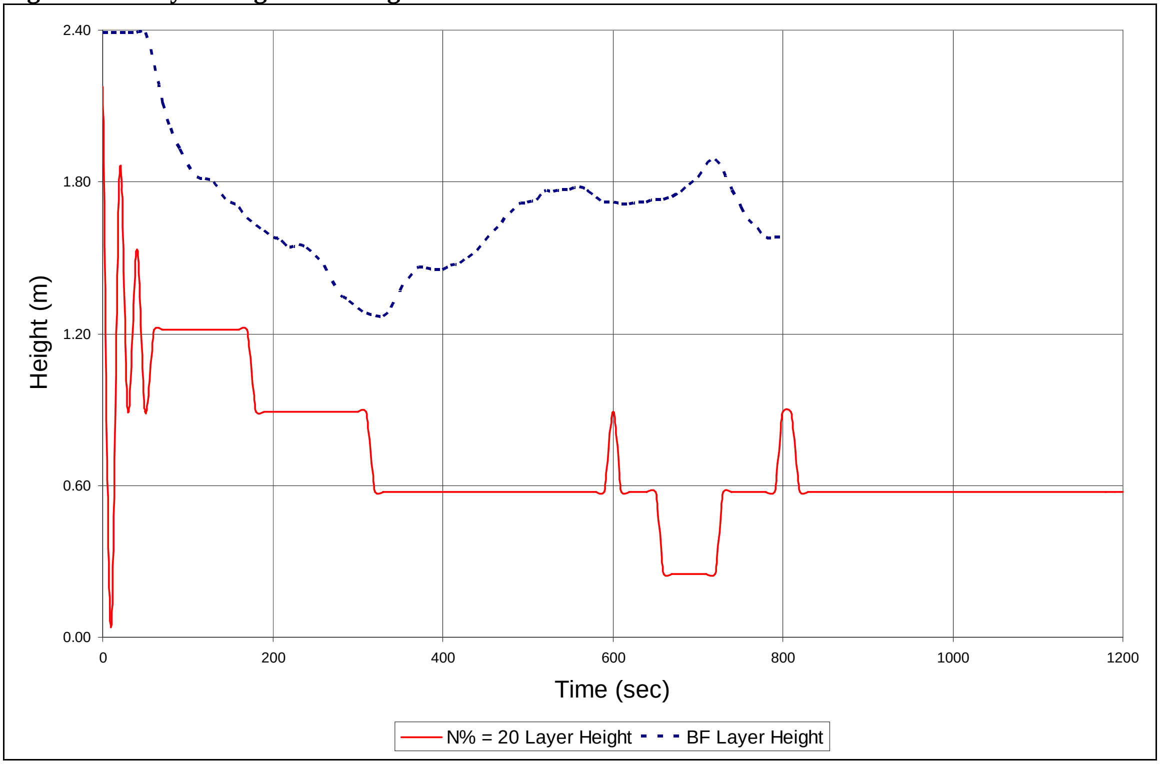
In the open bedroom the BRANZFIRE simulation predicts the layer height to decrease at approximately the same time as the N% method but does not predict the layer to lower as for as the N% method does. The N% method predicts the layer height to decrease to floor level after 420 seconds and remain there for the remainder of the test, while the BRANZFIRE simulation predicts the layer height to lower to a minimum of 0.26m above floor level at 430 seconds and then increase to 0.76m above floor level after 650 seconds. The vertical vent simulation predicts the layer height to lower further than the horizontal vent simulation.

7.2 Vertical Vent Simulation

7.2.1 Layer Height

The layer heights predicted by the N% method using N = 20 and by the BRANZFIRE simulation are shown for each of the compartments in Figures 7.24 to 7.28.

Figure 7.24 Layer Height in Lounge

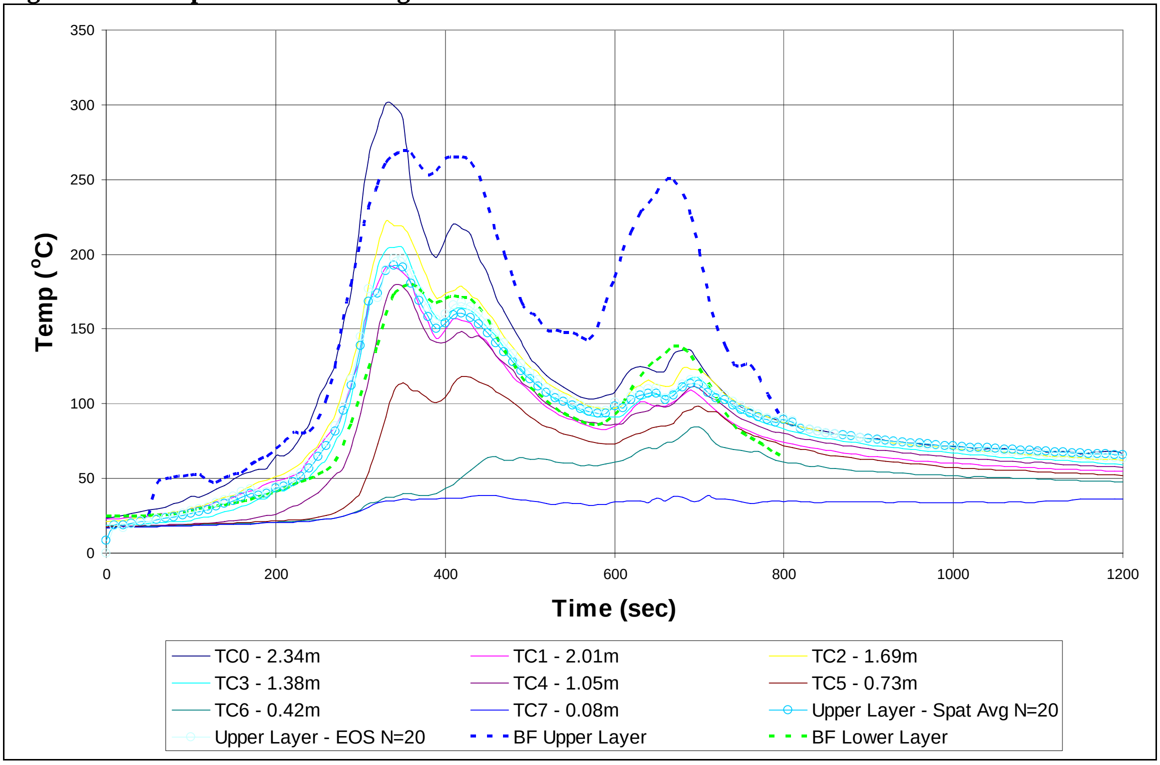


The prediction of the layer height in the lounge is very similar for both the horizontal and vertical vent simulations. The horizontal vent simulation predicts the layer height to descend to a slightly lower level than the vertical vent simulation.

7.2.2 Temperatures

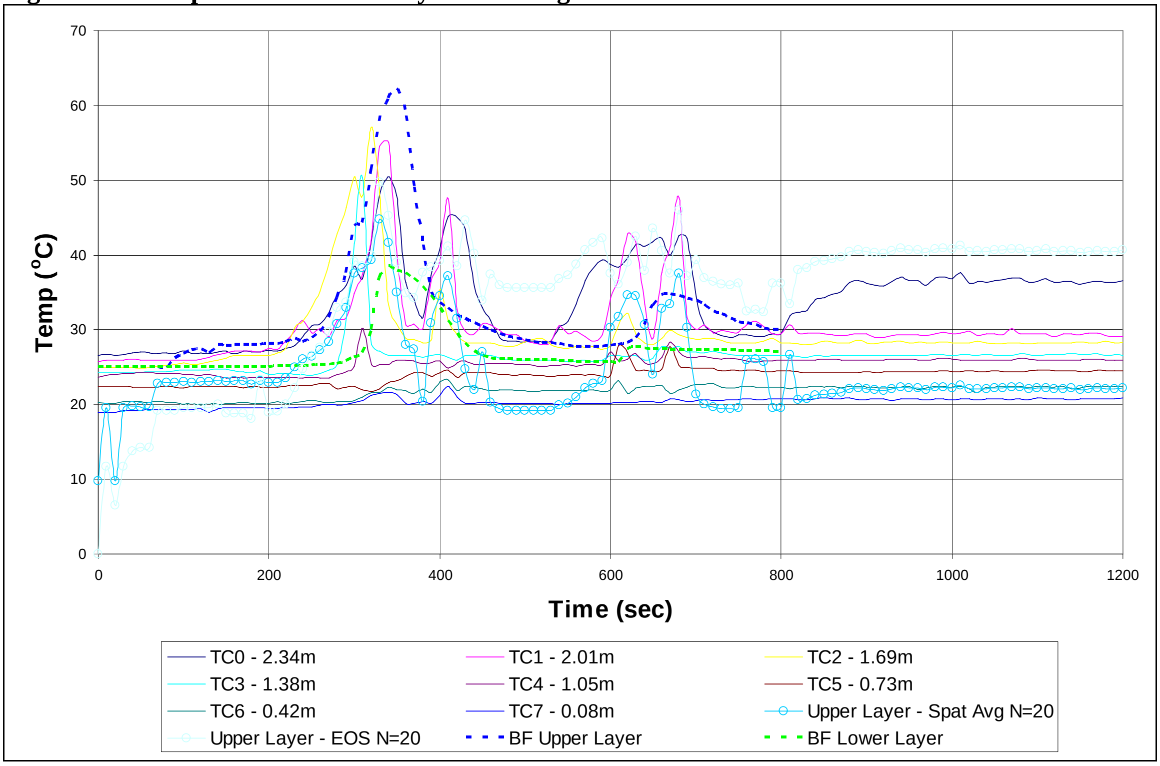
The temperatures recorded during the full scale rig testing and those predicted by the BRANZFIRE simulation for each of the compartments are shown in Figures 7.29 to 7.33.

Figure 7.29 Temperatures in Lounge



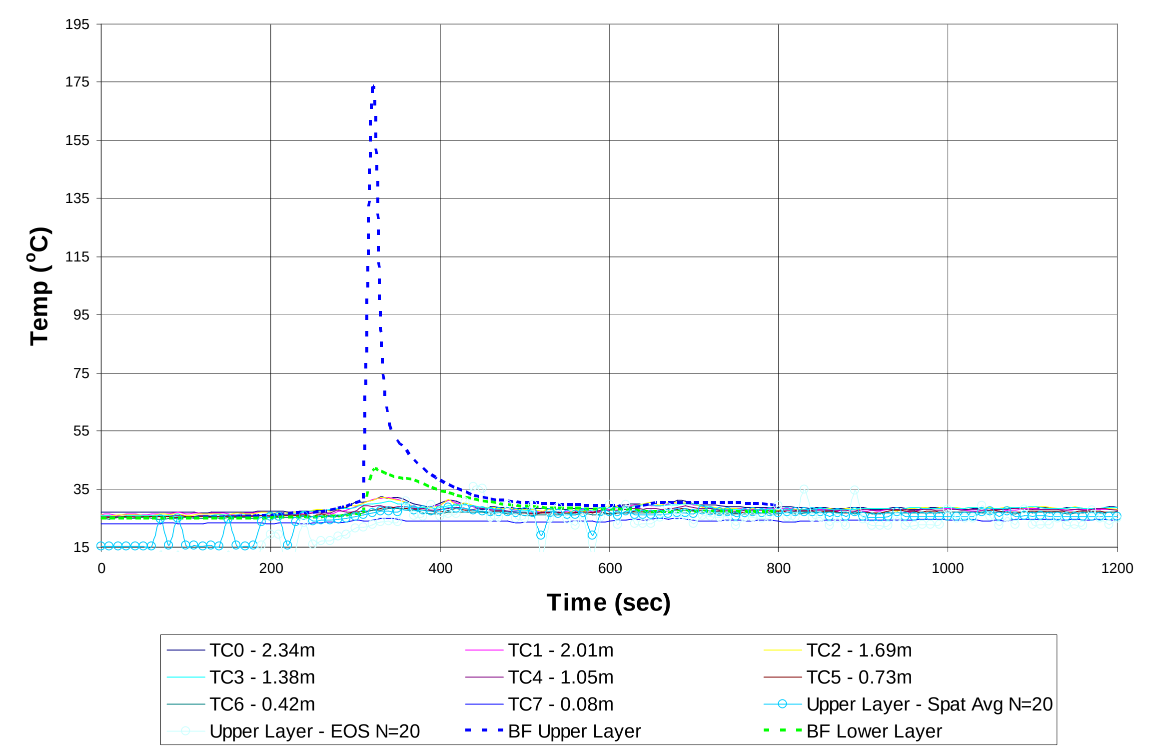
There is only a very small change in the temperatures predicted in the lounge for the horizontal and vertical vent simulations. The change can be seen in the shape of the temperature curve at the first peak where the vertical vent simulation predicts a slight decrease in temperature. The temperature predicted in the first peak by the two simulations is virtually identical.

Figure 7.30 Temperatures in Hallway near Lounge Door



In the hallway the BRANZFIRE simulation predicts a maximum upper layer temperature of 62°C to occur at 350 seconds. In comparison the equation of state and spatial average methods predict a maximum upper layer temperature of between 45°C and 50°C at 350 seconds. A second peak in the upper layer temperature is observed at 680 seconds where the spatial average and equation of state methods predict upper layer temperatures of 38°C and 45°C respectively. At 680 seconds the BRANZFIRE simulation predicts an upper layer temperature of 35°C. This is in contrast to the horizontal vent simulation where the upper layer temperature was under predicted.

