ABSTRACT

Title of Thesis: NUMERICAL MODELING OF FULL SCALE LIMITED VENTILATION FIRE TESTS

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Underventilated enclosure fires represent one of the largest causes of fire fatalities and understanding their behavior is of great interest. The newest major release of the Fire Dynamics Simulator (FDS) has made significant progress towards providing a tool for accurate modeling of underventilated fire behavior. This study sought to evaluate the effectiveness of the extinction model and two-step combustion model in FDS version 5 by simulating full scale fire tests in an apartment setting with realistic furniture items using heat release rate data from furniture calorimeter and load cell. The extinction model provides a more accurate representation of the fire behavior in the compartment but the oxygen and temperature results are not satisfactory for severely underventilated fires. The effects of the enclosure causes heat release rate data from free-burn calorimeter tests to give a poor representation of the burning behavior of real furniture items in a compartment.

NUMERICAL MODELING OF FULL SCALE LIMITED VENTILATED FIRE TESTS

By

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1 INTRODUCTION

1.1 Motivation

The occurrence of underventilated fires is common and because of their potential for slow growth and high yields of toxic products they are relevant both to life safety and material damage. The limited supply of fresh air starves the fire of oxygen and leads to increased yields of products of incomplete combustion such as soot and carbon monoxide (CO) which is responsible for a large fraction of all fire deaths (Gottuk and Lattimer 2002). However, in the majority of fire tests ventilation is provided to allow the fire to develop to flashover and fully involved burning.

Because of the importance of underventilated fires, computer models capable of predicting the behavior and effects of these fires are desirable. One of the most commonly used field models for fire simulations is the Fire Dynamics Simulator, FDS, in part because of its unrestricted availability and ease of use.

Until version 5 of FDS was released in 2007, the model was not capable of simulating important phenomena associated with underventilated combustion, such as local flame extinction and incomplete combustion and its effect on species yields. Version 5 of FDS includes a new and more advanced combustion model aimed at improving the accuracy of the predicted rate of combustion and the increased production of CO in under-ventilated fire conditions.

Since its release some studies comparing results from the newest version of FDS to data from limited ventilation fire experiments have been done. For example in a comparison of FDS results to data from burning of liquid fuel in a reduced-scale compartment it was found that FDSv5 gave temperature predictions outside of experimental uncertainty for a majority of the measurements (Floyd and McGrattan 2008). Comparing to full scale apartment experiment, FDS gave good predictions for global parameters such as time to flashover and response to ventilation conditions (Lazaro *et al.* 2008).

Data is rare for full scale underventilated fire tests where the mass loss rate of real furnishing items is monitored during the fire. This is very useful information for determining an appropriate fire source input to FDS. As part of this study one such test series was conducted in the summer of 2008 as part of a study to characterize the dynamics of underventilated fires and evaluate the performance of fire models under these conditions (Wolfe 2008). The study was funded by the U.S. Department of Justice, National Institute of Justice and performed by personnel from the office of Hughes Associates, Inc. in Baltimore, Maryland, USA.

1.2 Fire Dynamics Simulator

Fire Dynamics Simulator, FDS, is a Fortran 90 software package based on the principles of Computational Fluid Dynamics, CFD. The software is developed by the Building and Fire Research Laboratory at the National Institute of Standards and Technology, NIST. Development of the program has been in progress for over 25 years and the first publicly available version was released in 2000. The latest, version 5, was released in 2007 and can be downloaded from the official FDS website (NIST 2008).

1.3 Theoretical Background for FDS

The basis for FDS has been developed from the mathematical background common to many CFD models with an emphasis on slow moving flow and heat transfer caused by fire. Two of the important submodels used in FDS will be outlined below. For a more detailed description see the technical reference guide for FDS published by NIST (McGrattan *et al.* 2008)

1.3.1 Submodel for Turbulence

The flows in fires that are of most interest for practical engineering applications will always be turbulent and so a fundamental requirement of a CFD model is an accurate model for turbulence. The fluctuating velocities in fluids lead to a rotating flow with turbulent eddies. The flow pattern will change rapidly and the changes will depend on the size of the eddies. The size and propagation rate of the eddies quickly changes and small cells and short time intervals are necessary to achieve a close approximation to the exact solution of the Navier-Stokes equations. For practical applications a CFD model must have a method for modeling the dissipation of turbulent flow on length scales smaller than the size of the numerical grid. There are several possible submodels for turbulence, and the choice depends on the degree of accuracy desired (Karlsson and Quintiere 2000). The most common methods are Reynolds-Averaged Navier Stokes (RANS) and Large Eddy Simulation (LES) (Cox 2002). If a fine enough grid resolution is used the turbulent flow can be directly modeled without any sub-grid approximation. This is called a Direct Numerical Simulation (DNS). Both LES and DNS turbulence modeling is possible in FDS but as the DNS model is still almost exclusively reserved for research purposes because of computational cost, the LES model is of most interest for compartment fire applications.

The energy level in the turbulent eddies will be high when turbulence is generated. Gradually the energy dissipates and the size of the eddies decreases. The influence of the viscous forces will increase with diminishing energy level and eventually the eddies will expire (Cox 2002). The total flow picture will consist of several eddies with different lengths and energy levels. The energy levels in the eddies determine how effective they are with regards to transport of mass, species, energy and momentum. The fundamental assumption in the LES model is that the smaller eddies contribute a small amount of the total kinetic energy and can be estimated using an approximation, or possibly ignored. The eddies with the largest contribution to the kinetic energy on the other hand must be computed exactly using time-dependant equations. A large eddy simulation will simulate fully all fluctuations larger than the mesh size (Cox 2002). Novozhilov (Novozhilov

2001) is of the opinion that the estimation of the smaller eddies in this way implies little uncertainty since these eddies are of a uniform character.

1.3.2 Submodel for Combustion

The submodel treating the process of converting fuel and oxygen to products and heat is what separates FDS from most other CFD models, which only deal with fluid flow. Two submodels are available, a mixture fraction combustion model and a finite-rate reaction model. The latter is most appropriate when using the resolution of DNS calculations to resolve the diffusion of the gas species so will not be discussed further.

In version 5 of FDS the mixture fraction model was expanded from a single-step reaction model in previous versions to include options for modeling extinction and a two-step model including CO production. All of these models depend on the mixture fraction, the ratio of mass of fuel species to the total mass in a given volume. In previous versions of FDS the fuel was tracked through a single-component mixture fraction where fuel and oxygen would react immediately. In FDSv5 a multi-component mixture fraction and a local extinction function has been implemented in the combustion model allowing unburned fuel and oxygen to coexist without burning. Especially for underventilated fire the assumption of immediate reaction between oxygen and fuel may result in overestimation of the heat release rate. The extinction model is based on the concept of the critical flame temperature (McGrattan et al. 2008) and gives a critical mass fraction of oxygen $Y_{O_2 lim}$, as (Mowrer 2008):

$$Y_{O_2 lim} = \frac{\overline{C_p}(T_{f,lim} - T_m)}{\frac{\Delta H}{r_{O_2}}} \qquad \text{Equation 1-1}$$

Assumptions are made in FDS concerning the parameters in the equation. The average specific heat of the products ($\overline{C_p}$) is set to that of nitrogen of 1.1 kJ/kg-K and the critical flame temperature ($T_{f,lim}$) of hydrocarbon fires of 1700 K is used (Beyler 2002). The common value of $\frac{\Delta H}{r_{O_2}} = 13{,}100\ kJ/kg$ for the heat release per mass of oxygen consumed is used (Huggett 1980). This results in a simple relation between temperature and the limiting oxygen volume fraction used for the extinction model in FDS seen in Figure 1-1(McGrattan et al. 2008).

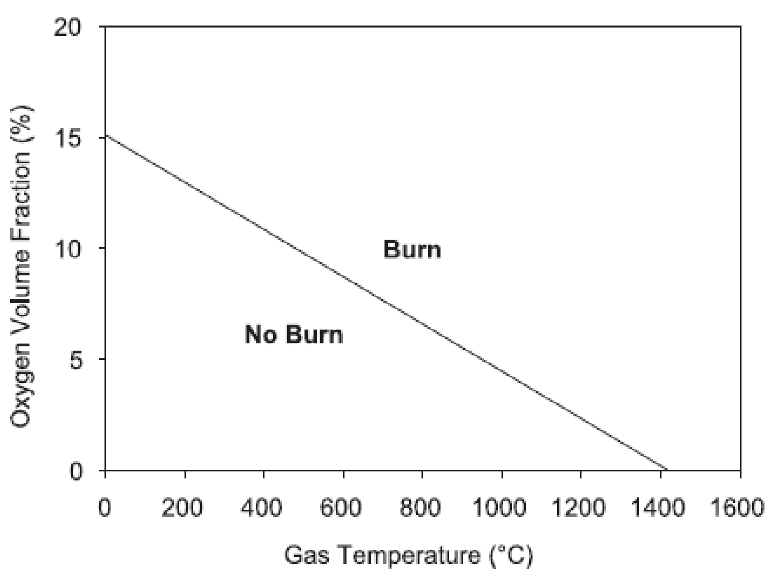


Figure 1-1. Relation between limiting oxygen volume fraction and gas temperature used in the extinction model in FDS to determine whether burning can take place.

When using the extinction model the reaction will still occur instantaneously wherever fuel and oxygen are mixed in cells where the combination of oxygen and gas temperature are within the “Burn” zone in Figure 1-1. If conditions in the cell enter the “No Burn” zone the oxygen and fuel will mix but not react. This is termed the “null” reaction. The extinction model is used as default in FDS version 5.

In the above one-step instantaneous reaction model products like CO, CO_2, H_2O and soot are produced by the combustion process proportional to the rate of fuel consumption. The yields of these products per mass of fuel consumed must be specified by the user. The most common way to find these values is from cone calorimeter and furniture calorimeter data for free-burning experiments and product tests. Yields from restricted burning tests are of limited use unless the conditions in the test match exactly those expected in the simulation. Using constant free burn yields in a limited ventilation compartment fire will lead to underpredictions of concentrations of especially CO and soot, which are produced in higher rates under poor ventilation conditions as the combustion become less efficient (Gottuk and Lattimer 2002). The CO and soot concentrations reported by FDS for an underventilated fire can be as much as a factor of ten lower than the actual value in the fire (Johnsson *et al.* 2007).

To address this issue and model the increased yield of CO under poorly ventilated conditions version 5 of FDS expands the mixture fraction to include three different states of fuel to allow for a two-step combustion process, which includes the production of CO. In the first step fuel is converted to CO and depending on the local conditions, CO is converted to CO_2 in the second step. The three forms of the mixture fraction are described as (McGrattan et al. 2008):

$$Z_1 = \frac{Y_F}{Y_F^I} \qquad \text{Equation 1-2}$$

$$Z_2 = \frac{W_F}{[x-(1-X_H)v_S]W_{CO}} \frac{Y_{CO}}{Y_F^I} \qquad \text{Equation 1-3}$$

$$Z_3 = \frac{W_F}{[x-(1-X_H)v_S]W_{CO_2}} \frac{Y_{CO_2}}{Y_F^I} \qquad \text{Equation 1-4}$$

The mass fraction of the fuel that originates at the burner is Y_F^I. The mass fraction of CO in a cell is calculated from Z_2 and may then be converted into CO_2, which is tracked by Z_3. FDS requires a CO yield measured for the burning material in free burning conditions as input to this model, termed v_{CO}. In addition, in the first step of the reaction the CO_2 yield, which would occur under stoichiometric conditions based on the number of carbon atoms in the fuel is instead given as v'_{CO} such that the yield of CO from the combustion process is $(v_{CO} + v'_{CO})$ moles. The CO is then tracked and if there is oxygen present the second reaction where CO_2 is produced will occur (McGrattan et al. 2008):

$$v'_{CO}\left[CO + \frac{1}{2}O_2 \rightarrow CO_2\right] \qquad \text{Equation 1-5}$$

If the fire is well ventilated the yield of CO will be the minimum value prescribed by the user of v_{CO}. However if there is no oxygen to fuel the second step of the reaction the total yield of CO will remain at $(v_{CO} + v'_{CO})$ and no CO_2 will be produced since this always has to go through the CO step. (McGrattan et al. 2008)

1.4 Limitations in FDS

A simulation performed in FDS will for most cases give a more accurate description of the fire than one performed using, for example, a two-zone model or hand calculations. However, it is important to remember that even though results obtained from a CFD model may appear convincing due to the apparently high accuracy they should not be accepted uncritically. Simplifications in the model may significantly influence the results, without it being readily apparent to the user to what degree. It can also be difficult to see in, which cases the model is invalid or less suitable. Some of the limitations in FDS of concern for this study in addition to those associated with the combustion model are presented below.

1.4.1 The Numerical Grid

The size of the cells the compartment is divided into and thereby the number of calculations that must be performed each time step is the parameter that is most important for the accuracy of the results. An FDS simulation using a course grid may give an estimate of the average temperature and pressure in the same way as a two-zone model.

These simulations may be performed relatively quickly, but will give a less accurate result than that obtained with a finer grid resolution (Salley 2007).

The discrepancy of the results because of the discretization of the continuous Navier-Stokes equations is proportional to the square of the cell size. The computational time however, is proportional to the cell size raised to the fourth power. By using half the cell size the discrepancy in the results will be reduced by a factor of four, while the computational time will in theory be increased by a factor of 16. The cell size required depends on how accurate the results need to be and which parameters are to be evaluated. Parameters like temperature and height of the smoke layer usually do not require as fine a resolution as for example calculations of heat flux to object close to the fire source (Salley 2007). An investigation conducted by Friday and Mowrer (Friday and Mowrer 2001) showed that the reduction in cell size may lead to even greater increases in computational time. A decrease in cell size from 60 cm (26 in) to 20 cm (8 in) led to a computational time that was 100 to 150 times longer. The authors explained this as being caused by problems related to memory allocation and caching issues in the computer.

The Poisson pressure solver used in FDS is based on Fast Fourier Transform, which requires that the number of cells in the y- and z-direction must be on the form $2^l3^m5^n$, where l, m and n are integers. A table with all integers from 1 to 1024 that fulfill this requirement is included in the user's guide for FDS (McGrattan *et al.* 2008b). To avoid instabilities in the calculations it is recommended that the cells are as close to cubic as possible with sides of approximately equal length (Floyd 2002).

Several sensitivity analyses have shown that the results are most sensitive to the size of the cells (McGrattan et al. 2008) (Friday and Mowrer 2001). For fire scenarios the relationship between the fire's characteristic diameter, *D**, and the size of the grid cells, δx, will indicate the accuracy of the LES modeling of the sub-grid motion of the fluids. The characteristic diameter is given as (McGrattan et al. 2008b):

$$D^* = \left(\frac{\dot{Q}}{\rho c_p T_\infty \sqrt{g}}\right)^{\frac{2}{5}} \qquad \text{Equation 1-6}$$

Where $\dot{Q}$ is the heat release rate of the fire in kW. Higher values of $D^*/\delta x$ means that a larger part of the fire dynamics is solved directly. It is reported that experience shows that this ratio should be between 5 and 10 to give satisfactory accuracy with an acceptable computational time (McGrattan *et al.* 2003). If this value becomes too low calculation of the fire itself and the combustion process can be adversely affected. It is emphasized that this rule is not a replacement for a sensitivity study of the cell size (McGrattan et al. 2008b). A more general requirement for achieving a well-resolved domain for the turbulence modeling is that the grid cells must be fine enough to properly resolve important length scales in the problem. Generally it is recommended that important objects such as vents, fire sources and the fire plume are resolved by at least 10 grid cells (Floyd 2002).

1.4.2 Fire Description, Development and Flow Conditions

The heat release rate is identified as the most important physical parameter governing the development of the fire (Babrauskas 1992). Therefore a correct description of this in the FDS model will be vital to achieve correct results. This represents one of the greatest challenges when trying to model a fire in FDS. Prescribing the heat release rate of the fire directly instead of having FDS resolve fire spread avoids many problems associated with the uncertainties about material parameters and how they affect fire spread. However, the problem then becomes what heat release rate to use. When modeling fires in dwellings data is often taken from well-ventilated furniture calorimeter tests as this is available for many different furniture items. There are questions concerning how well FDS is able to account for the reduced ventilation conditions inside a compartment and give an accurate representation of the fire conditions when this approach is used. The primary mechanisms in FDS that model this effect are the extinction model and the two-step mixture fraction combustion model discussed previously in chapter 1.3.2.

The user must be aware of how the definition of the fire source can greatly influence the results of the simulation. If the fire is defined with a known heat release rate, but with too small a surface area this can give incorrect or unphysical results. The fire plume will no longer be buoyancy driven, but rather behave as a jet fire that is driven by the momentum of the combustion products. When dealing with a small fire source the dominant force can be determined by evaluating the dimensionless heat release rate, $\dot{Q}^*$, defined as (Cox 2002):

$$\dot{Q}^* = \frac{\dot{Q}}{\rho_a c_a T_a D^2 (gD)^{1/2}} \quad \text{Equation 1-7}$$

Where $\dot{Q}$ is the heat release rate in kilowatt and D is the diameter of the fire. If the dimensionless heat release rate is larger than 2.5 the buoyancy is no longer the dominant force in the plume flow, as is normal in most fires in buildings. The exception is for example fires related to broken gas pipes where the momentum of the gas will be the dominant force (Cox 2002).

The equations used in FDS are restricted to problems where the flow is incompressible. In practice this means a mach number of 0.3 or less (Floyd 2003). Therefore the model cannot be used to simulate scenarios involving high velocities such as shock waves from explosions or jet flow from nozzles (McGrattan et al. 2008b)

1.5 Evaluation of FDS

Through evaluation work the model can be continuously improved to achieve lower uncertainties and reduced limitations, which will make it applicable for more complex scenarios, or will increase accuracy in existing scenarios. A thorough evaluation is a prerequisite for preventing incorrect use of the model. The evaluations give the user a good basis for choosing the correct model, assessing the safety levels and note any discrepancies in the results (Jones 2005)

A total evaluation of the model is not possible, but methods have been developed that make it possible to assess the performance of the model in different scenarios. Evaluation of a model involves both verification and validation. NIST uses the guide from the American Society for Testing and Materials, ASTM E1355, to evaluate FDS. This states that the evaluation should include the following (Jones 2005):

- Model and scenario definition
- Theoretical basis for the model
- Mathematical and numerical robustness
- Model sensitivity

1.5.1 Verification

Verification of a model includes evaluating the correctness of the results. The process will only assess whether the results are correct with regard to the equations used, not whether the correct equations are implemented in the model (Jones 2005).

The technical reference manual for FDS contains a description of work that has been carried out in this area and will not be discussed further.

1.5.2 Validation

Validation should reveal whether the mathematical model that is implemented is appropriate for the phenomenon of interest and how well it predicts the physics. A large number of experiments must be conducted to give a thorough evaluation of the model.

Validation performed for one fire scenario will not give a direct validation for other scenarios. This work is done by comparing results to standard fire tests, full scale tests, field experience, published literature or previously evaluated models. Results from validation studies are of interest when comparing FDS to experimental results and deciding whether discrepancies are within expected limits (Jones 2005)

Since the earliest versions of FDS validation studies of the model have continuously been performed. This has been done using comparison with experiments conducted specifically for this purpose or with data from previous experiments. A large amount of data is also available for standard tests of the fire resistance of materials, for example the ISO room fire test. A description of a large number of validation studies of FDS can be found in volume 3 of the technical reference guide for FDS (McGrattan et al. 2008).

Ideally the model should be validated for each case but this is an expensive and time consuming process. Most of the validation studies conducted as of today have focused on the ability of FDS to accurately model the transport of smoke and heat. Later studies attempt to a larger degree to look at more specific phenomena such as fire growth, flame spread and the sprinkler submodel (McGrattan et al. 2008).

Both in studies cited in the technical reference guide for FDS and in a comprehensive validation study performed by the U.S. Nuclear Regulatory Commission, NRC (Salley 2007), it is shown that FDS is capable of predicting the temperature in the compartment with reasonable accuracy, especially for spatially averaged values such as the hot gas layer temperature. When simulating an experimental setup performed specifically to validate FDS for use in the investigation of the fire in the World Trade Center the temperature estimates were found to be within the uncertainty of the measured heat release rate (McGrattan et al. 2008)

The study performed by the NRC (Salley 2007) compared results from FDS with results from six sets of full scale experiments. The results from this comparison found that the estimates for temperature and thickness of the upper layer were within ± 13%, which is within experimental uncertainty. However it is cautioned that the temperature estimates close to the fire source and the plume may have a high degree of uncertainty due to the complexity involved and that a fine resolution may be required here. The estimates of radiative flux and temperature rise on surfaces were mostly within experimental uncertainty, but also here it is cautioned that problems may arise when trying to estimate conditions very close to the fire. It is important to be aware that inaccurate estimates of surface temperature may be due to either error in heat transport predictions or incorrect material properties.

The conclusions in the NRC report showed that the results achieved with FDS are not considerably better than those achieved with the two-zone models that were evaluated, CFAST and MAGIC (Salley 2007). The exception is the estimate of radiative flux and surface temperature. If the heat release rate of the fire is known it can be generally assumed that FDS will be able to predict gas temperature, species concentrations and pressure with approximately 15% accuracy and surface temperatures with around 25% accuracy. (Salley 2007)

1.6 Scope of work

1.6.1 Full Scale Compartment Fire Tests

The work is based on a series of full scale enclosure fire tests conducted at the Bureau of Alcohol, Tobacco and Firearms (ATF) Fire Research Laboratory (FRL) in Beltsville, Maryland, U.S.A. during July and August of 2008. The tests were conducted under a grant from the National Institute of Justice to characterize the fire dynamics of unventilated and partially ventilated compartment fires. The tests were performed inside an instrumented, specially built four room apartment style enclosure measuring 40.5 m^2 (438 ft^2). The apartment structure was built inside the FRL Large Burn Room. Fifteen full scale tests were performed but only eight of these were used for the FDS simulations.

1.6.2 Simulations

The study was divided into three main parts. Using heat release rate data for the furniture items from calorimeter tests conducted for this study, simulations were performed without including any information about the actual burning behavior inside the compartment, referred to as the “calorimeter simulations” in this document. The natural gas burner tests were also included in this part.

After the tests were completed the mass loss data from the load cell, coupled with the heat of combustion for the items gathered from the calorimeter tests, was used to estimate the heat release rate for the items inside the compartment. This information was used in FDS to perform what is termed the "load cell simulations". The extinction model and two-step CO production model were used in both the calorimeter and load cell heat release rate simulation of the experiments.

For the third part, two sofa tests and two kitchen cabinet tests with closed and partially open window ventilation conditions were used for additional simulations where the combustion model parameters were changed. One set of the four simulations was done with the extinction model turned on but the CO production model turned off, the default setting in FDS. A second set of simulations of the same scenarios were conducted with both the extinction and CO production model turned off.

Table 1-1 shows the locations, ventilation conditions and input data for the three sets of simulations.

Table 1-1 Overview of Locations, Ventilation Conditions, Combustion Model Settings and Heat Release Rate (HRR) Input Used in the FDS Simulations.

Fire source	**Location**	**Ventilation**
Pre-Test	***HRR from Cone test.***	
Gas Burner	Living room	Closed
Gas Burner	Living room	Window open
Sofa	Living room	Closed
Sofa	Living room	Window half open
Elevated Cabinets	Kitchen	Closed
Elevated Cabinets	Kitchen	Window half open
Elevated Cabinets	Kitchen	No Window
Elevated Cabinets	Kitchen	Door Open
Post-Test	**HRR from load cell.**	
Sofa	Living room	Closed
Sofa	Living room	Window half open
Elevated Cabinets	Kitchen	Closed
Elevated Cabinets	Kitchen	Window half open
Elevated Cabinets	Kitchen	No Window
Elevated Cabinets	Kitchen	Door Open
Combustion model variations		
Default settings	*Extinction on, CO production off*	
Sofa	Living room	Closed
Sofa	Living room	Window half open
Elevated Cabinets	Kitchen	Closed
Elevated Cabinets	Kitchen	Window half open
"All off" settings	*Extinction off, CO production off*	
Sofa	Living room	Closed
Sofa	Living room	Window half open
Elevated Cabinets	Kitchen	Closed
Elevated Cabinets	Kitchen	Window half open

The parameters of interest in this study were the resulting heat release rate from the FDS simulations and any effects limited ventilation conditions might have, as well as the oxygen and carbon monoxide (CO) concentrations and temperatures in the fire room and the bedroom. For this study the errors in the FDS predictions of temperature were expressed in percent according to the equation:

$$\Delta(\%) = \frac{T_{FDS} - T_{EXP}}{T_{EXP}} \quad [K] \qquad \text{Equation 1-8}$$

By using absolute temperature small deviations where low temperatures are measured in the experiment will give a small error. The errors at higher temperatures are considered more important as they affect life safety, fire spread and structural damage to a larger degree.

The main areas of interest in this study were evaluating how the free-burn calorimeter heat release rate in FDS performs inside the compartment compared to actual mass loss data, and the effects of the new extinction and CO production routines in the combustion submodel.

A bug in the version of FDS used discovered late in the study caused an error in the CO production model, rendering the data obtained in the simulations invalid. The comparisons to the CO concentrations in the test are therefore not included.

2 FDS METHODS AND INPUT

2.1 Model Version Used

The simulations were conducted using the latest available release of the Fire Dynamics Simulator (FDS) at the start of the study, version 5.2.0. The grid resolution studies were performed before version 5.2 was available so the earlier version 5.1.4. was used. There were no changes reported in the release notes for the newer version, which should affect the results of the grid resolution study (NIST 2008b). For all simulations the serial version of FDS was used.

2.2 Compartment Geometry

The basic compartment layout was kept the same for all the fire tests. The only changes were to the fuel location, fuel type and ventilation conditions. The compartment represented a one bedroom apartment and consisted of a living room with an entrance door, a dining room, a kitchen and a bedroom. The openings between the rooms in the compartment were unobstructed during all the tests. The layout of the compartment are shown in Figure 2-1 (Wolfe 2008).

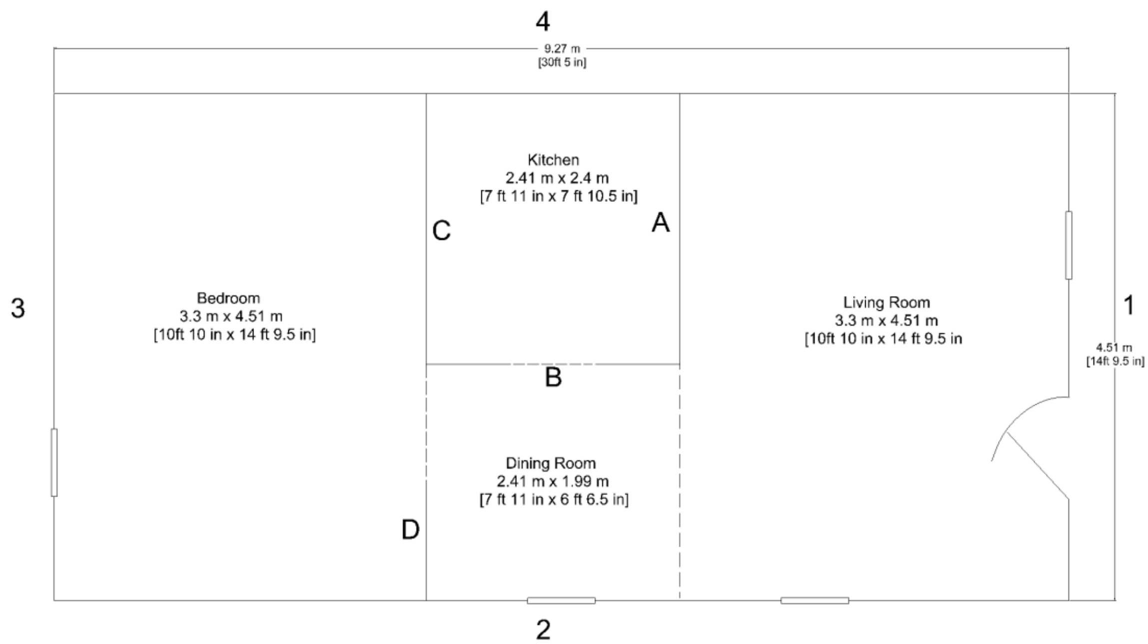


Figure 2-1. Layout of the four-room test compartment (Wolfe 2008).

The compartment measured 9.3 m (31 ft) long by 4.5 m (15 ft) wide internally. The living room and bedroom were the same size, 3.3 (11 ft) m by 4.5 m (15 ft). The kitchen measured 2.4 m (8 ft) by 2.4 m (8 ft) and the dining room was slightly smaller at 2.4 m (8 ft) by 2.0 m (7 ft). The only door into the compartment was in the living room. There were four windows: two in the living room, one in the dining room and one in the bedroom opposite the entrance door. The bedroom window was the only window that was opened for any of the tests, the other three windows were always kept closed. All the walls in the enclosure were constructed as a 38 mm (2 in) by 89 mm (4 in) timber frame covered by gypsum wallboards (see section 2.5). The floor and ceiling were made of 38 mm (2 in) by 235 mm (10 in) timber beams spanning from wall 2 to wall 4 in Figure 2-1. The compartment was entered into FDS as being 9.0 m (30 ft) long and 4.5 (15 ft) m wide. The ceiling height was 2.4 m (8 ft). The timber frame covers only a small surface area of the structure and was assumed to have a negligible impact on the heat transfer and was not included in the FDS model.

Four different ventilation conditions were used in the tests that were modeled with FDS. One was the completely unventilated condition where all windows and doors were closed and air or gases could only enter and exit the compartment through leakage in the structure. For the partially ventilated tests the bedroom window was used as the vent in two different configurations. Having the window half open gave a ventilation opening 60 cm (24 in) wide and 20 cm (8 in) high. The bottom of the window was 1.1 m (3.6 ft) above the floor. For the other configuration the whole window was taken out. This gave an opening 65 cm (25.5 in) wide and 103 cm (40.5 in) high. This was only used for one test with the kitchen cabinets. The final ventilation condition was all windows closed and the door from the living room to the outside open. Open door tests were only done using the kitchen cabinets. The open door gave a ventilation opening 1.0 m (3.3 ft) wide and 2.0 m (6.6 ft) high.

When simulating tests with a closed compartment the walls served as the boundary of the computational domain. For the tests with ventilation openings to the outside the computational domain was extended outside the vent. A study by Yaping He et. al (Yaping He *et al.* 2008) using FDS showed that extending the computational domain outside the ventilation openings would affect the results of the simulation. The study recommended that for a fuel-controlled fire the computational domain should extend beyond the vent opening by ½ times the hydraulic diameter of the opening. For a ventilation controlled fire this distance should be increased to the hydraulic diameter. The hydraulic diameter is defined as:

$$D_H = \frac{4A}{P} \qquad \text{Equation 2-1}$$

Where A and P are the vent area and perimeter respectively. Since the increase in number of cells is relative modest it was decided that the domain should extend at least one full length of the hydraulic diameter for these simulations. For the tests with a half open window this is 30 cm (12 in), 75 cm (30 in) when the window is removed and 114 cm (45 in) with the door open. For simplicity 70 cm (28 in) was added outside the window for all tests where this was open. Outside the door 130 cm (51 in) was added to better model the fluid flow.

The walls inside the compartment were modeled as obstructions one cell thick to avoid confusion as to where the walls were placed. If the walls are less than one cell in thickness this will also affect the modeling of the boundary layer and the tangential flow over the surface and thus the pressure solution in the compartment. The three interior doorways were created using the 'HOLE' function in FDS.

The leakage characteristics of the compartment were measured with all opening to the outside closed. This gave an equivalent leakage area of $0.015 m^2$ ($0.16 ft^2$). This was used as input into the leakage model, which is a new feature in version 5 of FDS. The gypsum wallboard material that makes up the exterior walls of the compartment in FDS was specified with the leak area measured for the test compartment. The whole compartment in FDS was specified as a pressure zone with leakage to the outside, which represents the other pressure zone. As the pressure increases or decreases in the compartment, gases will leak in or out. This occurs on the sub grid scale and over the whole boundary of the compartment. The volume of the flow through the leakage area A_L is given as (McGrattan et al. 2008b):

$$\dot{V}_{leak} = A_L \sqrt{2 \frac{|\Delta p|}{\rho_\infty}} \qquad \text{Equation 2-2}$$

The direction of the flow will depend on the whether the pressure difference Δp is negative or positive. The area of leakage specified for the pressure zone is used in FDS for each mesh separately so the leakage area had to be divided by two or three depending on how many meshes were used in the simulation.

Figure 2-2 shows the layout in FDS for the load cell heat release rate simulation of the sofa test with an open window (top) and kitchen cabinet test with window removed (bottom).

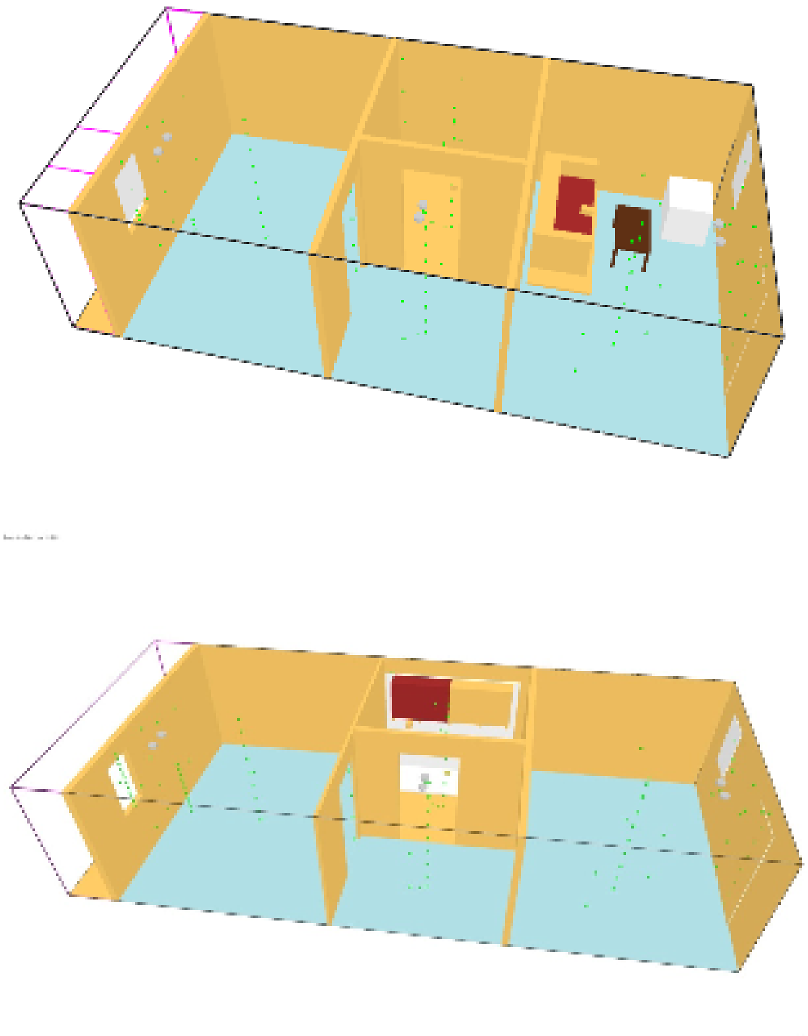


Figure 2-2. Layout in FDS for the load cell heat release rate simulations of the sofa test with the window half open (top) and the kitchen cabinet test with window removed.

The green dots in Figure 2-2 are the measurement points for temperature, heat flux, pressure, visibility and species concentration. The larger white objects in the bedroom, dining room and living room are the smoke detectors. The furniture placed in the compartment during the sofa tests is shown. In addition to the burning sofa were a coffee table and a small upholstered chair, here represented by the white block in the corner. In the cabinets tests conducted in the kitchen no other furniture items were present in the compartment. The red surfaces represent the burners, which release the fuel.

2.3 Measurements

Instrumentation was placed in all rooms in the compartment during the tests. A thermocouple tree was placed in each of the four rooms. Heat flux was recorded on the floor at the center of each room as well as in the vertical orientation in front of the fire and on the nearest wall. The concentrations of oxygen, carbon monoxide and carbon dioxide were measured at 0.6 m (3 ft), 1.5 m (5 ft) and 2.4 m (8 ft) height in the living room, kitchen and bedroom, as well as at the base of the fire. Other measurements included pressure at different points and velocity in the bedroom door. For a detailed description of the instrumentation and measurements in the tests see Wolfe (Wolfe 2008). All the same measurements were recorded in the FDS model but the analysis and comparison focused on a selected number of outputs, specifically heat release rate, temperature and concentrations of oxygen and carbon monoxide.

2.3.1 Temperature

Two thermocouple trees were used to analyze how well FDS predicts the temperature in the compartment. Recording the temperature in the fire room and in the room farthest away gives insight into the how heat transfer and fluid flow is resolved over short and longer distances. Depending on the test, the thermocouples in the living room or kitchen are in the fire room. For the point farther away from the fire the thermocouples in the bedroom were used for all the tests. Each tree consisted of nine thermocouples placed vertically at 31 cm (1 ft) spacing starting at 2.5 cm (1 in) above the floor. The thermocouples in the kitchen and living room were aspirated with a flow speed of 6.9 m/s (3.28 ft/s) while those in the dining room and bedroom were bare bead (Wolfe 2008). For the FDS simulation the aspirated thermocouples are best represented by the 'TEMPERATURE' output quantity. This directly measures the temperature of the gas in the cell where the measurement point is located without the effects of radiation on the thermocouple bead, in the same way an ideal aspirated thermocouple would (McGrattan et al. 2008b). For the bare bead thermocouples in the experiment the 'THERMOCOUPLE' output quantity in FDS was used as this takes into account the radiation effects on the bead by solving the equation for T_{TC} iteratively (McGrattan et al. 2008b):

$$\varepsilon_{TC}\left(\sigma T_{TC}^{4} - \frac{U}{4}\right) + h\left(T_{TC} - T_{g}\right) = 0 \qquad \text{Equation 2-3}$$

Here U is the radiative intensity and T_g is the temperature of the gas. The emissivity of the thermocouple is specified in the PROP line and has a default value of 0.85. This value is representative of oxidized materials and was used for these simulations. The other parameters associated with the thermocouple beads were also kept at default.

In the tests bare bead thermocouples were also placed at three heights along with the aspirated thermocouples in the fire room. These were at 0.61 m (2 ft) 1.52 m (5 ft) , and 2.13 m (7 ft) above the floor. These are included as the 'THERMOCOUPLE' output along with the gas temperature measurements.

The experimental accuracy of the thermocouples were reported as the larger value of 2.2 °C and 0.75% of indicated temperature (Omega 2002). Error bars indicating this uncertainty was included in the temperature plots for the burner test but it was found that for the furniture test the difference between FDS and the test data was much larger and the few degrees of experimental uncertainty was insignificant except for at a few measurement points.

2.3.2 Gas Measurements

The gas concentrations of most interest are those of oxygen and CO. Comparing these quantities to the test results from the fire room and the bedroom indicate how well FDS treats the formation and transport of the combustion products. The concentrations of these gases were all measured in FDS using the appropriate device line and recorded in mole fractions. The gas concentrations were recorded in the tests at 0.61 m (2 ft), 1.52 m (5 ft) and 2.13 m (7 ft) above the floor in the living room and in the bedroom. In the kitchen the measurements were only taken at 2.13 m (7 ft). It was initially planned to measure hydrocarbon concentrations in the compartment at 2.5 cm (1 in) from the ceiling in the same position as the gas analyzer tree in the fire room, but these measurements were not performed in the test. These were however still recorded in FDS in both the living room and kitchen using the 'fuel' output quantity. This gives the mole fraction of unburned fuel at these locations. The transport delay associated with the test measurements was accounted for by shifting the data.