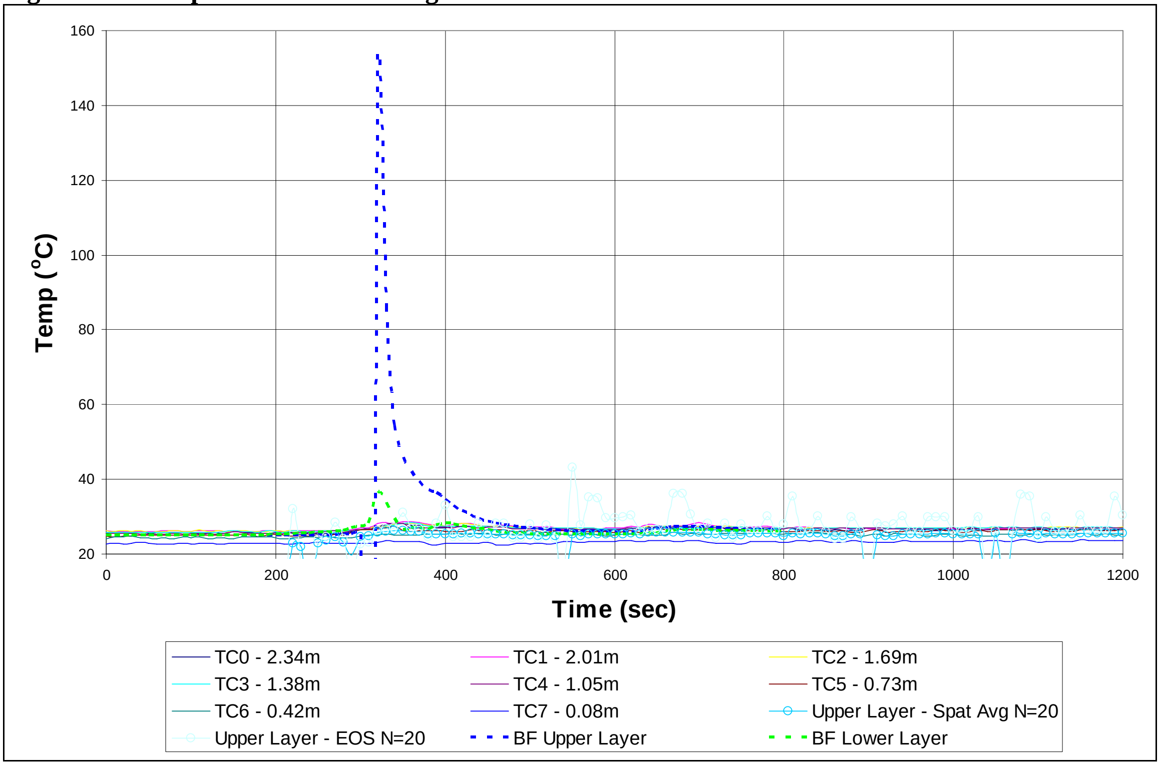
Figure 7.31 Temperatures on Stairs



During the full scale rig testing a small increase in the compartment temperature was recorded with a maximum temperature increase of approximately 5°C. The BRANZFIRE simulation predicts a very sharp temperature increase to a maximum temperature of 173°C at 320 seconds which then decreases rapidly. The horizontal vent simulation slightly over predicted the temperature on the stairs.

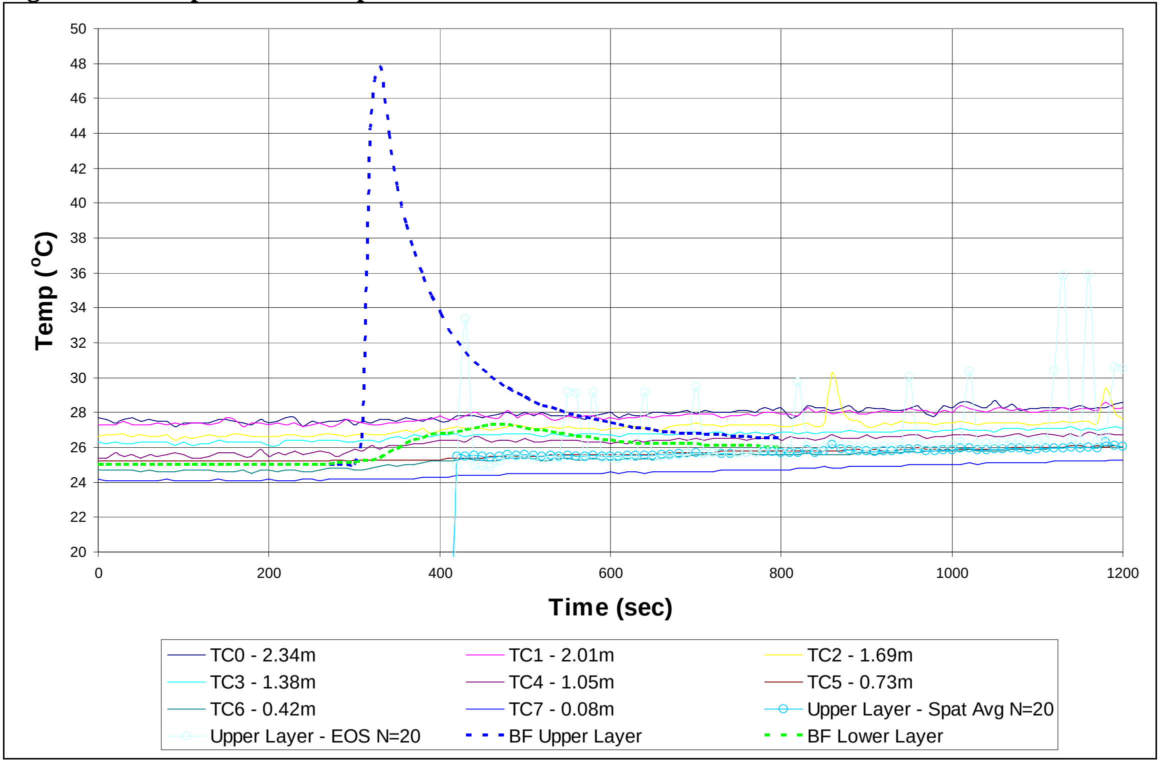
This result is unexpected and may be caused by an instability in the solver used by BRANZFIRE in the calculation of the compartment temperatures. The result was repeated on rerunning the simulation to investigate the irregularity.

Figure 7.32 Temperatures on Landing



The same sharp increase in the upper layer temperature was also predicted on the landing with a peak upper layer temperature of 148°C predicted by the BRANZFIRE simulation. Prior to the data point of 148°C at 320 seconds an upper layer temperature of -608°C was predicted at 310 seconds. This suggests the peak result may have been caused by an instability in the solver used by BRANZFIRE in the calculation compartment temperatures. The horizontal vent simulation slightly over predicted the temperature on the landing.

Figure 7.33 Temperatures in Open Bedroom

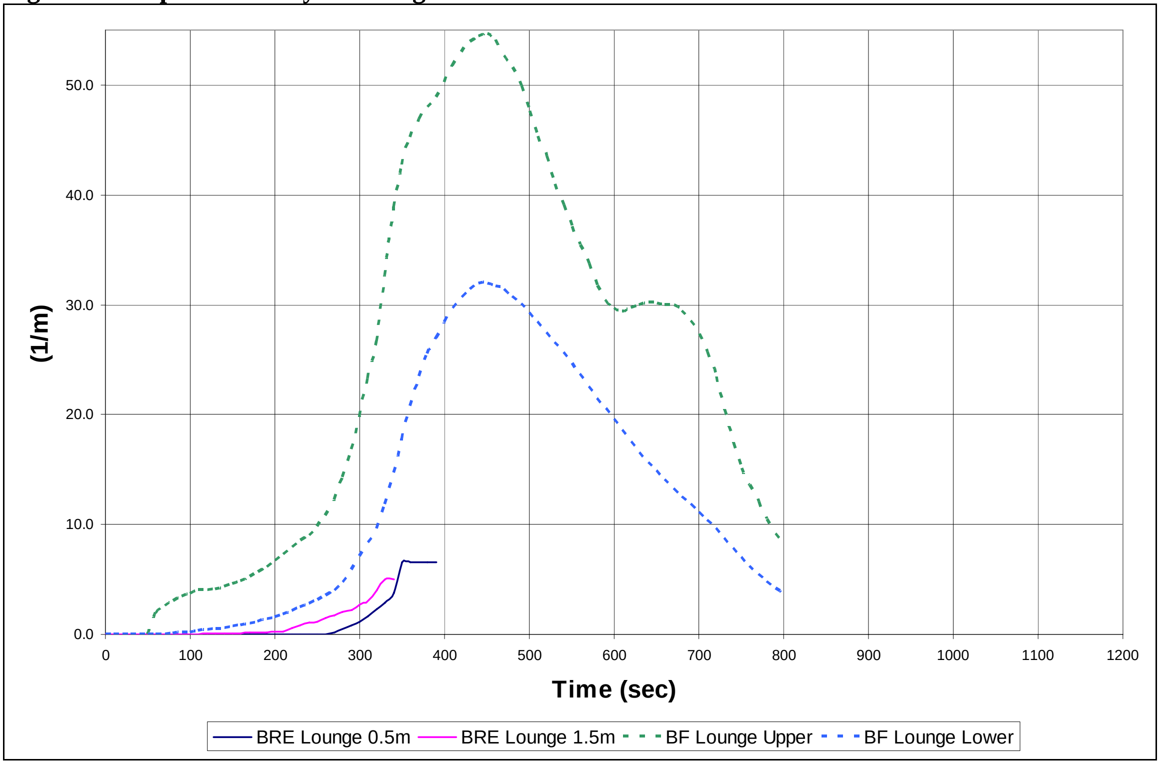


In the open bedroom the BRANZFIRE simulation again predicts a sharp increase in the upper layer temperature with a peak upper layer temperature of 48°C at 330 seconds. Very small temperature increases in the order of 1°C were observed during the full scale rig testing.

7.2.3 Optical Density

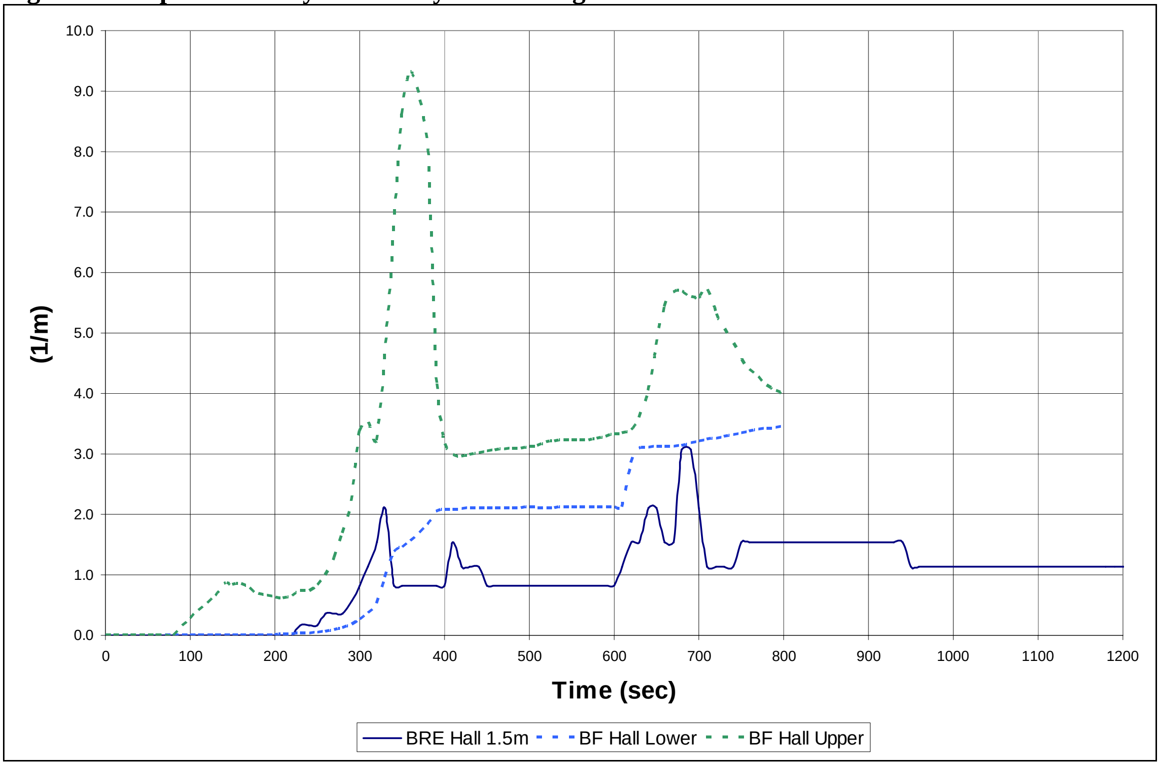
The optical density results predicted by the BRANZFIRE simulation and those recorded in the full scale rig testing for each of the compartments are shown in Figures 7.34 to 7.38.

Figure 7.34 Optical Density in Lounge



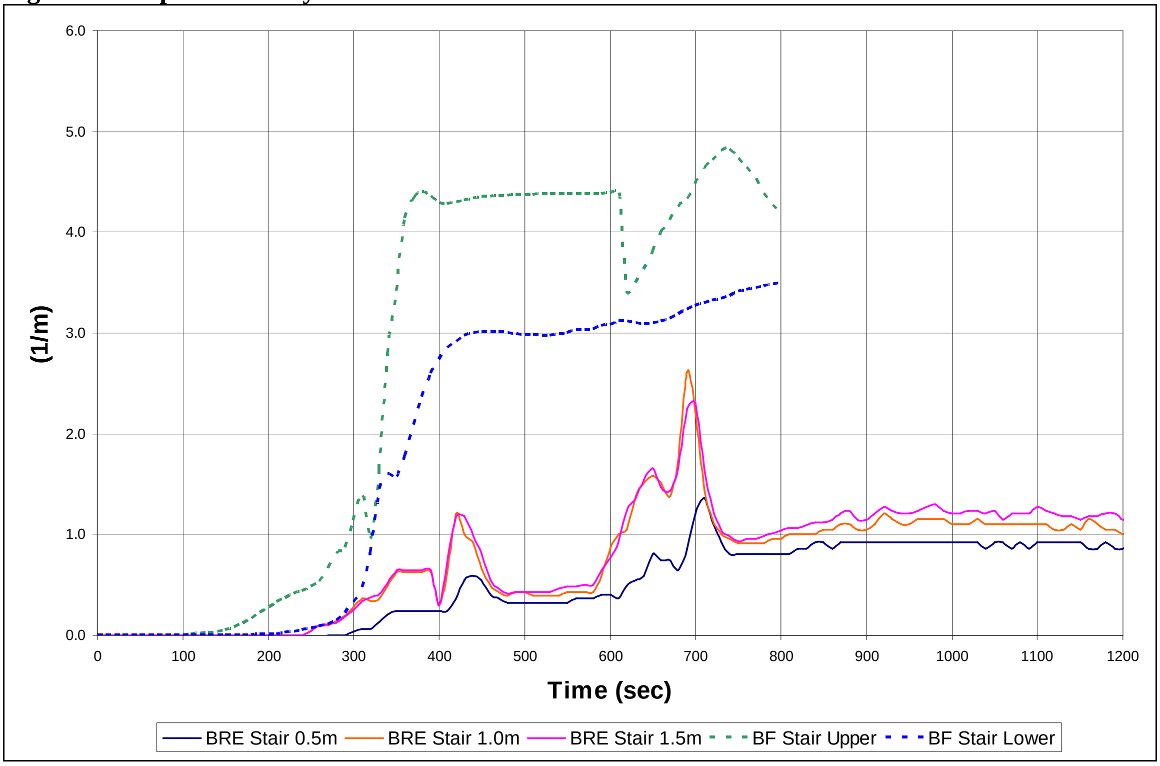
The optical density results predicted by the BRANZFIRE simulation for the lounge are slightly lower for the vertical vent simulation in comparison to the horizontal vent simulation. In the vertical vent simulation a maximum upper layer optical density of $55m^{-1}$ is predicted by the BRANZFIRE simulation compared to $60m^{-1}$ in the horizontal vent simulation. This is in comparison to a maximum value of $6.5m^{-1}$ recorded in the full scale rig testing before the range of the sampling equipment was exceeded.