2.3.3 Heat Flux

The heat flux was recorded with the same placement of the gauges as in the test: in the fire room and in the bedroom. A floor mounted heat flux gauge recorded heat emanating from the hot layer in each room. Gauges facing the fire were placed 1 m (3 ft) high and 1 m (3 ft) horizontally from the fire and on the opposite wall at two heights to measure the heat flux hitting horizontally oriented objects. In the tests the heat flux gauges were kept between 30- 40 °C using a water heater. Therefore the heat flux measurement devices in FDS were designated to have a constant temperature of 40 °C.

2.3.4 Visibility

The smoke density in the compartment was measured with optical density meters in the test. The locations of the meters corresponded to locations of smoke alarms and typical locations for assessing tenability along paths of egress as seen in Figure 2-3.

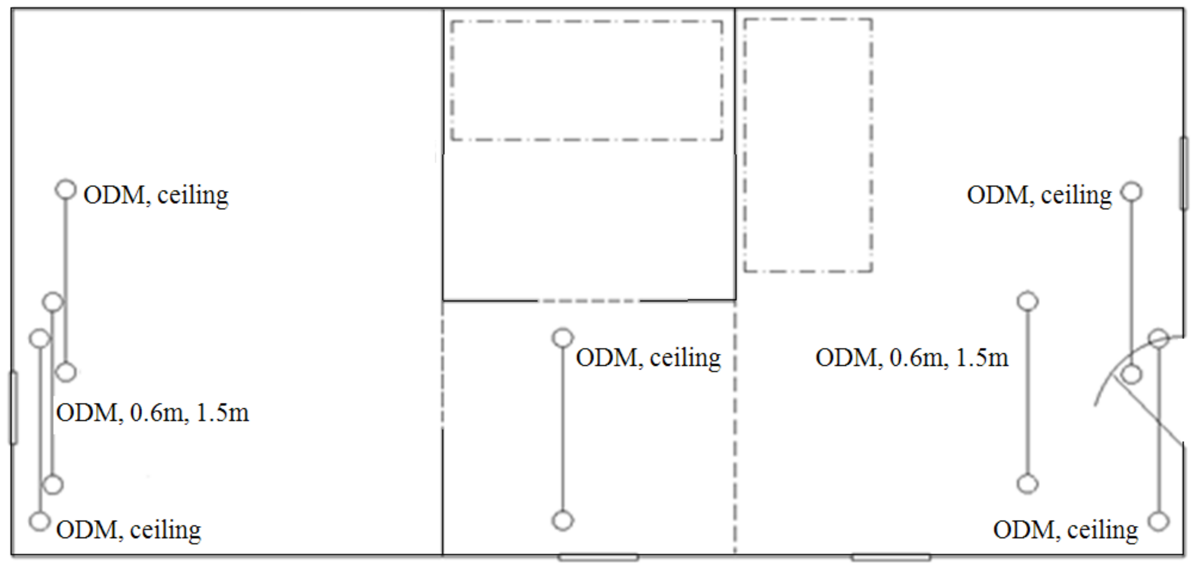


Figure 2-3. Placement of the Optical Density Meters in the compartment.

Two were placed in line at ceiling level by the door in the living room and by the window in the bedroom. This is to cover all the smoke detectors in these locations since the distance was too long for a single detector. One was placed at the ceiling in the dining room to cover the smoke detectors there. To measure obscuration at walking and crawling height an optical density meter was placed at 0.61 m (1 ft) and 1.52 m (5 ft) height in the egress path in the living room and in the bedroom. To get comparable data from FDS, beam detector devices were used. This measures path obscuration and can be specified to work over the distance given in the positional coordinates and gives a percentage of signal received relative to that sent. The single point ‘visibility’ outputs were also recorded in FDS at the middle point of each beam detector. This gives the visibility through the smoke in meters.

2.3.5 Smoke Detectors

To enter smoke detectors into FDS four parameters must be entered describing the properties of the detector. The FDS user's guide specifies the parameters for five different types of smoke detectors shown in Table 2-1 (McGrattan et al. 2008b).

Table 2-1. Values for the Parameters in the Five Different Smoke Detector Models.

Detector	α_e	β_e	α_c, L	β_c
Cleary Ionization - I1	2.5	-0.7	0.8	-0.9
Cleary Ionization - I2	1.8	-1.1	1.0	-0.8
Cleary Photoelectric - P1	1.8	-1.0	1.0	-0.8
Cleary Photoelectric -P2	1.8	-0.8	0.8	-0.8
Heskestad Ionization - HK	–	–	1.8	–

In the tests eight different smoke detectors were used: ionization, photoelectric and combo detectors. The default values in Table 2-1 only provide ionization and photoelectric detector function and it is not known how these values relate to the different brands of smoke detectors used in the test. Therefore instead of the row of eight smoke detectors only two were used in FDS. The three ionization detectors were all placed in the same position in FDS and similarly for the photoelectric detectors. The detector placement in the tests and in FDS are shown in Figure 2-4 where I1 and I2 are the Cleary Ionization detectors as in Table 2-1, P1 and P2 are the photoelectric detectors and HK is the Heskestad model.

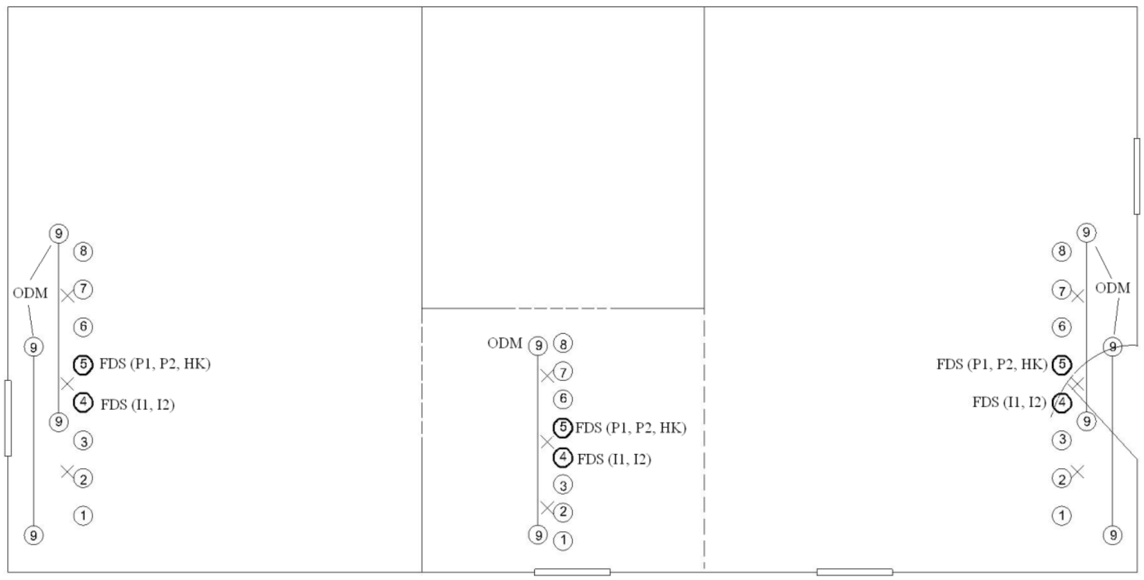


Figure 2-4. Placement of the eight smoke detectors in three locations in the tests and the corresponding placement of the detectors in FDS. Ionization detectors denoted by I1 and I2, photoelectric denoted by P1 and P2 and Heskestad photoelectric model denoted by HK, as per Table 2-1.

In the tests, detectors number one, four and six were ionization while number two, four and seven were photoelectric and three and eight were combo detectors.

2.4 Grid Size

A grid sensitivity study was conducted by simulating a simple 40 cm (16 in) by 40 cm (16 in), 125 kW methane burner fire placed in the kitchen with different grid resolutions. Three different mesh resolutions were considered; a coarse grid with 10 cm (4 in) cells, a fine grid with 5 cm (2 in) cells and a combination using 5 cm (2 in) cells in the fire room and 10 cm (4 in) cells in the rest of the compartment. Table 2-2 shows the number of cells required for each of the three resolutions as well as the number in relation to the finest grid.

Table 2-2. Number of Cells Required for the Three Different Resolutions

Resolution	Total cells	Percent of 5 cm
5cm	777,600	100.0%
10 cm	97,200	12.5%
10 cm & 5 cm fire room	204,000	26.2%

It was clear that increasing the resolution to 5 cm (2 in) cells in the whole compartment would give a significant increase in the number of cells compared to the other two options. In all cases the numbers of cells in the y and z directions was restricted to the numbers listed in the FDS user's guide to conform to the requirements of the Fast Fourier transform for the Poisson pressure solver. This is not a requirement for the number of cells in the x-direction (McGrattan et al. 2008b).

The length scale of the important objects involved in the fire must be properly resolved. Any ventilation openings and the fire source where fuel is injected should be resolved with a sufficient number of cells. The Smagorisky LES models require that ten cells are used to resolve the length scale of the plume (Floyd 2002). If it is assumed that the plume will have the width of the burning object and considering the sofa dimensions of 0.9 m (3 ft) and 1.8 m (6 ft) give 18 and 36 cells of 5 cm (2 in), this indicates adequate resolution in the living room. The kitchen cabinets have a more complex geometry since most of the burning occurs on the front face. The cabinets have a length of 1.9 m (6.2 ft), which is adequately resolved with 5 cm (2 in) cells. The depth of the cabinets is 0.31 m (1 ft), which is resolved by only 6 cells, but this is still a good resolution and it was assumed that the burning on the front face would yield a plume wider than the depth of the cabinets. Using 5 cm (2 in) cells in the fire room allows flames as short as 0.5 m (20 in) to be modeled with the required 10 cells. Taking the mean flame height as (Karlsson and Quintiere 2000):

$$L = 0.235\dot{Q}^{2/5} - 1.02D \qquad \text{Equation 2-4}$$

where D is the diameter of the fire. Taking the equivalent circular area of the largest fire area in the test, the 5.4 m^2 (58 ft^2) sofa gives a minimum heat release rate of 675 kW to give flames longer than 0.5 m (20 in). The sofa gives a heat release rate larger than 675 kW for the parts of interest in the test so the 5 cm (2 in) cells are considered adequate to model the flame. Similarly for the 3 m^2 (32 ft^2) cabinets require a fire of 386 kW to give a mean flame height of 0.5 m (20 in), which can be properly resolved. The majority of the cabinet fires are larger than this heat release rate.

For the ventilated test the size of the vent must be considered when deciding on the mesh size. At least 10 grid cells should also be used to describe each dimension of a vent to properly resolve the flow. The tests with the bedroom window removed and open door give relatively large vents where this requirement is fulfilled for the height of the vents but the width of the window and door is only six and eight cells respectively. The flow will vary more over the height of the vent than over the width and the flow changes over the height are considered to have a greater effect on conditions in the room. Therefore this configuration was still used despite the resolution of the vent width being lower than recommended. However, this restriction in resolution must be kept in mind when analyzing the results of these tests. For the tests with the window only half open the opening is 60 cm (23 in) by 20 cm (8 in) so a 10 cm (4 in) mesh here will only give two cells over the height of the vent, which will give a very poor resolution of the flow dynamics. Instead a finer 2.5 cm (1 in) mesh was placed around the window opening. This mesh was extended 70 cm (28 in) out the window to the end of the domain and the same distance into the room. Unfortunately it was difficult to extend the mesh equally to each side of the window in the y-direction without adding an inordinate number of cells because of the restriction on the number of cells associated with the Poisson pressure solver. It was therefore necessary to have the finer mesh flush with the window on one side and extended 20 cm (8 in) on the other side. The grids around the partially open bedroom window are shown in Figure 2-5.

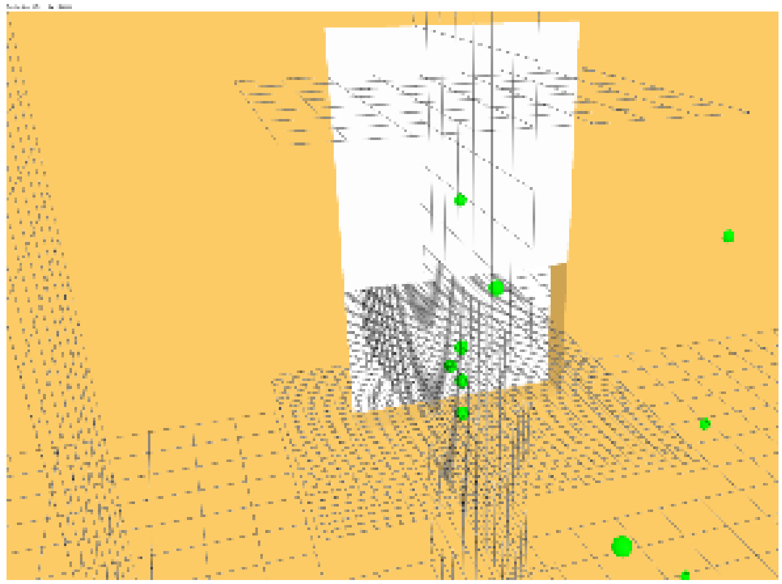


Figure 2-5. Different grid resolutions around the open bedroom window. 2.5 cm (1 in) cells were used for the opening while 10 cm (4 in) cells were used in the rest of the room.

The different cells sizes were checked for compliance with the guideline indicating that the relationship between the characteristic diameter and the cell size should be between 5 and 10. The resulting ratios of the characteristic fire diameter to the cell size for fires with a heat release rate of 125 kW and 1200 kW using 5 cm (2 in) and 10 cm (4 in) grid resolutions are shown in Table 2-3.

Table 2-3. Ratio of Characteristic Fire Diameter to Cell Size, $\boldsymbol{D^*/\delta x}$ for Fires With Heat Release Rate of 125 kW and 1200 kW Using Cells With δx, δy and δz of 5 cm (2 in) and 10 cm (4 in).

	D*/δx	
HRR \ Resolution	*5cm*	*10 cm*
125 kW	10.9	5.5
1200 kW	20.5	10.3

The 125 kW fire is the burner used in the calibration tests while the 1200 kW fire represent what can be expected from a burning furniture item. As seen in Table 2-3. for the 125 kW fire even the 10 cm (4 in) resolution satisfies the rule of thumb of a $D^*/\delta x$ between 5 and 10. For the 1200 kW fire both resolutions are more than fine enough according to this rule. But it is emphasized that this rule is only a guideline and not a substitute for a grid sensitivity analysis (Salley 2007) (McGrattan et al. 2008b).

Since it is expected that finer resolution will give more accurate modeling of the fire dynamics it would be preferable to use the finer 5 cm (2 in) resolution. However, this option is very intensive in terms of computational time so it is interesting to see whether the lower resolution configurations provide acceptable results. The computational time required for the multi mesh simulations using 5 cm (2 in) and 10 cm (4 in) cells proved to be acceptable and not much longer than required when 10 cm (2 in) cells are used everywhere. It is therefore most interesting to see what the difference is between 5 cm (2 in) cells and the 5/10 cm (2/4 in) multi mesh configuration. An added benefit of the 5 cm (2 in) cell size in the fire room is that this better resolves the object placed in the room. If the coarser grid is used objects in the fire room cannot have dimensions less than 10 cm (4 in).

A simulation of the burner fire in the kitchen was done with each of the two grid resolutions. It was found that for the temperature measurements, there was little difference between the 5 cm (2 in) and multi mesh configurations in the 125 kW fire test. The heat flux was very low with this small fire but still showed good agreement between the two configurations. In the fire room the resolution is 5 cm (2 in) in both simulations so the temperature in the upper layer was very close, especially early in the fire before the lower resolution in the rest of the compartment start to have an effect. The temperature at the ceiling in the kitchen is shown in Figure 2-6. The temperature in Figure 2-6 has been averaged over 6 seconds to avoid fluctuations in the graphs caused by noise in the data.

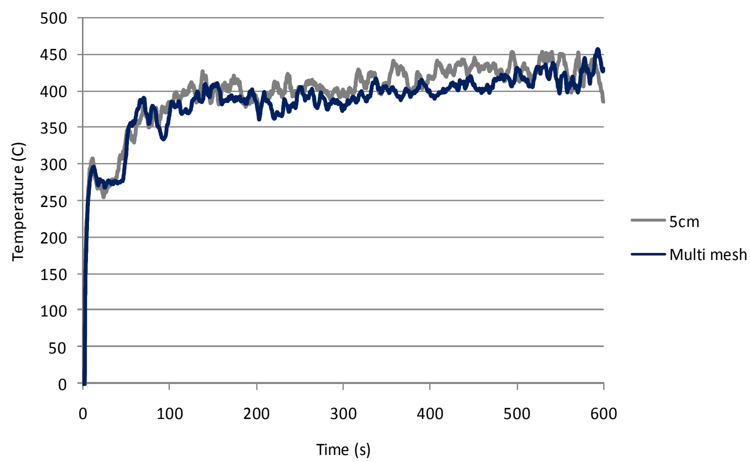


Figure 2-6. Temperature measured at the ceiling in the kitchen using the 5 cm (2 in) and multi mesh configurations.

The same trend was seen in the bedroom with temperature differences being less in the upper layer than in the lower layer. Data from the thermocouple tree was also used to view a height slice of the temperature at 450 s in the bedroom as shown in Figure 2-7.

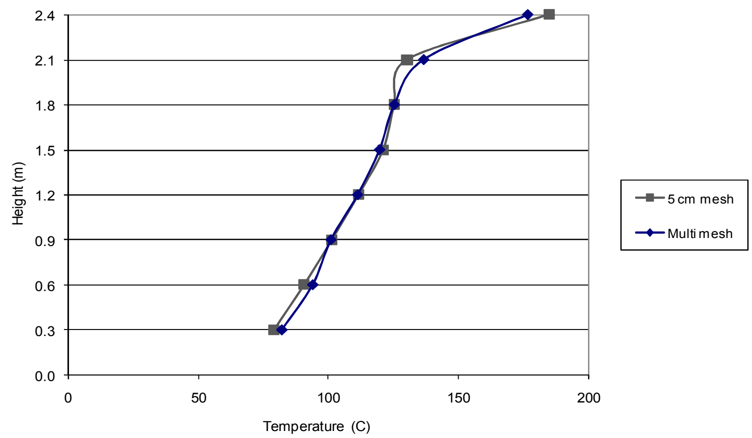


Figure 2-7. Temperature slice in bedroom at 450 s with 5 cm (2 in) and multi mesh configuration.

It is clear from Figure 2-7 and similar plot for the kitchen that the largest differences between the 5 cm (2 in) and multi mesh simulation occur at the layer interface. But even at this point the differences were so small that it was decided that the dramatic increase in computational time associated with the 5 cm (2 in) mesh was not justified.

As a result of the grid sensitivity analysis it was decided that a mesh configuration with 5 cm (2 in) cells in the fire room and 10 cm (4 in) cells in the other rooms of the compartment was adequate. For the sofa tests this meant 5 cm (2 in) cells in the living room and 10 cm (4 in) cells in the bedroom, kitchen and dining room. For the cabinet tests a 5 cm (2 in) mesh was used in the kitchen and dining room and a 10 cm (4 in) mesh in the living room and bedroom.

2.5 Materials

The exterior walls of the test compartment were made up of a double layer of 16 mm (5/8 inch) thick Type X gypsum wallboard. The interior walls consisted of 13 mm (1/2 inch) gypsum boards. The ceiling was single 16 mm (5/8 inch) boards and the floor a layer of 13 mm (1/2 inch) plywood boards protected by 13 mm (1/2 inch) gypsum boards. Over the fire in the kitchen and living room the ceiling was protected by an additional layer of 13 mm (1/2 inch) gypsum board. The thickness of the exterior walls, 32 mm (1.3 inch), was used for all surfaces in the compartment. This was decided by considering that the heat transfer through the exterior walls was deemed the most significant means of heat loss compared to heat transfer between rooms and through the floor and ceiling and that the difference in thickness is very small. Having only one surface thickness simplifies the construction of the compartment in FDS. The density of the gypsum wallboards was set to 800 kg/m^3 (Incropera 2002). The thermal conductivity was set to 0.17 W/m-K (Incropera 2002) and the specific heat to 1.1 kJ/kg-K (Gypsum Association 2005). The windows were included as glass surfaces, but only for the calculation of heat transfer to the outside. Window breakage was not considered and did not occur in any of the tests.

Fire spread to other objects in the room was not a focus of this study, and did not occur in the tests conducted. In the sofa tests there were only two other objects in the fire room and in the cabinet test none at all. Since these items did not ignite, the accuracy of the material properties of other furniture items was not of major concern beyond their abilities to act as heat sinks. The coffee table was specified with approximate geometry to conform to the grid cells with the properties of plywood (Incropera 2002). The upholstered chair was taken as a solid cube of upholstery. The density was taken from Ikea's product information (ikea.com 2008) and thermal properties for acrylic were used (matweb.com 2008).

2.6 Pre-test Simulation Heat Release Rate

The heat release rate curves for the sofa and cabinets to be used in the pre-test FDS model were taken from the furniture calorimeter test performed under well ventilated conditions. This method is often used when FDS is applied in engineering applications where the heat release rate of the actual items in the room is not known and empirical data for similar items from free-burn tests are used.

Similar tests were done twice for the sofa and twice for the cabinets. The ignition source was a cup with 4 ml (0.14 oz) of alcohol between two full tissue boxes. The heat release of the ignition source was also measured under the hood. This curve was used in the model for a separate fire to simulate these objects burning before the sofa or cabinets ignite and during the early phase. The sofa and cabinet items in FDS were given a prescribed heat release rate curve so the heat given off by the tissue boxes did not influence the ignition time and rate of burning of the main item. The time from ignition of the tissue boxes to start of burning of the sofa and cabinets was chosen based on the time it took for them to ignite during the open calorimeter test.

2.6.1 Natural Gas Burner

The burner tests were modeled with a constant heat release rate of 125 kW using a methane combustion reaction. The heat of combustion was set to 49,600 kJ/kg (Tewarson 2002). The ramp up time was not changed and is by default one second in FDS (McGrattan et al. 2008b). The burner surface area was set to 40 cm (16 in) by 40 cm (16 in) elevated 50 cm (20 in) above the floor in the same location as the sofa in the living room.

2.6.2 Sofa

The two heat release rate curves for the sofa calorimeter tests did not show any large variations and are shown in Figure 2-8. Tests 2 takes longer before it starts to increase but the overall shape of the two curves are the same.

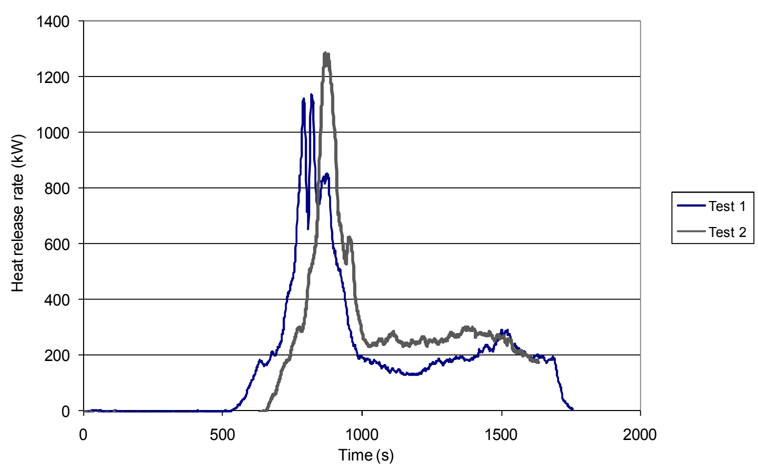


Figure 2-8. Heat release rate from the sofa calorimeter test.

Since the curves are so similar an average was used as input in FDS. The first 500 s where the sofa is not yet ignited and the fire is growing were not included to save computational time. The curve for Test 2 was also shifted approximately 50 s to the left so that the two peaks occur at the same time. The resulting curve and the average of the two are shown in Figure 2-9.

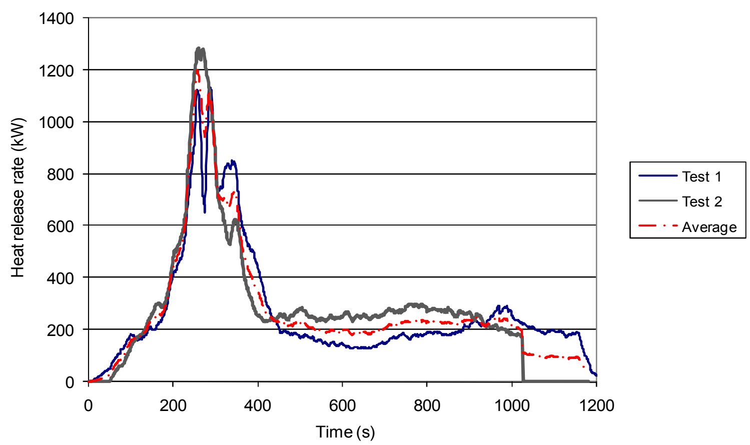


Figure 2-9. Shifted heat release rate curve for the two tests and the average value used as input to FDS.

When the FDS and experimental data are compared the heat release rate curve must therefore be shifted with respect to time to give a valid comparison of the parameters such as temperature and species concentration relative to time from ignition. An effort was made to make the growth rate and timing of the first peak value of the heat release rate from FDS and the test match as closely as possible for each comparison. This method was chosen since the focus of this study is not on how FDS predicts ignition and early stages of the fire but rather how the limited ventilation affects the development of the fire and the effects on the environmental parameters such as temperature and gas concentrations.

The upholstery in the sofa consisted of polyurethane foam (ikea.com 2008) and this was used for the reaction to describe its burning behavior (Babrauskas 2003). A study by Mealy (Mealy 2007) analyzed the composition of the products of a similar sofa under a furniture calorimeter and found the yield of CO to be 0.030 gram-CO per gram of fuel burned. The yield of soot, or pure carbon, was found to be 0.215 g/g (Mealy 2007). The SFPE Handbook of Fire Protection Engineering (Tewarson 2002) reports the yield of CO in well-ventilated fires for flexible polyurethane foams ranging from 0.010 g/g to 0.042 g/g. The test data fall within this range. The soot yield also shows agreement with the reported data, which is given as 0.131 – 0.227 g/g.

Mealy also calculated the heat of combustion of the sofa material under the calorimeter hood by analyzing the instantaneous heat release rate and the mass loss rate on the load cell. The average value obtained was 29.7 MJ/kg with a 7.6 MJ/kg standard deviation. As noted by Mealy this is higher than the value reported in the SFPE handbook for flexible polyurethane foams of 23.2 – 27.2 MJ/kg (Tewarson 2002). The handbook reports the heat of combustion of rigid polyurethane foams as high as 28.0 MJ/kg.

2.6.3 Kitchen Cabinets

The two calorimeter tests using kitchen cabinets gave differing results. In the second of the two tests the second cabinet ignited almost immediately after the first. In the other cabinet test and also in a similar hood test using the same cabinet layout evaluated in 2007 by Mealy (Mealy 2007) the four cabinets burned in sequence with a much larger delay between ignition of each cabinet. This can be seen by the four distinct peaks for each of the tests in Figure 2-10.

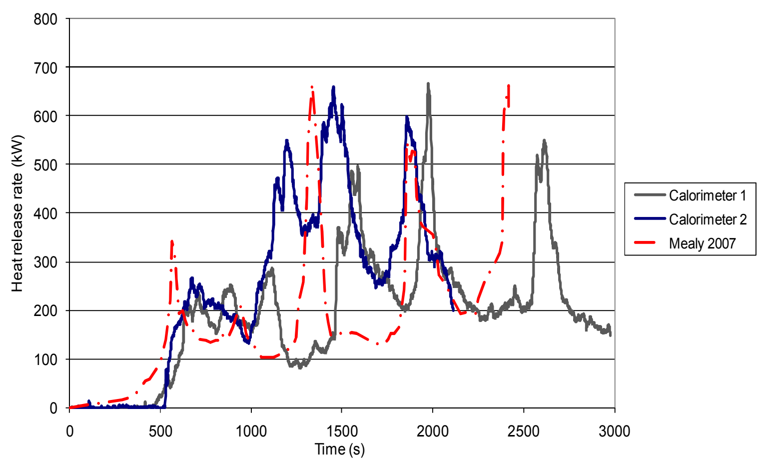


Figure 2-10. Cabinets heat release rate as measured in the calorimeter. Two tests were done for this test series and one calorimeter test was done using the same cabinets by Mealy (Mealy 2007).

For tests labeled Calorimeter 1 and Mealy 2007 the first cabinet burned less severely and served to preheat the other three. For the graph labeled Calorimeter 2 the first and second cabinet burned simultaneously and gives a different heat release rate curve and a shorter fire. By also considering observations from test conducted with similar cabinets (Mealy 2007) it was decided that the data from Calorimeter 1 represents a characteristic cabinet fire and this curve was used as input to FDS for the pre-test simulations.

Mealy found the heat of combustion of the cabinets to be 16.1 MJ/kg and the standard deviation is given as 3.4 MJ/kg. The SFPE handbook reports the heat of combustion of Douglas fir as 16.4 MJ/kg, red oak as 17.1 MJ/kg and pine as 17.9 MJ/kg (Tewarson 2002) showing good agreement with the cabinet test data reported by Mealy. The chemistry of the cabinets was taken as plywood reported by Richie (Richie *et al.* 1997) as $C_{3.4}H_{6.2}O_{2.5}$. The CO yield found from free burning furniture calorimeter test were 0.021 kg/kg and a soot yield of 0.253 kg/kg (Mealy 2007). The yields of CO and soot are both higher than what is reported in the SFPE handbook, which gives a CO yield of 0.004 – 0.005 g/g and a soot yield of 0.015 g/g. However the cabinets are not made of pure wood and also contain plastic cups, paper towels and tissue boxes, which will contribute to the yields of products. Especially the plastics tend to have higher yields of CO and soot than pure wood (Tewarson 2002).

The two tissue boxes and the cup containing 4 ml (0.14 oz) of alcohol were included in FDS in a simplified form. The heat from the burning alcohol was considered too small to have any noticeable effect and was neglected in FDS. The two tissue boxes were modeled with the heat release rate that was measured under the open hood test using the tissue boxes and cup of alcohol. However, the maximum heat release rate was only 3.5 kW and the fire is poorly resolved so its effect is limited.

The arrangement of the ignition sources in the sofa and cabinet tests is shown in Figure 2-11. The top picture shows the tissue boxes on the small shelf underneath the kitchen cabinets and the Smokeview rendering. The door to the cabinet is held open

2.5 cm (1 in). The bottom picture shows the tissue boxes used to ignite the sofa and a Smokeview rendering of the representation in FDS.

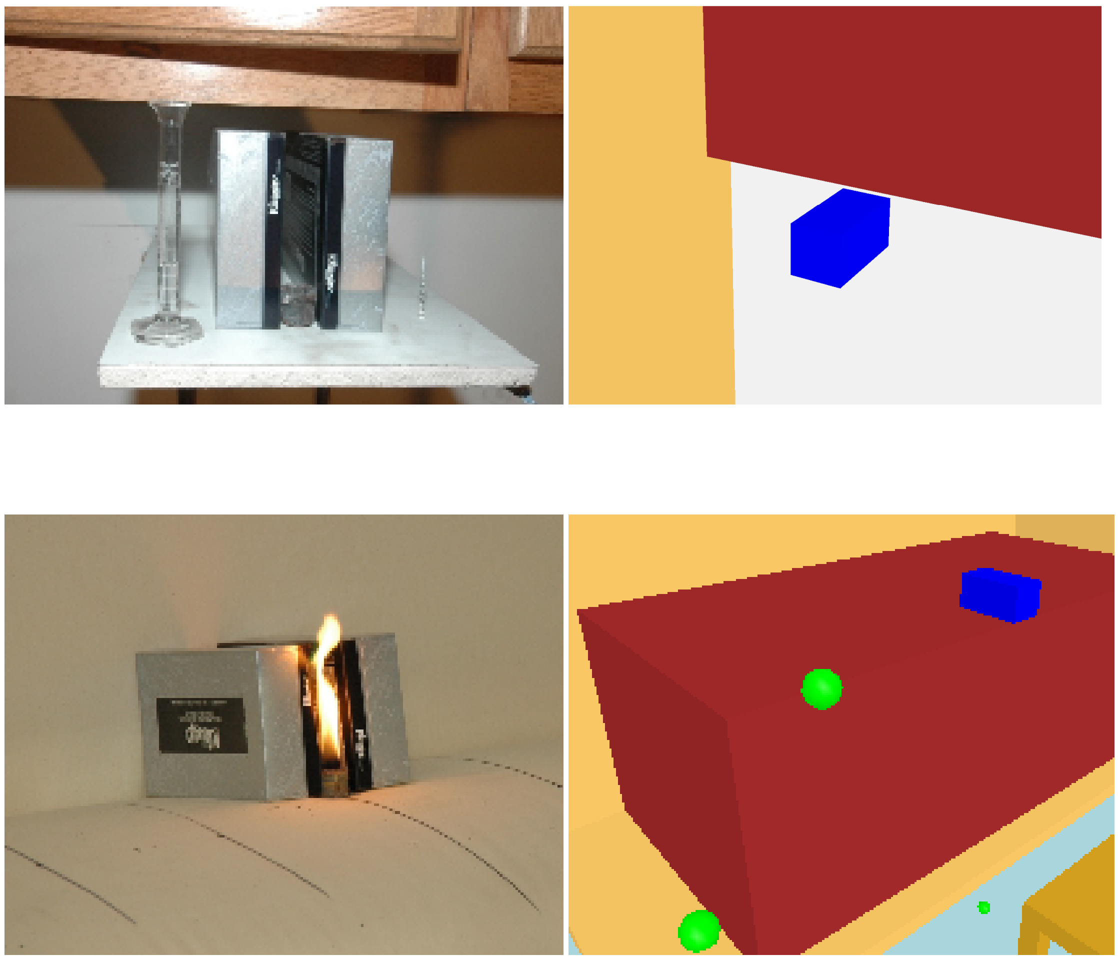


Figure 2-11. Tissue box and cup with 4 ml (0.14 oz) of alcohol ignition souce placed under the cabinets and on sofa seat and the smokeview rendering of the layout in FDS. The tissue boxes are blue and the main fire is red.

2.7 Post-test Input Data

The post-test simulations were kept similar to the pre-test simulations except for the heat release rate of the burning item. The load cell under the sofa and kitchen cabinets recorded the weight of the item every second during the test. This data was used to estimate the mass loss rate during the fire, $\dot{m}$. By multiplying with the energy released per kilogram of mass burned, ΔH_c, found by oxygen consumption calorimetry in fully ventilated conditions, an estimate of the heat release rate can be found (Drysdale 2002):

$$\dot{Q} = \dot{m}\,\Delta H_c \qquad \text{Equation 2-5}$$

A limitation with this method is that it assumes that all mass pyrolysed from the item undergoes combustion with the same efficiency as under the free burning calorimeter. For under-ventilated fires this will not be the case as there will not be enough oxygen in the compartment for all the fuel vapors released from the burning item to undergo combustion. (Drysdale 2002). If there is less oxygen available the combustion process will be less efficient and produce more incomplete products such as CO.

The heat release rate can also be estimated by using the empirical observation that the fire releases approximately 3 kJ/g of air consumed, or 13 kJ/g of oxygen consumed (Drysdale 2002). In this test the air flow into the compartment was only measured with one bidirectional probe in the window making accurate estimates of the air supply to the fire difficult. Additionally, the vent was 6-9 m (20-30 ft) away from the burning object and the incoming air had to pass obstructions and corners. It is unlikely that all the incoming air reacts with the fuel and there will also be a delay associated with the travel time to the reaction zone, which was not known. The test scenarios with a closed compartment present further problems to using the ventilation flow to estimate the heat release rate. The simplified method of using the mass loss data and the free burning heat of combustion was therefore considered the most accurate method available for estimating the heat release rate of the fire inside the compartment. It must be remembered that because of the above limitations this will overestimate the heat release rate of the fire inside the compartment.

The mass measured over time for the first 2,000 s after ignition in the sofa test with half open window is shown in Figure 2-12.

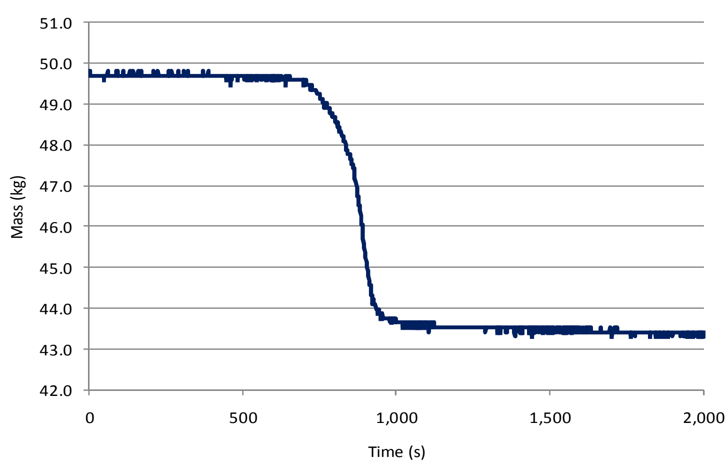


Figure 2-12. Mass of the burning sofa inside the compartment during the first 2,000 s of the test with half open window.

The data for the mass of the item shows noise and fluctuations. Conditions in the room disturbing the load cell platform and electronic noise in the data recording apparatus lead to mass variations between time steps not associated with actual mass loss. The mass of the object at each time step was therefore taken as the average over 20 s to minimize the effects of noise in the measurements. Likewise the mass loss rate at time t was taken as:

$$\dot{m}_t = \frac{m_{t-10} - m_{t+10}}{20} \qquad \text{Equation 2-6}$$

It was found that this gave a reasonably clean graph for the mass loss rate for all the tests. The cabinet tests appear to give a more fluctuating signal than the two sofa tests, probably caused by more even burning of the polyurethane foam. The final heat release rate curve from each test was put into FDS via the 'RAMP' function as done for the calorimeter heat release rate.

It was observed in the fire that the surface area used to represent the burner in the pre-test simulations was not the best match for the surface area that actually burned in the tests. For the calorimeter heat release rate simulations, five sides of the blocks representing the sofa and the cabinets were set to burn. However in the test most of the burning occurred on the seat and backrest of the sofa so for the load cell heat release rate simulations the burner surface was restricted to this area. For the cabinet tests the majority of the burning to be included in test analysis, i.e, before the cabinets fell down, occurred in the first two cabinets so this was considered a suitable average surface area to use for all the cabinet tests. The heat release rate remains the same so this was not expected to have a major impact on the results.

3 GAS BURNER TEST SIMULATION RESULTS

The results of the 125 kW natural gas burner tests performed in the living room compared to the FDS simulations are presented for oxygen concentration and temperature versus height at three time steps. The burner tests were run with all windows and the door closed and also with the bedroom window fully open giving an opening of 60 cm (24 in) wide and 40 cm (16 in) high.

3.1 Closed Compartment Gas Burner Test

The test was performed with the door and all windows closed. The leakage into the compartment was measured before the test to be 0.015 m^2 (0.16 ft). This leakage area was used as input to the leakage model in FDS. Both the test and simulation were run for 600 s.

3.1.1 Heat Release Rate

The heat release rate was prescribed with a constant value of 125 kW as in the experiment. The default ramp up time in FDS of 1 s is used. The resulting heat release rate from the FDS simulation is shown in Figure 3-1.