Figure 7.35 Optical Density in Hallway near Lounge Door



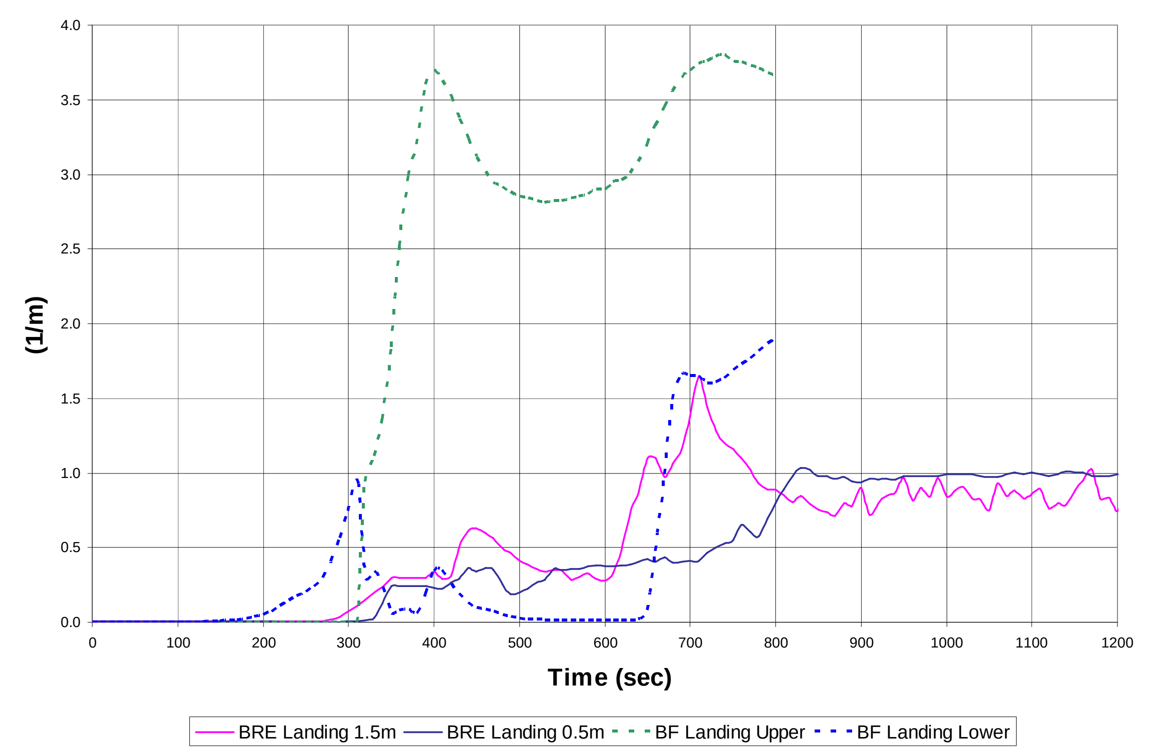
In the vertical vent simulation the optical density in the hallway is over predicted by the BRANZFIRE simulation. The BRANZFIRE simulation predicts a peak upper layer optical density of $9.3m^{-1}$ at 360 seconds in comparison to a value of $2.1m^{-1}$ recorded at 320 seconds in the full scale rig testing. The BRANZFIRE simulation predicts the second increase in the optical density well but over predicts the upper layer optical density by approximately 100%. The horizontal vent simulation made a very good approximation of the optical density in the hallway.

Figure 7.36 Optical Density on Stairs



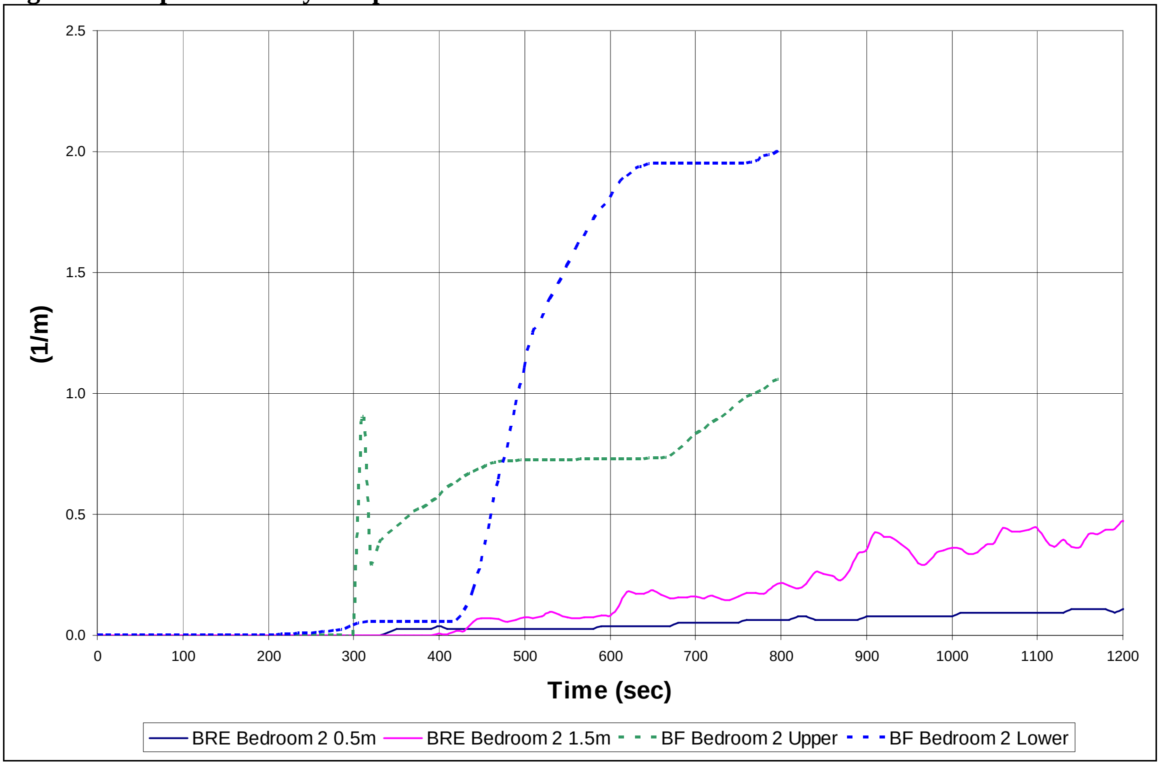
On the stairs the BRANZFIRE simulation predicts a maximum upper layer optical density of approximately 4.8m^{-1} at 740 seconds compared to a value of 2.3m^{-1} recorded at 690 seconds in the upper layer during the full scale rig testing. The BRANZFIRE simulation predicts the upper layer optical density to increase to approximately its peak value by 350 seconds and remain reasonably constant whereas the full scale rig testing recorded two distinct peaks in the upper layer optical density. The optical densities predicted by the vertical vent simulation are approximately twice the values predicted by the horizontal vent simulation.

Figure 7.37 Optical Density on Landing



On the landing the BRANZFIRE simulation predicts the increase in the optical density sooner than was recorded during the full scale testing with a peak optical density of $3.7m^{-1}$ predicted at 400 seconds by the BRANZFIRE simulation. The full scale rig testing recorded a maximum value of $1.65m^{-1}$ at 710 seconds in the upper layer. The horizontal vent simulation made a good approximation of the upper layer optical density.

Figure 7.38 Optical Density in Open Bedroom



In the open bedroom the BRANZFIRE simulation predicts a much larger increase in the optical density than was recorded in the full scale testing. The BRANZFIRE simulation predicts the lower layer optical density to be greater than the upper layer optical density and to reach a maximum value of 1.99m^{-1} at 800 seconds. The upper layer optical density reaches a peak value of 1.05m^{-1} at 800 seconds.

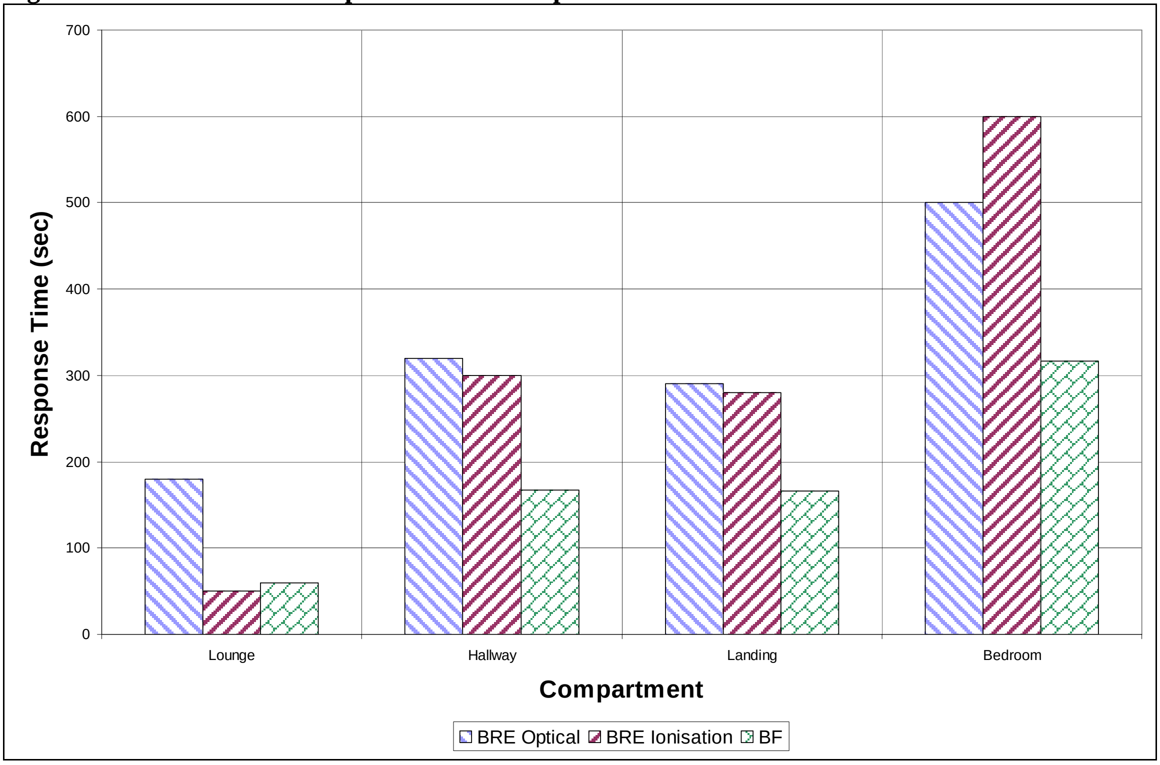
The trend of the lower layer optical density exceeding the upper layer optical density is not seen in the full scale rig testing. The upper layer optical density recorded in the full scale rig testing reached a peak value of 0.47m^{-1} at 1200 seconds.

The horizontal vent simulation also over predicted the optical densities in the open bedroom.

7.2.4 *Smoke Alarm Response*

The smoke alarm response times for each of the compartments for the full scale rig testing and the activation times predicted by the BRANZFIRE simulation are shown in Figure 7.39.

Figure 7.39 Smoke Alarm Response for All Compartments



The BRANZFIRE simulation predicts an activation time of 60 seconds in the lounge for the optical smoke alarm. This is in comparison to an activation time of 180 seconds recorded in the full scale rig testing for the optical smoke alarm.

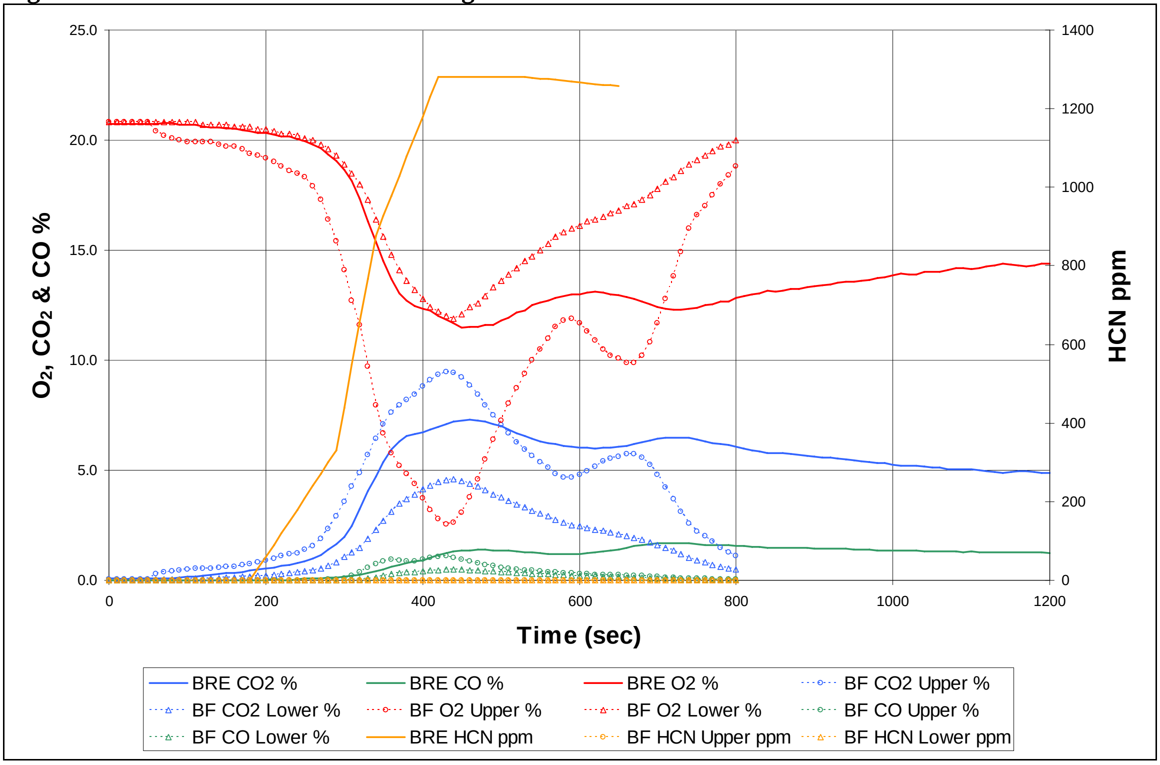
An activation time of approximately 170 seconds is predicted in the hallway by the BRANZFIRE simulation, approximately 150 seconds faster than the optical and ionisation smoke alarms in the full scale rig testing. On the landing the activation time predicted by the BRANZFIRE simulation for the optical smoke alarm is 170 seconds in comparison to values of 290 and 280 seconds recorded in the full scale rig testing for the optical and ionisation smoke alarms respectively.