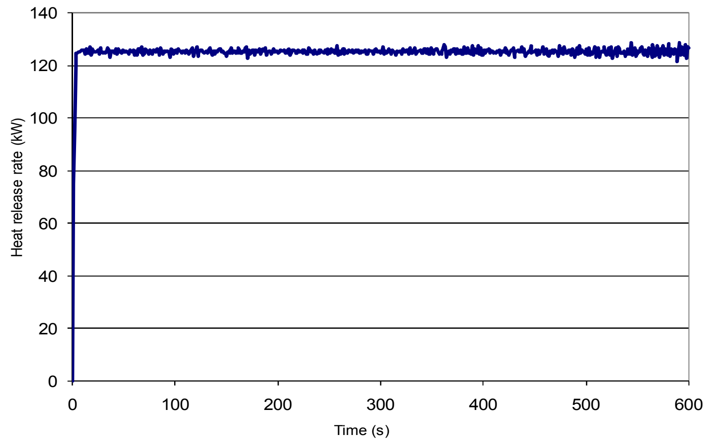


Figure 3-1. Resulting heat release rate from the FDS simulation of the natural gas burner test with closed compartment.

It is clear from Figure 3-1 that the heat release rate of the fire is not affected by any lack of oxygen in the compartment and remains at its prescribed value throughout the test.

3.1.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the living room (top) where the burner was placed and in the bedroom (bottom) are shown in Figure 3-2.

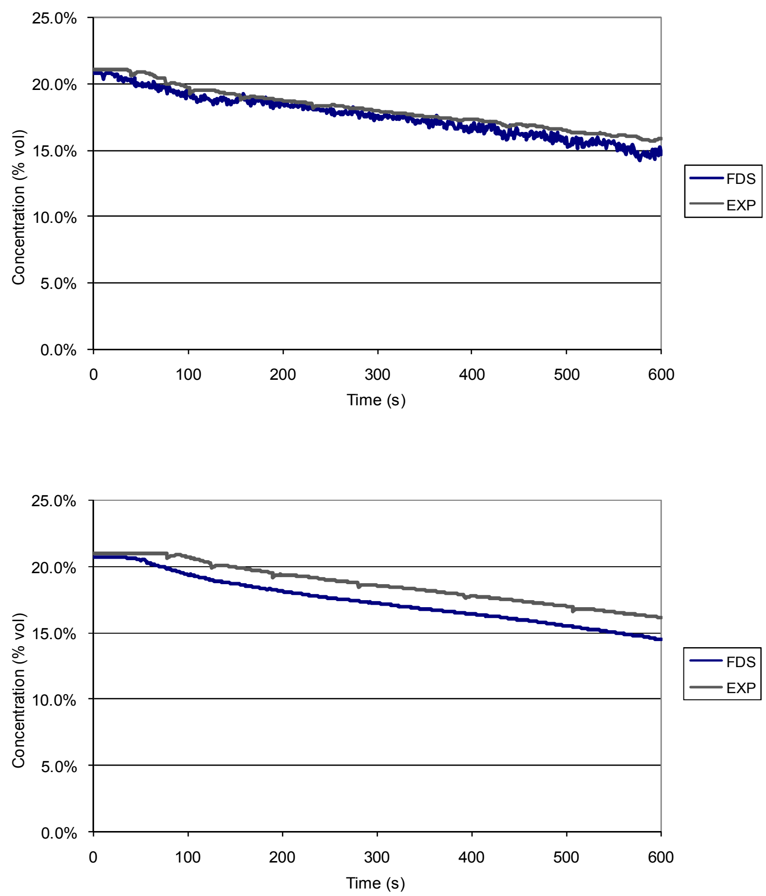


Figure 3-2. Oxygen concentrations at 1.5 m (5 ft) in the living room (top) and bedroom (bottom) for the burner fire with compartment closed.

The oxygen concentration only decrease to a minimum of 14.2% in the living room at the end of the simulation. As seen in Figure 3-1 this is not low enough to affect the heat release rate.

3.1.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 50 s, 200 s and 500 s in the living room and bedroom. The data was averaged over 10 s for each of the measurement points.

Temperature measured over the height of the room at 50 s in the living room (top) and bedroom (bottom) are shown in Figure 3-3. Straight lines have been drawn between the measurements points to aid in the visualization of the temperatures and do not imply a functional relationship. Error bars show the uncertainty for the thermocouples in the experiment.

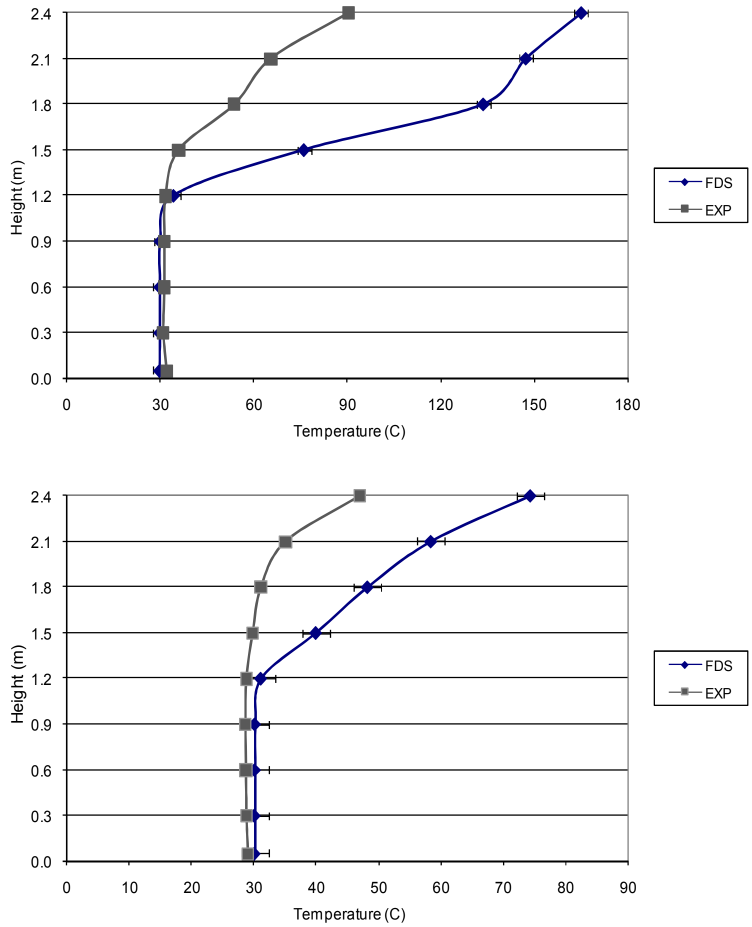


Figure 3-3. Vertical variations of temperature at 50 s in the living room (top) and bedroom (bottom) for the burner fire with compartment closed.

The ambient temperature was around 30 °C and the lower five thermocouples have not yet started to increase at this time and FDS shows results for these within experimental uncertainty. The top four thermocouples have increased for both the simulation and experiment, but FDS predicts a larger increase. In the living room the top thermocouple in FDS shows over 160 °C but the same thermocouple in the experiment only shows 90 °C.

Temperature measured over the height of the room at 200 s in the living room (top) and bedroom (bottom) are shown in Figure 3-4.

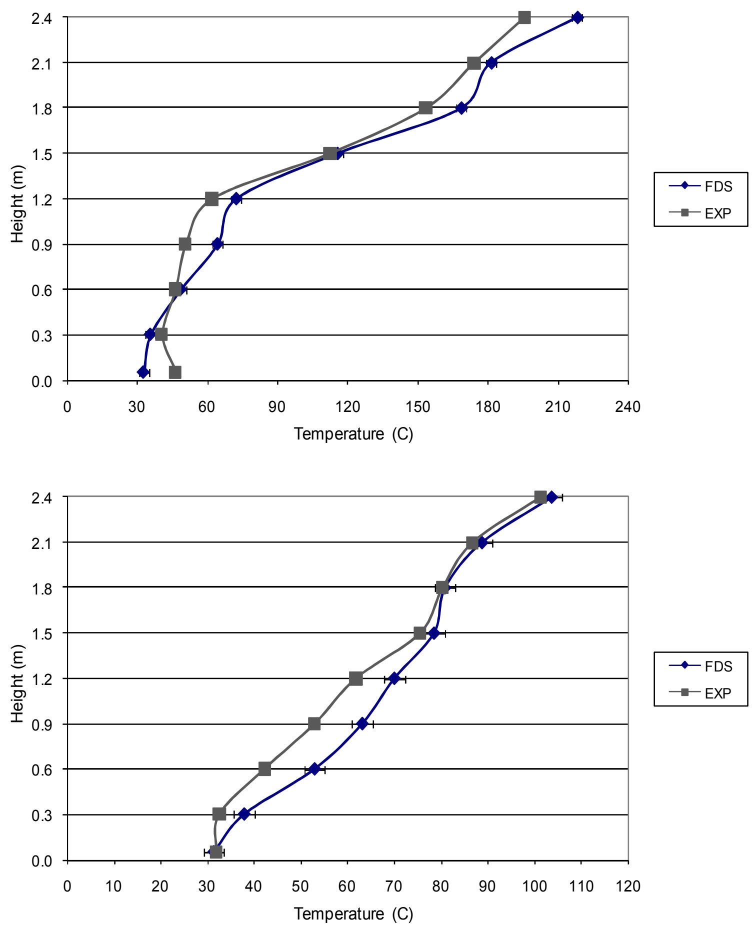


Figure 3-4. Vertical variations of temperature at 200 s in the living room (top) and bedroom (bottom) for the burner fire with compartment closed.

At 200 s into the test the temperature has increased at all heights in both the test and in the FDS simulation. A clear temperature difference in the living room between 1.2 m (4 ft) and 2.1 m (7 ft) indicates the transition zone between the lower and upper layers. This is less clear in the bedroom where the temperature increase is close to linear with height.

FDS follows the test data closely in both rooms but tends to overpredict the temperature. FDS is within 5% of the test data in the living room. In the bedroom FDS is within experimental uncertainty from 1.5 m (5 ft) and up and shows at a maximum a temperature 3% higher below 1.5 m (5 ft).

Temperatures measured over the height of the room at 500 s in the living room (top) and bedroom (bottom) are shown in Figure 3-5.

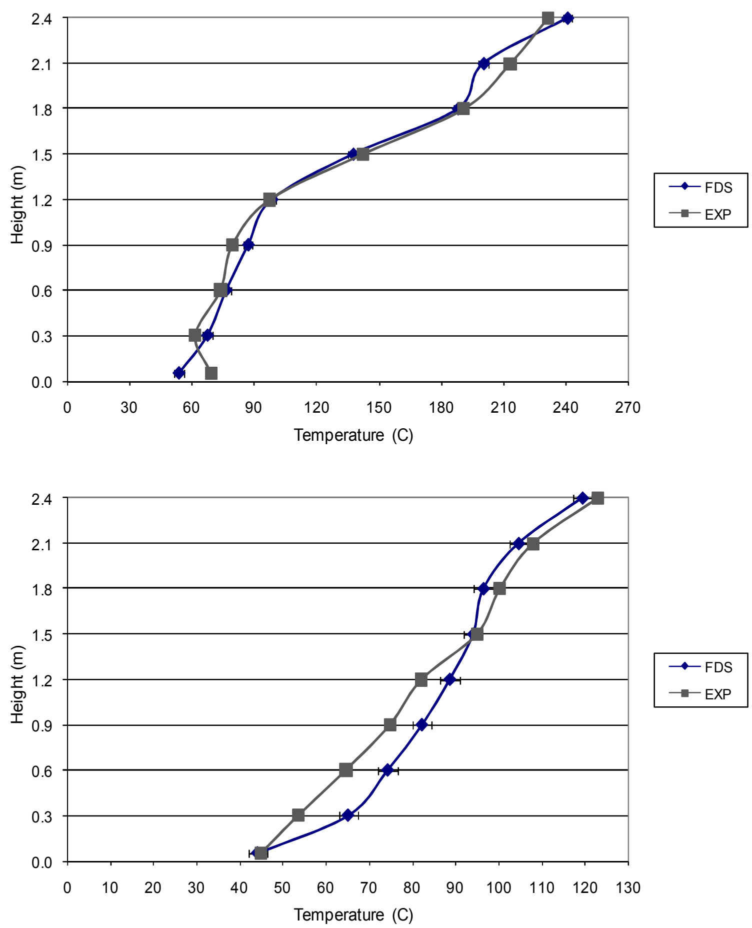


Figure 3-5. Vertical variations of temperature at 500 s in the living room (top) and bedroom (bottom) for the burner fire with compartment closed.

At 500 s the temperature in the living room and bedroom has increased for all heights. The shape of the curve remains the same with a more pronounced layer separation in the living room than in the bedroom. FDS is within 5% of the test data in the living room. In the bedroom FDS is within 4% of the test measurements and within experimental uncertainty from 1.5 m (5 ft) and up. FDS shows 3.5% higher temperature at 0.3 m (1 ft) as the maximum deviation.

3.2 Open Window Gas Burner Tests

The simulation and test were both run for 600 s. The bedroom window was kept open giving a ventilation opening 60 cm (24 in) wide and 40 cm (16 in) high, an area of 0.24 m^2 (2.6 ft^2). This was in addition to any leaks in the structure. In FDS the leakage model cannot be used with an open boundary condition so the only opening in the FDS model was the bedroom window (McGrattan et al. 2008b).

3.2.1 Heat Release Rate

The prescribed heat release rate was the same as in the closed compartment test, 125 kW, and the resulting heat release rate from the simulation is shown in Figure 3-6.

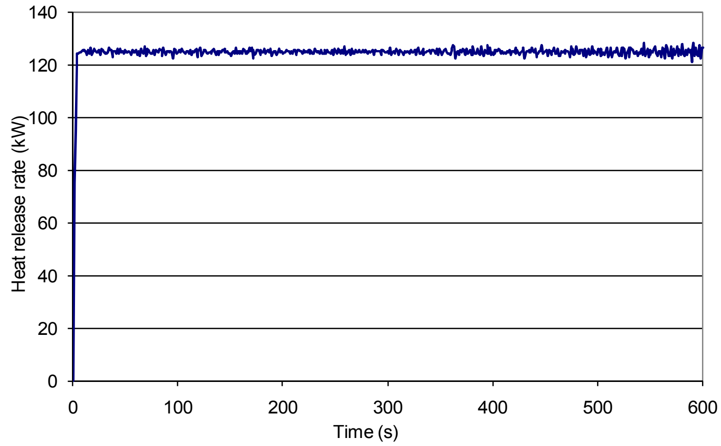


Figure 3-6. Resulting heat release rate from the FDS simulation of the 125 kW natural gas burner test with open window.

As in the closed test simulation the heat release rate shows no signs of oxygen vitiation and gives the prescribed 125 kW throughout the test.

3.2.2 Oxygen concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the living room (top) where the burner was placed and in the bedroom (bottom) are shown in Figure 3-7.

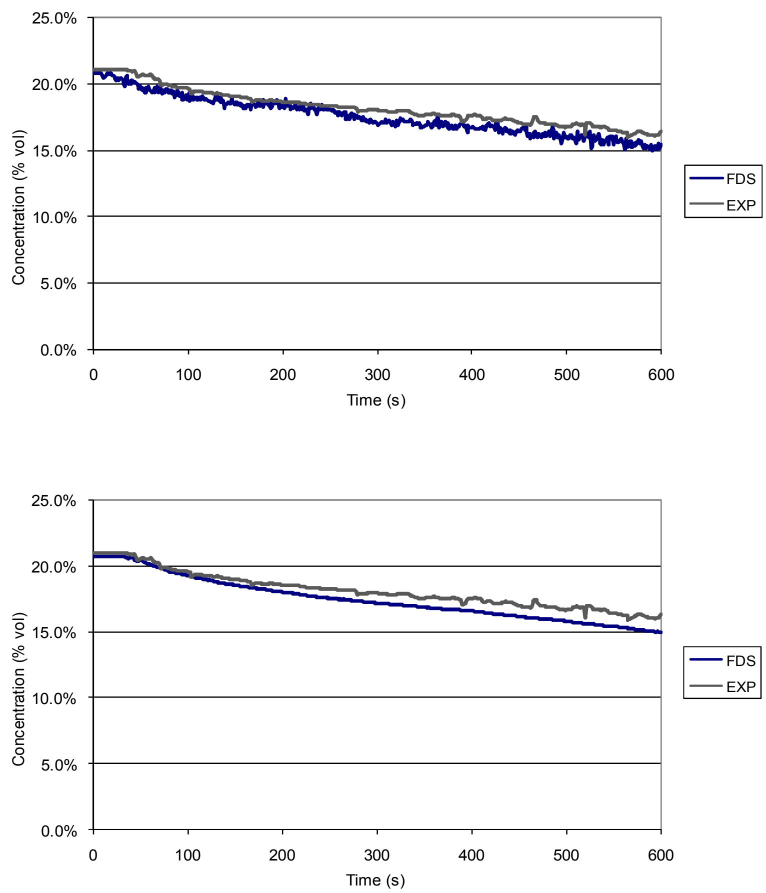
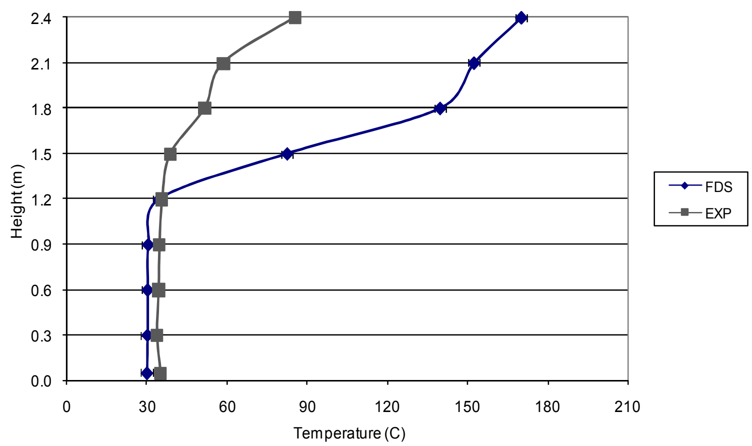


Figure 3-7. Oxygen concentrations at 1.5 m (5 ft) in the living room (top) and bedroom (bottom) for the natural gas burner test with open window.

In both rooms the oxygen concentration steadily decreases throughout the experiment in both the test and in the simulation and end up at a minimum value around 15%. The minimum value is slightly higher than seen in the closed burner test, which would be expected due to increased inflow of fresh air.

3.2.3 Temperature

Temperature measured over the height of the room at 50 s in the living room (top) and bedroom (bottom) are shown in Figure 3-8.



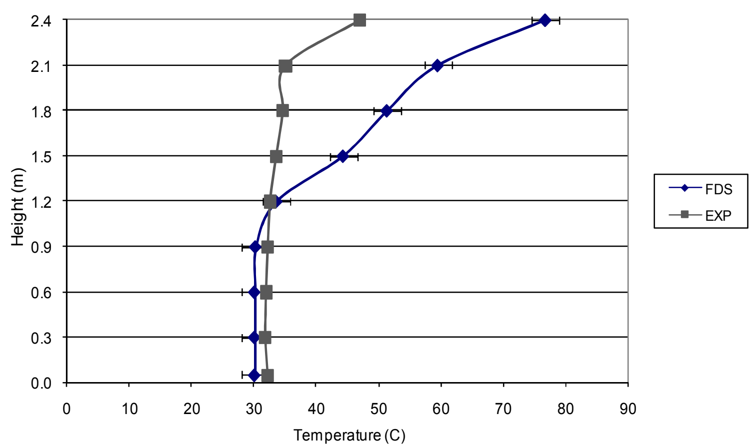


Figure 3-8. Vertical variations of temperature at 50 s in the living room (top) and bedroom (bottom) for the natural gas burner test with open window.

As in the closed burner tests the top four thermocouples see an increase in temperature whereas the bottom five remain at or close to ambient. There is also the same tendency for FDS to give a higher temperature in the upper layer. For the top thermocouple in the living room FDS estimates 170 °C, but only 85 °C was measured on the experiment. FDS give results within experimental uncertainty up to 1.2 m (4 ft) in both locations.

Temperature measured over the height of the room at 200 s in the living room (top) and bedroom (bottom) are shown in Figure 3-9.

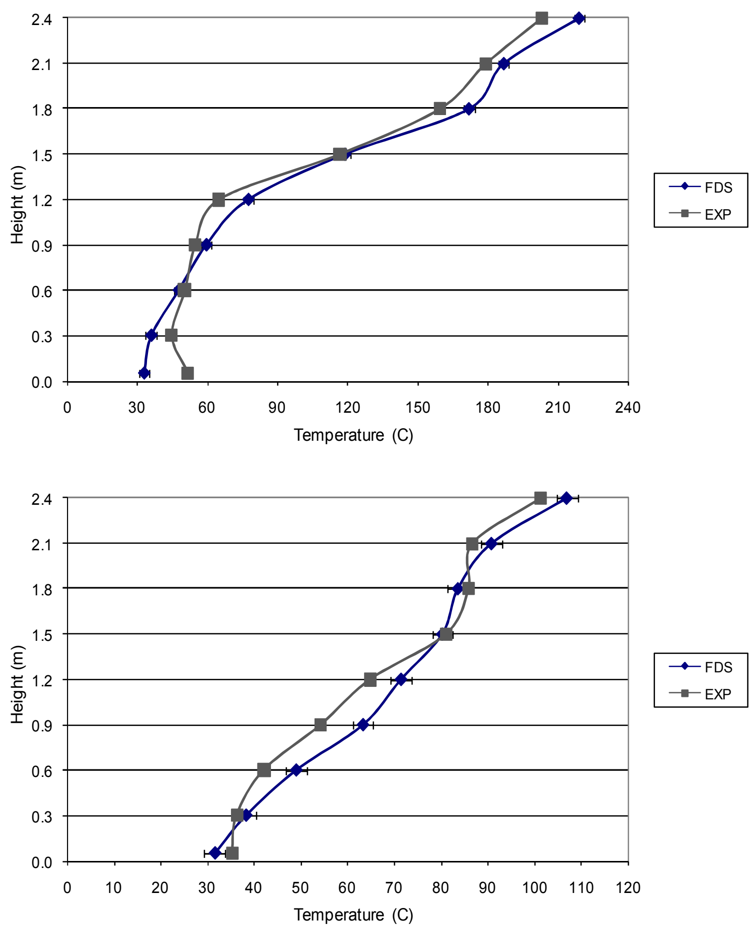
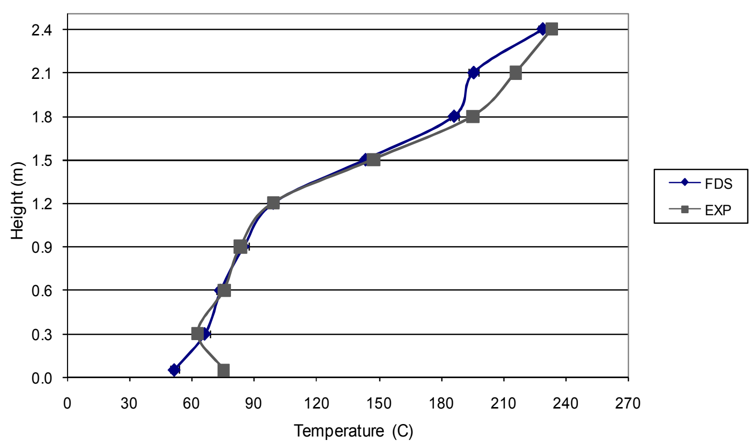


Figure 3-9. Vertical variations of temperature at 200 s in the living room (top) and bedroom (bottom) for the natural gas burner test with open window.

The temperature rise signifying the layer interface is still visible in the living room around 1.5 m (5 ft) above the floor and FDS agrees with the experiment concerning both temperature and position of the layer. FDS is within 5% of the test data everywhere in the living room except at the floor. The simulation shows some deviations for the temperature in the lower layer in the bedroom but follows the same trend as the experimental data as is within 3% at all heights.

Temperature measured over the height of the room at 500 s in the living room (top) and bedroom (bottom) are shown in Figure 3-10.



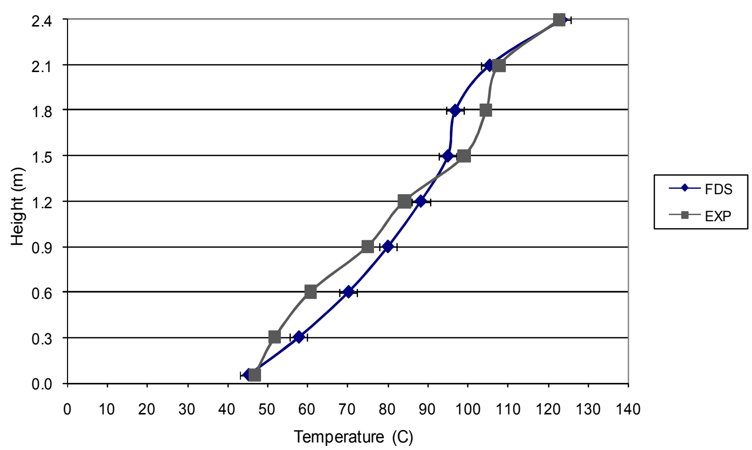


Figure 3-10. Vertical variations of temperature at 500 s in the living room (top) and bedroom (bottom) for the natural gas burner test with open window.

At 500 s the FDS predictions are very close in the living room except for outliers at floor level and 2.1 m (7ft) above the floor. Excluding the floor level thermocouple gives temperature within 5% of the test measurements. In the bedroom FDS tends to show an overprediction in the lower layer. The thermocouples at 1.5 m (5 ft), 1.8 m (6 ft) and 2.1 m (7 ft) are close in temperature, indicating a uniform temperature in the upper layer. This can also be seen in the right plot in Figure 3-9. In FDS the temperature at the same heights is not as uniform and is lower. FDS is within 5% of the test data for all heights in the bedroom.

4 COMPARISON OF CALORIMETER HEAT RELEASE RATE SIMULATIONS AND EXPERIMENTS

4.1 Comparing Experimental and FDS Data

As explained in Section 2.6.2, the resulting heat release rate curve was shifted so that the peak agrees with the one from FDS to remove the influence of uncertainties associated with modeling the ignition sequence from alcohol to tissue boxes and then sofa or cabinets, which were not of interest in this study. As an example the heat release rate curve for the sofa test with open window had to be shifted 280 s back, shortening the time from ignition to rise in heat release rate. The resulting heat release rates from FDS and the test for the sofa test with window half open is shown in Figure 4-1.

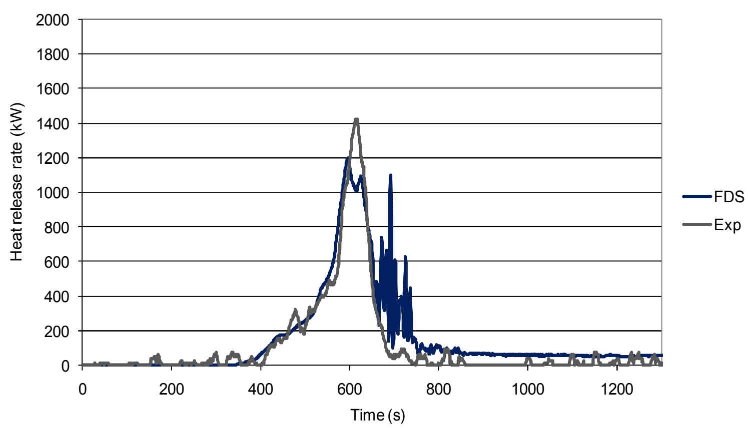


Figure 4-1. Heat release rate curves for the experiment and FDS simulation of the sofa test with half open window. The experiment curve has been shifted 280 s to the left.

The shape of the two curves line up well except for the lower peak in the FDS simulation. The fluctuations in the FDS curve occurring from about 650 s are due to oxygen vitiation effects. The data for temperature and species concentration from the experiment will also have to be shifted 280 s back when they are compared to the FDS results. Table 4-1 shows the time shift used to align the heat release rate curve for the calorimter simulations with the experimental data. For all tests except the closed cabinet test the experimental data were shifted to the left on the time axis, indicated by the negative value. For the closed cabinet test the FDS data was shifted 250 s to the left, indicated by a positive sign in Table 4-1.

Table 4-1. Time Shift Used To Align the Heat Release Rate Curve for the Experiment and FDS and Applied to the Temperature and Species Data. A Negative Value Indicates the Experimental Data Was Moved to the Left of the Time Axis. A Possitive Value Indicates the FDS Data Was Shifted To the Left.

Fire source	Ventilation	Time shift
Elevated Cabinets	Closed	+ 250 s
Elevated Cabinets	Window half open	- 130 s
Elevated Cabinets	No Window	- 150 s
Elevated Cabinets	Door Open	- 130 s
Sofa	Closed	- 350 s
Sofa	Window half open	- 280 s

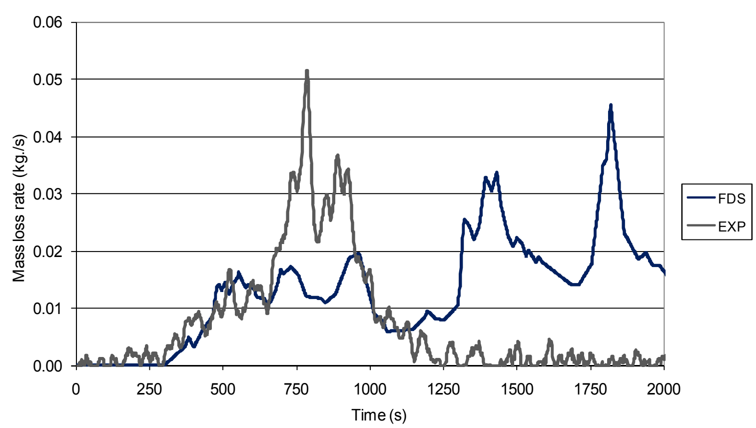
As in the presentation of the burner data the oxygen concentrations and vertical variations of temperature in the fire room and bedroom are shown. The lines drawn between the temperature measurement points is only to aid in visualization and do not imply a functional relationship.

4.2 Elevated Kitchen Cabinet in Closed Compartment

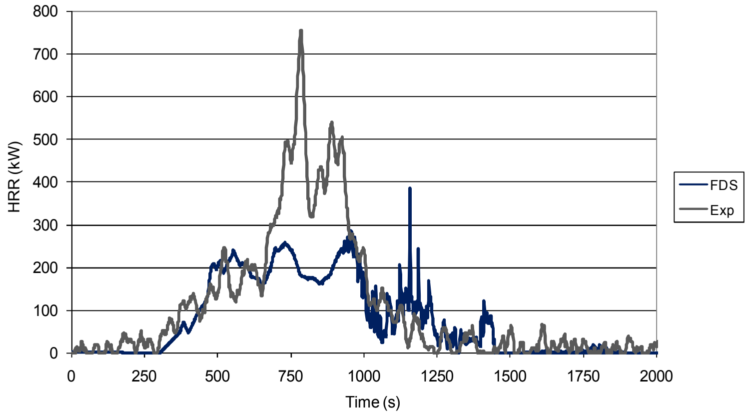
The FDS simulations used the heat release rate measured for four kitchen cabinets under the furniture calorimeter. In the experiment the fire burned through the two first cabinets but died out due to oxygen starvation before the third and fourth cabinets became involved. In the simulation FDS gave off the prescribed heat release rate over the surface of all four cabinets.

4.2.1 Heat Release Rate

The resulting heat release rate from FDS is compared to the heat release rate calculated for the experiment by using the mass loss rate data and the heat of combustion measured in the free burning hood. The heat release rate curve from the experiment was shifted 250 s to the right to match up with the point where it starts to increase in FDS. Figure 4-2 shows the mass loss rate in FDS and the test (a) and the resulting heat release rates (b).



(a)



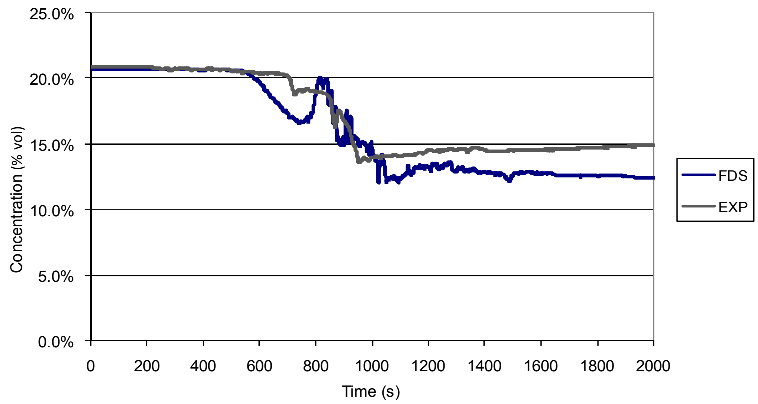
(b)

Figure 4-2. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Elevated kitchen cabinets in the closed compartment.

It is clear that the heat released in the experiment is significantly higher than in the FDS simulation. At around 1000 s the simulation starts to show fluctuations due to lack of oxygen and the fire dies down at around 1200 s. This occurs before the second peak in heat release rate associated with burning of the second cabinet in the calorimeter is achieved. In the experiment both the first and second cabinets burned and the peak heat release rate is higher. This may be due to compartment effects where the hot smoke layer radiates heat back to the burning cabinets, which intensifies the wood pyrolysis.

4.2.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-3. The FDS data in the kitchen was averaged over 5 s because of fluctuations in the data.



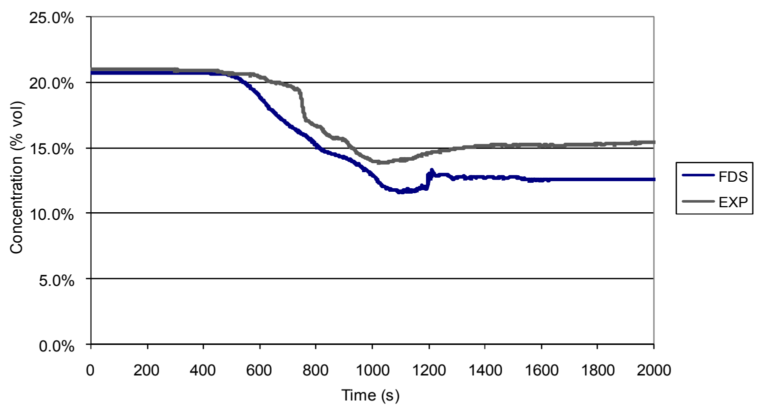


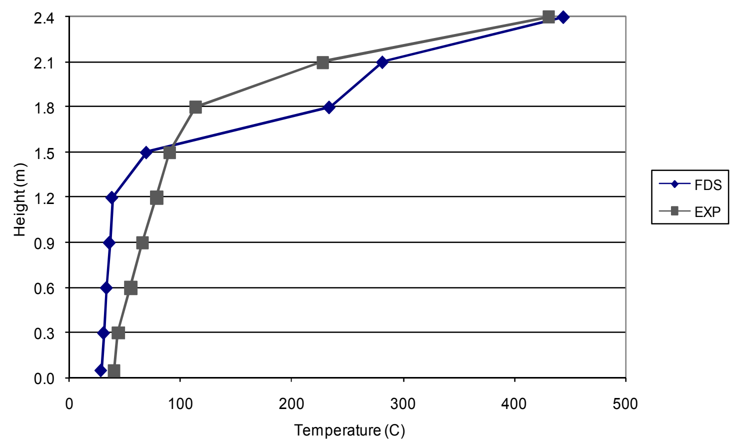
Figure 4-3. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the kitchen cabinet test in the closed compartment.

The test data and FDS results show good agreement for the reduction in oxygen concentration in the kitchen. The test reaches a steady value of 15% by volume at 1000 s. FDS goes down to 13% and stays there for the remainder of the test. FDS also shows a quick drop between 600-800 s but goes back up to ambient values. This coincides with the first peak and drop of the heat release rate. In the bedroom the oxygen concentration starts to decrease in FDS about 230 s earlier than in the experiment and reaches a lower minimum value around 12% by volume compared to 14% in the test.

4.2.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 700 s, 800 s and 2000 s in the kitchen and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 25° C.

Temperature measured over the height of the room at 700 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-4.



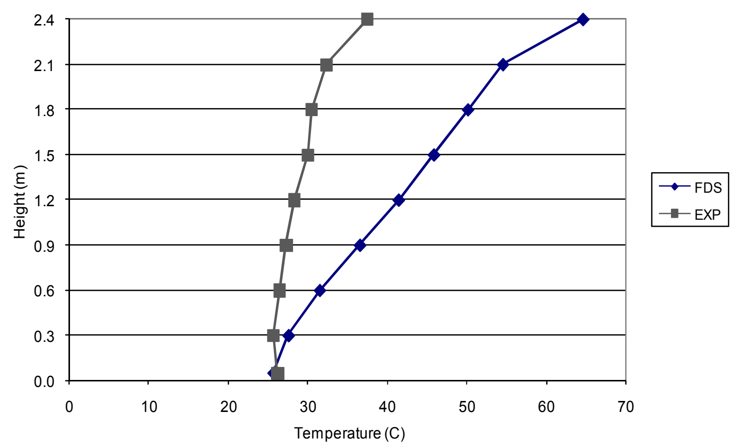


Figure 4-4. Vertical variations of temperature at 700 s. in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with compartment closed

After 700 s the heat release rate in the experiment is only 50 kW higher that predicted by FDS and the temperature profile in the kitchen shows that FDS place the interface between the lower and upper layer around 1.5 m – 1.8 m (5 ft – 6 ft) whereas the experimental data indicate this is between 1.8 m (6 ft) and 2.1 m (7 ft). Except for the thermocouples at 1.2 m (4 ft) and 1.8 m (6 ft), which show 11% and 31% deviation respectively from the experimental data, the largest discrepancy in the kitchen is less than 10%. In the bedroom FDS predicts a larger temperature rise than was recorded, up to a 8% difference. This may indicate that FDS overpredicts the amount of hot combustion products flowing from the fire room to the bedroom, which would be consistent with the results for the oxygen concentration as seen in Figure 4-3.

Temperature measured over the height of the room at 800 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-5.

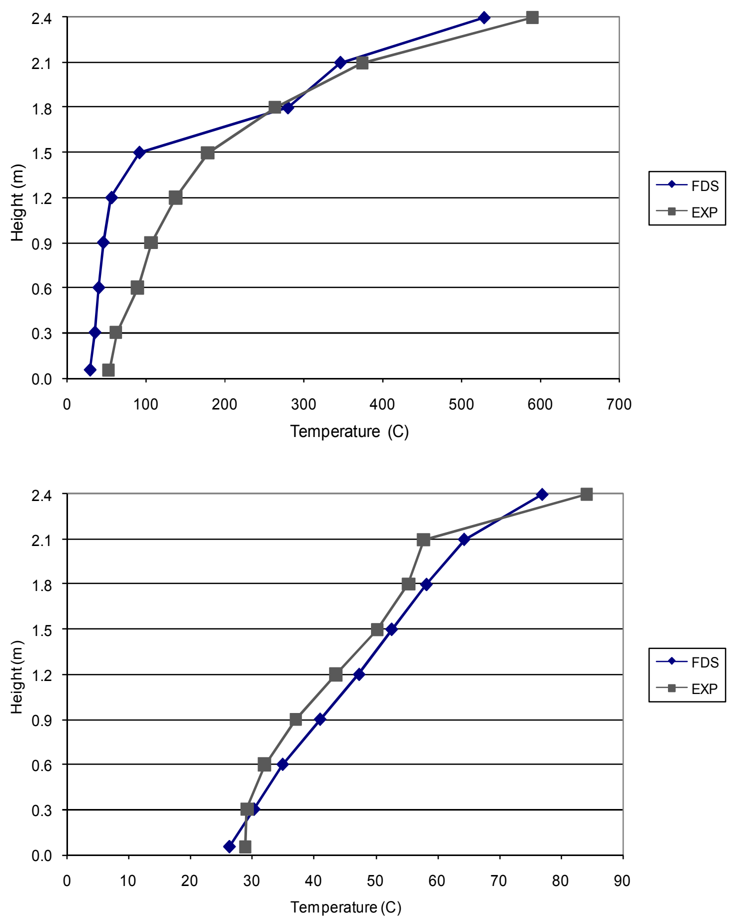


Figure 4-5. Vertical variations of temperature at 800 s. in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with compartment closed

At 800 s the heat release rate in the experiment is over double that predicted by FDS but the temperature measurements in both the kitchen and bedroom show good agreement. In the kitchen FDS underpredicts the temperature in the lower layer somewhat but the placement of the interface and temperature in the three topmost thermocouples is not off by more than 60 °C, or about 7%. In the bedroom the FDS predictions are within 3% of the experimental data at all heights.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-6.

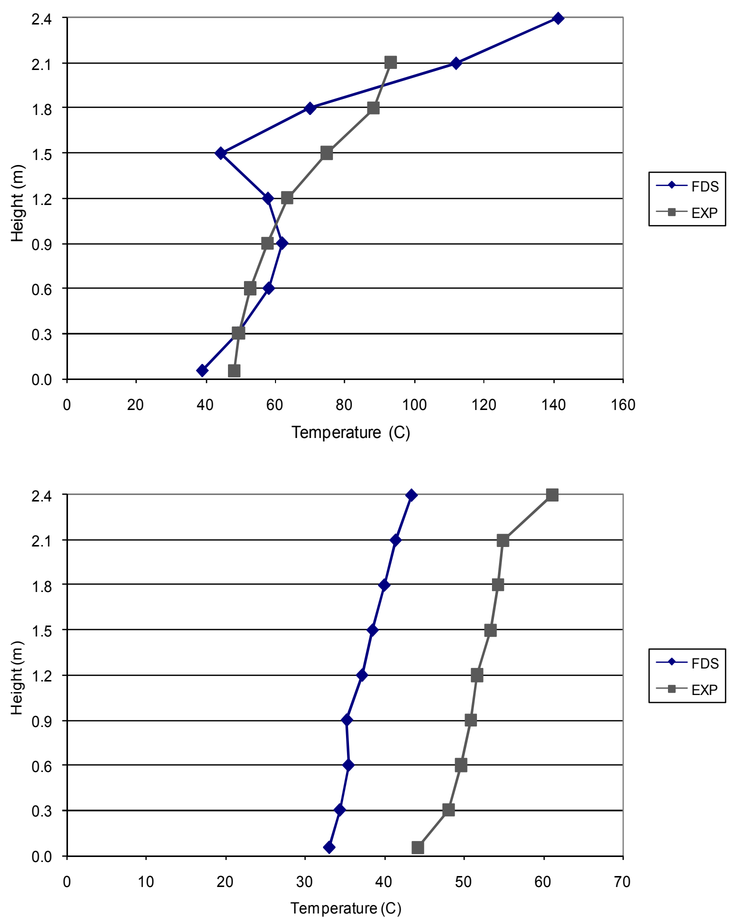


Figure 4-6. Vertical variations of temperature at 2000 s. in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with compartment closed

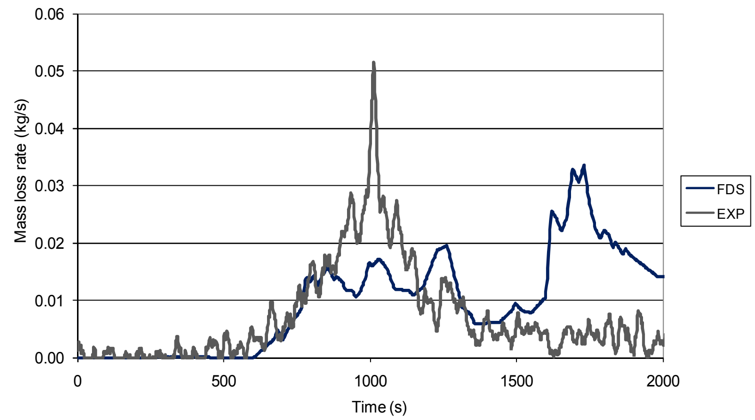
At 2000 s both the fire in the experiment and the FDS simulation have self-extinguished due to lack of oxygen. The top thermocouple in the kitchen was destroyed in the test and is not included in Figure 4-6. The temperature profile in the kitchen for the FDS simulation shows an unusual behavior at 1.5 m (5 ft) where the temperature is lower than three of the thermocouples lower down. This behavior was not seen in other simulations and it is not know why it occurred. The other thermocouples in the kitchen are within 20% of the experimental results. In the bedroom the FDS predictions are about 3% lower than the experimental data for all heights.

4.3 Elevated Kitchen Cabinets with Half Open Window

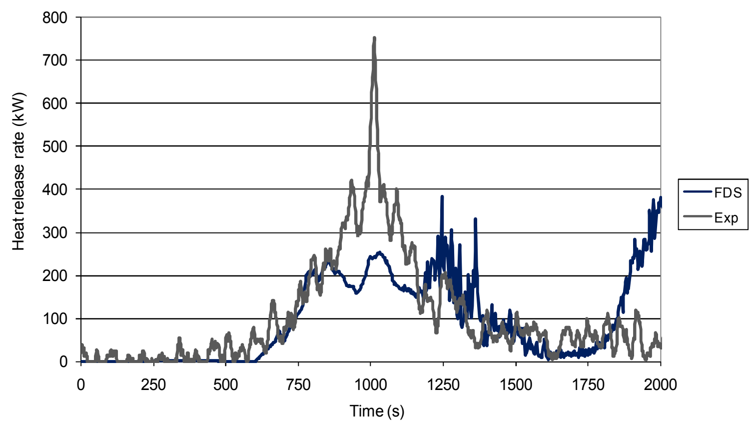
The scenario was similar to the fully closed compartment except for having the bedroom window half open, giving a ventilation opening 20 cm (8 in) high and 60 cm (24 in) wide.

4.3.1 Heat Release Rate

Figure 4-7 shows the mass loss rate in FDS and the test (a) and the resulting heat release rates (b). The heat release rate curve from the experiment was shifted 130 s to the left to match up with the point where it starts to increase in FDS.



(a)



(b)

Figure 4-7. Mass loss rate (a) and heat release rate (b) in the FDS pre-test simulation compared to the test data. Kitchen cabinets with window half open

As in the closed compartment the heat release rate from the test is higher than for FDS during the peak, but when the fire in the test dies down at around 1200 s the simulation still shows a slight increase before it too dies down due to lack of oxygen. At around 1800 s the FDS simulation starts to increase again, but with some fluctuations. Since the test fire did not show any activity beyond 2000 s the data was not analyzed beyond this. In the test there was a flare up of the fire about one hour after it first died down but this was considered outside the scope of this analysis.

4.3.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-8. The FDS data was averaged over five seconds because of fluctuations in the data.

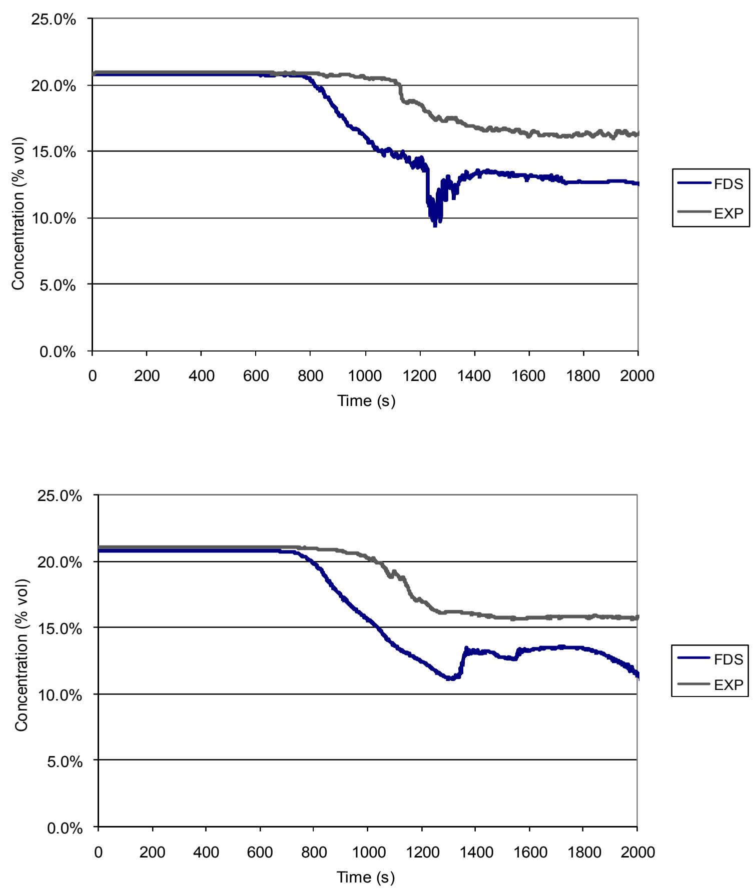


Figure 4-8. Oxygen concentrations 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test with window half open.

The oxygen concentrations show a similar trend seen in the closed compartment tests where FDS predicts shorter time before oxygen concentrations starts to decrease, about 200 s, and a lower minimum value in the kitchen. The tests show a minimum value of 16% by volume but FDS goes as low as 10%. In the bedroom the same trend can be seen, FDS predicts that concentrations start to decrease about 200 s earlier than the experimental data shows. FDS also predicts a minimum value down to 10% but the test never shows concentrations dropping below 15%.

4.3.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 900 s, 1000 s and 2000 s in the kitchen and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 25° C in both FDS and the test.

Temperature measured over the height of the room at 900 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-9.

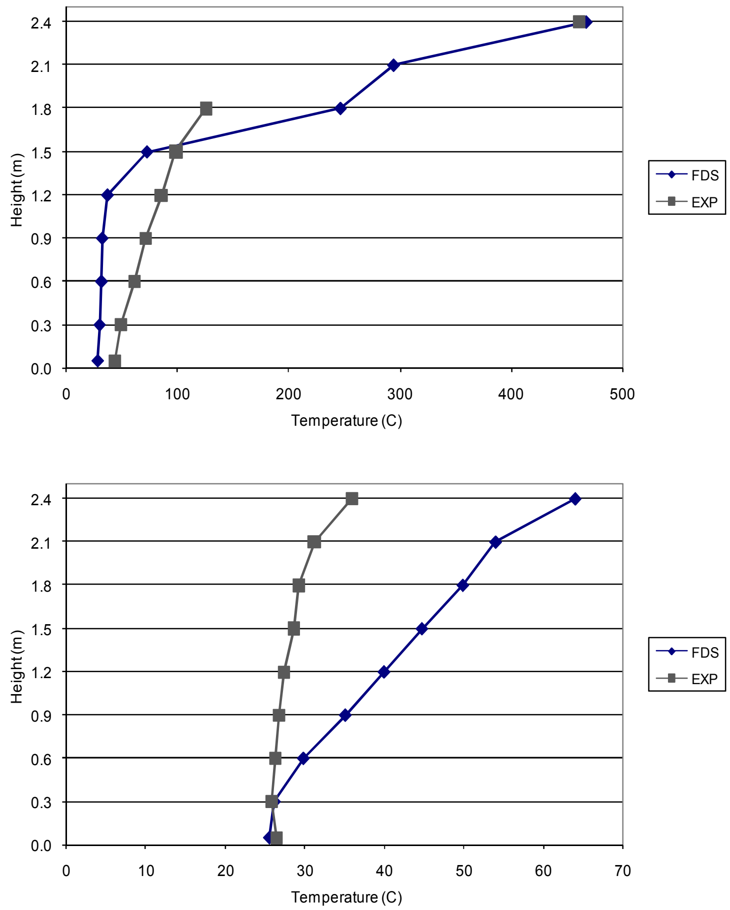


Figure 4-9. Vertical variations of temperature at 900 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window half open.

In the kitchen the thermocouple at 2.1 m (7 ft) showed negative values so was not included in the analysis. FDS shows good agreement at the top thermocouple but a large overprediction at 1.8 m (6 ft), possibly due to differences in placement of the hot gas layer in FDS and the experiment. Below 1.5 m FDS shows an underprediction from 13% decreasing downward to 5%. In the bedroom FDS shows an overprediction of the gas temperature, which increase with height.

Temperature measured over the height of the room at 1000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-10.

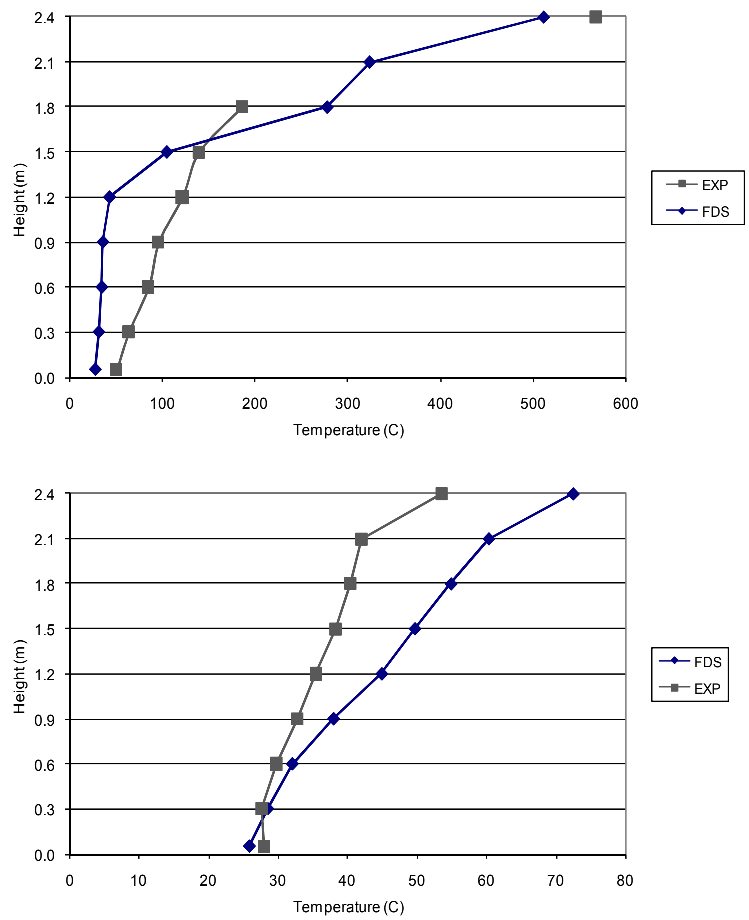


Figure 4-10 Vertical variations of temperature at 1000 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window half open.

At 1000 s the temperature profiles show the same shape. The overprediction in the upper layer in the kitchen is lower at about 20% and the underprediction below 1.5 m (5 ft) is between 15 – 20%. In the bedroom FDS overpredicts the temperatures by up to 6%.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-11.

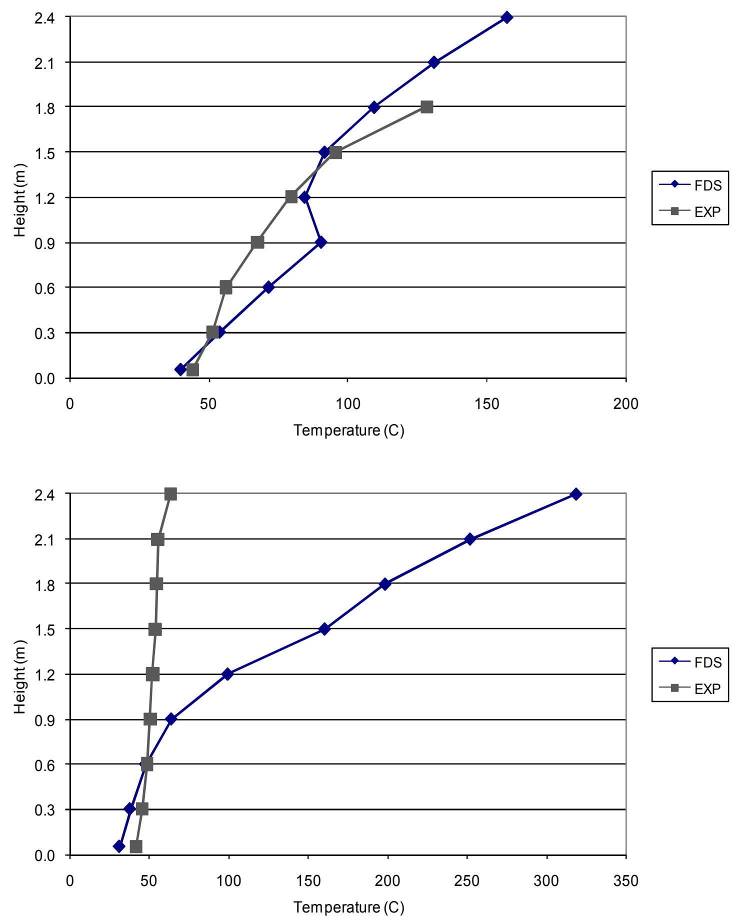


Figure 4-11. Vertical variations of temperature at 2000 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window half open.

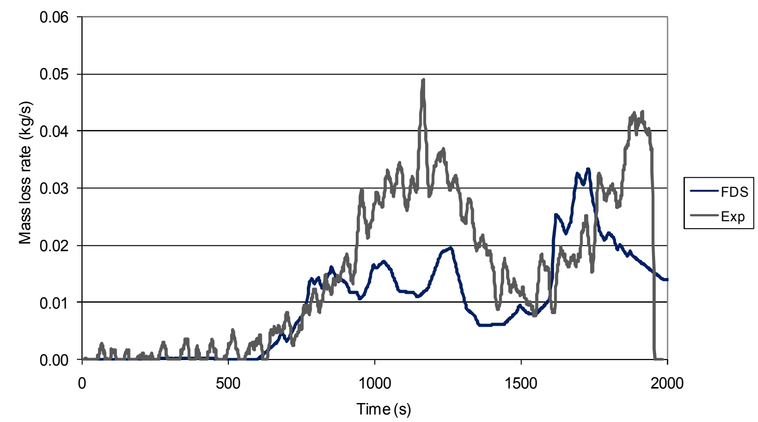
At 2000 s the thermocouple at 2.1 m (7 ft) in the kitchen had stopped showing negative values but there was concern that it did not give reliable readings so it was not included. The top thermocouple in the kitchen was destroyed by the heat at this time so is also not included. The temperature rise with height in the kitchen from FDS generally follows the same trend as seen in the experimental data. In the bedroom however FDS predicts a much higher temperatures. This is likely caused by the increase in heat release in FDS around 1800 s.

4.4 Elevated Kitchen Cabinet with Window Removed

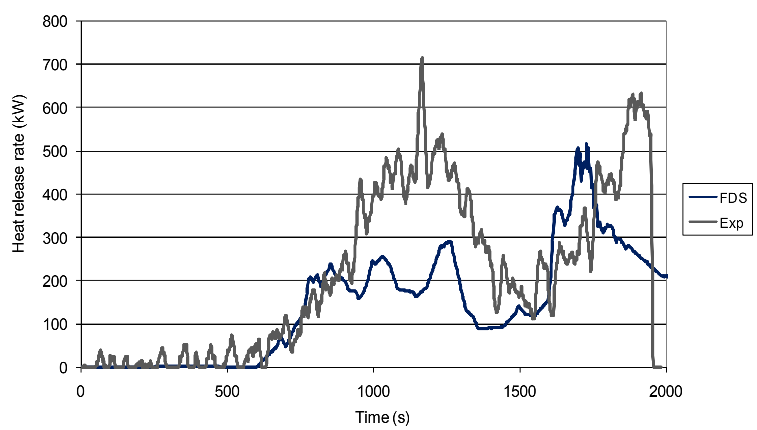
The FDS simulations used the heat release rate measured for four kitchen cabinets under the furniture calorimeter hood. In the test all four cabinets fell down from the wall at 1776 s, about 20 s after the third cabinet became involved in the fire. In the simulation all four cabinets were set to burn with the prescribed heat release rate from the start. The bedroom window was completely removed giving a ventilation opening 65 cm (25.5 in) wide and 103 cm (40.5 in) high.

4.4.1 Heat Release Rate

The heat release rate curve from the experiment was shifted 150 s to the left to match up with the point where it starts to increase in FDS. Figure 4-12 shows the mass loss rate in FDS and the test (a) and the resulting heat release rates (b).



(a)



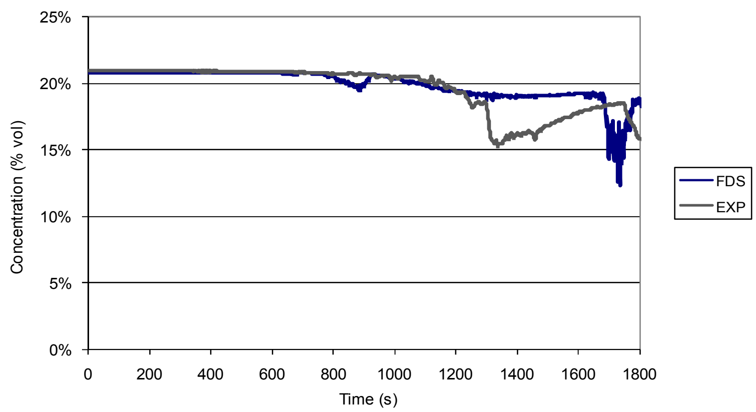
(b)

Figure 4-12. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Elevated kitchen cabinets with window removed.

The heat release rate in FDS is lower than calculated for the experiment from 900 s after ignition. The test data rise to a peak of 700 kW while FDS only reaches 300 kW at this time. Both FDS and the test show a second peak, which was about 200 s earlier in FDS. During the second peak FDS reached 500 kW while the test reached 600 kW.

4.4.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-13.



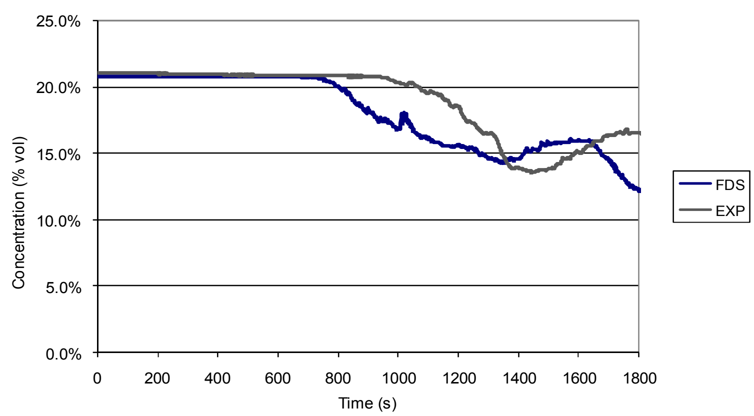


Figure 4-13. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the kitchen cabinet test with window removed.

The large ventilation opening results in oxygen concentration remaining higher than in the two previous tests. In the kitchen FDS only show a small drop in oxygen concentration at 880 s, which match the first peak in the heat release rate, but the concentration goes back up to close to ambient shortly after. After a slow reduction down to 19% by volume at 1600 s there is a sharp drop in the FDS data caused by the second peak in heat release rate. The experimental data also show two drops in oxygen concentration with a rise in between, which match up with the two peaks in heat release rate but the oxygen concentration is much lower for each drop in the test. This is most likely caused by the higher peak heat release rates in the test. At the end of the test the oxygen concentration drops to a minimum of 9%. In the bedroom both the test and FDS show a larger drop in oxygen concentration throughout the test than seen in the kitchen. The concentration starts to drop between 700-800 s for both FDS and the test with slightly slower reduction in the test. There is an increase in oxygen around 1500 s and then a continued reduction shortly after. For the test the initial drop in oxygen in both the kitchen and bedroom end at about the same value of 15%. This is not the case in FDS, where the drop in the bedroom is much larger than in the kitchen. It is not clear what causes this result.

4.4.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 900 s, 1200 s and 2000 s in the kitchen and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 26° C in the test and 25 °C in FDS.

Temperature measured over the height of the room at 900 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-14.

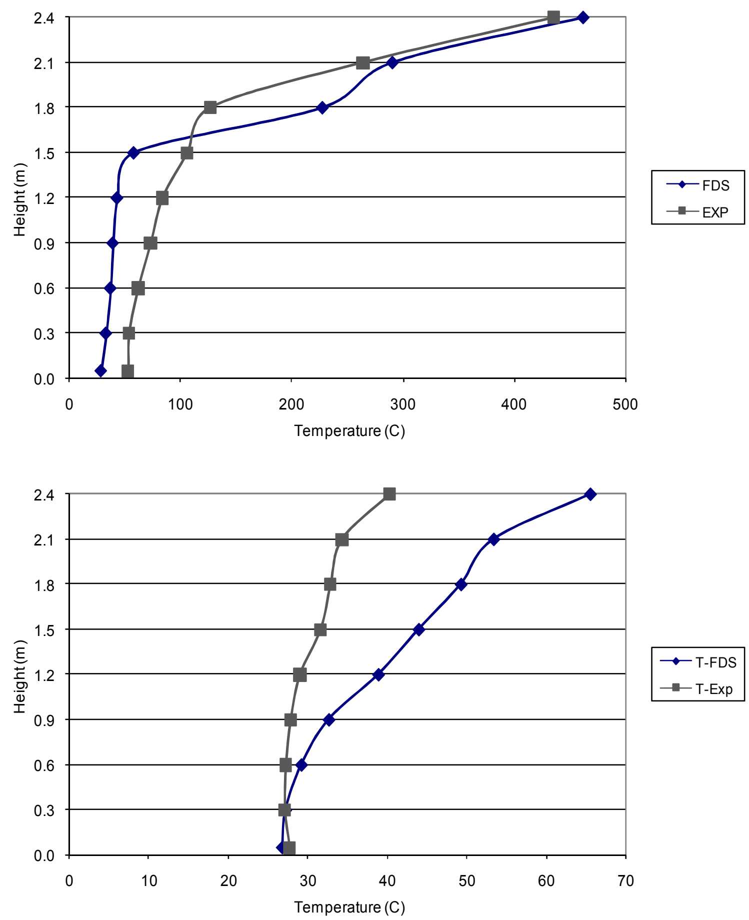


Figure 4-14. Vertical variations of temperature at 900 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

In the kitchen FDS shows an overprediction of the temperature in the top three thermocouples and in the lower layer, from 1.5 m (5 ft) and down; an underprediction from 7-13%. FDS places the layer interface 0.3 m (1 ft) lower than the experimental data shows. In the bedroom FDS shows an overprediction increasing with height ending at 8% higher value for the top thermocouple.

Temperature measured over the height of the room at 1200 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-15.

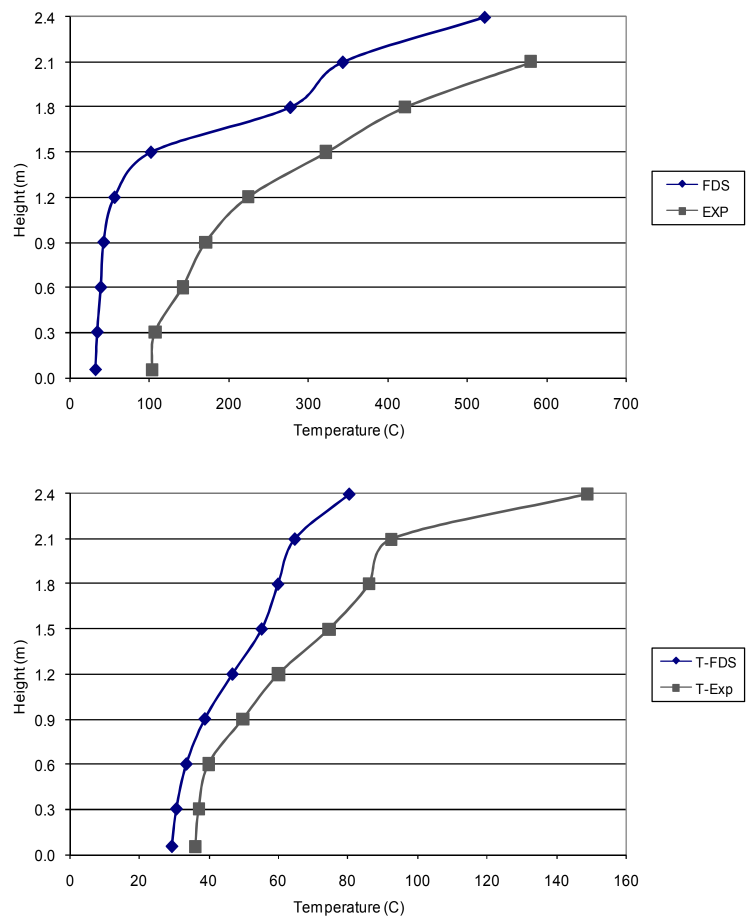


Figure 4-15. Vertical variations of temperature at 1200 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

At 1200 s FDS appears to show the same general shape of the curve for temperature in the kitchen but with a value 20-30% lower than seen in the test. In the bedroom FDS also shows an underprediction but not as severe. The deviations increase with height reaching a maximum of 16% difference for the top thermocouple.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-16.

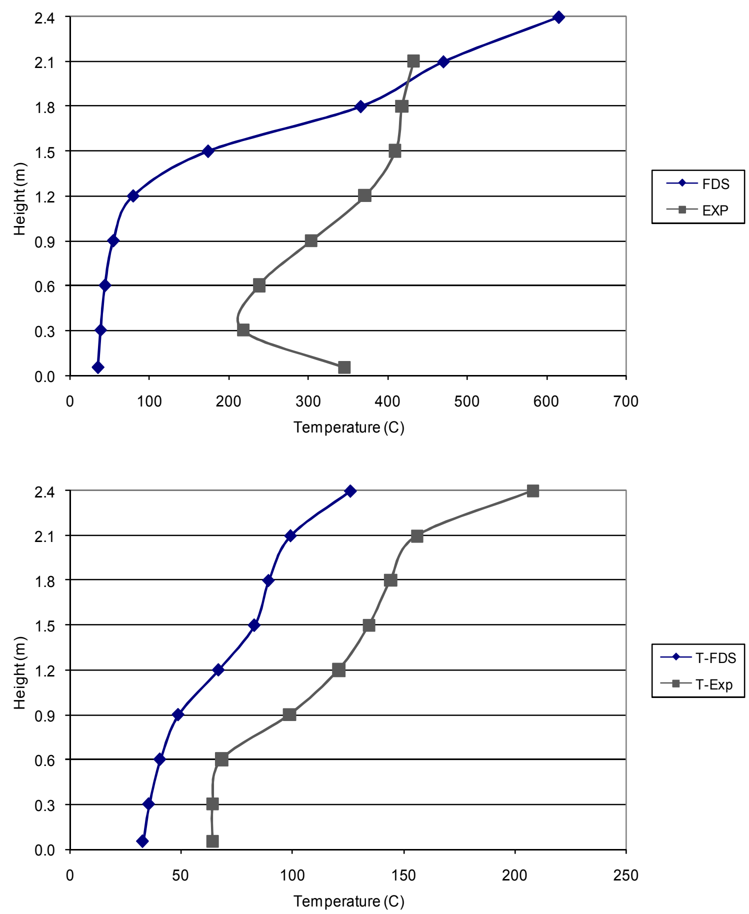


Figure 4-16. Vertical variations of temperature at 2000 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

After 2000 s the thermocouple at the ceiling in the kitchen was destroyed by the fire so is not included in Figure 4-6. The fire had been reduced to a smoldering at this time in the test and gave of little heat as can be seen in Figure 4-6. The fire in FDS still continued and so shows a layer configuration with less heat in the lower layer than seen in the test, most likely caused by the cabinets falling down and continuing to burn at the floor about

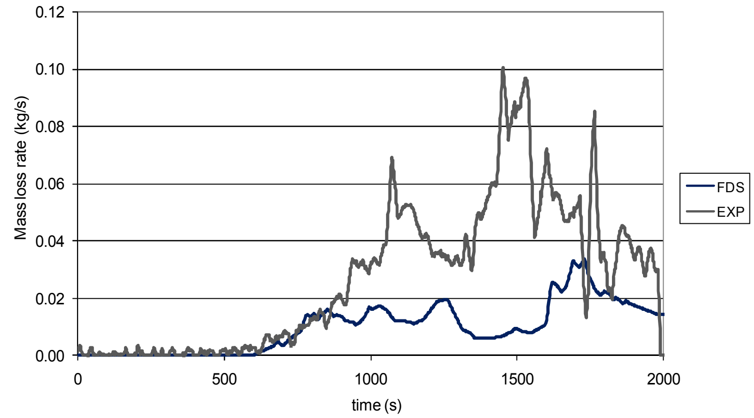
400 s earlier. In the bedroom FDS shows temperatures constantly 10-17% lower than recorded in the test.

4.5 Elevated Kitchen Cabinets with Open Door

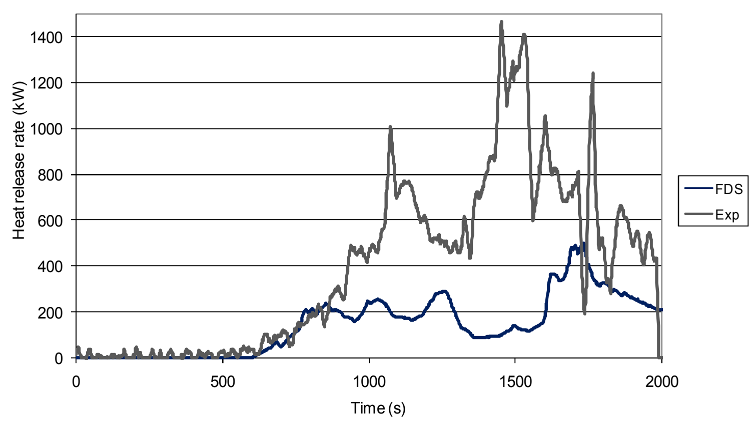
The scenario was similar to the other cabinet tests except the entrance door from the living room to the outside was open giving a ventilation opening 1.0 m wide and 2.0 m high. The two first cabinets fell off the wall at 1590 s and at 1630 s the two remaining cabinets also fell. The four cabinets continued to burn but most of the cabinets fell onto the load cell. The data was used after the cabinets fell but there may be questions about its reliability. The criterion for suppression was flashover, which was observed at 2198 s and the fire was extinguished.

4.5.1 Heat Release Rate

Figure 4-17 shows the mass loss rate in FDS and the test (a) and the resulting heat release rates (b). The heat release rate curve from the experiment was shifted 130 s to the left to better match up with the point where it starts to increase in FDS.



(a)



(b)

Figure 4-17. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Kitchen cabinets with door open.

The open door test provided more favorable ventilation conditions and gave the largest recorded heat release rate for the cabinet test with a maximum over 1400 kW, almost 1000 kW higher than was reached in FDS in the same time period. In the calorimeter test the highest heat release rate reached for any of the cabinet tests was 650 kW. In the calorimeter the fire spread from one cabinet to the next and in general the previous cabinet had died down when the next was fully involved so only one cabinet burned fully at any time. In the kitchen cabinet test with open door the fire spread more rapidly between cabinets, which is the likely cause of the higher heat release rate compared to unrestricted free burning.

4.5.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-18.

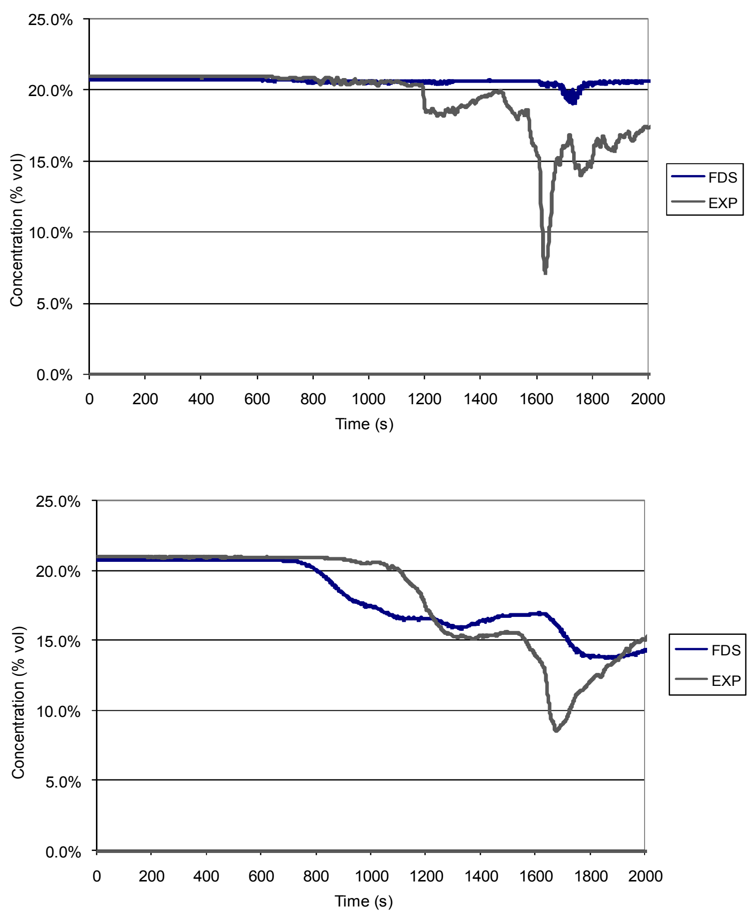


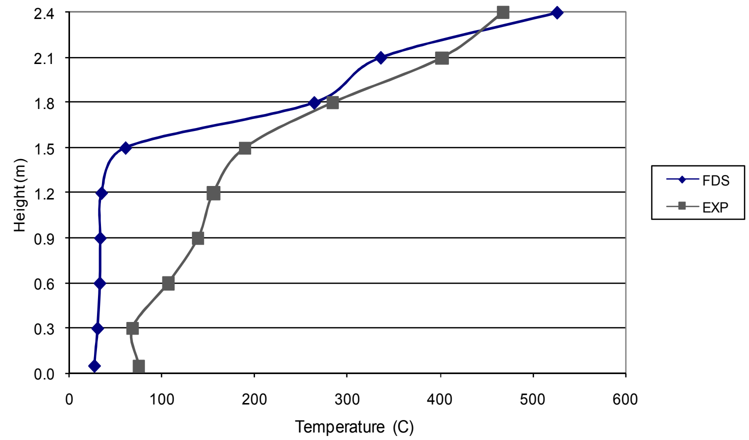
Figure 4-18. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test with door open.

The large ventilation opening and the low heat release rate in the FDS simulation results in only marginal decrease in oxygen concentration in the kitchen. The experimental data show a large decrease down to a minimum of 7% by volume at 1500 s. There is in both the simulation and the test a larger decrease in oxygen concentration in the bedroom. FDS predicts a minimum value of 14% near the end of the test. This might be because fresh air was drawn from the bedroom into the fire room but air coming in the door in the living room went to feed the fire before it reached the bedroom. Smoke from the fire room traveled into the bedroom as well as out the door.

4.5.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 1050 s, 1450 s and 2000 s in the kitchen and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 25° C in both the test and the simulation.

Temperature measured over the height of the room at 1050 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-19.