The activation time predicted by the BRANZFIRE simulation in the open bedroom is approximately 320 seconds in comparison to 500 seconds for the optical smoke alarm and 600 seconds for the ionisation smoke alarm in the full scale rig testing.

7.2.5 *Gas Concentration*

The gas concentrations for each of the compartments predicted by the BRANZFIRE simulation and the values recorded in the full scale rig testing are shown in Figures 7.40 to 7.43.

Figure 7.40 Gas Concentrations in Lounge

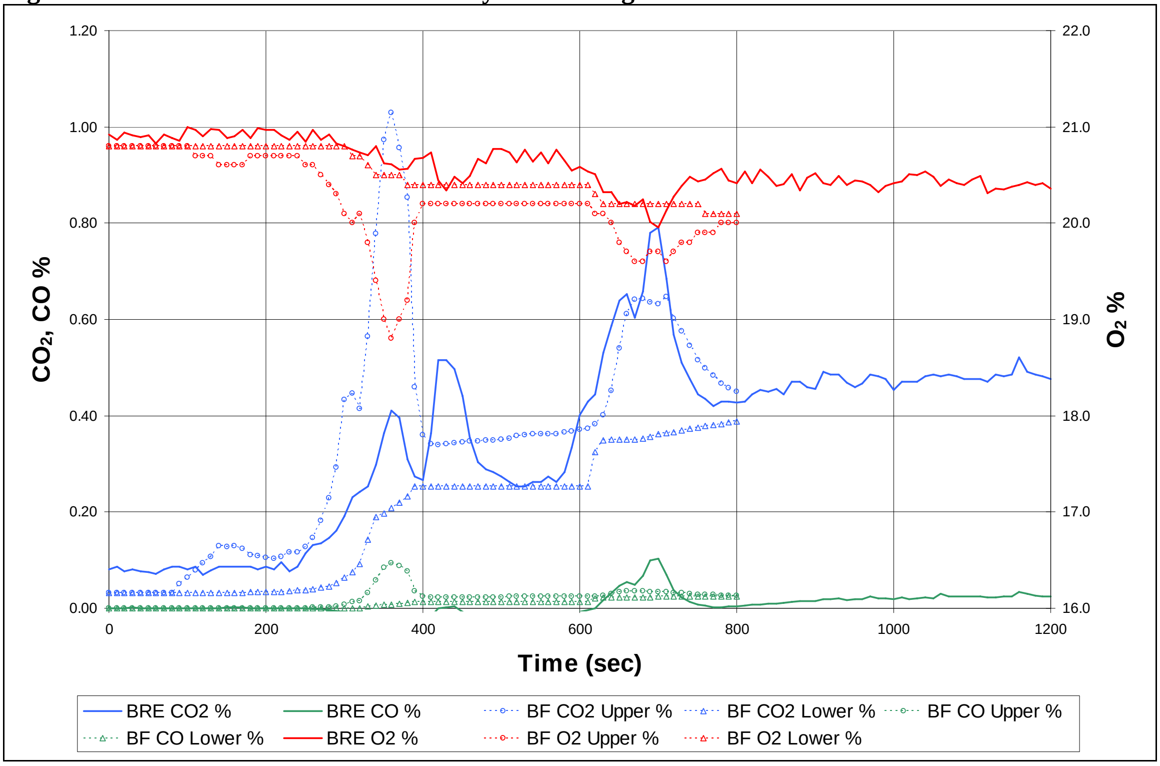


The vertical vent simulation predicts the oxygen concentration to lower to approximately 2.6% compared to 11.5% recorded during the full scale rig testing. The horizontal vent simulation predicted the oxygen concentration to lower to 1.7%.

The carbon dioxide concentration predicted by the BRANZFIRE vertical vent simulation reaches a peak of 9.5% at 430 seconds in comparison to the full scale rig testing where a value of 7.1% is recorded at the same time. The horizontal vent simulation predicted a maximum value of 9.7%, very similar to the vertical vent simulation.

The carbon monoxide and hydrogen cyanide concentrations were under predicted by the horizontal vent simulation and were also under predicted by the vertical vent simulation.

Figure 7.41 Gas Concentrations in Hallway near Lounge Door

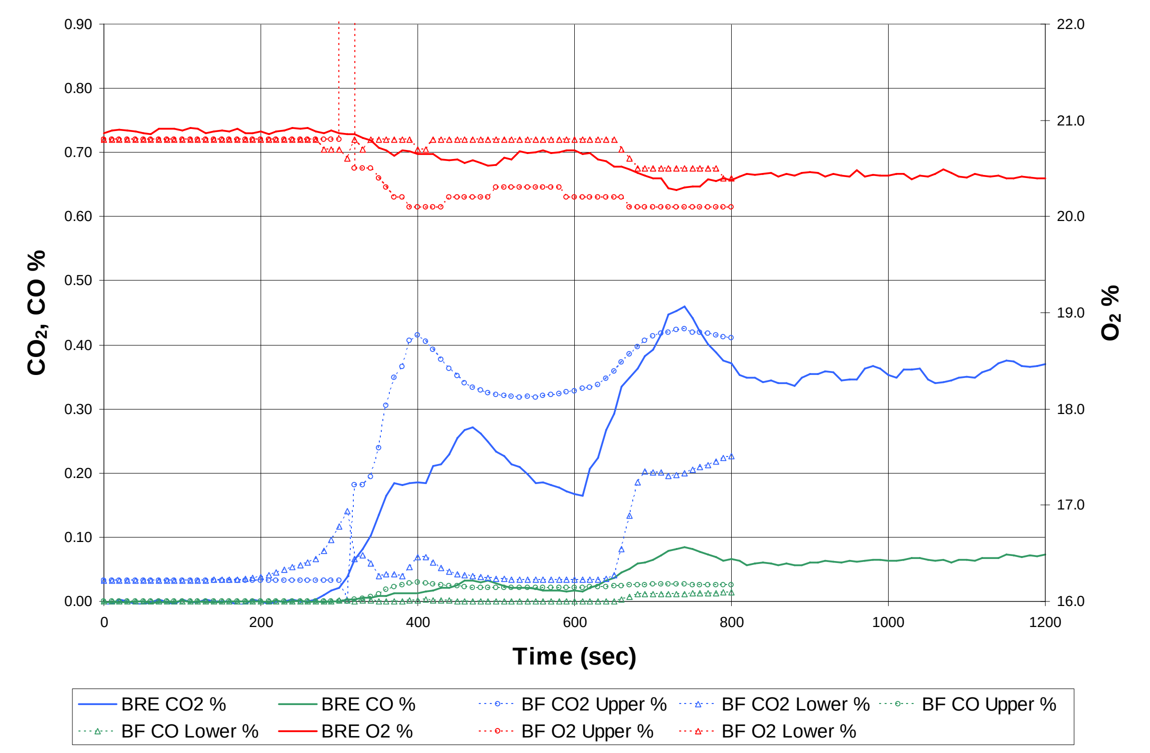


In the hallway the BRANZFIRE simulation predicts the oxygen concentration to decrease to 18.8% after 360 seconds in comparison to the full scale rig testing where the minimum oxygen concentration of 19.95% was recorded at 700 seconds. At 700 seconds the BRANZFIRE simulation predicts an oxygen concentration of 19.6% in the upper layer. The horizontal vent simulation made a better approximation of the oxygen concentration in the hallway.

The carbon dioxide concentration predicted by the BRANZFIRE simulation reaches a peak value of 1.03% at 360 seconds in comparison to the full scale rig testing where a maximum value of 0.8% was recorded at 700 seconds. The vertical vent simulation makes a better approximation of the carbon dioxide concentration than the horizontal vent simulation.

A maximum carbon monoxide concentration of 0.1% was recorded at 700 seconds in the full scale rig testing. The BRANZFIRE simulation predicts a maximum upper layer concentration of 0.09% at 360 seconds.

Figure 7.42 Gas Concentrations on Landing

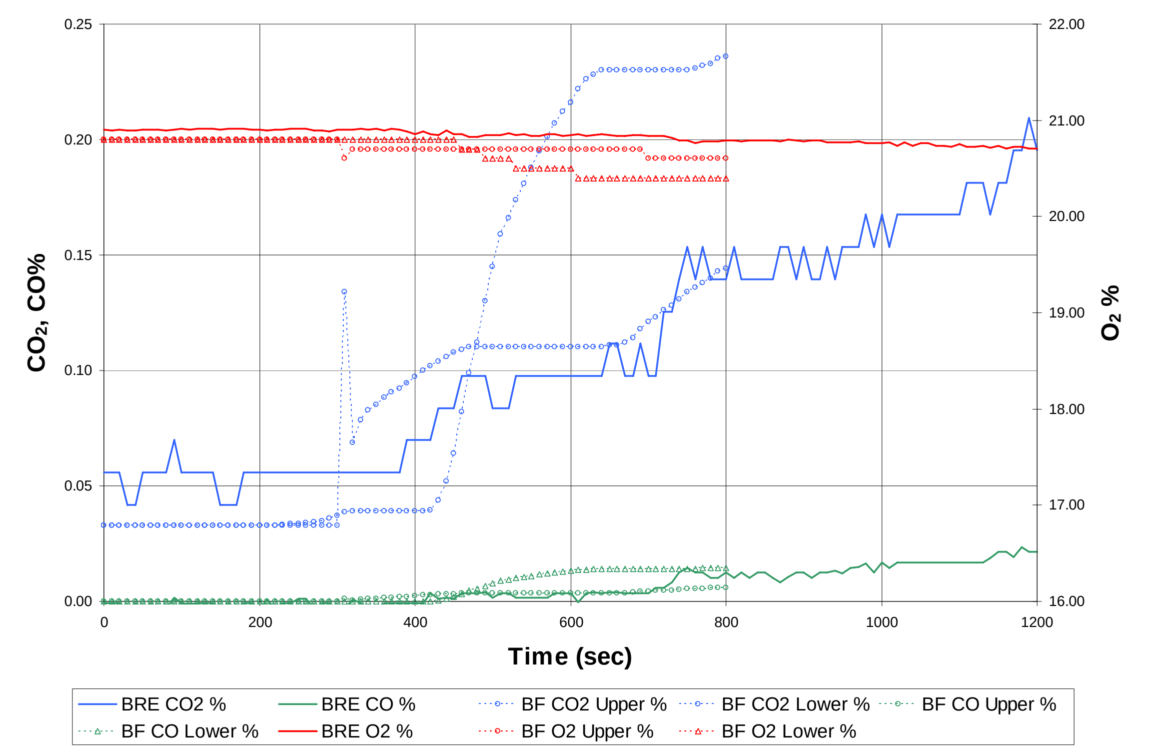


On the landing the BRANZFIRE simulation predicts the oxygen concentration in the upper layer to lower to 20.1% after 390 seconds and remain at approximately that concentration for the remainder of the simulation. The full scale rig testing recorded a gradual decrease in the oxygen concentration to a minimum value of 20.3% at 730 seconds. This is a better approximation than the horizontal vent simulation. A spike in the oxygen concentration is shown at the same time as the peak temperature was predicted in this compartment by the BRANZFIRE simulation. This also suggests an instability in the BRANZFIRE solver routine.

The BRANZFIRE simulation predicts a peak carbon dioxide concentration of 0.41% in the first peak at 400 seconds and 0.42% in the second peak at 740 seconds. A maximum value of 0.27% was recorded in the first peak at 470 seconds and 0.46% in the second peak at 740 seconds in the full scale rig testing. This is a better approximation than the horizontal vent simulation.

A maximum carbon monoxide concentration of 0.08% was recorded at 740 seconds in the full scale rig testing. The BRANZFIRE simulation predicts a maximum upper layer carbon monoxide concentration of 0.03% to occur at 400 seconds.

Figure 7.43 Gas Concentrations in Open Bedroom



In the open bedroom a decrease in the oxygen concentration of less than 1% is predicted by both the BRANZFIRE simulation and recorded in the full scale rig testing. The BRANZFIRE simulation predicts the change in the oxygen concentration to be approximately two times larger than was recorded in the full scale rig testing. Both the horizontal and vertical vent simulations make reasonable predictions of the oxygen concentration.