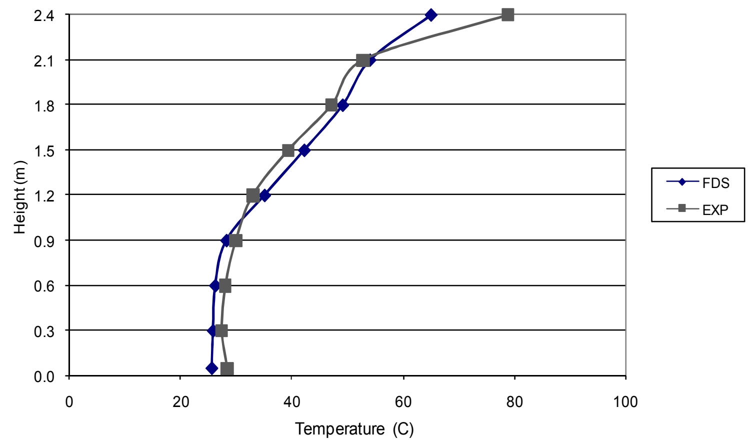
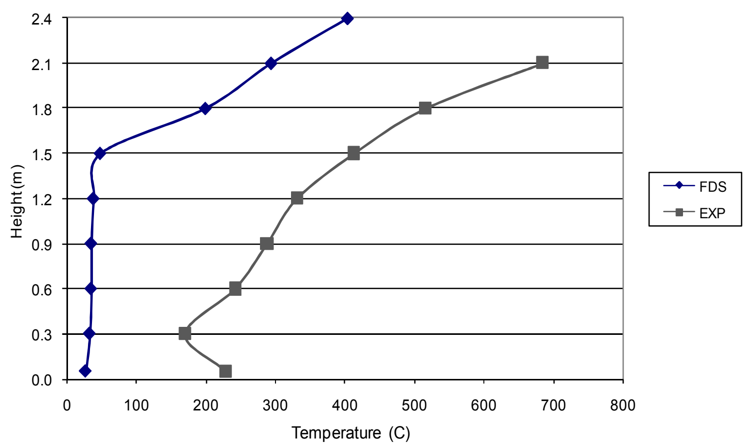


Figure 4-19. Vertical variations of temperature at 1050 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

The fire in FDS produces a marked layer interface in the kitchen at 1.5 m [5 ft] at 1050 s after ignition. The experimental data show a more gradual increase in temperature with height. FDS shows a lower temperature at all but the topmost thermocouple placement. In the lower layer a temperature from 11% to 30% lower than in the test. This is not unexpected given the lower heat release rate seen in the FDS simulation. At this time the heat release rate in the test is over double that of the FDS simulation. In the bedroom the effects of this difference is not as apparent. Except for the thermocouple at the ceiling, which show a temperature 4% lower in FDS, none of the FDS predictions are outside of

1% of the experimental results. Six of the nine FDS predictions are within experimental uncertainty. A possible explanation is that the majority of the hot smoke escapes out the door so only minimal amounts have reached the bedroom by this time thereby delaying the effects of the higher heat release rate in the test. The higher temperature at the ceiling indicates that more hot gases have started entering the bedroom in the test than in FDS.

Temperature measured over the height of the room at 1450 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-20.



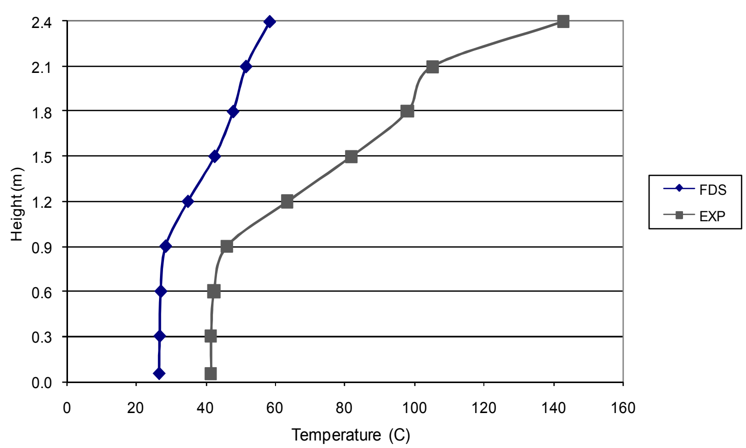


Figure 4-20. Vertical variations of temperature at 1450 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

The thermocouple at the ceiling in the kitchen was destroyed by the heat from the fire so is not included in Figure 4-20. The temperature in both the kitchen and the bedroom continue to show the effects of the higher heat release rate in the tests with underpredictions by FDS in both rooms at all heights from 10% to 50%.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-21.

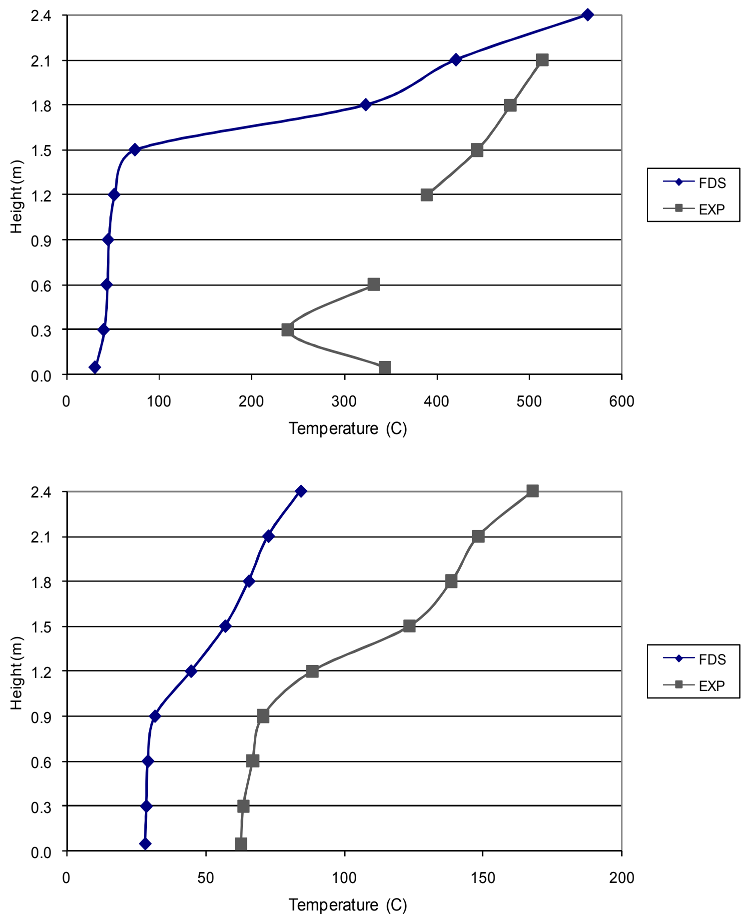


Figure 4-21. Vertical variations of temperature at 2000 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

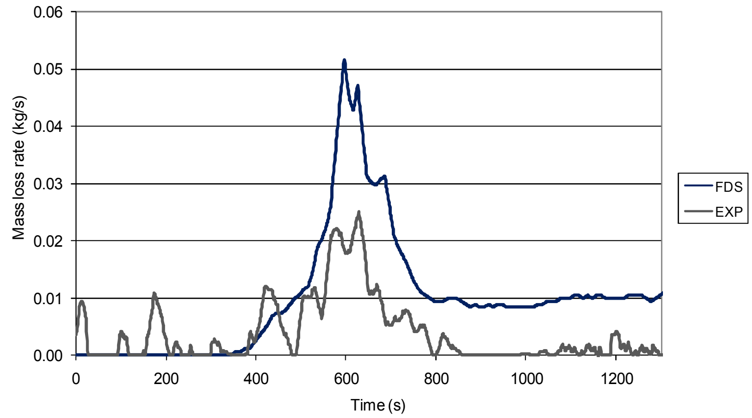
At 2000 s the predictions by FDS have improved slightly as the fire in the fire was extinguished while it continued in FDS, but still give lower temperatures for all heights. The thermocouple at 0.9 m (3 ft) was destroyed as the cabinets burned on the floor and is not included.

4.6 Sofa in Closed Compartment

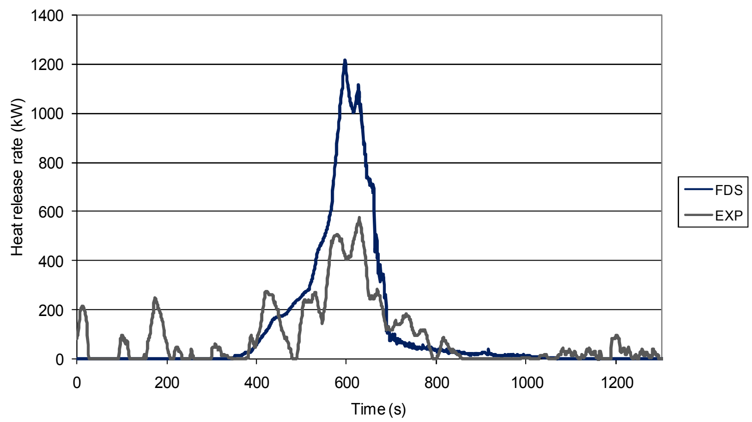
The heat release rate measured for the sofa under the furniture calorimeter hood was used as input to FDS. After 1300 s the sofa had burned out in the calorimeter test so the simulation was run for 1350 s.

4.6.1 Heat Release Rate

The mass loss rate from the test data and FDS is shown in Figure 4-22 (a). The resulting heat release rate from FDS compared to the heat release rate calculated for the experiment by using the mass loss rate data and the heat of combustion measured for the sofa in the free burning hood is shown in Figure 4-22 (b). The heat release rate curve from the experiment was shifted 350 s to the left to match up with the point where it starts to increase in FDS.



(a)



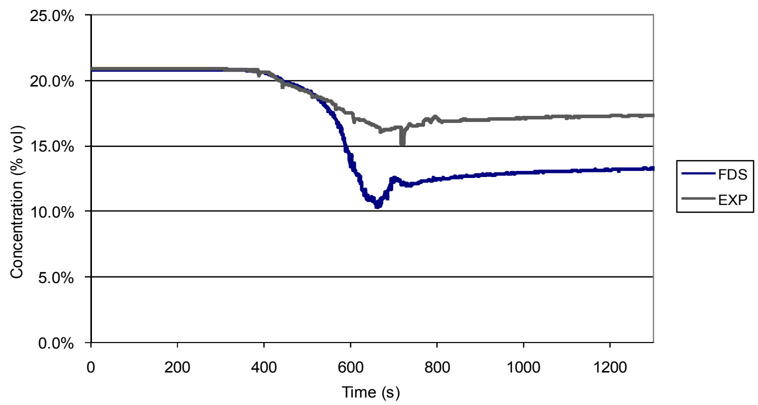
(b)

Figure 4-22. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Sofa in the closed compartment.

The heat release rate in the test was clearly reduced by the compartment compared to the open calorimeter test where it reached a peak value of 1200 kW. The resulting heat release rate from FDS does not show any signs of oxygen vitiation despite being placed in the closed compartment.

4.6.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 4-23.



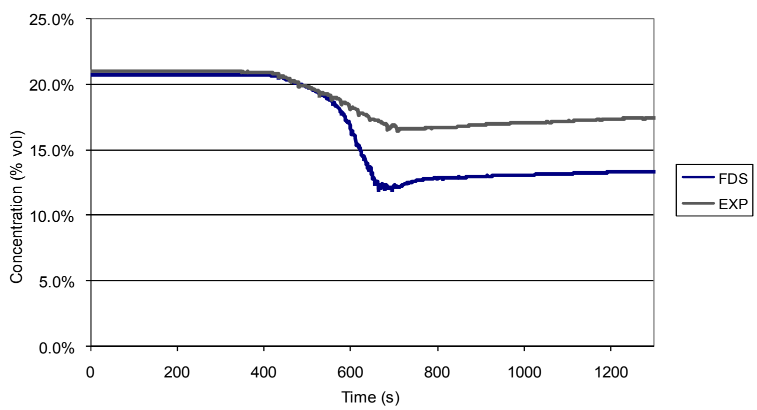


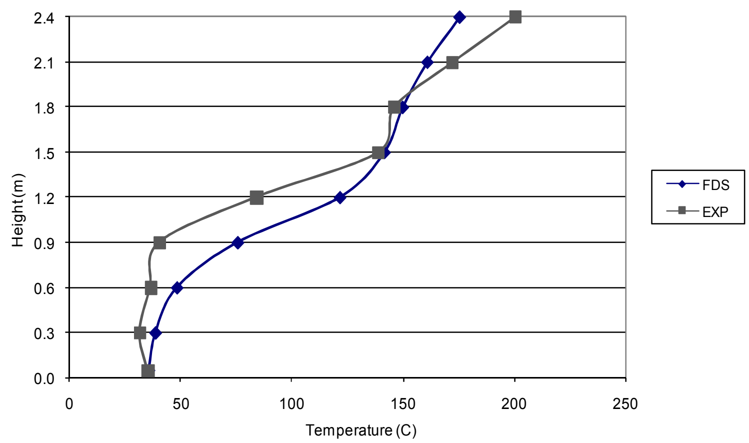
Figure 4-23. Oxygen concentrations at 1.5 m (5 ft) in the living room (top) and bedroom (bottom) for the sofa test in the closed compartment.

Even though the heat release rate in the test is less than half of what was achieved in the open calorimeter test the oxygen concentration remains high in the living room, never dropping below 15% by volume. This makes it less likely that it was simply the lack of oxygen in the compartment that caused the reduced heat release rate in the test. FDS also show a much lower oxygen concentration with a minimum of 10% before it settle around 13% without showing signs of reduced burning. Either the combustion chemistry in FDS is inaccurate, requiring less oxygen that what the real material does or there were other factors contributing to the reduced heat release rate in the test.

4.6.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 500 s, 650 s and 1300 s in the living room and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 27° C in the test and 26 ° C in FDS.

Temperature measured over the height of the room at 500 s in the living room (top) and bedroom (bottom) are shown in Figure 4-24.



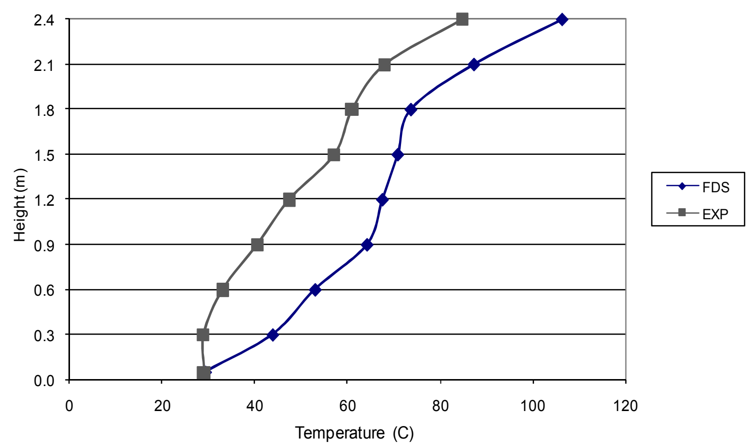


Figure 4-24. Vertical variations of temperature at 500 s in the living room (top) and the bedroom (bottom) for the sofa test in the closed compartment.

In the living room the shape of the two curves from FDS and the test show good agreement but, with FDS giving temperatures up to 11% higher in the lower layer,. This is expected with the higher heat release rate in FDS. The temperatures in the bedroom are also higher in FDS at all heights by about 5%.

Temperature measured over the height of the room at 650 s in the living room (top) and bedroom (bottom) are shown in Figure 4-25.

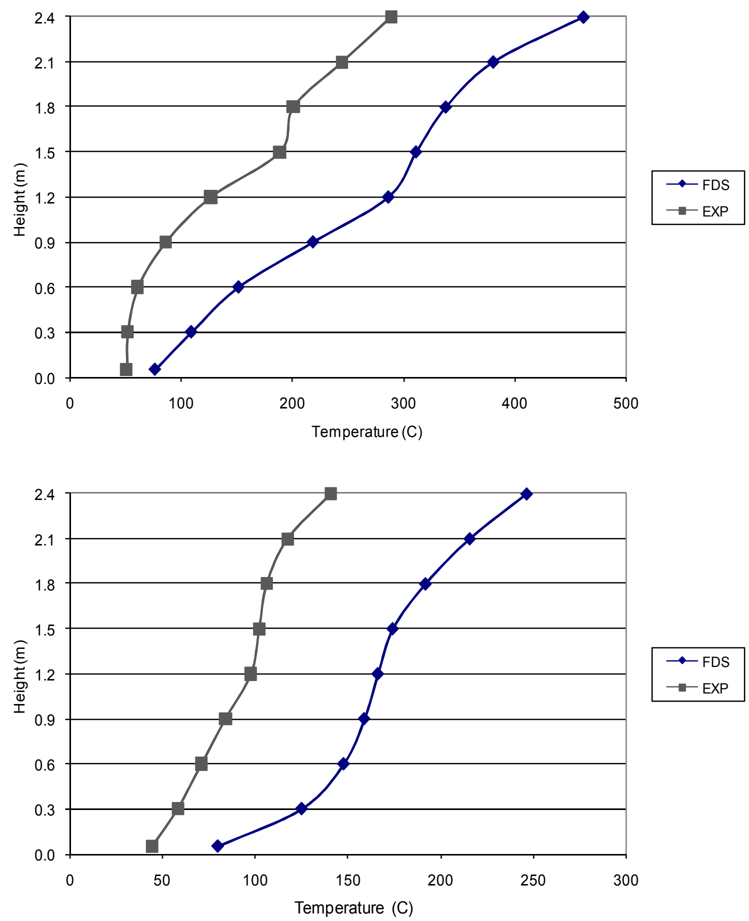
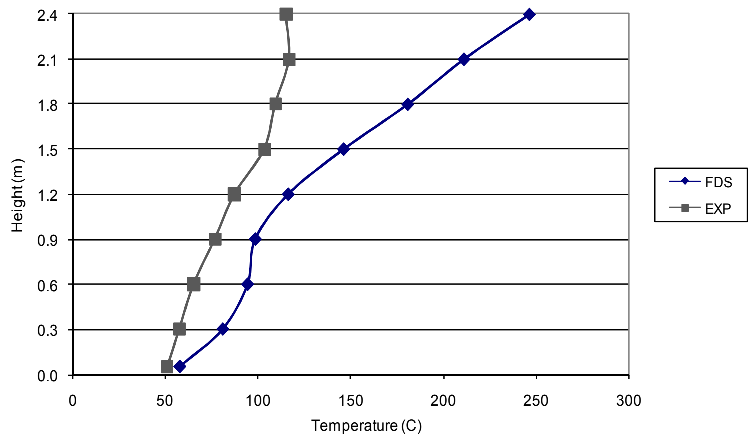


Figure 4-25. Vertical variations of temperature at 650 s in the living room (top) and the bedroom (bottom) for the sofa test in the closed compartment.

The higher heat release rate in FDS continues to give higher temperatures in both the living room and the bedroom. At 650 s FDS gives temperature up to 30 % higher in the living room and 25 % higher in the bedroom.

Temperature measured over the height of the room at 1300 s in the living room (top) and bedroom (bottom) are shown in Figure 4-26.



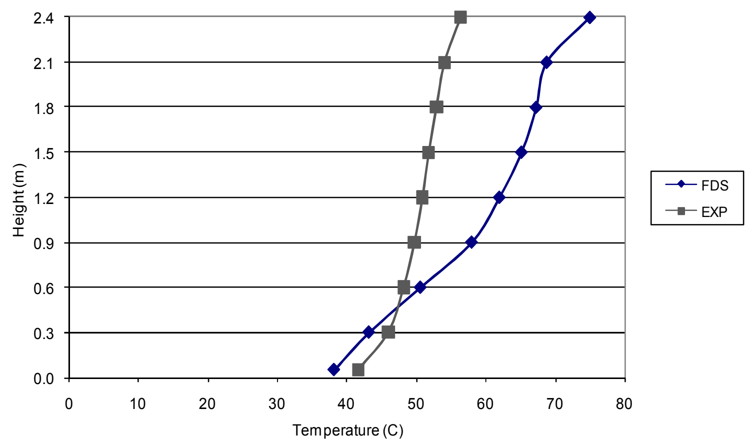


Figure 4-26. Vertical variations of temperature at 1300 s in the living room (top) and the bedroom (bottom) for the elevated cabinet test in the closed compartment.

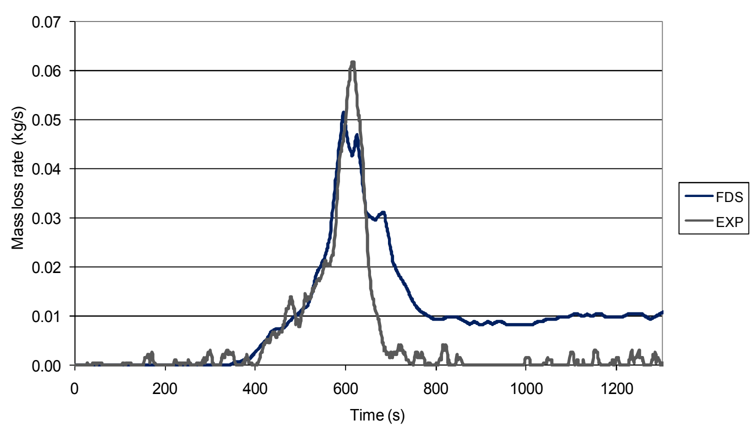
At 1300 s the fire in both FDS and the test had died down and there had been no significant burning for over 500 s, although smoldering was still seen in the test. There are still large differences between the two curves in both rooms, but in the lower half of the living room FDS is within 10% of the test data. In the bedroom FDS shows a maximum temperature at the ceiling 6% higher than the test and the difference is reduced with height.

4.7 Sofa Test with Half Open Window

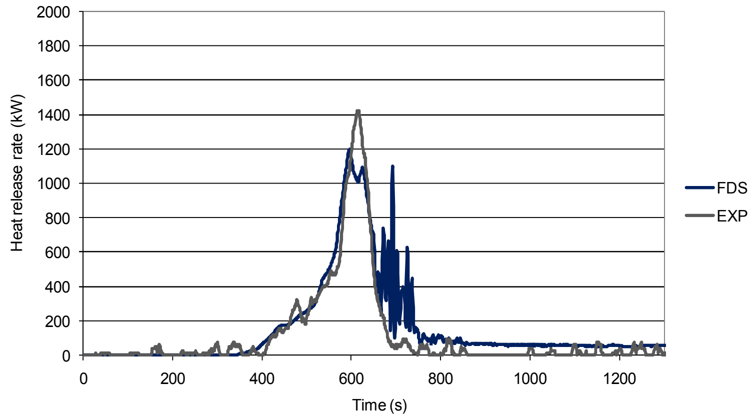
The scenario was similar to the fully closed compartment except for having the bedroom window half open, giving a ventilation opening 20 cm (8 in) high and 60 cm (24 in) wide. The simulation was run for 1350 s.

4.7.1 Heat Release Rate

The heat release rate curve from the experiment was shifted 280 s to the left to match up with the point where it starts to increase in FDS. The FDS data was averaged over five seconds because of large fluctuations starting at 700 s. Figure 4-27 shows the mass loss rate in FDS and the test (a) and the resulting heat release rates (b).



(a)



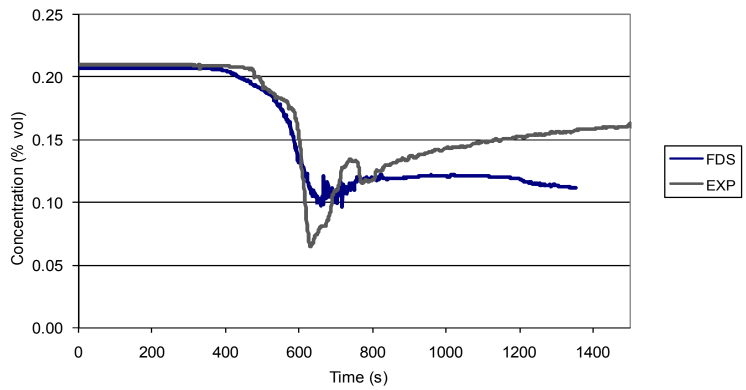
(b)

Figure 4-27. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Kitchen cabinets with window half open

Unlike the closed compartment test the heat release rate does reach a peak value comparable to that seen in the calorimeter of 1200 kW. The burning behavior of the sofa is very similar to that seen in the calorimeter test. FDS starts to show fluctuations at 700 s, which indicate lack of oxygen restricting the burning.

4.7.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-28.



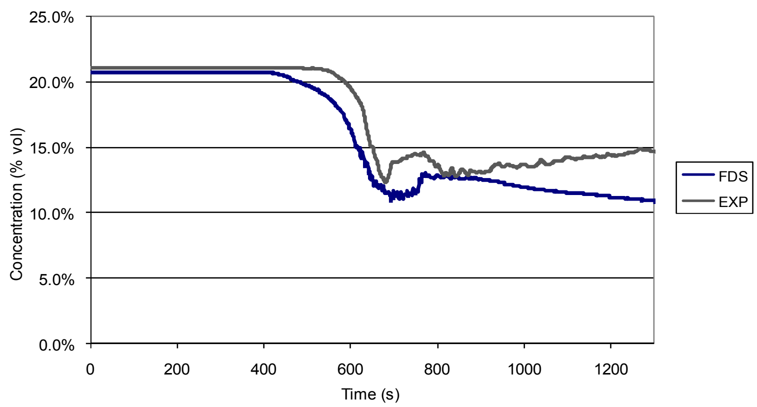


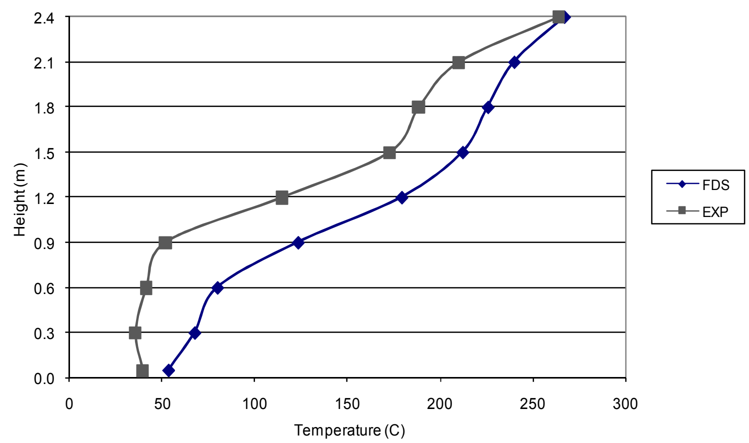
Figure 4-28. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test with window half open.

At 600 s the oxygen concentration in the living room reach its minimum value in both the test and FDS of 7% and 10% by volume respectively. The oxygen concentration in the bedroom also shows good agreement between FDS and the test. The point where it starts to drop and the minimum value are both close.

4.7.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 550 s, 600 s and 1300 s in the living room and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 27° C in both the test and FDS.

Temperature measured over the height of the room at 550 s in the living room (top) and bedroom (bottom) are shown in Figure 4-29.



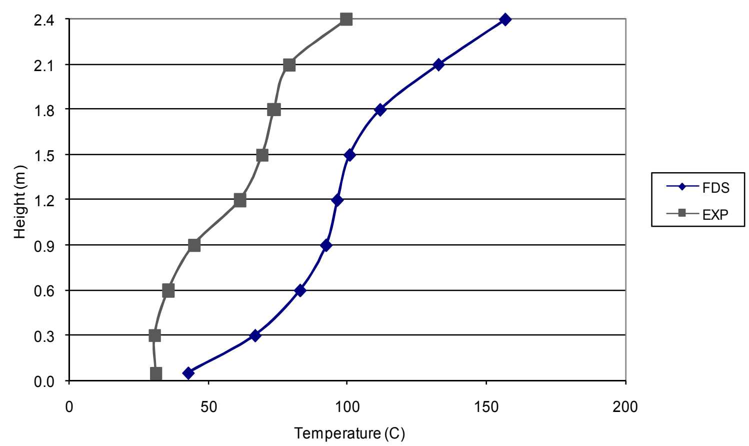
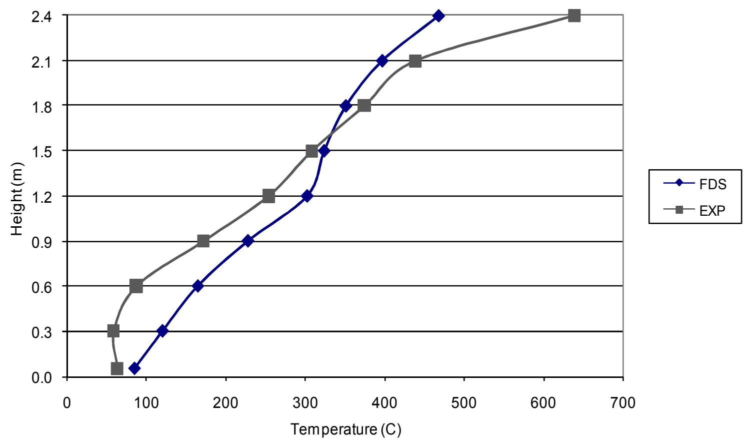


Figure 4-29. Vertical variations of temperature at 550 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open.

After 550 s the heat relate rate in FDS and the test are almost identical but FDS shows a higher temperature rise in both the living room and the bedroom. FDS shows good agreement at the top thermocouple in the kitchen but a large overprediction for all other heights. The gas layer interface is placed at similar height in both FDS and the test, but with different temperatures. In the bedroom FDS shows an overprediction of the gas temperature, which decrease with height.

Temperature measured over the height of the room at 600 s in the living room (top) and bedroom (bottom) are shown in Figure 4-30.



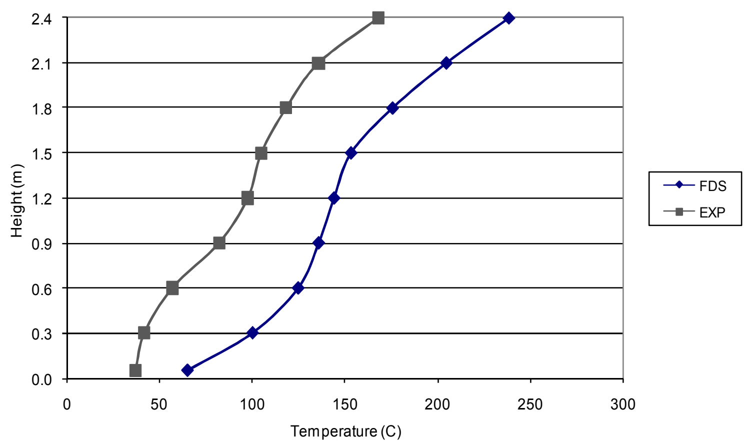
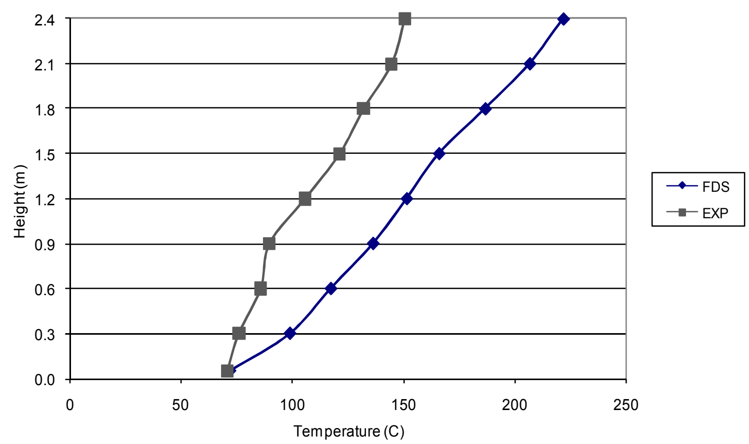


Figure 4-30 Vertical variations of temperature at 600 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open.

After 600 s the predictions in the living room are closer, being within 20% of the test data for all the thermocouples. In the bedroom FDS gives temperatures at least 9% higher than the test data for all heights, and up to 20% higher. Since the heat release rates are still very close it would be expected that FDS give reasonably accurate predictions at this time. The higher temperature in the bedroom indicates that FDS predicts more transport of hot products from the living room.

Temperature measured over the height of the room at 1300 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-31.



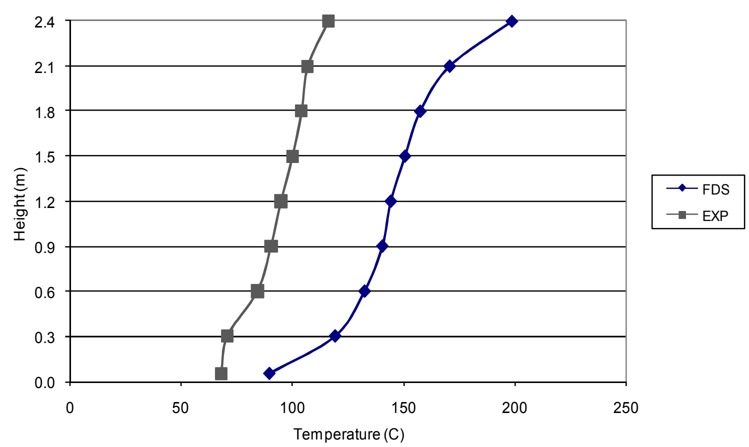


Figure 4-31. Vertical variations of temperature at 1300 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open.

At this time both fires had gone out. The temperatures in both rooms have been reduced but FDS still shows an overall higher temperature, which is not unexpected considering the higher temperature earlier.

5 COMPARISON OF LOAD CELL HEAT RELEASE RATE SIMLATIONS AND EXPERIMENTS

5.1 Kitchen Cabinet in Closed Compartment

The heat release rate used as input to this FDS simulation was derived from the mass loss data from the cabinet test in the closed compartment and the heat of combustion calculated from the calorimeter tests. The burning area in FDS has also been reduced to only the two first cabinets as the third and fourth cabinet did not show significant burning in the test. The simulation was run for 1700 s after, which the heat release rate in the test dropped below 5% of peak value. The heat release rate from the test is thus the input to the FDS model.

5.1.1 Heat Release Rate

The resulting heat release rates from the FDS simulation and the test are shown in Figure 5-1. The FDS data was averaged over five seconds because of fluctuations in the data.

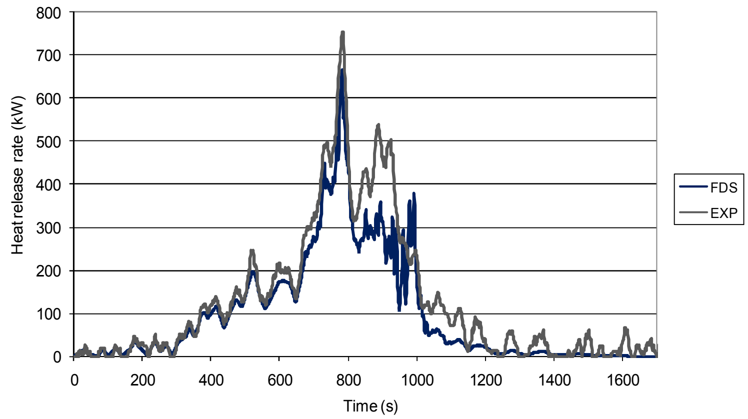


Figure 5-1. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Kitchen cabinets in the closed compartment.

Since the experimental heat release rate is used as input to FDS the two graphs obviously show good agreement. However, at about 800 s the heat release rate in FDS starts to show signs of lack of oxygen and does not reach the second peak of 500 kW.

5.1.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-2. The oxygen concentration data from FDS in the kitchen has been averaged over five seconds because of fluctuations in the data.

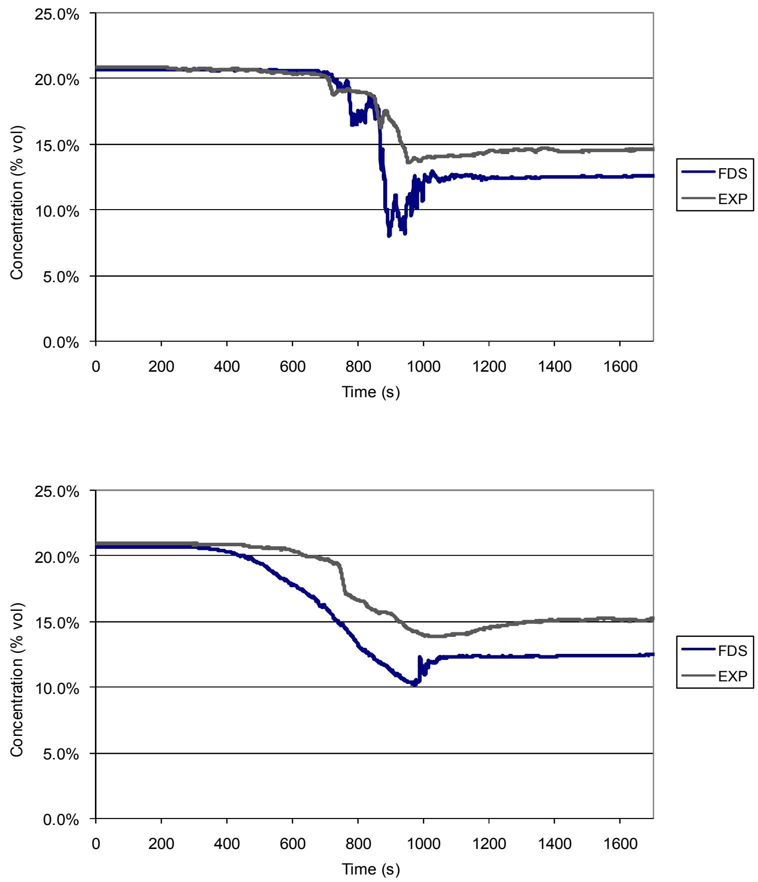


Figure 5-2. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the cabinet test in the closed compartment.

During the initial decrease the oxygen concentration in the kitchen show agreement between FDS and the experiment but at 900 s the oxygen concentration in the test reaches a steady value just under 15% by volume while the simulation reaches as low as 8% before it settle around 13% at 1000s The simulation also shows a lower oxygen concentration in the bedroom throughout the test.

5.1.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 700 s, 800 s and 1700 s in the kitchen and bedroom. The ambient temperature was 25 °C.

Temperature measured over the height of the room at 700 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-3.

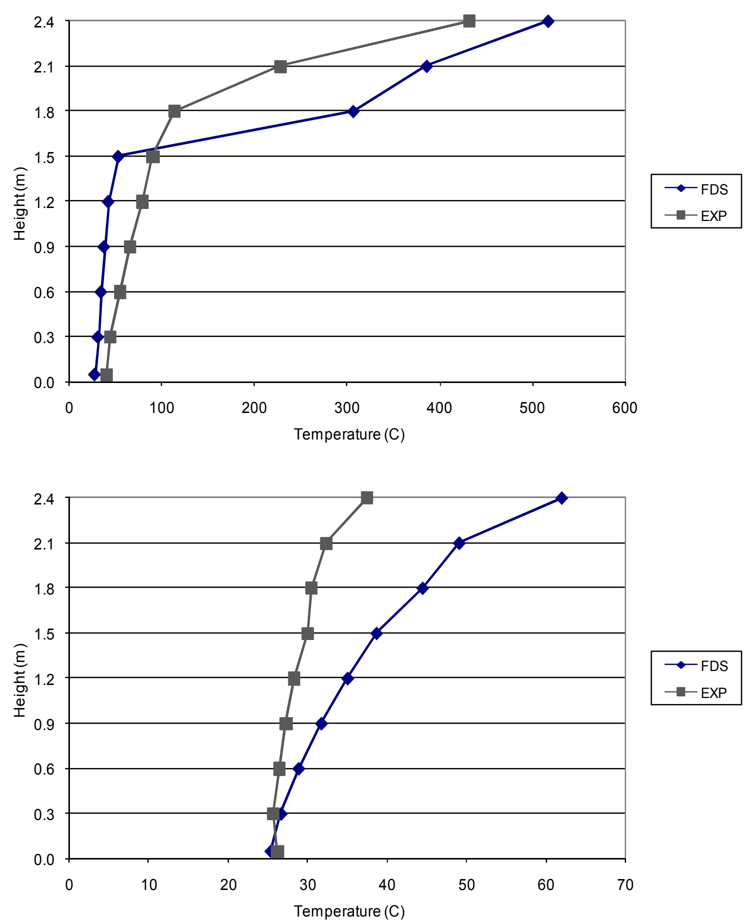


Figure 5-3 Vertical variations of temperature at 700 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the cabinet test in closed compartment.

At 700 s FDS shows the same tendency as in the calorimeter heat release rate simulation to underpredict the temperature in the lower layer and overpredicts the temperature in the upper layer. FDS places the layer interface between 1.5 m (5 ft) and 1.8 (6 ft), which is lower than in the test, which is between 1.8 (6 ft) and 2.1 m (7 ft). This is the same results for the layer interface seen from the calorimeter heat release rate simulations. In the bedroom FDS overpredicts the temperature with the deviations becoming larger further up in the room showing an 8% higher value for the ceiling thermocouple.

Temperature measured over the height of the room at 800 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-3

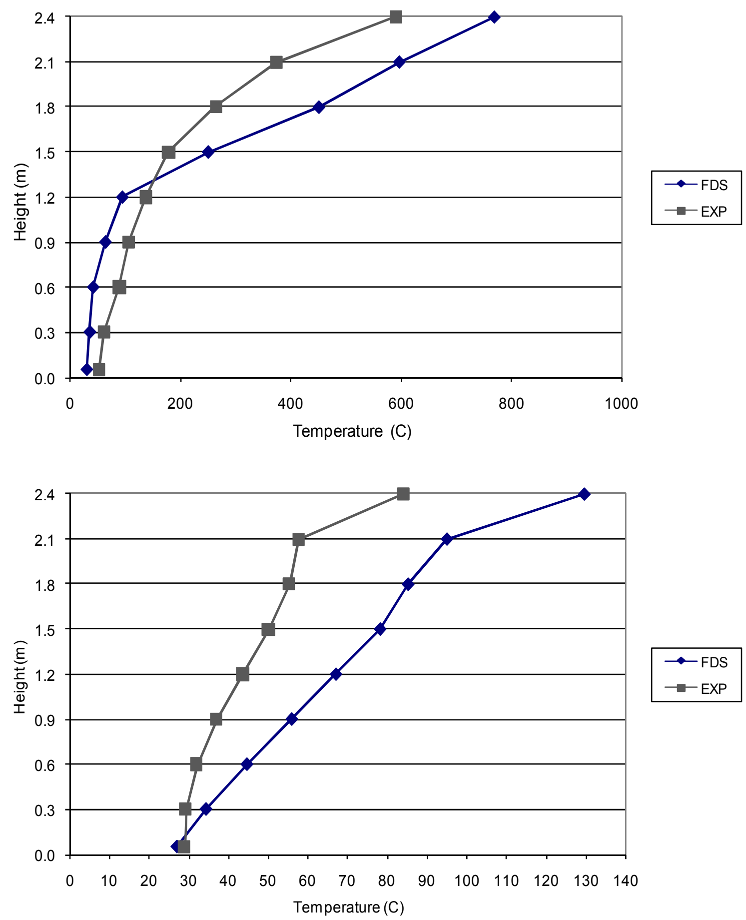
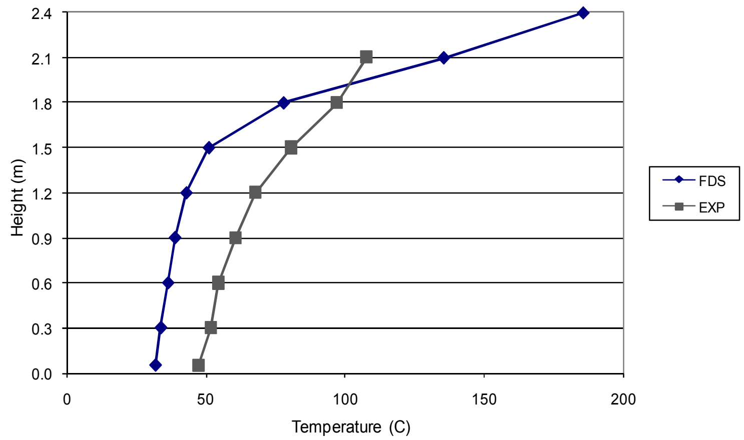


Figure 5-4. Vertical variations of temperature at 800 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the cabinet test in the closed compartment.

FDS shows the same tendency to underpredict the temperature in the lower layer and overpredict in the upper layer in the kitchen at 800 s as was seen at 700 s in Figure 5-3. In the lower layer FDS shows a value up to 16% lower than recorded and in the upper layer a value up to 35% higher than seen in the test. The temperature in the bedroom also shows the same tendency at 800 s as at 700 s with FDS showing temperatures with progressively larger deviations up to 13% higher.

Temperature measured over the height of the room at 1700 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-5.



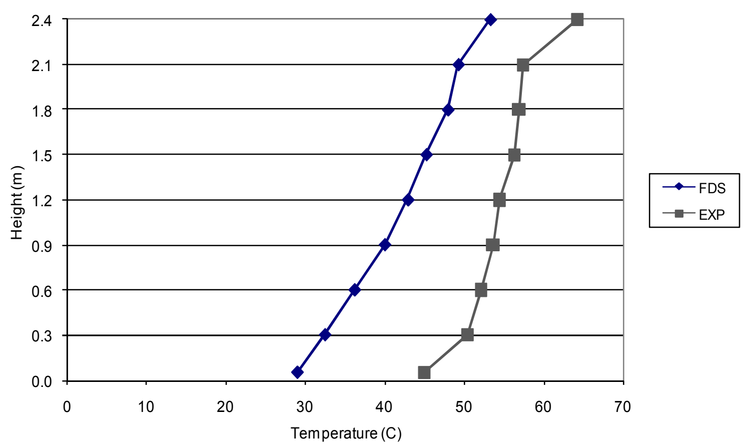


Figure 5-5. Vertical variations of temperature at 1700 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the cabinet test in closed compartment.

The thermocouple 2.5 cm (1 in) from the ceiling was destroyed by the temperature so is not included in the profile at 1700 s also at the end of the simulation FDS shows a temperature in the lower layer in the kitchen up to 8% lower than recorded in the test. The temperature profile from the test also show a more linear increase compared to a more noticeable layer interface in FDS. In the bedroom FDS shows constantly lower values than recorded in the test, from 2% to 6% lower.

5.2 Kitchen Cabinets with Half Open Window

The scenario was similar to the fully closed compartment except for the bedroom window was half open, giving a ventilation opening 20 cm (8 in) high and 60 cm (24 in) wide.

5.2.1 Heat Release Rate

The resulting heat release rates from the FDS simulation and from the experiment are shown in Figure 5-6.

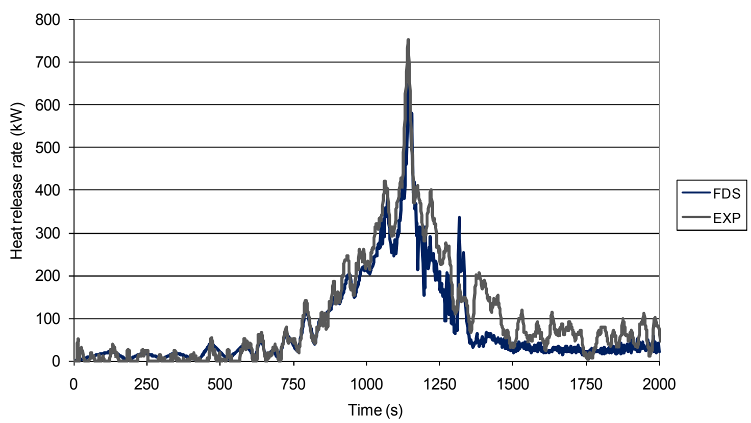
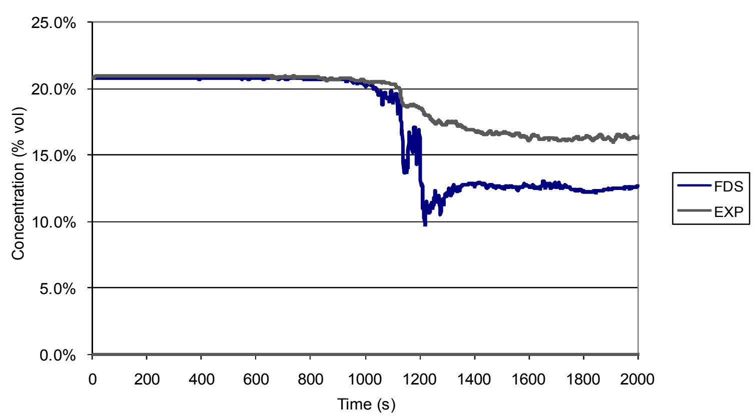


Figure 5-6. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the mass loss data from the test. Kitchen cabinets with half open window.

The resulting heat release rate from FDS follows the prescribed test heat release rate until about 1200 s into the simulation where the FDS curve starts to show fluctuations from lack of oxygen. This results in a slightly lower heat release rate for the remainder of the test.

5.2.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-7. The oxygen concentration data from FDS in the kitchen has been averaged over five seconds because of fluctuations in the data.



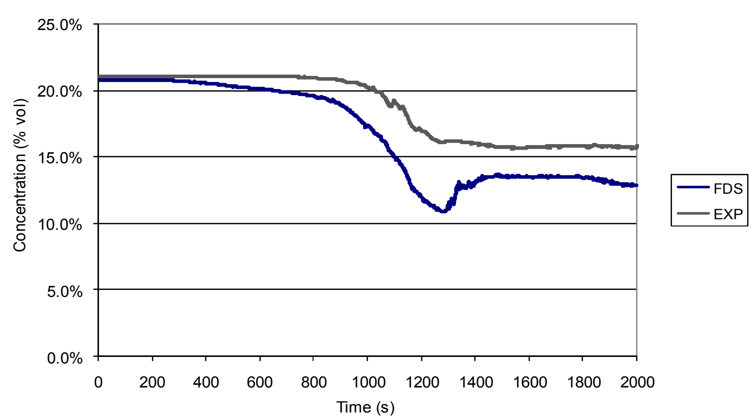


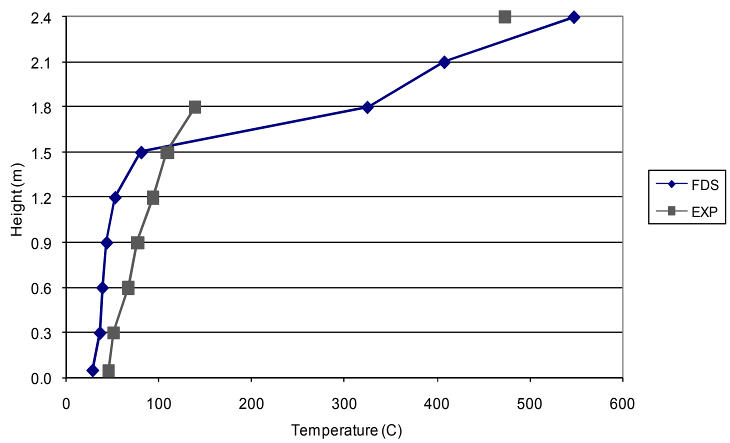
Figure 5-7. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with window half open.

In the kitchen FDS shows a rapid reduction in oxygen concentration at 1.5 m (5 ft) at 1100 s, reaching as low as 10% by volume before settling around 13%. The test data only decrease slowly and never go below 15%. In the bedroom FDS appear to predict faster transport of combustion products from the fire room and thus a more rapid decrease in oxygen concentration. FDS reaches a minimum value below 11% before it starts to increase again around 1300 s. The concentration in the experiment decreases to just over 15% and remain at that value for the remainder of the test.

5.2.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 1050 s, 1150 s and 2000 s in the kitchen and bedroom. The ambient temperature was 25 °C in both the experiment and FDS.

Temperature measured over the height of the room at 1050 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-8.



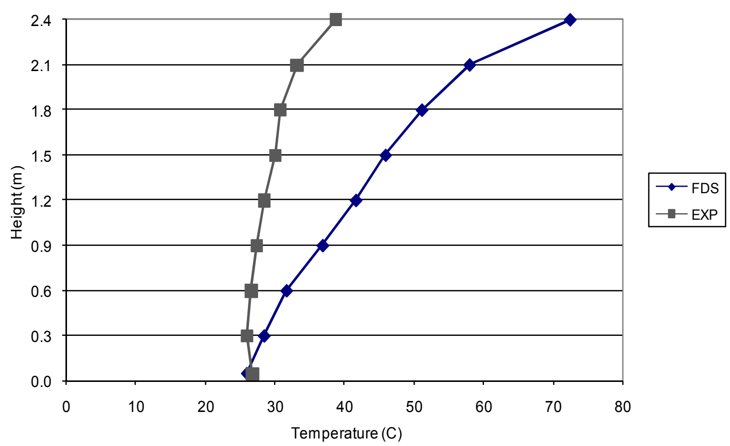


Figure 5-8. Vertical variations of temperature at 1050 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with window half open.

In the kitchen the thermocouple at 2.1 m (7 ft) did not give usable values so is not included. FDS shows a temperature up to 11% lower than the experiment in the lower layer in the kitchen. The layer interface in FDS is between 1.5 m (5 ft) and 1.8 m (6 ft), which appear to be at least 0.3 m (1 ft) lower than in the experiment. At the ceiling FDS give a 10% higher value. In the bedroom FDS shows higher values than the experiment throughout the room height similar to that seen in the calorimeter heat release rate simulation. The maximum temperature is here about 30° C higher giving a value 11% higher than the experiment.

Temperature measured over the height of the room at 1150 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-9

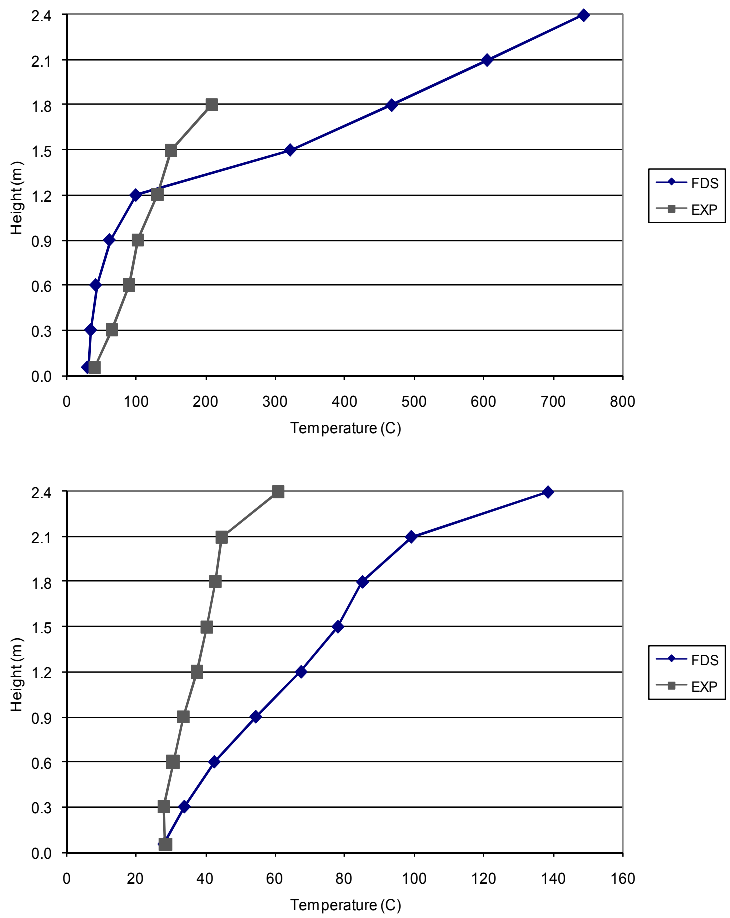
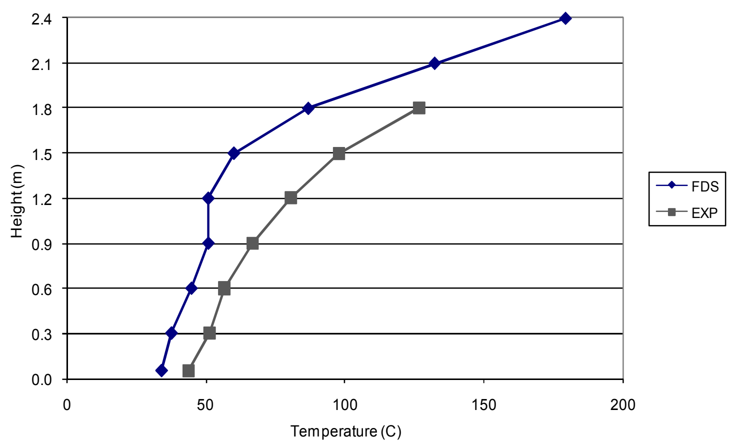


Figure 5-9. Vertical variations of temperature at 1150 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with window half open.

The top two thermocouples gave zero or negative values at this time so were not included. FDS show the same tendencies in the kitchen as seen in Figure 5-8 with underpredictions in the lower layer and a layer interface lower than seen in the experiment. Because of the lack of thermocouples above 1.8 m it is not possible to compare temperatures in the upper layer in the kitchen. The overprediction in the bedroom for all heights is similar to that seen for the calorimeter heat release rate simulation but with a higher temperature in FDS for the load cell heat release rate simulation. At the ceiling the load cell heat release rate simulation reaches 140° C compared to only 75° C in the calorimeter heat release rate simulation.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-10.



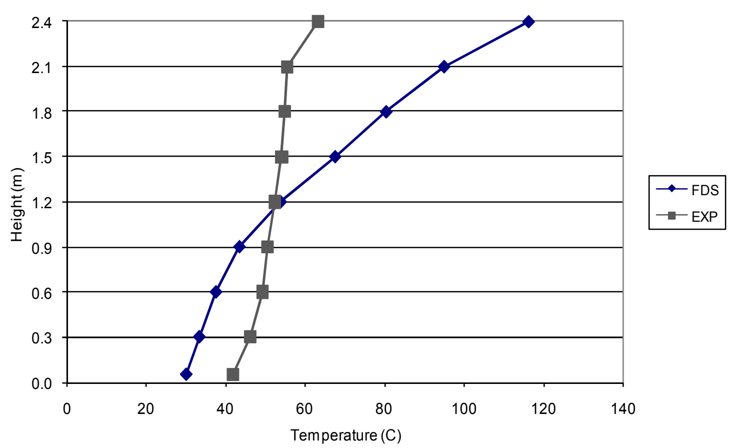


Figure 5-10. Vertical variations of temperature at 2000 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with window half open.

In the kitchen the top two thermocouples from the test are not included. FDS shows the same shape as the test data in the kitchen but at value up to 10% lower. In the bedroom the test data indicate only a slight temperature increase throughout the height of the room. FDS predicts a steep increase starting at 0.9 m (3 ft).

5.3 Kitchen Cabinet with Window Removed

The load cell data from the test was used to estimate a heat release rate for the cabinets as input to the FDS simulations. In the simulation only the two first cabinets were set to burn as in the other post test simulations. The bedroom window was completely removed giving a ventilation opening 65 cm (25.5 in) wide and 103 cm (40.5 in) high.

5.3.1 Heat Release Rate

The heat release rate from the test load cell data and the resulting heat release rate from FDS when this was used as input are seen in Figure 5-11.

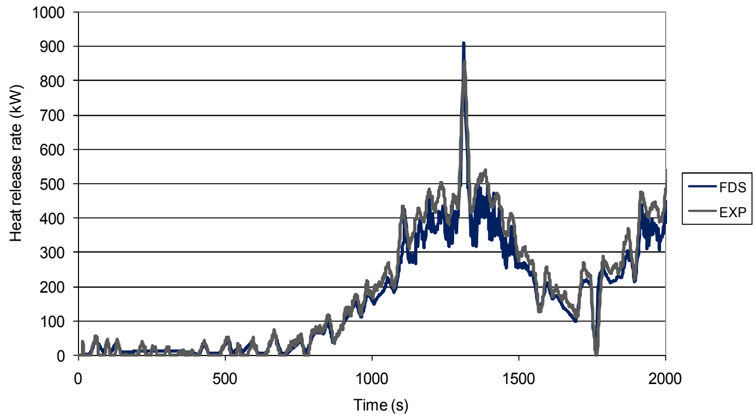
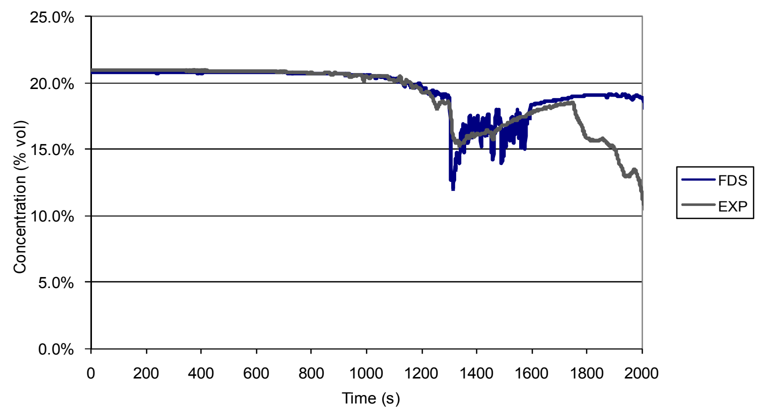


Figure 5-11. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Elevated kitchen cabinets with window removed.

The heat release rate in FDS follows the prescribed input taken from the experiment and shows only minor signs of fluctuations usual caused by oxygen vitiation.

5.3.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-12. Because of fluctuations in the data from FDS the oxygen concentration in the kitchen was taken as the average over five seconds.



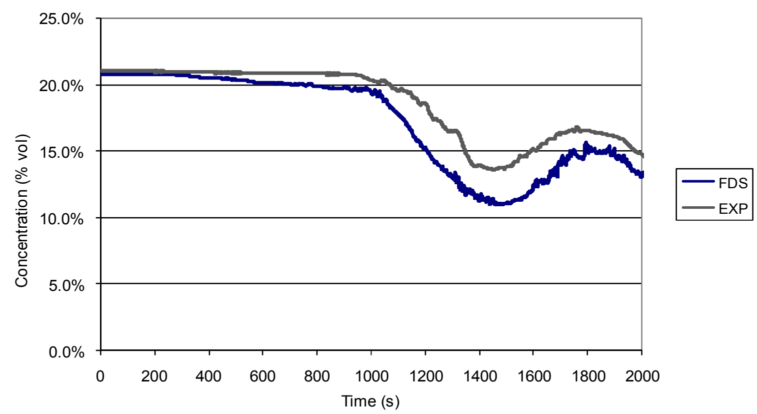


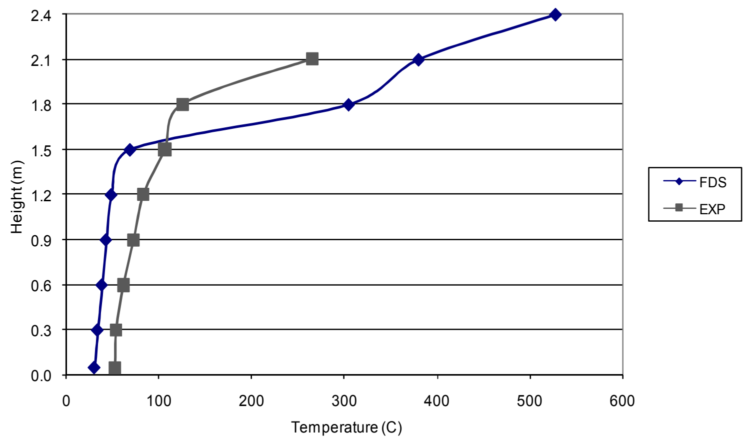
Figure 5-12. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the kitchen cabinet test with window removed.

The oxygen concentration in the kitchen shows a sudden drop at 1280 s in both the test and FDS. In the test the concentration drops to 16% by volume before starts to increase again. In FDS it reaches 12% before it starts to increase and it shows large fluctuations possibly numerical instabilities caused by the air flow rapidly changing directions. In the bedroom FDS shows the same shape of the curve for the oxygen concentration but with a lower value. At the lowest point FDS gives 11% whereas the test shows 14%.

5.3.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 1100 s, 1300 s and 1900 s in the kitchen and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 26° C in the test and FDS.

Temperature measured over the height of the room at 1100 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-13.



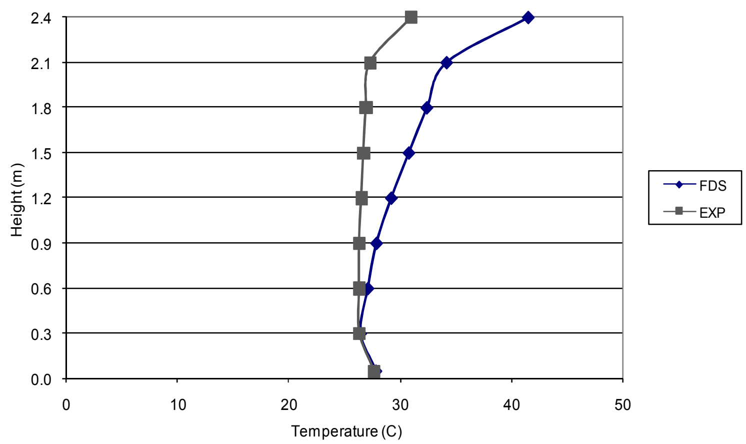
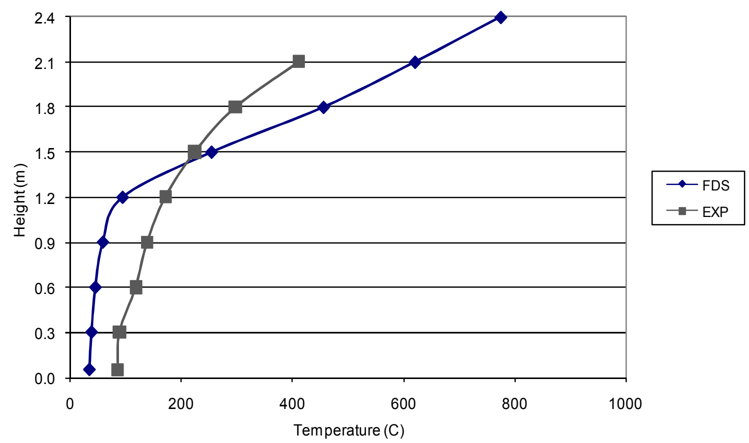


Figure 5-13. Vertical variations of temperature at 1100 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

The thermocouple at the ceiling in the kitchen did not give a signal after 1080 s. FDS gives the height of the hot upper layer in the kitchen as 1.8 m (6 ft), which is 0.3 m lower than seen in the test. Below 1.5 m (5 ft) FDS gives temperatures around 10% lower than seen in the test. For the one point in the upper layer FDS gives a value 45% higher than the test. In the bedroom the experimental data remains at ambient temperatures except for the top thermocouple at 2.4 m (8 ft). The FDS predictions are within 3% of the test data for all the thermocouples.

Temperature measured over the height of the room at 1300 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-14.



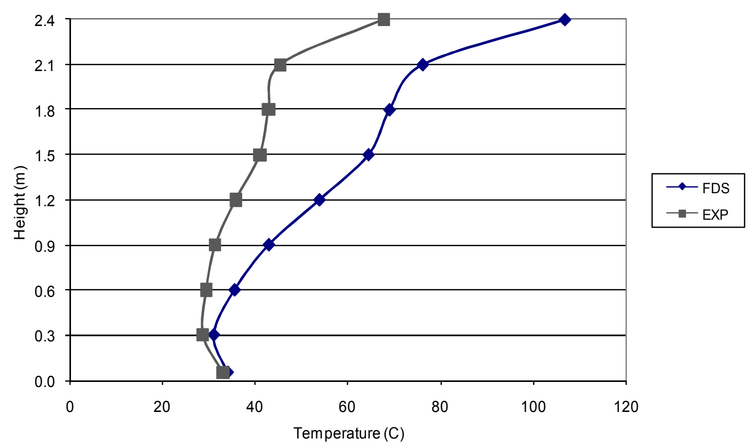


Figure 5-14. Vertical variations of temperature at 1300 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

At 1300 s the layer interface in the kitchen for FDS has moved to between 1.2 – 1.5 m (4 – 5 ft). The layer interface is not as marked in the test data. FDS still shows an underprediction of the temperature in the lower layer and overprediction in the upper layer. The transport of heat to the bedroom is also overestimated by FDS as seen by the higher temperature at all heights, while still showing the same general shape of the curve as the test.

Temperature measured over the height of the room at 1900 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-15.

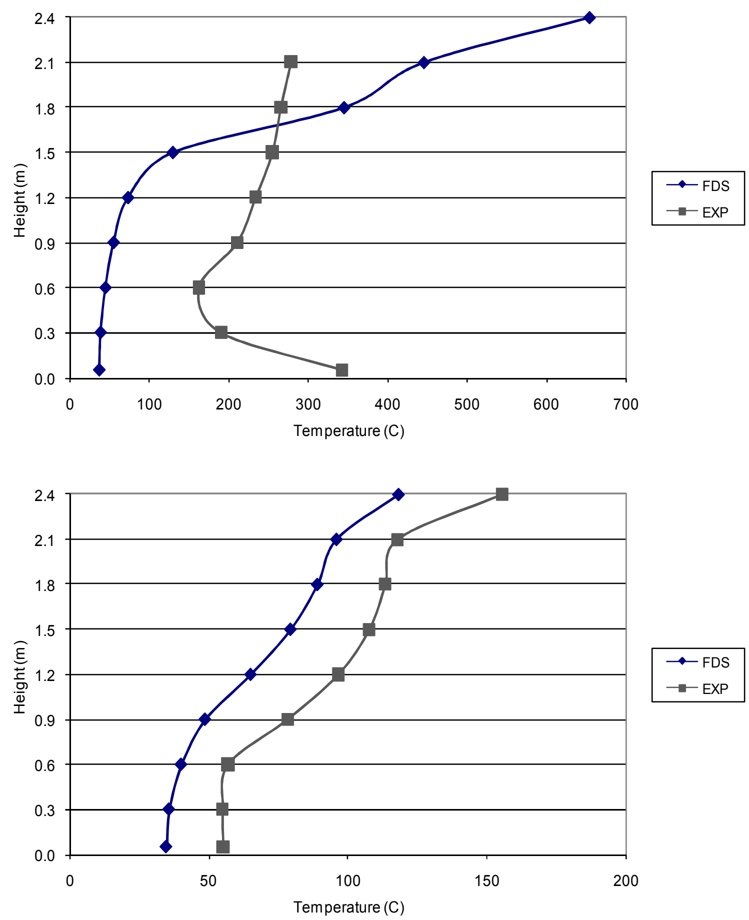


Figure 5-15. Vertical variations of temperature at 1900 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

All the cabinets fell off the wall at 1776 s and continued burning on the floor. This was not considered in FDS. This explains why the test data show a higher temperature in the lower layer in the kitchen than is seen in FDS, which keep the layer structure. In the bedroom FDS consistently shows temperatures 5 – 10% lower than in the test.

5.4 Kitchen Cabinets with open door

The scenario was similar to the other cabinet tests except the entrance door from the living room to the outside was open giving a ventilation opening 1.0 m (3 ft) wide and 2.0 m (6 ft) high. The two first cabinets fell off the wall at 1590 s and at 1630 s the two remaining cabinets also fell. The four cabinets continued to burn on the floor, but parts were not on the load cell so heat release data after this point is not reliable. The criterion for suppression was flashover, which was observed at 2198 s and the fire was extinguished.

5.4.1 Heat Release Rate

The heat release rate from the experiments was calculated from the mass loss information and used as input to FDS. The resulting heat release rates from FDS and the experiment are shown in Figure 5-16.

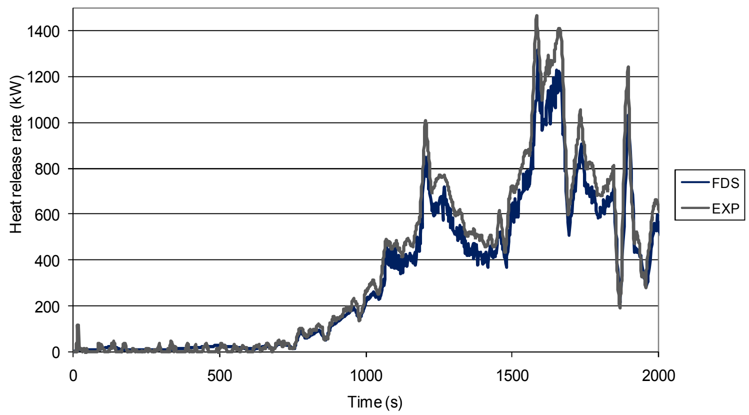
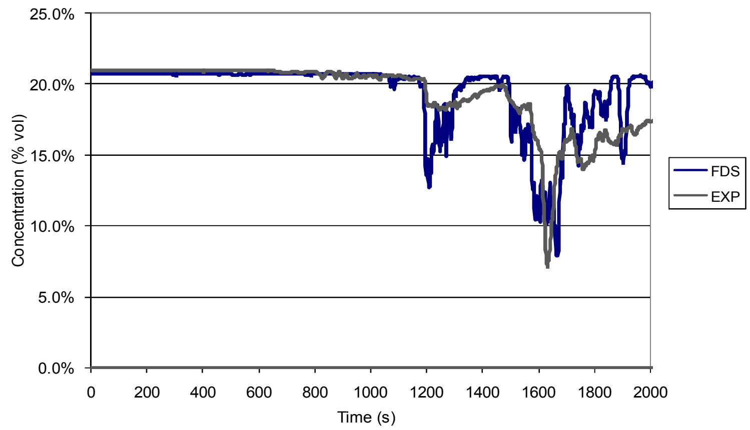


Figure 5-16. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Kitchen cabinets with door open.

The FDS simulation and experiment have close to identical heat release rate curves. There are no signs of oxygen vitiation affecting the heat release rate in FDS.

5.4.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-17. The FDS data in the kitchen was averaged over five seconds because of fluctuations in the data.



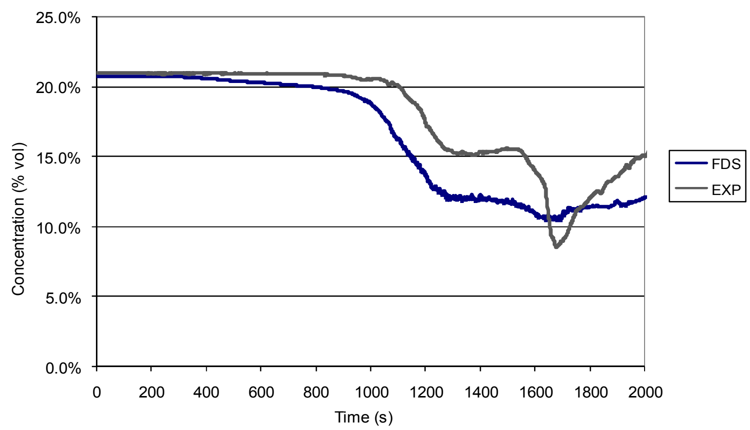


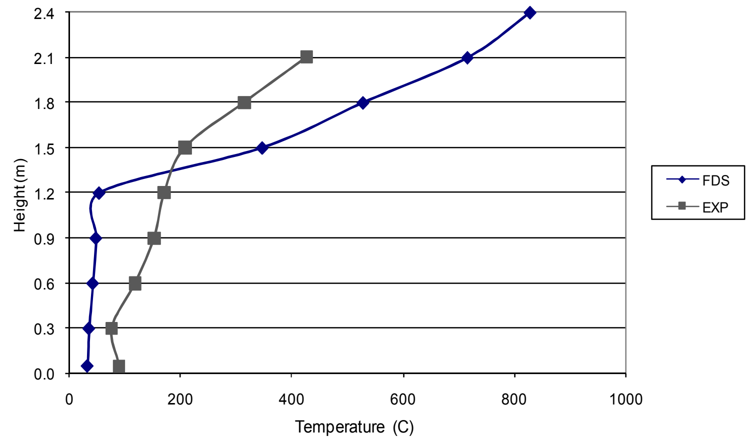
Figure 5-17. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test with door open.

The oxygen concentration in the kitchen predicted by FDS show some fluctuating behavior similar to what was seen in Figure 4-2 for the test with window removed. It may be caused by rapidly changing flow velocities. Both FDS and the test show two drops with the second being the largest. For the first FDS give a smaller minimum value than seen in the test whereas for the second drop FDS and the test show agreement and both give a minimum value around 7% by volume although FDS drops to 5% briefly. The drop in the test at 1600 s is likely a result of the cabinets falling to the floor at 1589 s in the test and burning below the gas probe. It is unclear why FDS shows a similar drop as this was not included in the model. In the bedroom FDS shows earlier and larger reduction in oxygen concentration, which plateau around 12% after 1300 s and remains at that value. The test data show a drop to 9% at 1700 s coinciding with the largest peak in the heat release rate, which is not seen in FDS.

5.4.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 1200 s, 1600 s and 2000 s in the kitchen and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 25° C in both the test and the simulation.

Temperature measured over the height of the room at 1200 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-18



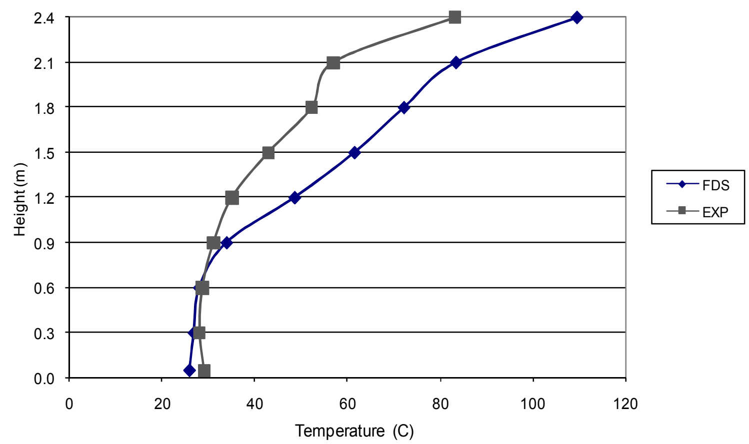
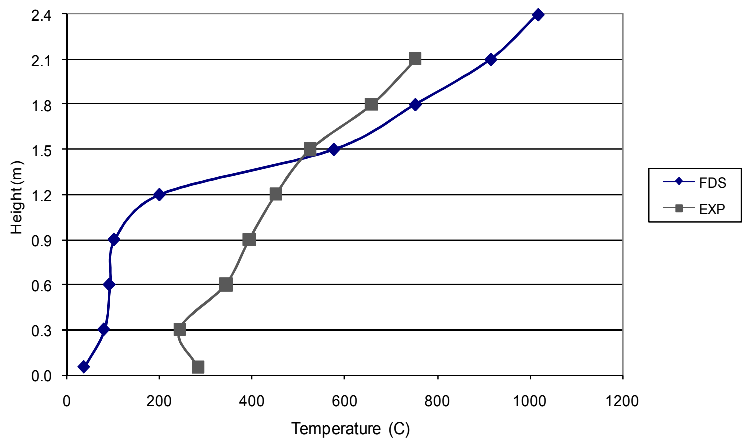


Figure 5-18. Vertical variations of temperature at 1200 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

The thermocouple at the ceiling was destroyed by the heat early in the test and is not included in the figure. As seen for the previous test with window removed FDS also here show a clearer layer separation, which is not as apparent in the test data. FDS also here show an underprediction for the temperatures in the lower layer and an overprediction in the upper layer. The same trend is seen in the bedroom where both FDS and the test data remain close to ambient below 0.9 m (3 ft) but FDS give a temperature up to 8% higher than the test above this.