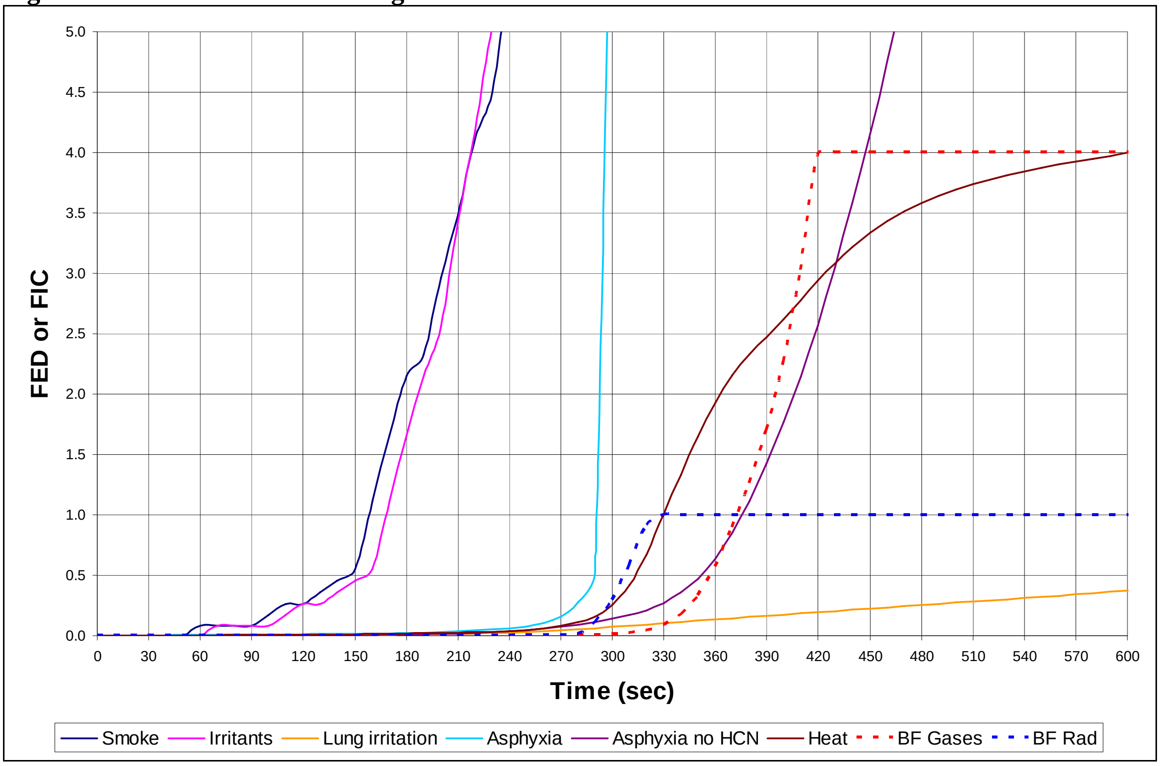
The BRANZFIRE vertical vent simulation predicts an increase in the carbon dioxide concentration to a maximum value of 0.24% at 800 seconds in comparison to the full scale rig testing where a value of 0.2% was recorded at 1200 seconds. This is similar to the horizontal vent simulation.

A very small increase in the carbon monoxide concentration was observed in the open bedroom with a maximum value of 0.02% in the full scale rig testing and a maximum value of 0.014% predicted by the BRANZFIRE simulation.

7.2.6 *Fractional Effective Dose*

The fractional effective dose and fractional irritant concentration determined from the observations in the full scale rig testing and the values predicted by the BRANZFIRE simulation for the lounge are shown in Figure 7.44.

Figure 7.44 FED and FIC in Lounge



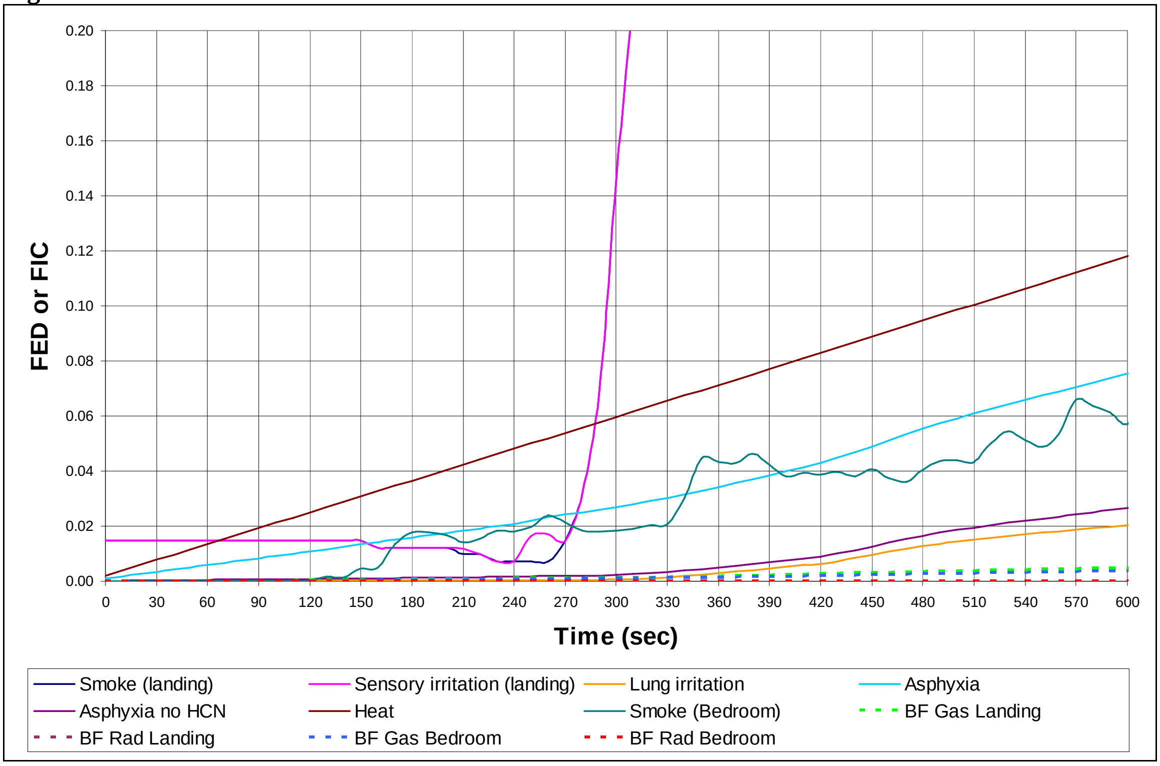
The BRANZFIRE simulation predicts a fractional effective dose of 1.0 due to radiation to be reached after 320 seconds, in comparison to the full scale rig testing where a value of 1.0 is reached after 330 seconds.

The fractional effective dose due to asphyxiant gases not including hydrogen cyanide reaches a value of 1.0 after 380 seconds in both the full scale rig testing and in the BRANZFIRE simulation.

These results are very similar to the results of the horizontal vent simulation.

The fractional effective dose and fractional irritant concentration for the open bedroom are shown in Figure 7.45.

Figure 7.45 FED and FIC in Bedroom



The BRANZFIRE simulation predicts no increase in the fractional effective dose due to radiation because of the small temperature increase in this room. The full scale rig testing predicts a maximum value of 0.12 at 600 seconds which is well below an incapacitating dose.

The BRANZFIRE simulation predicts a value of 0.004 for the fractional effective dose due to asphyxiant gases in comparison to a maximum value of 0.03 in the full scale rig testing for asphyxiant gases with no hydrogen cyanide.

8 Discussion

The discussion of the results presented in the Sections 5 to 7 is divided into three parts. Section 8.1 discusses the general accuracy with which the BRANZFIRE simulations predict the conditions in the room of fire origin and the compartments remote from the fire. Section 8.2 discusses the accuracy of the two methods for representing the hallway, stair and landing compartments with the two and three compartment models and Section 8.3 discusses the accuracy of the results for predicting life safety.

8.1 General accuracy of simulations

The general accuracy of the simulations for each of the variables that has been presented in Sections 5 to 7 is discussed below.

8.1.1 Layer Height

Using the N% method with N = 20 the layer height in the lounge is predicted to lower to approximately 0.6m above floor level in most of the simulations. In all of the simulations BRANZFIRE under predicts the lowering of the interface layer height in the lounge in comparison to the N% method. Due to the large temperature differences recorded between individual thermocouples on a thermocouple trees the lounge is one area where a relative degree of confidence can be placed in the results of the N% method. In other rooms where there are only small temperature differences between individual thermocouples, determining the location of the interface height using the N% method can be difficult.

The layer height in the hallway is well predicted for the two compartment model simulations but is not well predicted by the three model compartment simulations. The layer height on the landing is well predicted in all of the simulations that were modelled which suggests good modelling of the hot gas transfer to this compartment.

The elevation of the layer height in the open bedroom was generally predicted well by the BRANZFIRE simulations. However the timing of the lowering of the layer height was predicted later in the BRANZFIRE simulations than was seen in the full scale rig testing. There is a low level of confidence in the layer height predicted by the N% method in this room due to the negligible temperature changes observed during the full scale rig testing.

8.1.2 Temperatures

Based on the results presented in Sections 5 to 7 it can be seen that the BRANZFIRE simulations over predict the temperature in the fire compartment in all of the simulations. In some simulations this over prediction is significant. The over prediction of the temperature results may be caused by too high a value for the heat of combustion being used for the fuel. The prediction of the upper and lower layer temperature is also dependent on the prediction of the layer interface height. The layer interface height determines the volume of the upper and lower zones in the computational model. An inaccurate prediction of the layer interface will produce inaccurate predictions of the layer temperatures.

In all of the simulations the predicted temperatures in the hallway were slightly below what was measured during the full scale rig testing but were a reasonable approximation of the upper layer temperature.

On the landing the BRANZFIRE simulation generally makes very good predictions of the upper layer temperature. The temperature in the stair compartment for the three compartment simulations is generally under predicted by the BRANZFIRE simulations. The BRANZFIRE simulations appear to model the transfer of hot gases to the landing reasonably well.

In the simulations with the lounge door open the temperature in the open bedroom is under predicted by the BRANZFIRE simulations. The transfer of hot gases between the landing and bedroom is not well predicted by the BRANZFIRE simulations.

As noted in Section 3.2, the location of the fire influences the upper layer temperatures and layer heights due to the amount of entrainment in the fire plume. Further study using an unbounded fire plume could be carried out to determine the effect of the fire location on the compartment temperatures and layer heights.

8.1.3 Optical Density

In all of the compartments the optical densities predicted by the BRANZFIRE simulations were far in excess of the readings recorded during the full scale testing. It should be noted that in the lounge, hallway and the open bedroom the range of the optical density equipment used in the full scale testing was exceeded, so a full comparison of results could not be made. The BRANZFIRE simulations also predicted a rise in optical density sooner than was observed during the full scale testing. The magnitude of the difference between the predicted and recorded optical densities suggests that the value chosen for the yield of smoke for the fire was too high.

Because the optical density was over predicted to such an extent by the BRANZFIRE simulations, a sensitivity analysis was carried out to determine the impact of changing the value for the smoke yield on the optical density and smoke alarm activation times. The sensitivity analysis was carried out using the highest and lowest values of the smoke yield from the information from Tewarson (2002) and using the three compartment simulation for test CDT17.

The results of the optical density sensitivity analysis for the lounge and for the open bedroom are shown in Figures 8.1 and 8.2. Note that in the figures presented in this section BRANZFIRE has been abbreviated to BF in the data series legend.

Figure 8.1 Optical Density Sensitivity Analysis in Lounge

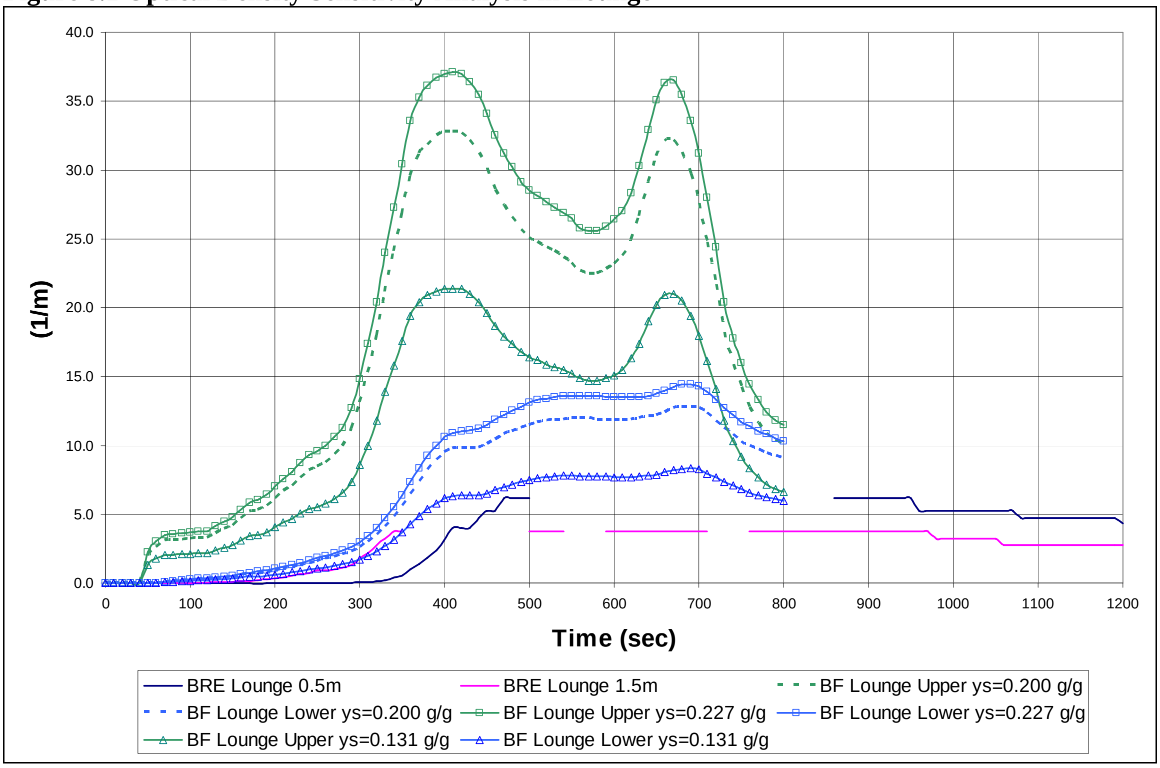
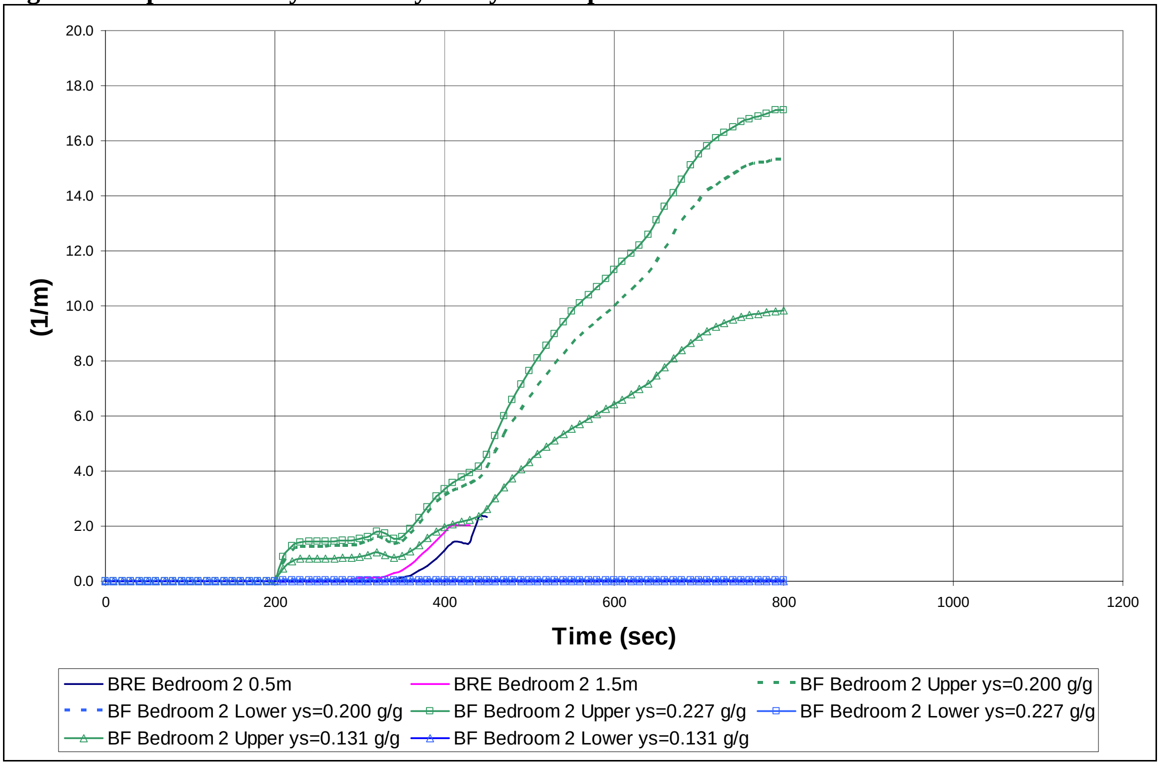