Temperature measured over the height of the room at 1600 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-19.



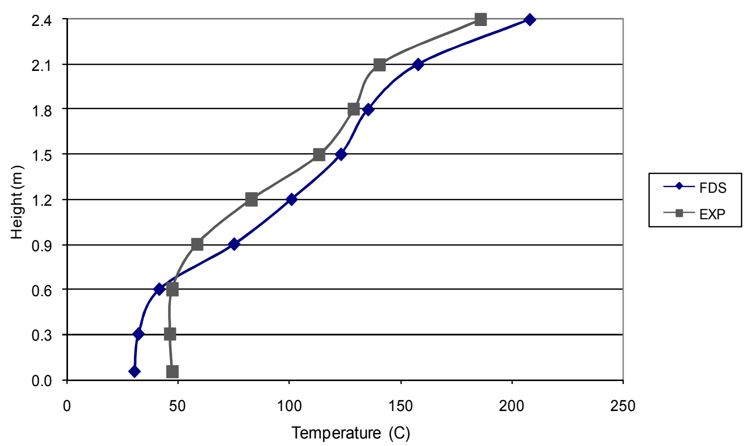


Figure 5-19. Vertical variations of temperature at 1600 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

At 1600 s FDS still show a marked layer separation between 1.2 m (4 ft) and 1.5 m (5 ft), which is not visible in the experimental data. For the thermocouples above 1.5 m (5 ft) the FDS results are within 16% of the test data. In the bedroom FDS is within 5% of the test data.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-20.

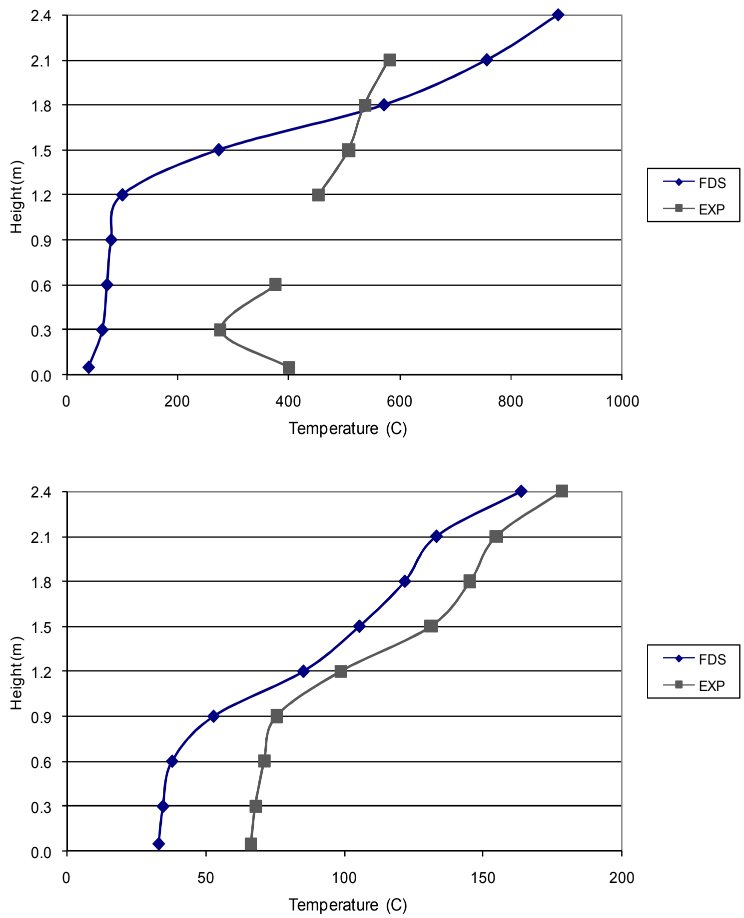


Figure 5-20. Vertical variations of temperature at 2000 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

The thermocouple at 0.9 m (3 ft) was destroyed as the cabinets burned on the floor and is not included. The burning of the cabinets on the floor is clearly affecting the temperature in the lower part of the kitchen as FDS show much lower values than the test. In the bedroom FDS give better correlation with values at most 6.4% lower from 1.2 m (4 ft) and up and within 10% below 1.2 m (4 ft).

5.5 Sofa in Closed Compartment

The load cell data from the test was used with the heat of calculated from the calorimeter test to create the heat release rate input to FDS. After 1300 s the sofa had burned out in the calorimeter test so the simulation was run for 1350 s.

5.5.1 Heat Release Rate

The resulting heat release rate from FDS is compared to the heat release rate calculated for the experiment by using the mass loss rate data and the heat of combustion measured for the sofa in the free burning hood is shown in Figure 5-21.

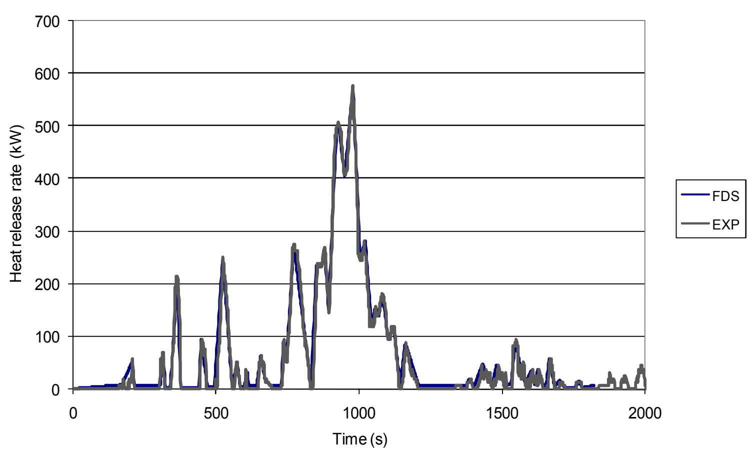


Figure 5-21. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Sofa in the closed compartment.

The resulting heat release rate from FDS is identical to the input from the experiment and show no signs of additional oxygen restriction.

5.5.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 5-22.

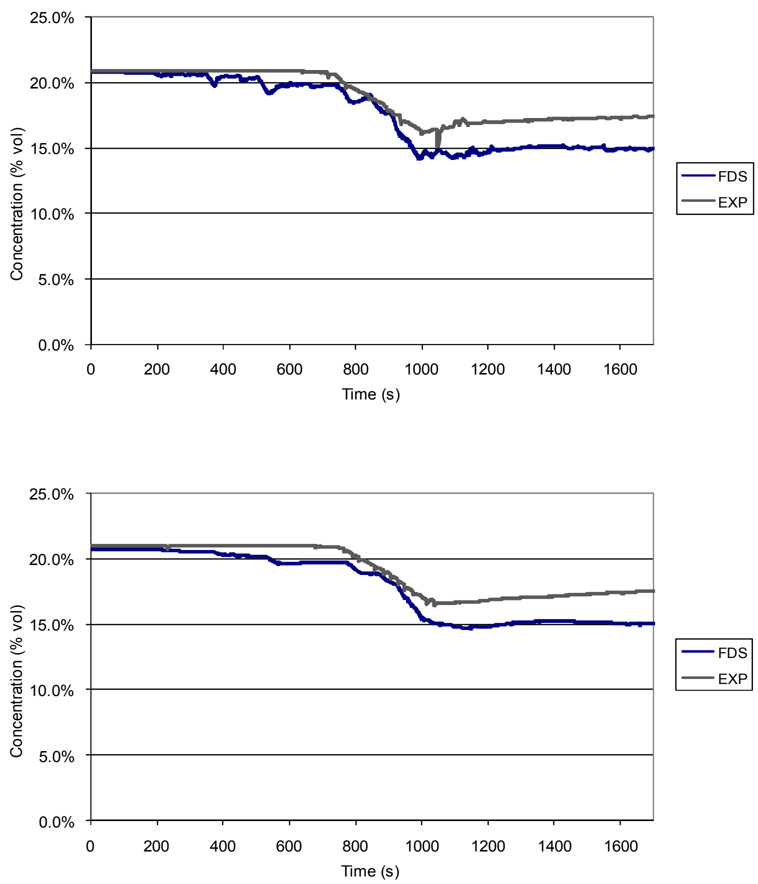


Figure 5-22. Oxygen concentrations at 1.5 m (5 ft) in the living room (top) and bedroom (bottom) for the sofa test in the closed compartment.

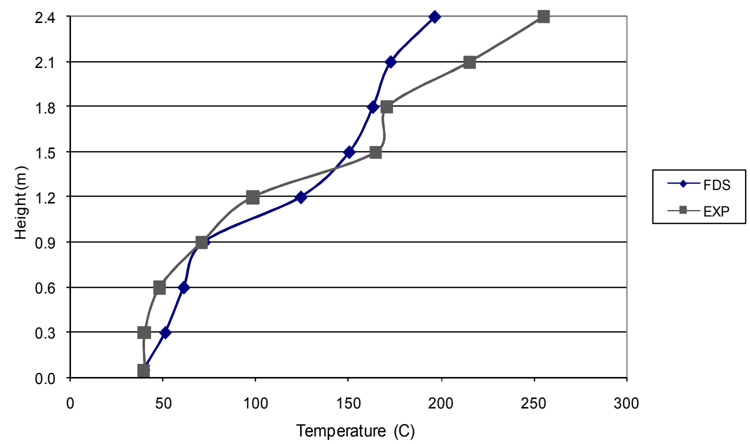
The oxygen concentration in FDS starts to decrease slightly in the living room earlier than in the test, but remain above 20% by volume until at 700 s when both the test and

FDS show a similar decrease. FDS reaches a lower minimum value of 15% compared to 16% in the test. The same behavior is seen in the bedroom.

5.5.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 900 s, 1000 s and 1700 s in the living room and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 27° C in both the test and FDS.

Temperature measured over the height of the room at 900 s in the living room (top) and bedroom (bottom) are shown in Figure 5-23.



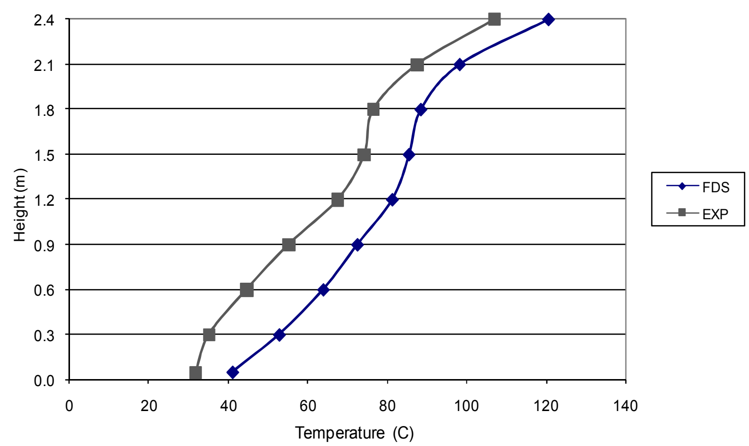


Figure 5-23. Vertical variations of temperature at 900 s in the living room (top) and the bedroom (bottom) for the sofa test in the closed compartment.

In the living room the FDS predictions are within 11% of the test data and in line with the shape of the curve for most of the height of the room, showing an underprediction for the top two thermocouples. Above 1.2 m (4 ft) in the bedroom FDS is within 4% of the experimental results. Lower down FDS predicts temperatures up to 7% higher than was measured.

Temperature measured over the height of the room at 1000 s in the living room (top) and bedroom (bottom) are shown in Figure 5-24.

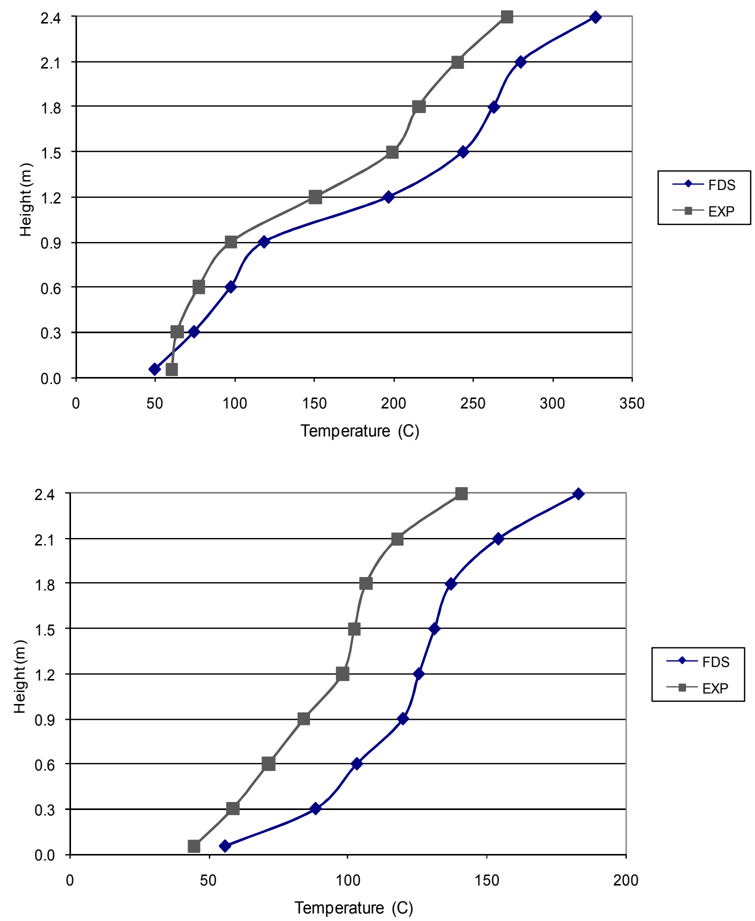
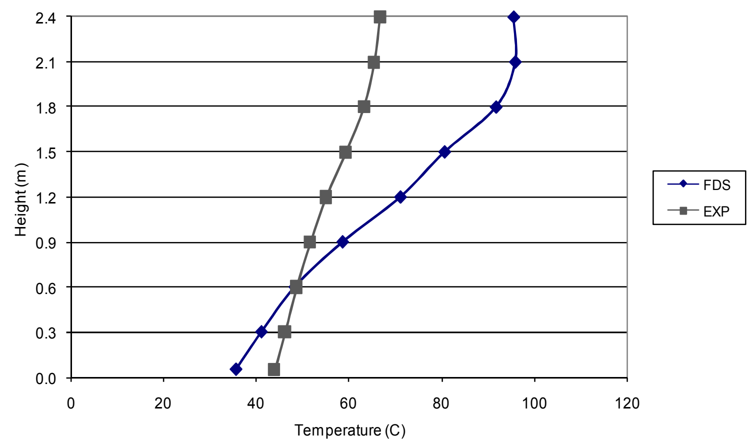


Figure 5-24. Vertical variations of temperature at 1000 s. in the living room (top) and the bedroom (bottom) for the sofa test in the closed compartment.

At 1000 s FDS still give the same shape as the curve for the experimental results but with higher temperatures in both locations. In the living room it is constant around 10% and in the bedroom between 3 – 10%.

Temperature measured over the height of the room at 1700 s in the living room (top) and bedroom (bottom) are shown in Figure 5-25.



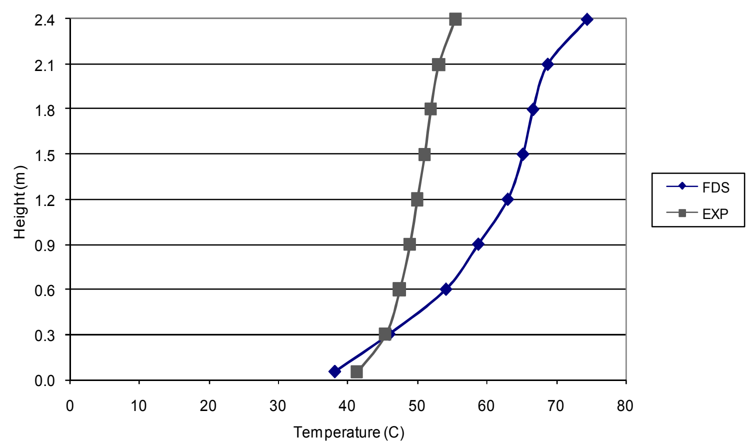


Figure 5-25. Vertical variations of temperature at 1700 s in the living room (top) and the bedroom (bottom) for the elevated cabinet test in the closed compartment.

At the end of the simulation FDS appear to stay have higher temperatures in the gases in the upper layer compared to the test data, which show a larger drop in temperatures. For the bottom four thermocouples in the living room FDS is within 3%, but show up to 10% higher temperatures higher up.

5.6 Sofa Test with Half Open Window

The scenario was similar to the fully closed compartment except for having the bedroom window half open, giving a ventilation opening 20 cm high and 60 cm wide. The simulation was run for 1700 s.

5.6.1 Heat Release Rate

The resulting heat release rates from FDS and the experiment are shown in Figure 5-26.

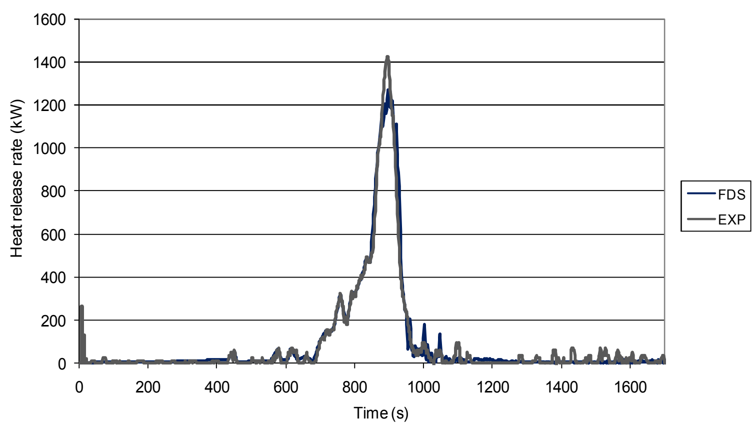


Figure 5-26. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Sofa with window half open

The peak has been cut off slightly in FDS indicating lack of oxygen influenced the combustion. Everywhere else the FDS and experimental heat release rate is identical.

5.6.2 Oxygen concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-27

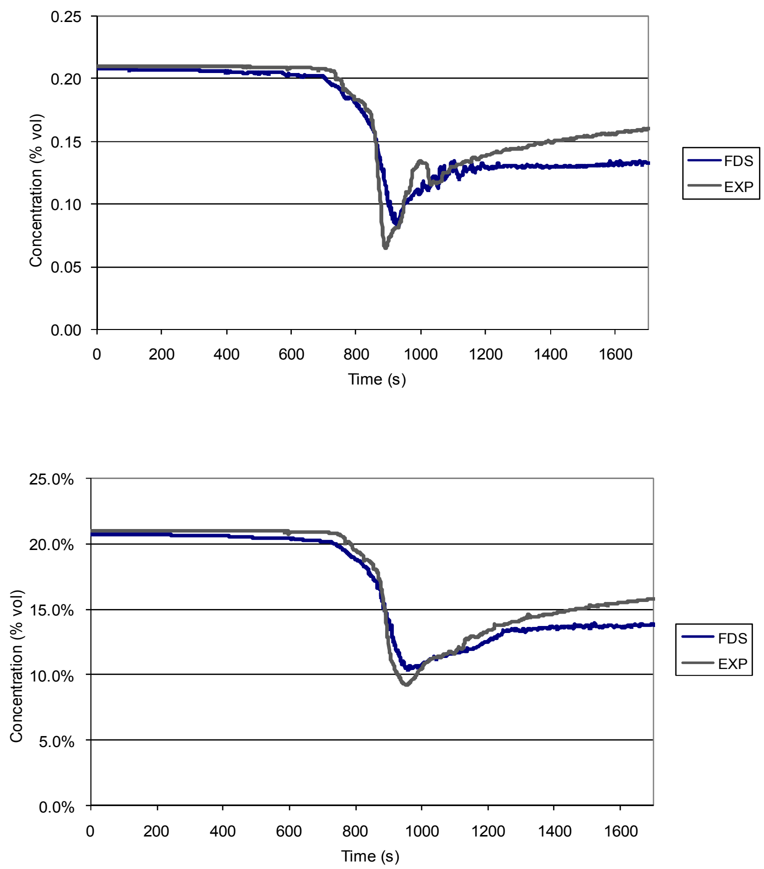


Figure 5-27. Oxygen concentrations at 1.5 m (5 ft) in the living room (top) and bedroom (bottom) for sofa test with bedroom window half open

The oxygen concentration measurements show very good agreement between FDS and the test data. In both rooms they start to decrease at the same time and reach very close to the same minimum value. In the living room the test end at 6.5 & by volume compared to 8% from FDS. In the bedroom the test and FDS show a minimum of 10% and 9% respectively. The test does show a more rapid increase in oxygen after the fire self-extinguished, indicating larger inflow if fresh air.

5.6.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 850 s, 900 s and 1700 s in the living room and bedroom. This represents the times when the experimental mass loss rate reaches 50% and 100% of peak value and the end of the simulation. The data was averaged over 10 s for each of the measurement points. The ambient temperature was around 27° C in both the test and FDS.

Temperature measured over the height of the room at 850 s in the living room (top) and bedroom (bottom) are shown in Figure 5-28.

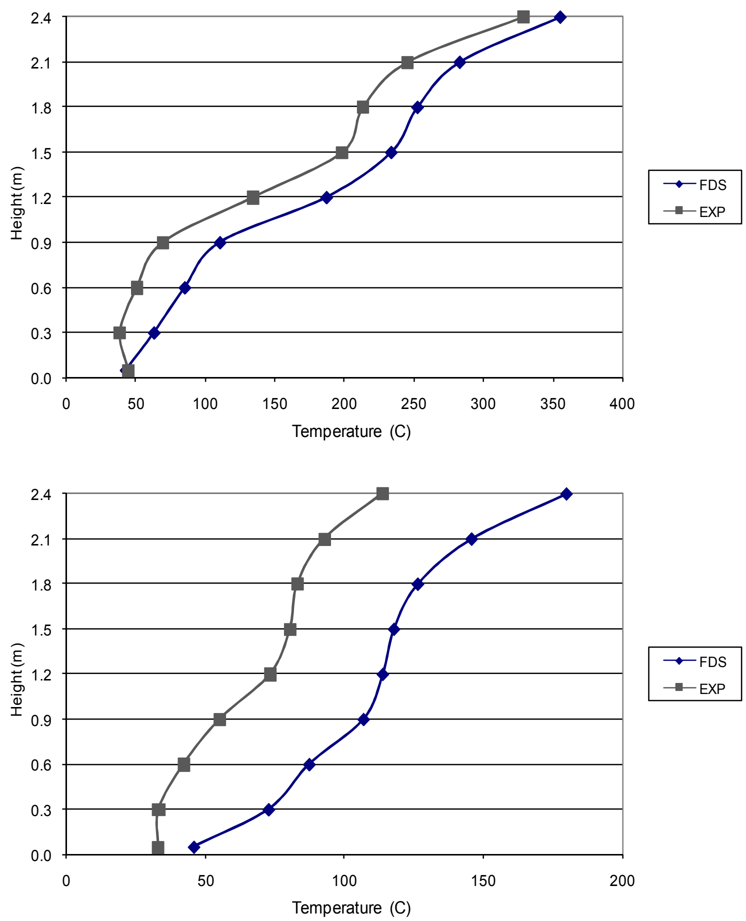
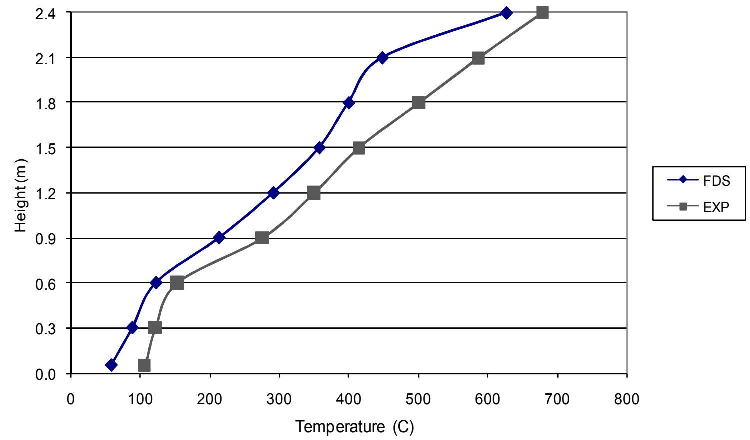


Figure 5-28. Vertical variations of temperature at 850 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open.

The shape of the two graphs is clearly similar but FDS shows a higher temperature in both locations. In the living room, except for at the floor and ceiling, this ranges from 7% to 13% higher, with the largest deviations at the lower thermocouples. The deviations in the bedroom range from temperatures 4% to 17% higher.

Temperature measured over the height of the room at 900 s in the living room (top) and bedroom (bottom) are shown in Figure 5-29.



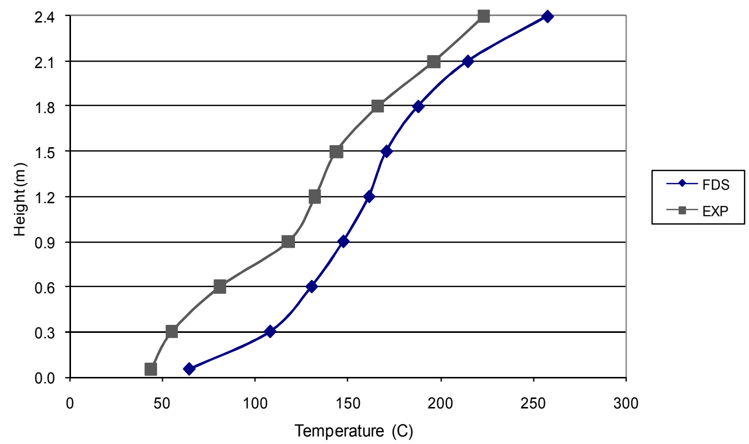
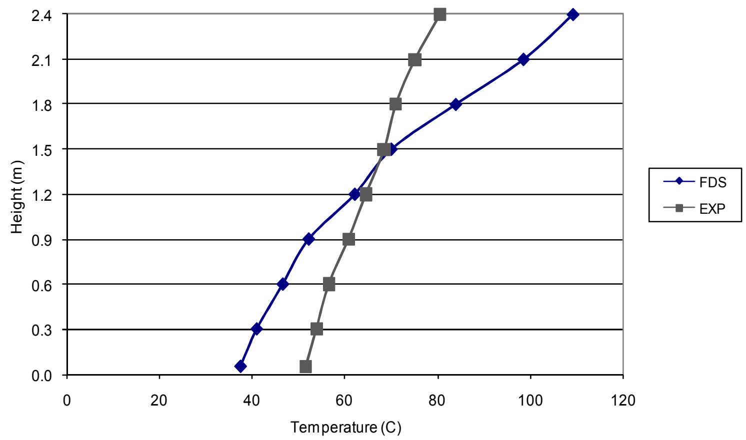


Figure 5-29 Vertical variations of temperature at 900 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open.

Just 50 s later FDS give lower temperatures at all locations in the living room, within 20%. The temperatures in the bedroom are no more than 16% higher in FDS.

Temperature measured over the height of the room at 1700 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-30.



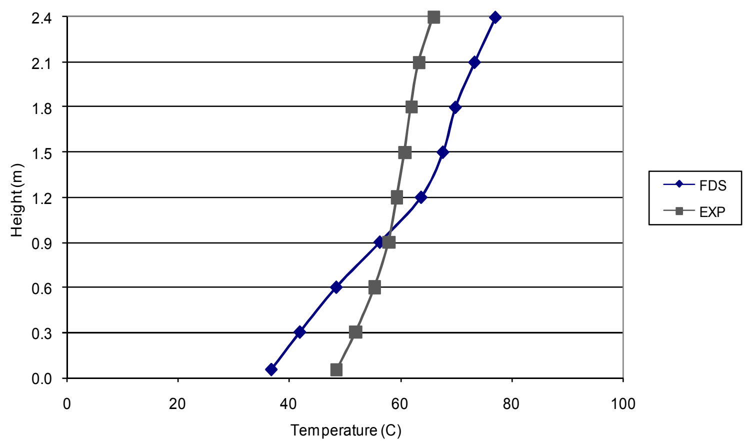


Figure 5-30. Vertical variations of temperature at 1300 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open.

At the end of the fire a similar picture is seen in both locations. As in the closed sofa test FDS appear to retain more heat in the hot gases under the ceiling. But the predictions are within 10% in the living room and within 5% in the bedroom. A larger or more rapid inflow of fresh air after the fire self-extinguished could explain the difference, which also agrees with the observation concerning the behavior of the oxygen concentrations.

6 COMPARISON OF SIMULATIONS WITH DIFFERENT COMBUSTION MODEL SETTINGS

Four of the test scenarios were simulated with two other configurations of the combustion model, giving a total of three different configurations for each test. For all the simulations discussed above the extinction model and the CO production model were used, termed +ext/+CO. The second is the default setting in FDS, which is extinction on and CO production off, termed +ext/-CO. The third is with both the extinction model and CO production model turned off, termed –ext/-CO.

6.1 Elevated Kitchen Cabinet in Closed Compartment

6.1.1 Heat Release Rate

The heat release rate was taken from the load cell data from the experiment and gave similar input for all three simulations. The resulting heat release rates from the simulations are shown in Figure 6-1.

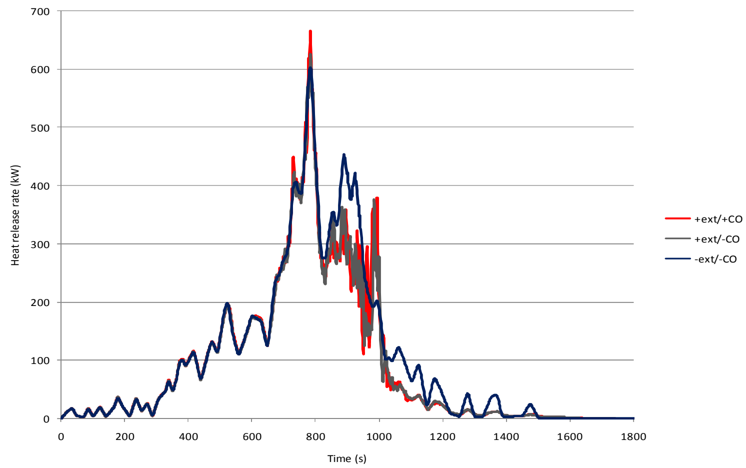


Figure 6-1. Heat release rate from three FDS simulations with different combustion model settings for kitcehn cabinet test in closed compartment. +ext/+CO :Extinction on, CO production on. +ext/-CO:extinction on, CO production off. –ext/-CO: extinction off, CO production off.

There three heat release rate curves are averaged over five seconds to reduce fluctuations, which appear at 800 s. The largest differences between the three curves are seen at the peak and after 800 s when two of the simulations start to show signs of oxygen vitiation. The simulation with both extinction and CO production turned off does not show any effects of lack of oxygen at 800 s where the two other simulations start to show a reduction in burning. At the peak the simulation with both models off reach a lower maximum value than the two other simulations.

6.1.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 6-2. Data from the kitchen is averaged over five seconds.

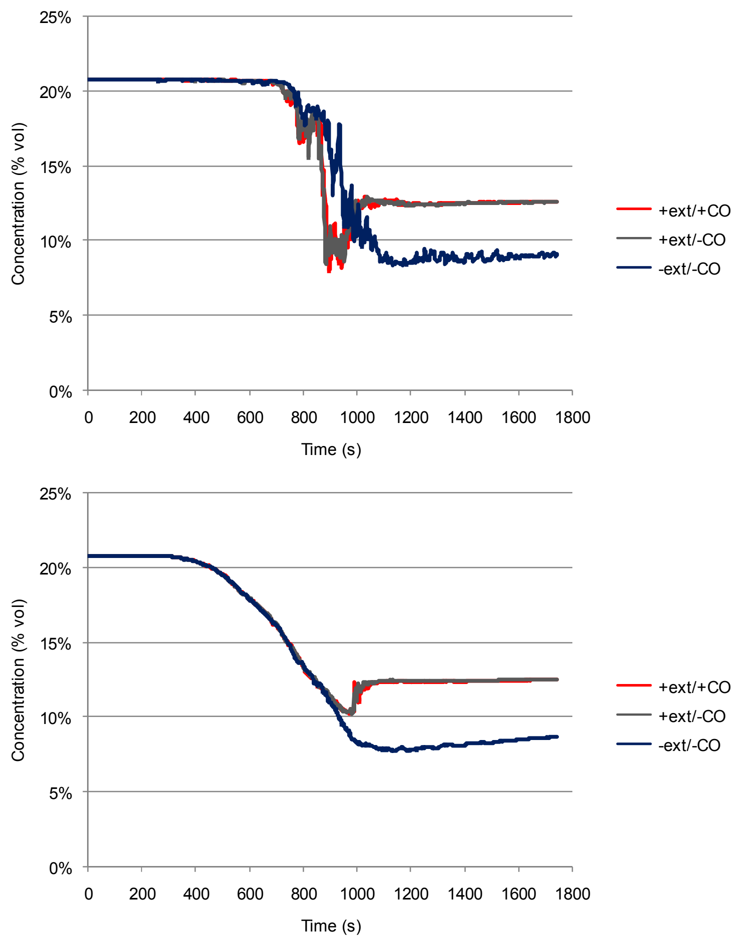


Figure 6-2. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the three different combustion model settings in closed compartment kitchen cabinet test.

The oxygen concentrations in the kitchen show a clear difference between the three models. The reduction in heat release rate after 800 s is caused by a more rapid reduction on oxygen in the fire room for the extinction on simulations. The extinction off simulation shows a slower decrease but also remains at the minimum value of 9% oxygen by volume whereas the two others increase slightly to 12% for the remainder of the test. In the bedroom the decrease is similar but the extinction on simulations plateau at a higher value, possible due to the reduced burning.

6.1.3 Temperature

Temperature slices were taken over the height of the room as for the experiment comparison at the same time steps, at 50% and 100% of peak heat release rate and at the end of the simulation. This was at 700 s, 800 s, and 1700 s in this simulation.

Temperature measured over the height of the room at 700 s in the kitchen (top) and bedroom (bottom) are shown in Figure 6-3.

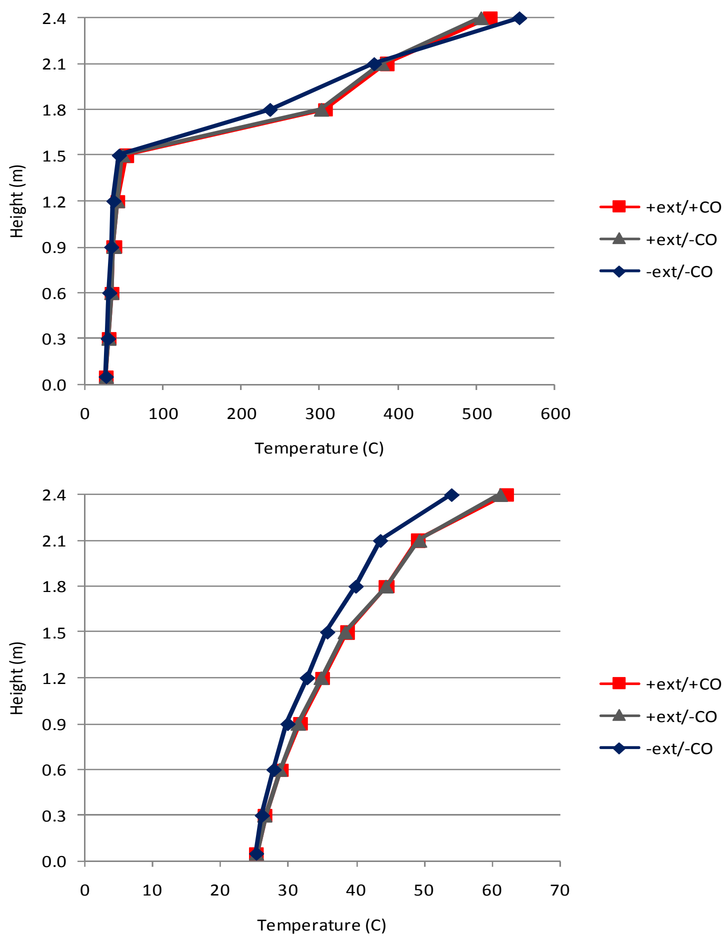


Figure 6-3. Vertical variations of temperature with the three different simulation configurations at 700 s in the kitchen (top) and the bedroom (bottom) for the closed compartment cabinet test.

As seen for heat release rate and oxygen concentration the two simulations with extinction on are within 2% of each other. The extinction off configuration gives temperatures 12% lower at 1.8 m in the kitchen and over the whole room in the bedroom. This would follow from the lower peak heat release rate seen for that simulation.

Temperature measured over the height of the room at 800 s in the kitchen (top) and bedroom (bottom) are shown in Figure 6-4.

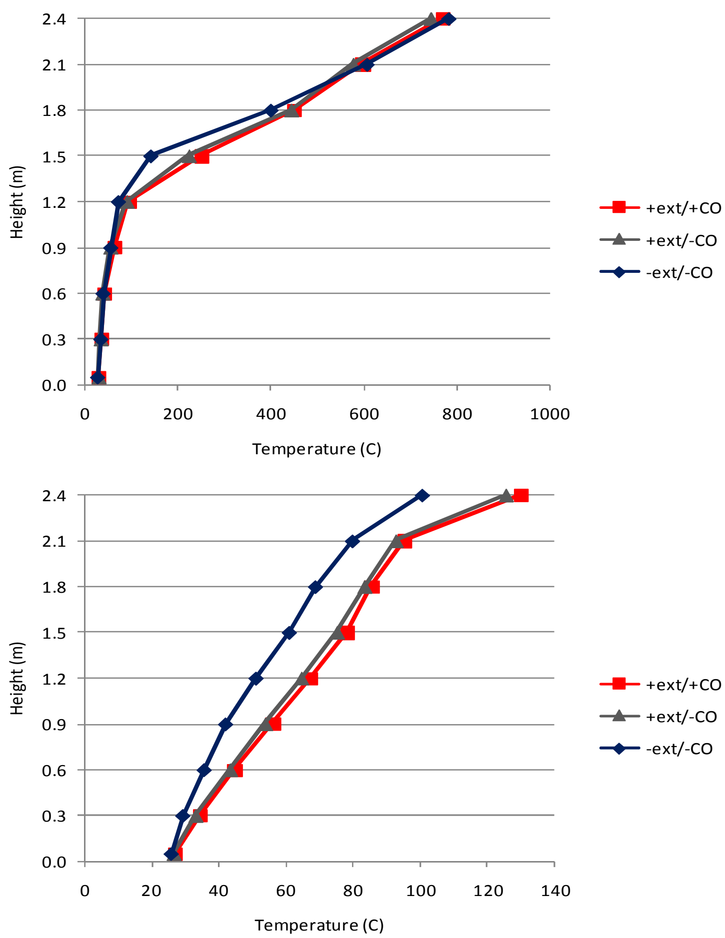


Figure 6-4. Vertical variations of temperature with the three different simulation configurations at 800 s in the kitchen (top) and the bedroom (bottom) for the closed compartment cabinet test.

At 800 s the differences between the extinction on or off configurations are a more pronounced in the kitchen with the simulations with extinction being up to 20% higher. The largest deviations occur between 0.9 m (3 ft) and 1.8 m (6 ft). The simulations without extinction is up to 7% lower on the bedroom.