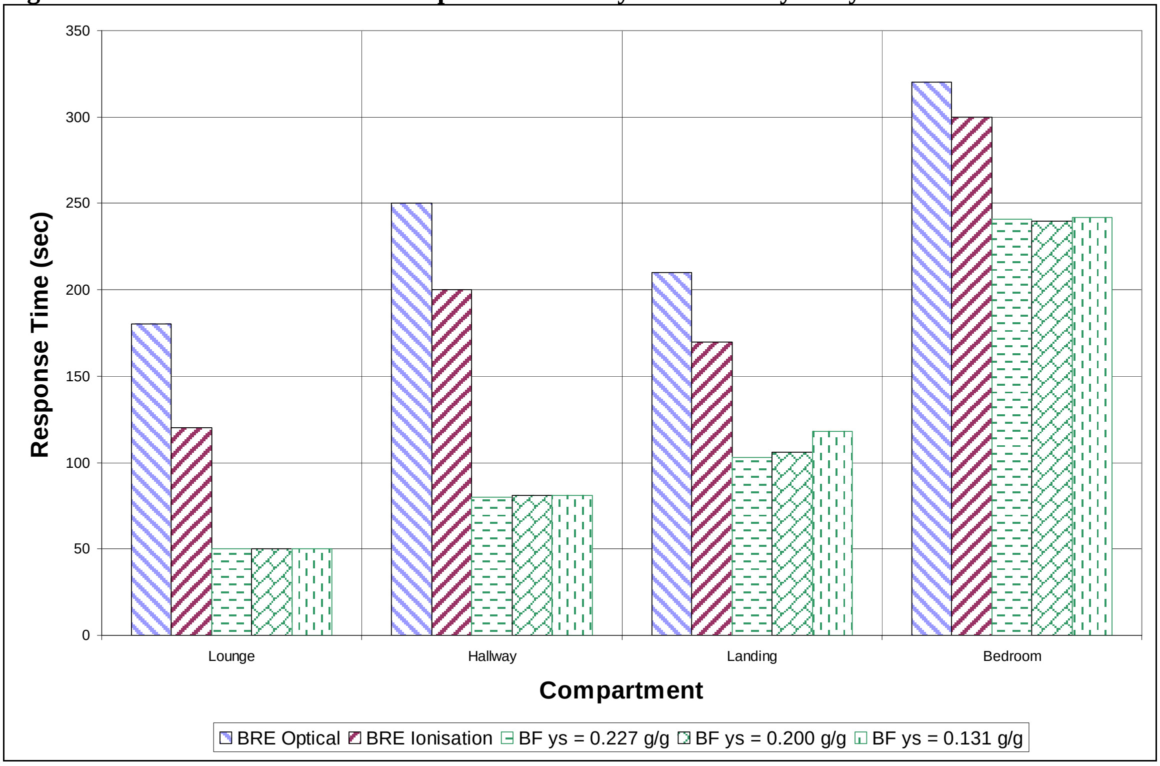
Figure 8.2 Optical Density Sensitivity Analysis in Open Bedroom



The sensitivity analysis shows that reducing the smoke yield value to the lowest value improves the prediction of the optical density by the BRANZFIRE simulation but does not reduce the predicted optical densities sufficiently to be an accurate prediction of the full scale rig testing.

Figure 8.3 shows the smoke alarm response times for the varied smoke yields

Figure 8.3 Smoke alarm activation response to smoke yield sensitivity analysis



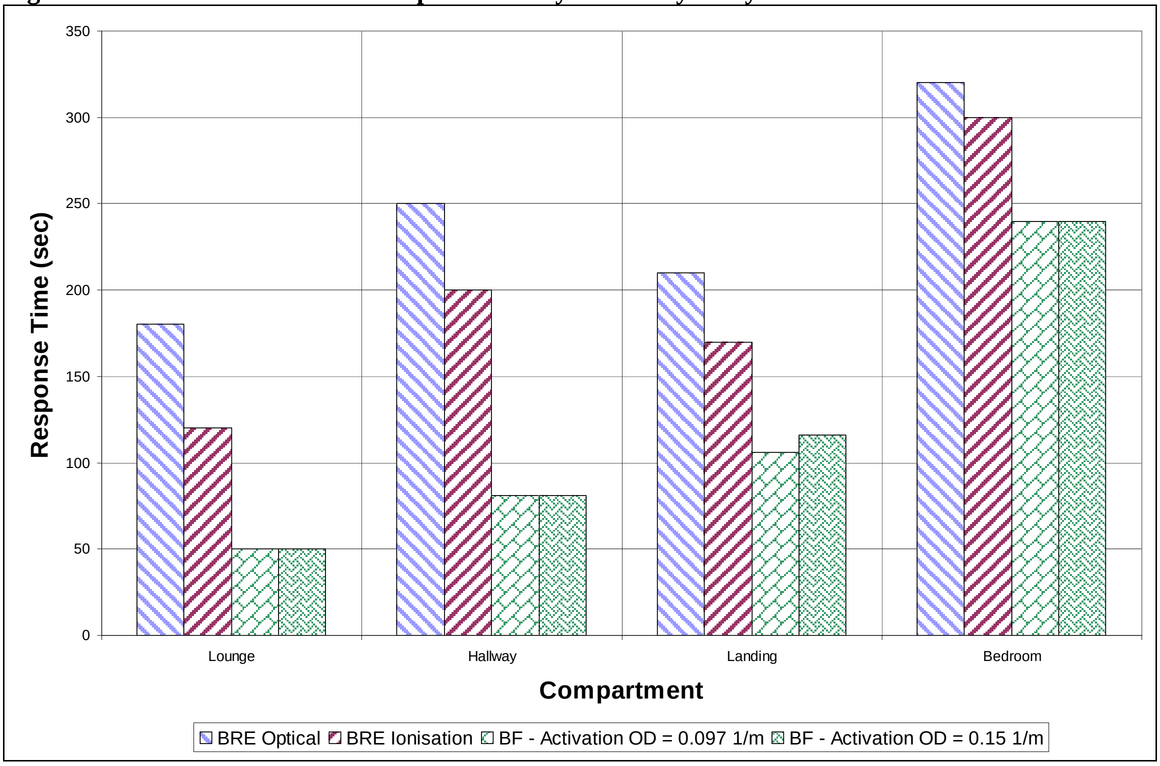
From the sensitivity analysis it can be seen that altering the smoke yield value has only a very small effect on the predicted smoke alarm activation times. Reducing the smoke yield to the lowest value from Tewarson (2002) does not increase the smoke alarm activation times sufficiently for the predicted activation times to be an accurate prediction of the full scale rig testing.

8.1.4 Smoke alarm response

The optical smoke alarm response times predicted by the BRANZFIRE simulations are faster than the optical and ionisation smoke alarm response times recorded during the full scale rig testing. This is partly due to the higher optical densities predicted by the BRANZFIRE simulations which is due to an over prediction of the soot yield from the fire. The activation optical density used in the BRANZFIRE simulation may also be more sensitive than the activation optical densities of the smoke alarms used in the full scale rig testing. The activation optical density for the smoke alarms in the full scale tests was not provided by Purser et al (1998) and BS5446 allows a range of optical density at activation.

Figure 8.4 shows a comparison of the smoke alarm activation times for the optical and ionisation smoke alarms recorded during the full scale rig testing. It also shows the activation times predicted by the BRANZFIRE simulation using smoke alarm activation optical densities of $0.097m^{-1}$ and $0.15m^{-1}$. It was noted in Section 3 that BS5446 requires smoke alarms to activate before a maximum optical density of not less than $0.15m^{-1}$ is reached during certification testing. The value of $0.097m^{-1}$ is the activation optical density specified by AS1603.2 for normal sensitivity smoke alarms.

Figure 8.4 Smoke alarm activation optical density sensitivity analysis



The sensitivity analysis shows that there is no change in the predicted smoke alarm activation times for the smoke alarms in the lounge, hallway and bedroom for the BRANZFIRE simulations using the two activation optical density values. There is an increase of 10 seconds in the predicted activation time on the landing with the activation optical density set to $0.15m^{-1}$. Smoke alarms with high or very high sensitivity to AS1603.2 have not been tested in the sensitivity analysis as they would produce more rapid activation times.

The optical density figures in Sections 5 to 7 show that the optical densities of $0.10m^{-1}$ to $0.15m^{-1}$ that would cause activation of the smoke alarms are reached very quickly in the simulations. The activation optical densities are small values in comparison to the maximum optical densities predicted in the BRANZFIRE simulations. Predicting the generation and movement of the quantity of smoke particulate required to cause activation of the smoke alarms would require a computational model with greater sophistication than a two zone model.

Brammer (2002) showed the difficulty in achieving good prediction of the smoke alarm activation times using FDS with a 75mm grid mesh.

It should be noted that although BRANZFIRE may quantitatively over predict the activation times of the smoke alarms, it does qualitatively predict the correct order of activation of smoke alarms through the compartments of the house with the exception of the order of the landing and the hallway.

The difference in the activation time between the BRANZFIRE simulations and the full scale rig tests may be more attributable to differences in the time predicted for smoke to enter the compartment or to enter the smoke alarm chamber, rather than being due to the smoke alarm activation optical density. The activation optical density sensitivity analysis indicated that varying the smoke alarm activation optical density caused only a slight change in the predicted smoke alarm activation times as shown in Figure 8.4.

8.1.5 Gas Concentration

The reduction in the oxygen content is over predicted by the BRANZFIRE simulations in the lounge. The minimum oxygen concentration predicted by the BRANZFIRE simulations in rooms other than the lounge is generally a good approximation of the full scale rig testing but the minimum oxygen concentration is generally predicted to occur earlier than was recorded during the full scale rig testing.

The BRANZFIRE model calculates the oxygen concentration based on the quantity of oxygen consumed by the fire in the room of fire origin, and by the contamination of the oxygen layer by fire products in rooms remote from the fire. The over estimation of the reduction in the oxygen concentration in the lounge may be due to a higher heat release rate being specified in the simulations than was used in the full scale testing. This would also account for the over prediction of temperatures in the fire compartment.

The carbon dioxide concentration in the lounge is generally over predicted by the BRANZFIRE simulations. In the compartments remote from the fire origin the peak carbon dioxide concentration is often under predicted by the BRANZFIRE simulations. The peak carbon dioxide concentration predicted by the BRANZFIRE simulation is also predicted to occur earlier than was observed in the full scale rig testing.

In the full scale rig testing a second peak in the carbon dioxide concentration was seen in most of the tests. This second peak was not predicted by the BRANZFIRE simulation which under predicts the second peak in the carbon dioxide concentration, and in some cases does not predict a second peak in the carbon dioxide concentration. The second peak in the carbon dioxide concentration is driven by a second peak in the heat release rate of the fire. The BRANZFIRE simulation appears to under predict the product yields from this second peak.

The carbon monoxide concentration was under predicted by the BRANZFIRE simulations in all of the compartments for tests CDT16 and CDT17. The prediction of the carbon monoxide concentration for test CDT18 was better predicted than for the tests CDT16 and CDT17. The BRANZFIRE model calculates the carbon monoxide concentration based on correlations for hexane burner data, and based on the global equivalence ratio with a higher yield of carbon monoxide for vitiated fires. The carbon monoxide generation rate based on the hexane correlation under predicts the carbon monoxide generation from the fuel in the full scale rig testing.

The product yields of carbon monoxide will increase when the fires become vitiated or oxygen depleted. It was observed in the full scale testing that the fires did not grow rapidly and often self extinguished before causing ignition of other combustible items in the fire room. The BRANZFIRE simulation may under estimate the equivalence ratio in the rooms during the second peak in the heat release rate, leading to an under prediction of the carbon monoxide concentration.

8.1.6 Fractional Effective Dose

From the figures of the fractional irritant concentration and fractional effective dose it can be seen that the BRANZFIRE simulations generally provide a good estimate of the fractional effective dose due to heat, and due to asphyxiant gases not including hydrogen cyanide in the lounge. In the bedroom of all of the simulations, BRANZFIRE makes a very poor prediction of the fractional effective dose due to both gases and heat.

In the BRANZFIRE simulations a very low yield of hydrogen cyanide was predicted and this is notable when comparing the fractional effective dose predictions due to asphyxiant gases. The hydrogen cyanide concentration that is predicted by the BRANZFIRE simulation has been calculated based on combustion chemistry using the chemical composition of flexible polyurethane foam.

It is interesting to note that the BRANZFIRE simulation does under predict the fractional effective dose considering it over predicts variables like the oxygen and carbon dioxide concentration in the lounge. The methods used by BRANZFIRE to calculate the fractional effective dose due to asphyxiant gases are based on techniques developed from the full scale rig testing. The under prediction of the fractional effective dose may be due to the under prediction of the carbon monoxide concentration in the lounge by the BRANZFIRE simulations.

The BRANZFIRE model does not make an estimate of the fractional irritant concentration so no comparison against the full scale testing can be made for this variable.

8.2 Simulation Geometries

As outlined in Section 3 the hallway, stair and landing rooms were simulated in two different ways. One compartment arrangement used two compartments in BRANZFIRE to describe the three rooms, and the other used three compartments. In a number of the variables predicted by the BRANZFIRE simulation there is little difference in the accuracy of the results to recommend one simulation over the other. In some of the simulation outputs one of the simulations provides a better prediction than the other, although this may not be significantly more accurate a prediction of the results of the full scale test data.

Both methods produced very similar predictions of the layer height in the lounge. The two compartment simulations produced better results for the prediction of the layer height in the hallway in comparison to the three compartment simulation. The three compartment simulation produced better estimates of the layer height on the landing and in the open bedroom. As noted previously, the prediction of the layer height by the N% method is considered to be less accurate in rooms remote from the fire origin, especially those where there is a relatively small increase or a small temperature differential between thermocouples. Therefore in terms of a comparison of whether the two or three compartment simulation is a more accurate method, comparison against the N% method may not be realistic on the landing and in the open bedroom.

The better prediction of the layer height in the three compartment simulations may be due to a slower transportation time because of the greater number of compartments. The rate of transport of the fire products is driven by equilibrium between compartments. The greater the number of compartments the longer it will take for the equilibrium state to occur across all of the compartments.

The better prediction of the layer height in the three compartment simulations may also be a function of BRANZFIRE's capabilities in modelling horizontal vents in comparison to vertical vents. By using a compartment with a horizontal vent to the compartment above to represent the hallway, stair and landing the rate of smoke transportation will be faster than using horizontal vents in the initial stages of the fire. This is because soon after smoke enters the upper layer in the first compartment smoke transfer to the second compartment will start to occur over the whole area of the horizontal vent.

In the simulations using three compartments with horizontal vents between each compartment the area over which transfer of smoke products occurs is limited to the depth of the upper layer multiplied by the width of the vent. Until the layer height has descended to a sufficient depth that the area of the vertical vent is equal to the area of the horizontal vent the flow rate through the horizontal rate will be greater. However, once the layer height descends to a sufficient depth that the area of the vertical vent is be greater, the rate of smoke transportation will be greater. In the later stages of the fire the use of a horizontal vent may act to slow smoke transportation in comparison to a vertical vent.

Although Figure 3.2 is drawn with the horizontal vent shown at the end of the hallway, BRANZFIRE assumes that the vent is located in the centre of the compartment so there is no time delay for the smoke to reach the vent. Using a horizontal vent may provide a short circuit in the system in the initial stages of the fire with more rapid transportation of smoke to the upper compartment in comparison to the three compartment simulation with vertical vents until the layer height in the first compartment is well developed.

The two and the three compartment simulations produce similar results for the prediction of the compartment temperatures with the two compartment simulations produced slightly better estimates of compartment temperatures. The temperatures predicted by BRANZFIRE are a function of the prediction of the layer height. With the two simulation methods producing varying results for the layer height predictions it is unexpected that one method make better predictions of the compartment temperatures.

The optical density results are consistently predicted more accurately by the three compartment simulations. The two compartment simulation produced optical densities that were in cases more than five times the values observed during the full scale testing. The optical density in a compartment is a function of the quantity of soot produced and the volume of the compartment. Given that the soot yield and the compartment volumes are the same for both the two and three compartment simulations it would be expected that the optical density results would be similar.

The smoke alarm response times for the two and three compartment simulations are very similar with predicted activation times far more rapid than were observed during the full scale testing. As noted previously this has been attributed to the significantly higher optical densities produced by the BRANZFIRE simulations and the prediction of the early compartment optical density. There is a relatively small difference in the optical densities predicted by the two and three compartment simulations. However, in comparison to the large difference to the optical density results from the full scale tests, the difference in smoke alarm response times between the two simulations is somewhat irrelevant.

The oxygen concentrations predicted by the three compartment simulations in all of the compartments are more accurate a prediction of the full scale testing than the two compartment simulation. The carbon dioxide concentrations in all of the compartments are more accurately predicted by the two compartment simulations in comparison to the three compartment simulations. The carbon monoxide concentrations recorded were generally low and were predicted more accurately by the two compartment simulations.

The analysis of the results of the two and three compartment simulations indicates that neither of the two compartments produces significantly more accurate results. The two compartment simulation makes better predictions of the compartment temperatures whereas the three compartment simulation makes better predictions of layer heights, optical densities and gas concentrations. The results suggest that sensitivity analysis should be carried out where there is a complex geometry and more than one compartment configuration should be analysed. It is difficult to determine which variables may be critical at the beginning of an analysis and carrying out a sensitivity analysis will indicate which variables are critical.

The comparison of the results of the BRANZFIRE simulations for test CDT16 using the horizontal and the vertical vent simulations showed that the horizontal vent configuration produced more accurate results for the compartment temperatures, optical densities, smoke alarm activation times, oxygen concentrations and fractional effective doses in the open bedroom. The vertical vent simulation predicted more accurate results for the compartment layer heights, carbon dioxide concentrations and the fractional effective doses in the lounge.

Overall the horizontal vent simulation predicted more accurate results and the accuracy of the results was surprising given the challenge that this type of modelling presents to BRANZFIRE.

It was noted in Section 3 that the area of the vent between the compartments that were used to describe the hallway, stair and landing were adjusted to allow for the drag coefficient that is applied to the vent flow rate. Based on the layer heights that have been predicted by the BRANZFIRE simulations this method appears to have been acceptable. If the vent area had not been adjusted by a value of 0.68^{-1} the lowering of the layer in compartments remote from the room of fire origin would have occurred later due to a reduced vent flow rate. If the vent areas had not been adjusted slower smoke alarm activation times may have been predicted. However, given the short period of time for the optical density in a compartment to reach the smoke alarm activation optical density, the potential change in smoke alarm activation time is not considered to be significant.

8.3 Predictions of life safety

As discussed in Section 3 BRANZFIRE is often used as a design tool in the design of buildings and to evaluate the available safe egress times from a building.

Although in a number of compartments the BRANZFIRE simulations over predicted the temperature, optical density and gas concentrations compared to the full scale testing data it tended to under estimate the fractional effective dose due to toxic gases and radiation in the open bedroom. It also predicted faster smoke alarm activation times than were observed in the full scale testing.

The first two tests, CDT14 and CDT15, that were carried out in the full scale rig involved a non flaming fire and these were not able to be modelled in BRANZFIRE because a heat release rate could not easily be determined for the fires. From the summary of the results of the full scale testing in Section 2 it was noted that in test CDT14 with the lounge door closed that the conditions in the lounge became untenable after 53 minutes but the time to untenability in the open bedroom was greater than 60 minutes. This suggests that occupants would have been able to exit the building once alerted to the fire.

In test CDT15 the lounge door was open and a greater heat release rate and temperature increase was observed in the lounge. Although the temperature increase in the lounge was greater, the time to untenability in both the lounge and the open bedroom was recorded as being greater than 60 minutes. This shows that in the context of the full scale rig testing the inability of BRANZFIRE to model non flaming fires is not significant in terms of life safety prediction for non flaming fires.

For tests CDT16 – CDT18 conditions quickly became life threatening in the rooms remote from the fire origin, including the scenarios where the lounge door was closed. This result was also predicted by the BRANZFIRE simulations.

8.4 Summary

The comparison of the outputs of the BRANZFIRE simulations for tests CDT17 and CDT18 against the full scale rig testing shows that the selection of the heat of combustion for the fire object is critical. The heat of combustion and heat release rate of the fire determine the layer height and the temperature increases in the compartments. The magnitude of the temperature differential across vents influences the flow through the vent so the compartment temperatures will have a significant impact on the predicted vent flows. In a design situation where the fuel is unknown a sensitivity analysis with varying values for the heat of combustion should be carried out.

The BRANZFIRE simulations showed that the appropriate selection of the soot yield of the fire product is critical as it determines the optical density in the compartments and the activation times for smoke alarms. A sensitivity analysis should be carried out to determine the sensitivity of the outputs to the soot yield. Using a sensitivity analysis it was shown that the smoke alarm activation optical density that is specified by the user is less influential on the smoke alarm activation time than the optical density in the compartment which is a function of the soot yield of the fire.

Wade (2004a) states that BRANZFIRE is capable of carrying out simulations with a maximum of 10 compartments. The simulations carried out in BRANZFIRE using the three compartment simulations showed that BRANZFIRE is capable of producing relatively accurate results for a simulation incorporating six compartments. The use of BRANZFIRE for simulations incorporating more than six compartments has not been verified in this report. The simulations have shown that BRANZFIRE is capable of producing accurate results for two storey buildings.

The comparison of the horizontal and vertical vent simulations showed that the vertical vent simulation produced some erroneous temperature predictions in compartments remote from the fire but in general the BRANZFIRE simulations performed well in predicting the downstream effects in simulations with the lounge door closed. Vents must be carefully specified in the simulations to generate accurate results. In a design with a complex compartment geometry a sensitivity analysis if the compartment and vent geometry should be carried out.

Wade (2004b) notes:

> BRANZFIRE is a zone model used to determine the flow of smoke and gases and its properties through a building. BRANZFIRE is based on a set of differential equations that predict state variables using enthalpy and mass flux over small time steps. These equations are derived from the conservation of energy and mass and the ideal gas law. Therefore the main contributions to any errors or differences that exist between model predictions and real life of full scale experiments are due to the many simplifying assumptions that must be made. …
>
> …It is important that users be familiar with the underlying physics and assumptions on which the program is based in order to be able to critically evaluate the results obtained.

Although Wade (2004b) notes that there will be some inaccuracies due to simplifying assumptions that have to be made in writing the software, the greatest inaccuracies in using the information in a design will come from lack of understanding of erroneous results. The quality of the data which is input into the simulation has a significant bearing on the accuracy of the results and the old adage of "garbage in equals garbage out" holds true. To enable accurate simulations to be used for design the continued testing and publishing of material properties for both well ventilated and vitiated conditions to develop databases of information needs to continue. The onus is on the designer to select model inputs which accurately describe the physical properties of the building and the potential uses of the building being designed.

9 Conclusions

From the modelling of the BRE testing data in BRANZFIRE it has been shown that the BRANZFIRE simulations made a reasonable prediction of the layer interface height in the majority of the compartments but tended to under predict the descent of the layer in the room most remote from the fire origin. The BRANZFIRE simulations produced upper layer temperatures in the room of fire origin which were higher than those recorded in the full scale testing. Temperatures predicted in other compartments of the model were the same as or less than those recorded in the full scale testing.

The optical densities predicted by the BRANZFIRE simulations were far in excess of those recorded during the full scale testing. However, it should be noted that the readings from the full scale testing were often beyond the range of the sampling equipment used. The extent of the over prediction of the optical densities suggests that too high a soot yield may have been used in the modelling.

The BRANZFIRE simulations predict the decrease in the oxygen concentration in most of the compartments to be greater than was observed during the full scale testing. The BRANZFIRE simulations tend to under predict the maximum carbon dioxide concentration in most of the compartments. The under prediction of the carbon dioxide concentration is most significant during a second peak in the carbon dioxide concentration caused by a second peak in heat release rate in the fire. The carbon monoxide concentrations predicted by the BRANZFIRE simulations are significantly less than those observed during the full scale testing in most simulations.

The smoke alarm activation times that were predicted by the BRANZFIRE simulations were significantly faster than those recorded during the full scale testing. This is attributable to the predicted optical densities which were significantly higher than the values recorded in the full scale testing. The fractional effective dose due to heat predicted by the BRANZFIRE simulations are very accurate in comparison to the fractional effective dose observed during the full scale testing. This is attributable to the reasonable prediction of the compartment temperatures. The prediction of the fractional effective dose due to asphyxiant gases by the BRANZFIRE simulations is less than that recorded during the full scale testing. This may be due to the under prediction of the carbon monoxide concentration.

BRANZFIRE is often used as a design tool based on the output of simulations. Based on the comparison of the output from the BRANZFIRE simulations and the results of the full scale rig testing the temperature and oxygen concentration values which are over predicted by the simulations would result in designs that would err on the side of safety. Data on the fractional effective dose and layer height if used in a design would result in a design which is potentially unsafe.

The values that were shown to be critical in achieving accurate results were the heat of combustion and heat release rate of the fire object, and the soot yield of the fire object. These variables determine the compartment layer heights and temperatures as well as the optical densities, smoke alarm activation times and fractional effective doses.

The modelling of fires in multi compartment buildings is a very complex process and it is difficult at the start of an analysis to determine which variables are going to be the most critical in the analysis. A sensitivity analysis should be carried out to determine which variables have the greatest impact on the output of the simulations. The impact of the sensitivity analysis on the design needs to be carefully analysed. A sensitivity analysis should also be carried out for the compartment configurations where a complex geometry is being analysed.

As noted by Wade (2004b) there are a number of simplifying assumptions that have been made in setting up the equations that form the basis of BRANZFIRE and users must understand the physics and processes used by BRANZFIRE to be able to interpret the accuracy of the results.

Ongoing small scale testing to determine the material properties and species yields of typical fuels for both well ventilated and vitiated conditions is required so that accurate inputs can be entered into the simulations to improve the usefulness of the outputs. The results of the small scale testing should be compared to the results of full scale rig testing when possible.

The output from the model must be treated as approximate and not exact data as there are a great many unknowns when it comes to setting up a simulation, particularly with regard to the fuel sources that may be present in a building during its life.

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11 Appendix

Appendix A - Input file for simulation of test CDT17

```
Input Filename : C:\BF\Test CDT17c.mod

BRANZFIRE Multi-Compartment Fire Model (Ver 2004.33)

Copyright Notice - This software is provided for evaluation only and may not be used for
commercial purposes.

Test CDT17 - Hall / Landing modelled as two rooms, one above the other with a ceiling vent

====================================================================
Description of Rooms
====================================================================
Room  1  : Lounge
         Room Length (m) =                                  3.14
         Room Width (m) =                                   3.90
         Maximum Room Height (m) =                          2.39
         Minimum Room Height (m) =                          2.39
         Floor Elevation (m) =                              0.000
         Room  1  has a flat ceiling.

         Wall Surface is plasterboard, gypsum paper-faced
         Wall Density (kg/m3) =                             760.0
         Wall Conductivity (W/m.K) =                        0.160
         Wall Emissivity =                                  0.88
         Wall Thickness (mm) =                              10.0

         Wall Substrate is brick
         Wall Substrate Density (kg/m3) =                   1600.0
         Wall Substrate Conductivity (W/m.K) =              0.690
         Wall Substrate Thickness (mm) =                    70.0

         Ceiling Surface is plasterboard, painted gypsum paper-faced
         Ceiling Density (kg/m3) =                          731.0
         Ceiling Conductivity (W/m.K) =                     0.170
         Ceiling Emissivity =                               0.88
         Ceiling Thickness (mm) =                           10.0

         Floor Surface is concrete
         Floor Density (kg/m3) =                            2300.0
         Floor Conductivity (W/m.K) =                       1.200
         Floor Emissivity =                                 0.50
         Floor Thickness = (mm)                             100.0

Room  2  : Hallway
         Room Length (m) =                                  2.09
         Room Width (m) =                                   3.90
         Maximum Room Height (m) =                          2.39
         Minimum Room Height (m) =                          2.39
         Floor Elevation (m) =                              0.000
         Room  2  has a flat ceiling.

         Wall Surface is plasterboard, gypsum paper-faced
         Wall Density (kg/m3) =                             760.0
         Wall Conductivity (W/m.K) =                        0.160
         Wall Emissivity =                                  0.88
         Wall Thickness (mm) =                              10.0

         Wall Substrate is brick
         Wall Substrate Density (kg/m3) =                   1600.0
         Wall Substrate Conductivity (W/m.K) =              0.690
         Wall Substrate Thickness (mm) =                    70.0

         Ceiling Surface is plasterboard, painted gypsum paper-faced
         Ceiling Density (kg/m3) =                          731.0
         Ceiling Conductivity (W/m.K) =                     0.170
         Ceiling Emissivity =                               0.88
         Ceiling Thickness (mm) =                           10.0
```

```
         Floor Surface is concrete
         Floor Density (kg/m3) =                           2300.0
         Floor Conductivity (W/m.K) =                      1.200
         Floor Emissivity =                                0.50
         Floor Thickness = (mm)                            100.0

Room  3  : Landing
         Room Length (m) =                                 2.09
         Room Width (m) =                                  3.50
         Maximum Room Height (m) =                         2.39
         Minimum Room Height (m) =                         2.39
         Floor Elevation (m) =                             2.590
         Room  3  has a flat ceiling.

         Wall Surface is plasterboard, gypsum paper-faced
         Wall Density (kg/m3) =                            760.0
         Wall Conductivity (W/m.K) =                       0.160
         Wall Emissivity =                                 0.88
         Wall Thickness (mm) =                             10.0

         Wall Substrate is brick
         Wall Substrate Density (kg/m3) =                  1600.0
         Wall Substrate Conductivity (W/m.K) =             0.690
         Wall Substrate Thickness (mm) =                   70.0

         Ceiling Surface is plasterboard, painted gypsum paper-faced
         Ceiling Density (kg/m3) =                         731.0
         Ceiling Conductivity (W/m.K) =                    0.170
         Ceiling Emissivity =                              0.88
         Ceiling Thickness (mm) =                          10.0

         Floor Surface is medium density fibreboard
         Floor Density (kg/m3) =                           700.0
         Floor Conductivity (W/m.K) =                      0.120
         Floor Emissivity =                                0.88
         Floor Thickness = (mm)                            12.0

Room  4  : Bedroom 1
         Room Length (m) =                                 3.15
         Room Width (m) =                                  3.20
         Maximum Room Height (m) =                         2.39
         Minimum Room Height (m) =                         2.39
         Floor Elevation (m) =                             2.590
         Room  4  has a flat ceiling.

         Wall Surface is plasterboard, gypsum paper-faced
         Wall Density (kg/m3) =                            760.0
         Wall Conductivity (W/m.K) =                       0.160
         Wall Emissivity =                                 0.88
         Wall Thickness (mm) =                             10.0

         Wall Substrate is brick
         Wall Substrate Density (kg/m3) =                  1600.0
         Wall Substrate Conductivity (W/m.K) =             0.690
         Wall Substrate Thickness (mm) =                   70.0

         Ceiling Surface is plasterboard, painted gypsum paper-faced
         Ceiling Density (kg/m3) =                         731.0
         Ceiling Conductivity (W/m.K) =                    0.170
         Ceiling Emissivity =                              0.88
         Ceiling Thickness (mm) =                          10.0

         Floor Surface is medium density fibreboard
         Floor Density (kg/m3) =                           700.0
         Floor Conductivity (W/m.K) =                      0.120
         Floor Emissivity =                                0.88
         Floor Thickness = (mm)                            12.0

Room  5  : Bedroom 2
         Room Length (m) =                                 3.14
         Room Width (m) =                                  3.90
         Maximum Room Height (m) =                         2.39
```

```
        Minimum Room Height (m) =                        2.39
        Floor Elevation (m) =                            2.590
        Room  5  has a flat ceiling.

        Wall Surface is plasterboard, gypsum paper-faced
        Wall Density (kg/m3) =                           760.0
        Wall Conductivity (W/m.K) =                      0.160
        Wall Emissivity =                                0.88
        Wall Thickness (mm) =                            10.0

        Wall Substrate is brick
        Wall Substrate Density (kg/m3) =                 1600.0
        Wall Substrate Conductivity (W/m.K) =            0.690
        Wall Substrate Thickness (mm) =                  70.0

        Ceiling Surface is plasterboard, painted gypsum paper-faced
        Ceiling Density (kg/m3) =                        731.0
        Ceiling Conductivity (W/m.K) =                   0.170
        Ceiling Emissivity =                             0.88
        Ceiling Thickness (mm) =                         10.0

        Floor Surface is medium density fibreboard
        Floor Density (kg/m3) =                          700.0
        Floor Conductivity (W/m.K) =                     0.120
        Floor Emissivity =                               0.88
        Floor Thickness = (mm)                           12.0

====================================================================
Description of Wall Vents
====================================================================
From room  1  to  2 , Vent No 1
                  Vent Width (m) =                       0.750
                  Vent Height (m) =                      2.000
                  Vent Sill Height (m) =                 0.000
                  Vent Soffit Height (m) =               2.000
                  Opening Time (sec) =                   0
                  Closing Time (sec) =                   0

From room  1  to outside, Vent No 1
                  Vent Width (m) =                       1.700
                  Vent Height (m) =                      1.300
                  Vent Sill Height (m) =                 0.800
                  Vent Soffit Height (m) =               2.100
                  Opening Time (sec) =                   0
                  Closing Time (sec) =                   0
                  Glass fracture is modelled for this vent
                  Glass Thickness (mm) =                 4.0
                  Glass Fracture to Fallout Time (sec) = 1200
                  Glass Shading Depth (mm) =             15.0
                  Glass Fracture Stress (MPa) =          47
                  Glass Expansion Coefficient (/C) =     0.0000095
                  Glass Conductivity (W/mK) =            0.76
                  Glass Diffusivity (m2/s) =             3.6E-07
                  Glass Modulus (W/mK) =                 72000
                  Glass is heated by gas layers only.

From room  3  to  4 , Vent No 1
                  Vent Width (m) =                       0.750
                  Vent Height (m) =                      0.020
                  Vent Sill Height (m) =                 0.000
                  Vent Soffit Height (m) =               0.020
                  Opening Time (sec) =                   0
                  Closing Time (sec) =                   0

From room  3  to  5 , Vent No 1
                  Vent Width (m) =                       0.750
                  Vent Height (m) =                      2.000
                  Vent Sill Height (m) =                 0.000
                  Vent Soffit Height (m) =               2.000
                  Opening Time (sec) =                   0
                  Closing Time (sec) =                   0
```

```
From room  4  to outside, Vent No 1
                   Vent Width (m) =                        1.700
                   Vent Height (m) =                       1.300
                   Vent Sill Height (m) =                  0.800
                   Vent Soffit Height (m) =                2.100
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0
                   Glass fracture is modelled for this vent
                   Glass Thickness (mm) =                  4.0
                   Glass Fracture to Fallout Time (sec) =  1200
                   Glass Shading Depth (mm) =              15.0
                   Glass Fracture Stress (MPa) =           47
                   Glass Expansion Coefficient (/C) =      0.0000095
                   Glass Conductivity (W/mK) =             0.76
                   Glass Diffusivity (m2/s) =              3.6E-07
                   Glass Modulus (W/mK) =                  72000
                   Glass is heated by gas layers only.

From room  5  to outside, Vent No 1
                   Vent Width (m) =                        1.700
                   Vent Height (m) =                       1.300
                   Vent Sill Height (m) =                  0.800
                   Vent Soffit Height (m) =                2.100
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0
                   Glass fracture is modelled for this vent
                   Glass Thickness (mm) =                  4.0
                   Glass Fracture to Fallout Time (sec) =  1200
                   Glass Shading Depth (mm) =              15.0
                   Glass Fracture Stress (MPa) =           47
                   Glass Expansion Coefficient (/C) =      0.0000095
                   Glass Conductivity (W/mK) =             0.76
                   Glass Diffusivity (m2/s) =              3.6E-07
                   Glass Modulus (W/mK) =                  72000
                   Glass is heated by gas layers only.

====================================================================
Description of Ceiling/Floor Vents
====================================================================
Upper room  3  to lower room  2 , Vent No 1
                   Vent Area (m2) =                        2.51
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0
                   Open method =                           Manual

====================================================================
Ambient Conditions
====================================================================
Interior Temp (C) =                                        25.0
Exterior Temp (C) =                                        25.0
Relative Humidity (%) =                                    65

====================================================================
Tenability Parameters
====================================================================
Monitoring Height for Visibility and FED (m) =             2.00
Occupant Activity Level =                                  Light
Visibility calculations assume:                            reflective signs
FED Start Time (sec)                                       0
FED End Time (sec)                                         10000

====================================================================
Sprinkler / Detector Parameters
====================================================================
No thermal detector or sprinkler installed.
Smoke Detector in Room 1
         Smoke Optical Density for Alarm (1/m)             0.097
         Detector Characteristic Length Number (m)         15.0
         Radial Distance from Plume (m)                    1.400
         Distance below Ceiling (m)                        0.025
         Detector response is based on OD inside the detector chamber.
Smoke Detector in Room 2
```

```
         Smoke Optical Density for Alarm (1/m)            0.097
         Detector Characteristic Length Number (m)        15.0
         Radial Distance from Plume (m)                   0.400
         Distance below Ceiling (m)                       0.025
         Detector response is based on OD inside the detector chamber.
Smoke Detector in Room 3
         Smoke Optical Density for Alarm (1/m)            0.097
         Detector Characteristic Length Number (m)        15.0
         Radial Distance from Plume (m)                   0.400
         Distance below Ceiling (m)                       0.025
         Detector response is based on OD inside the detector chamber.
Smoke Detector in Room 5
         Smoke Optical Density for Alarm (1/m)            0.097
         Detector Characteristic Length Number (m)        15.0
         Radial Distance from Plume (m)                   2.000
         Distance below Ceiling (m)                       0.025
         Detector response is based on OD inside the detector chamber.
====================================================================
Mechanical Ventilation (to/from outside)
====================================================================
Mechanical Ventilation not installed in Room 1
Mechanical Ventilation not installed in Room 2
Mechanical Ventilation not installed in Room 3
Mechanical Ventilation not installed in Room 4
Mechanical Ventilation not installed in Room 5

====================================================================
Description of the Fire
====================================================================
Radiant Loss Fraction =                                   0.52
Soot Alpha Coefficient =                                  2.80
Smoke Epsilon Coefficient =                               1.30
Smoke Emission Coefficient (1/m) =                        1.20
Characteristic Mass Loss per Unit Area (kg/s.m2) =        0.011
Air Entrainment in Plume uses McCaffrey (default)

Burning Object No 1
Test CDT17 (26,000 kJ/kg)
              Located in Room                             1
              Energy Yield (kJ/g) =                       26.0
              CO2 Yield (kg/kg fuel) =                    1.550
              Soot Yield (kg/kg fuel) =                   0.200
              Fire Height (m) =                           0.500
              Fire Location (m) =                         Corner

              Time (sec)              Heat Release (kW)
               0                      0
               10                     0
               20                     0
               30                     0
               40                     0
               50                     21
               60                     21
               70                     21
               80                     0
               90                     21
               100                    0
               110                    0
               120                    21
               130                    21
               140                    21
               150                    21
               160                    42
               170                    21
               180                    21
               190                    42
               200                    42
               210                    42
               220                    42
               230                    62
               240                    42
               250                    42
```

```
        260                    62
        270                    62
        280                    83
        290                    146
        300                    188
        310                    229
        320                    333
        330                    375
        340                    417
        350                    500
        360                    495
        370                    474
        380                    495
        390                    495
        400                    495
        410                    500
        420                    479
        430                    438
        440                    375
        450                    292
        460                    250
        470                    229
        480                    188
        490                    188
        500                    188
        510                    166
        520                    161
        530                    161
        540                    140
        550                    120
        560                    141
        570                    146
        580                    167
        590                    188
        600                    208
        610                    250
        620                    333
        630                    438
        640                    500
        650                    521
        660                    500
        670                    417
        680                    292
        690                    188
        700                    146
        710                    84
        720                    42
        730                    21
        740                    0
        750                    0
        760                    0
        770                    0
        780                    0
        790                    21
        800                    21

====================================================================
Postflashover Inputs
====================================================================
Postflashover model is OFF.

====================================================================
Flame Spread Inputs
====================================================================
```

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