Temperature measured over the height of the room at 1900 s in the kitchen (top) and bedroom (bottom) are shown in Figure 6-5.

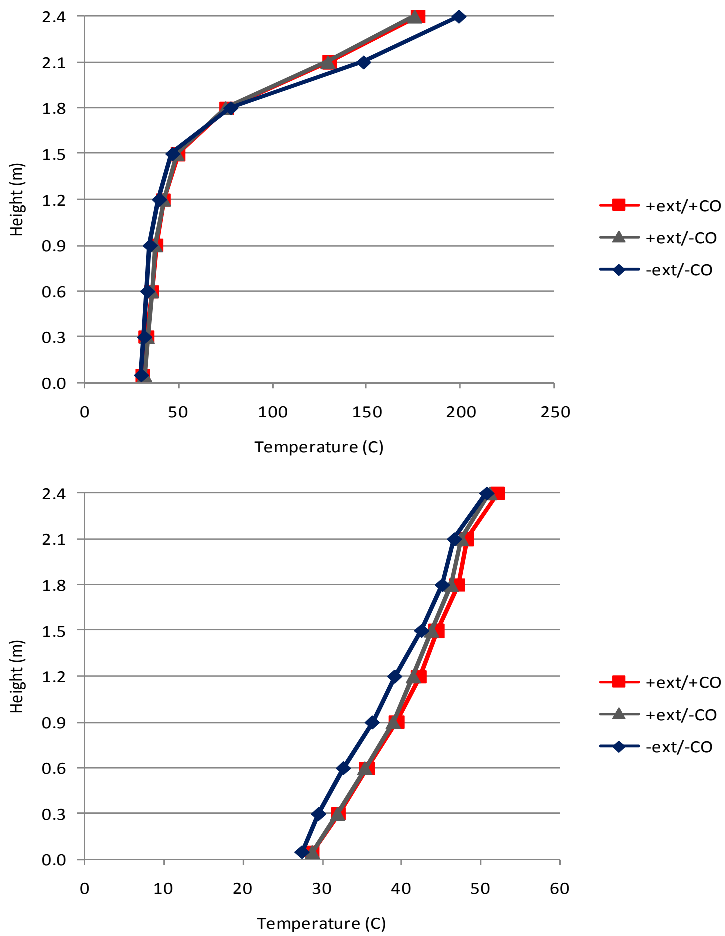


Figure 6-5. Vertical variations of temperature with the three different simulation configurations at 1900 s in the kitchen (top) and the bedroom (bottom) for the closed compartment cabinet test.

At 1700 s the difference between the three configurations are smaller again with the simulations with extinction being within 2% of each other and extinction off show a maximum of 14% deviation from the others.

6.2 Elevated Kitchen Cabinet with Window Half Open

6.2.1 Heat Release Rate

The heat release rate was taken from the load cell data from the experiment and gave similar input for all three simulations. The resulting heat release rates from the simulations are shown in Figure 6-6. All three heat release rates were averaged over five seconds to reduce fluctuations in the data.

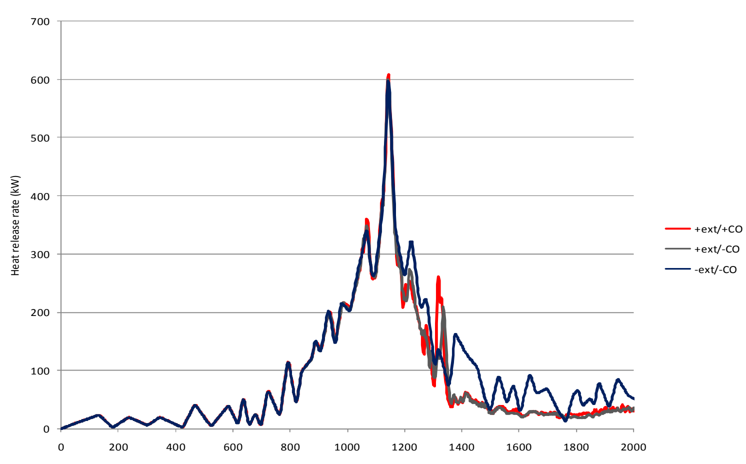


Figure 6-6. Heat release rate from three FDS simulations with different combustion model settings for kitchen cabinet test with open window. Extinction on, CO production on; extinction on, CO production off; extinction off, CO production off.

There are less signs of oxygen vitiation than was seen in the closed compartment test as would be expected. The two simulations with the extinction on also give similar results, which differ from the simulation with both models off after the peak around 1200 s. The model with the extinction model off show the small peaks after 1300 s, which are not seen in the two other simulations because of lack of oxygen.

6.2.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 6-7. Data from the kitchen is averaged over five seconds.

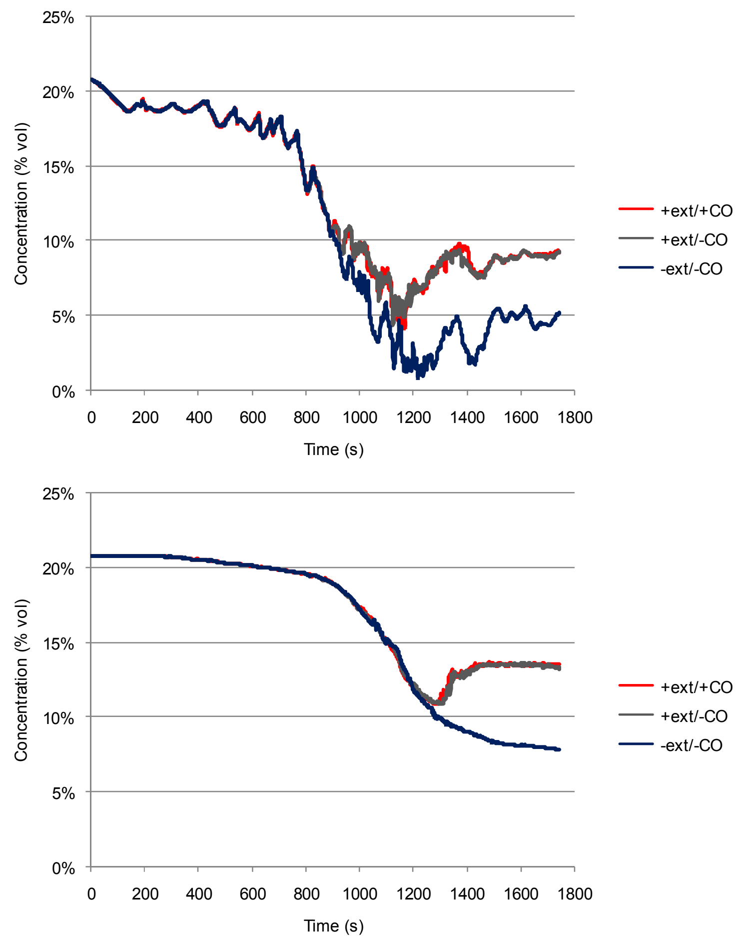


Figure 6-7. Oxygen concentrations at 1.5 m (5 ft) in the kitchen (top) and bedroom (bottom) for the three different combustion model settings in closed compartment kitchen cabinet test.

The oxygen concentration measurements show similar behavior in the kitchen and bedroom. In both rooms the three simulations predict the decrease identically up to a point where the simulations with the extinction model starts to show a slower rate of decrease and plateau at a higher value than the simulation without extinction, which continues to decrease.

6.2.3 Temperature

Temperature slices were taken over the height of the room as for the experiment comparison at the same time steps, at 50% and 100% of peak heat release rate and at the end of the simulation. This was at 1050 s, 1150 s, and 2000 s in this simulation.

Temperature measured over the height of the room at 1050 s in the kitchen (top) and bedroom (bottom) are shown in Figure 6-8.

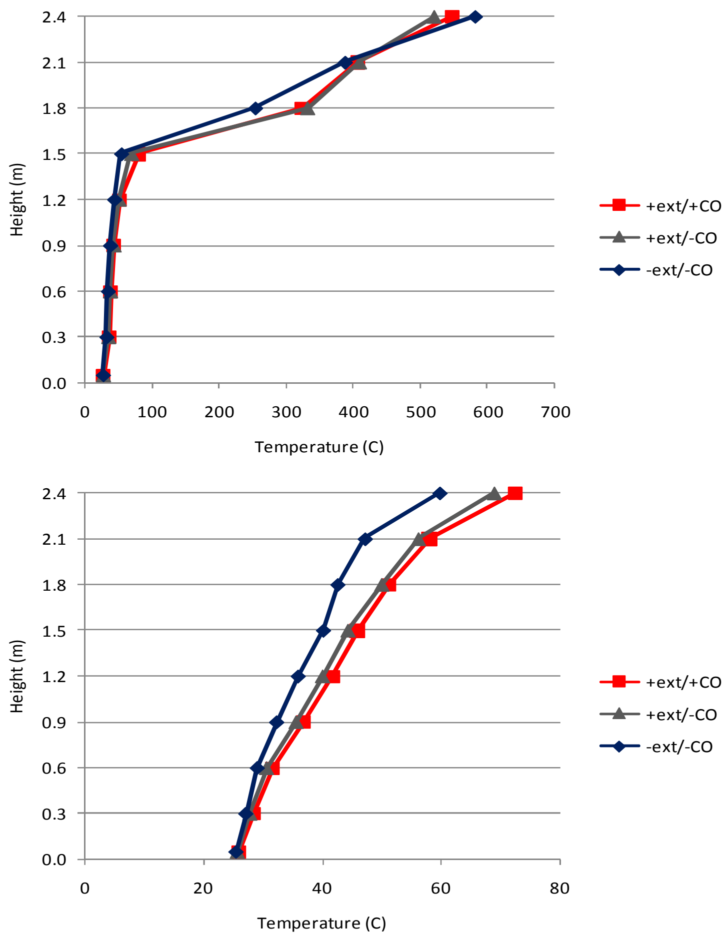
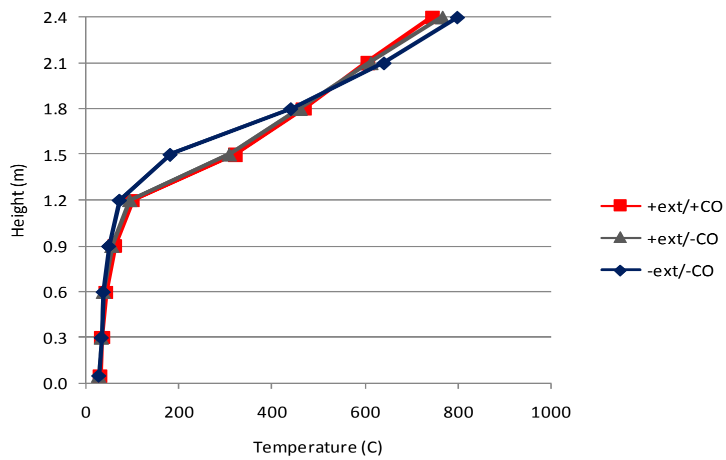


Figure 6-8. Vertical variations of temperature with the three different simulation configurations at 1050 s in the kitchen (top) and the bedroom (bottom) for the closed compartment cabinet test.

The temperature in the kitchen show results similar to that seen in the close compartment test where the two simulations with the extinction model on show results within 3% of each other. Without the extinction model and CO production the simulation shows a temperature 7% lower at 1.5 m (5 ft) and 12% lower at 1.8 m (6 ft). All other heights are within 5%. The simulation with both models off also gives temperatures up to 4% lower in the bedroom. The two other simulations are within 1% of each other.

Temperature measured over the height of the room at 1150 s in the kitchen (top) and bedroom (bottom) are shown in Figure 6-9.



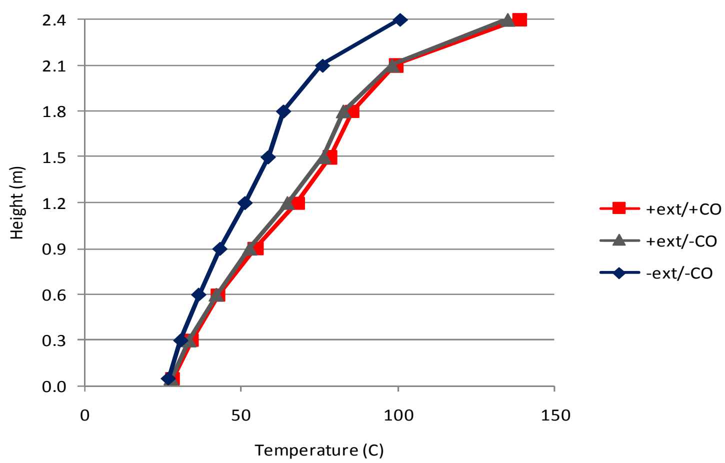


Figure 6-9. Vertical variations of temperature with the three different simulation configurations at 1150 s in the kitchen (top) and the bedroom (bottom) for the closed compartment cabinet test.

At 1150 s the simulation without the extinction model gives up to a 24% lower temperature in the kitchen and up to 9% lower in the bedroom. The difference between the two models with the extinction model on remains less than 1% in the both rooms.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 6-10.

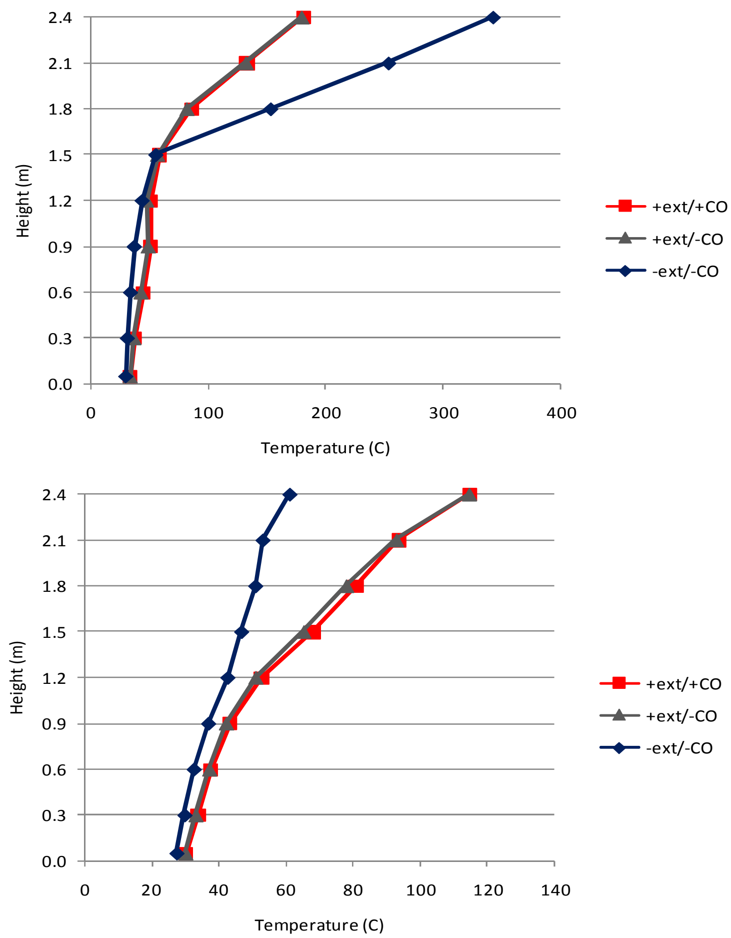


Figure 6-10. Vertical variations of temperature with the three different simulation configurations at 2000 s in the kitchen (top) and the bedroom (bottom) for the closed compartment cabinet test.

At the end of the fire the simulation with the extinction model off show a significantly higher temperature for the three top measurement points in the kitchen. This is an expected result of the higher heat release rate seen for this simulation after 1300 s in Figure 6-6. Unexpectedly the simulations without extinction give lower temperatures than the two other models in the bedroom, despite the higher temperatures in the kitchen and higher heat release rate.

6.3 Sofa in Closed Compartment

The simulation using heat release rate data from the sofa test in the compartment were run with the three different setting for the combustion model. The sofa test in the closed compartment had a heat release rate with a peak almost half of what was seen in the open calorimeter test despite oxygen concentrations remaining above 15% for the whole test. The earlier analysis does did not show signs of under-ventilation.

6.3.1 Heat Release Rate

The heat release rate was taken from the load cell data from the experiment and gave identical input for all three simulations. The resulting heat release rates from the three simulations are shown in Figure 6-11.

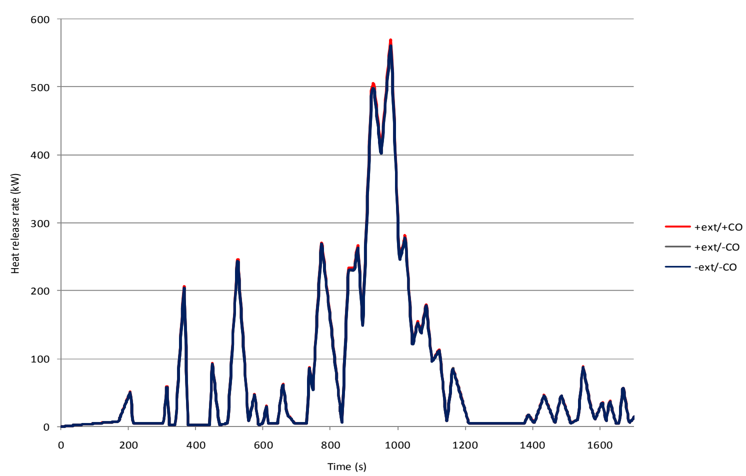


Figure 6-11. Heat release rate from three FDS simulations with different combustion model settings for sofa test in closed compartment. Extinction on, CO production on; extinction on, CO production off; extinction off, CO production off.

The three heat release rates are identical for the duration of the test except a minor difference at the peaks. None of the three show any fluctuations seen for oxygen limited burning.

6.3.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 6-12

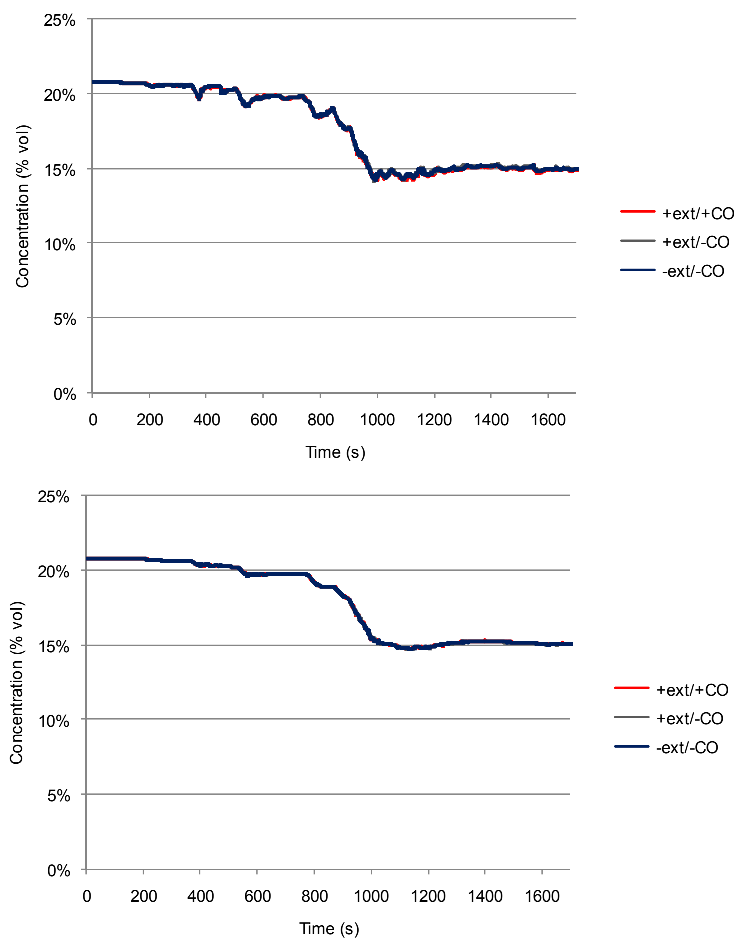


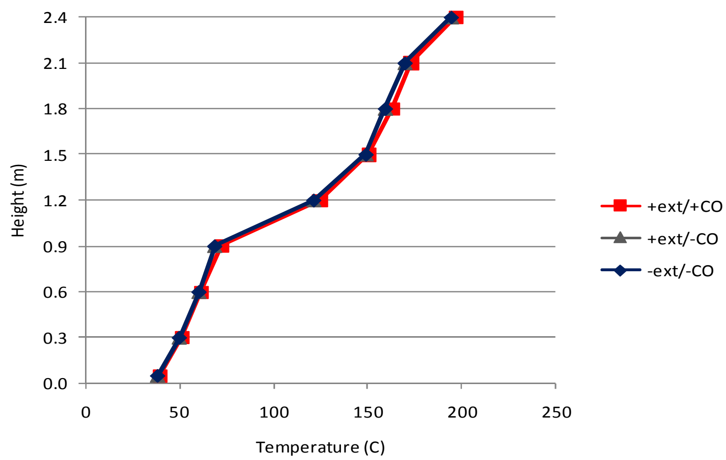
Figure 6-12. Oxygen concentrations at 1.5 m (5 ft) in the living room (top) and bedroom (bottom) for the three different combustion model settings in sofa test in closed compartment.

As suggested by the heat release rate there are no indication that the oxygen levels reach a level low enough to impair the combustion in any of the FDS simulations. There is no difference between the oxygen levels in the three simulations.

6.3.3 Temperature

Temperature slices were taken over the height of the room as for the experiment comparison at the same time steps, at 50% and 100% of peak heat release rate and at the end of the simulation. This was at 900 s, 1000 s, and 1700 s in this simulation.

Temperature measured over the height of the room at 900 s in the living room (top) and bedroom (bottom) are shown in Figure 6-13.



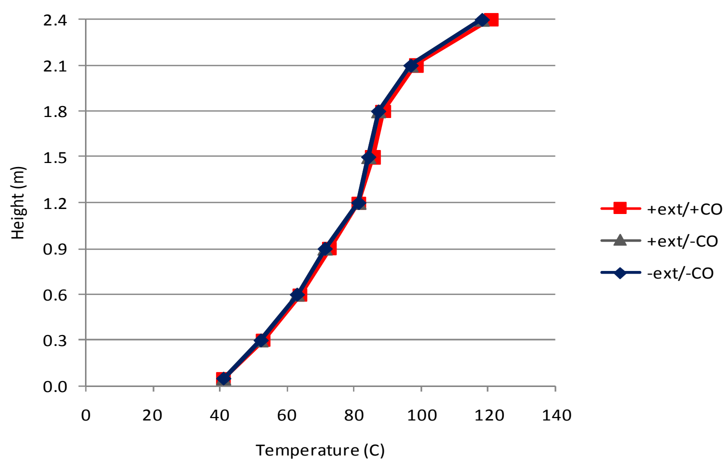


Figure 6-13. Vertical variations of temperature with the three different simulation configurations at 900 s in the living room (top) and the bedroom (bottom) for sofa test in closed compartment.

The identical heat release rate and oxygen levels results in variation between the simulations of at most 2 °C in both the living room and bedroom. At all heights the model with both the extinction model and CO production on give the highest temperatures, with the model with both turned off giving the lowest.

Temperature measured over the height of the room at 1000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 6-14.

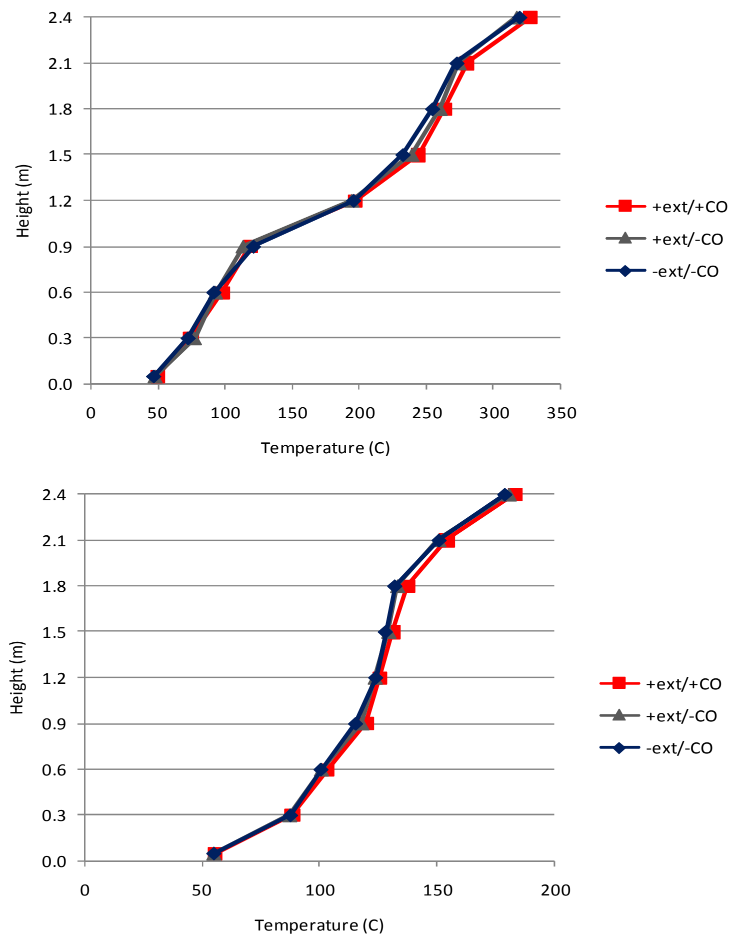


Figure 6-14. Vertical variations of temperature with the three different simulation configurations at 1000 s in the living room (top) and the bedroom (bottom) for sofa test in closed compartment.

At peak heat release rate at 1000 s there are still only minor differences between the three simulations with the order being the same as at 900 s. The simulation with both options turned on gives the highest temperatures and the simulation with both off give temperatures 2-3 °C lower with the third one being somewhere between.

Temperature measured over the height of the room at 1300 s in the living room (top) and bedroom (bottom) are shown in Figure 6-15.

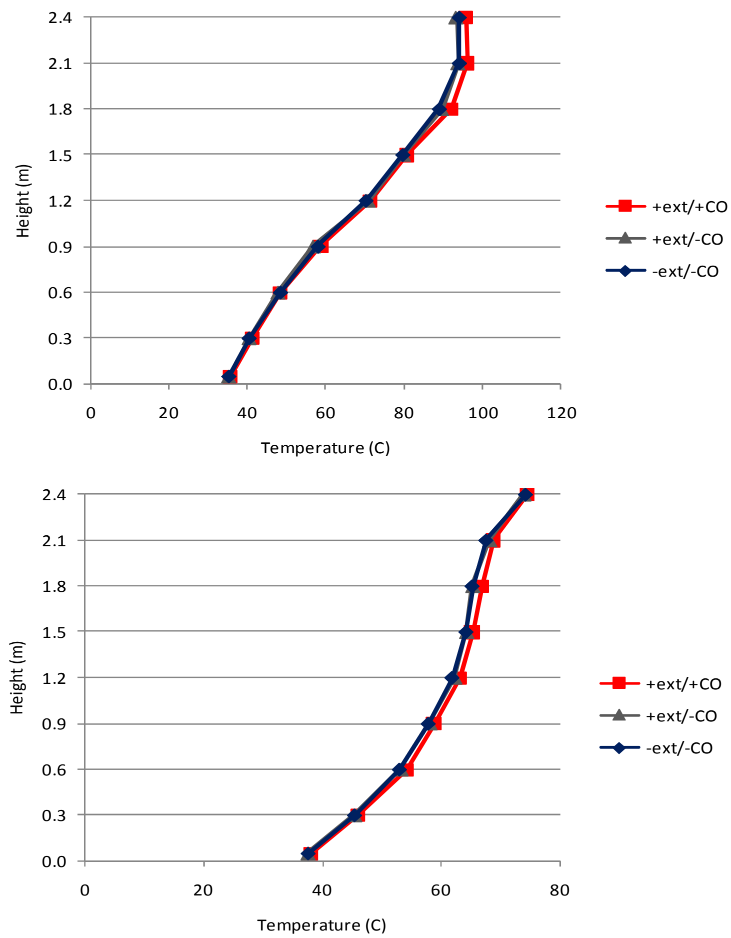


Figure 6-15. Vertical variations of temperature with the three different simulation configurations at 1300 s in the living room (top) and the bedroom (bottom) for sofa test in closed compartment.

At the end of the fire the differences are less than seen at the peak, at most 2 °C. The two simulations with the CO production model off are very close while the simulation with CO production on is slightly higher.

6.4 Sofa with Window Half Open

The layout of the test was similar to the closed compartment test except the half open window in the bedroom giving a ventilation opening of 60 cm (24 in) wide by 20 cm (8 in) high.

6.4.1 Heat Release Rate

The heat release rate was taken from the load cell data from the experiment and gave similar input for all three simulations. The resulting heat release rates from the simulations are shown in Figure 6-16.

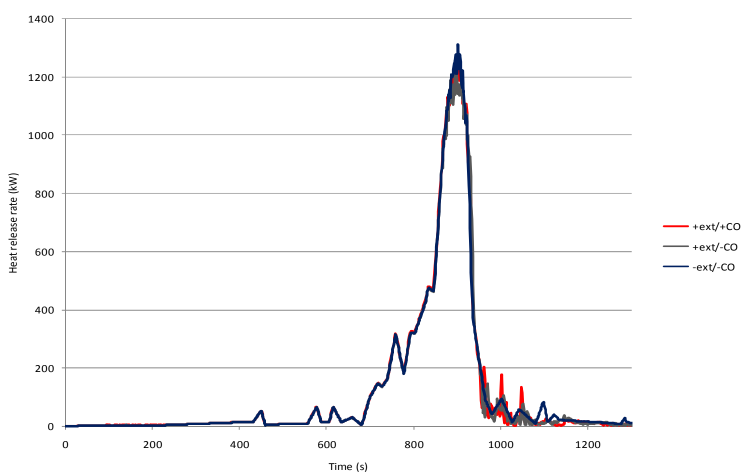


Figure 6-16. Heat release rate from three FDS simulations with different combustion model settings for sofa test in with window half open. Extinction on, CO production on; extinction on, CO production off; extinction off, CO production off.

The heat release rate is close to identical in all three simulations. The two simulations with the extinction model show some fluctuations around the small peaks at 100 s, which are not seen in the simulation with this model off.

6.4.2 Oxygen Concentration

The oxygen concentrations measured 1.5 m (5 ft) above the floor in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 6-17.

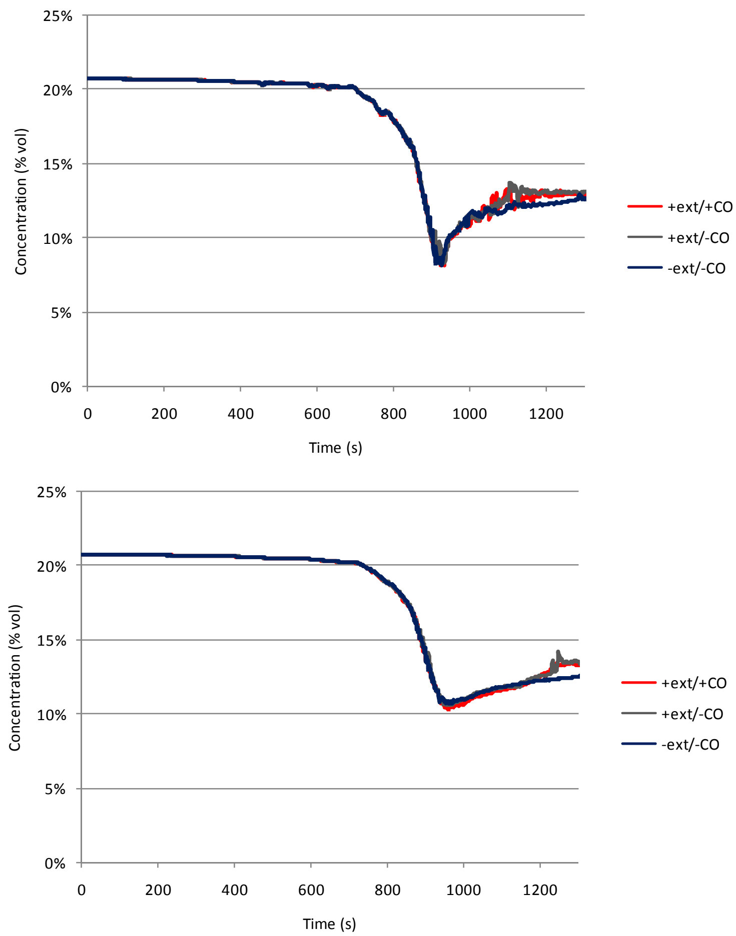


Figure 6-17. Oxygen concentrations at 1.5 m (5 ft) in the living room (top) and bedroom (bottom) for the three different combustion model settings in sofa test with window half open

The identical heat release rate curves result in similar curves for oxygen concentration. Only late in the simulation when the fire starts to show signs of lack of oxygen do any differences appear. The two models with extinction model active starts to show an increase in oxygen concentration. This is caused by local flame extinction occurring where there is still oxygen but not in sufficient quantities to satisfy the limiting temperature criteria for combustion. In the simulation with the extinction model off this oxygen will be consumed by fire. This is consistent with the fluctuations in the heat releases rate seen around 1000 s in Figure 6-16.

6.4.3 Temperature

Temperature slices were taken over the height of the room as for the experiment comparison at the same time steps, at 50% and 100% of peak heat release rate and at the end of the simulation. This was at 850 s, 900 s, and 1300 s in this simulation.

Temperature measured over the height of the room at 850 s in the living room (top) and bedroom (bottom) are shown in Figure 6-18.

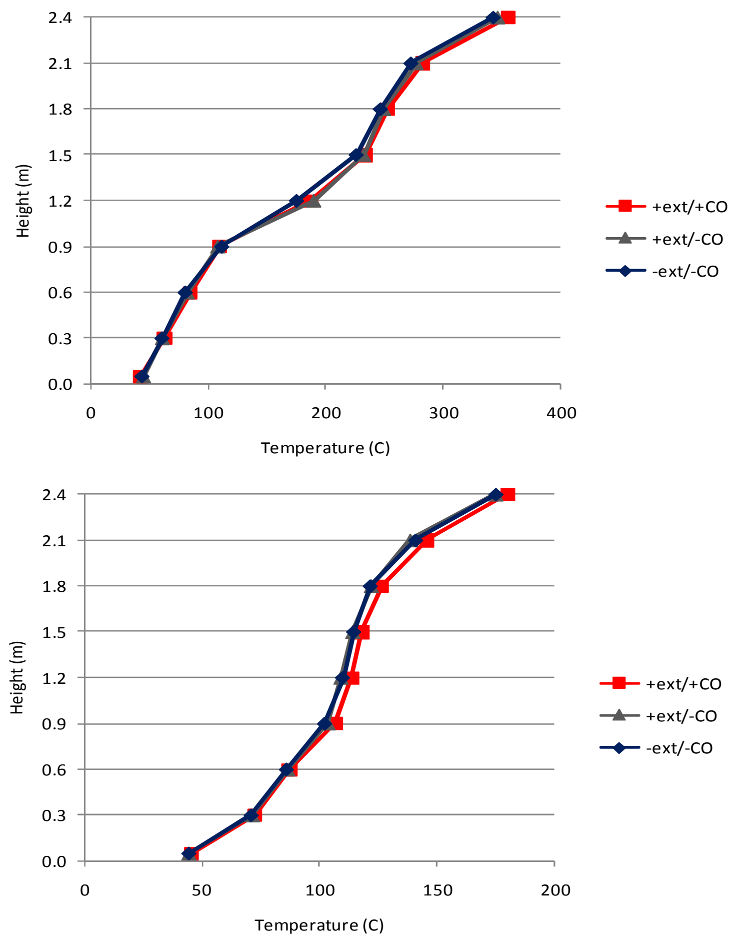


Figure 6-18. Vertical variations of temperature with the three different simulation configurations at 850 s in the living room (top) and the bedroom (bottom) for sofa test with window half open.

When the fire is at 50% of peak heat release rate there is no sign if oxygen vitiation and as expected the three simulations are close to identical. Some local extinction occurs giving a few percent differences between the two models with extinction turned on. However it would be expect6ed that this would lead to higher temperatures, but the opposite is seen, mostly in the middle of the room height at the layer interface.

Temperature measured over the height of the room at 900 s in the living room (top) and bedroom (bottom) are shown in Figure 6-19.

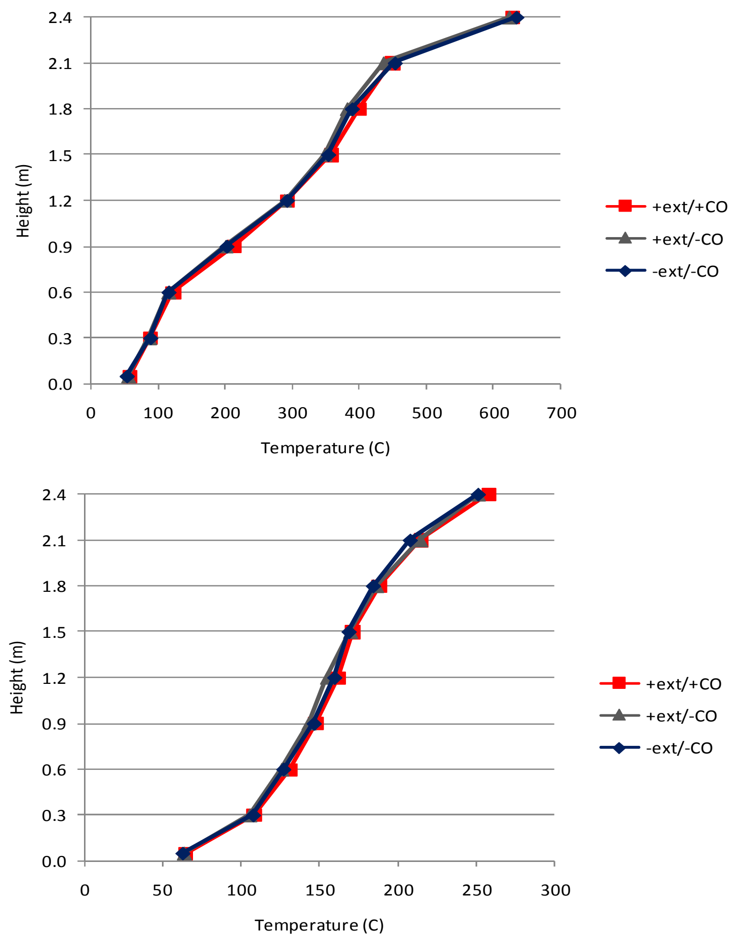
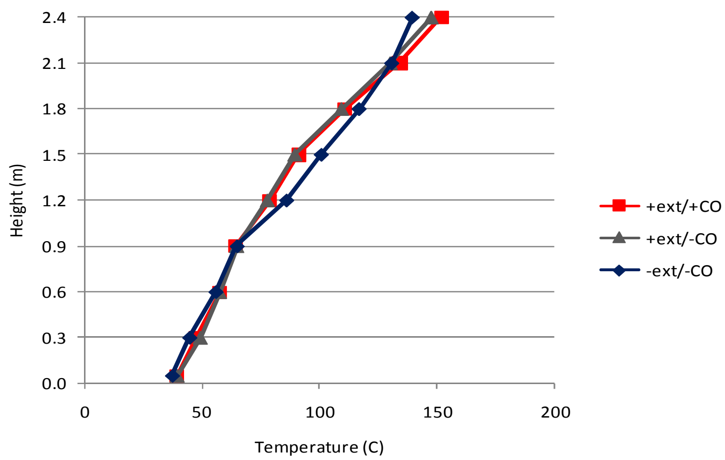


Figure 6-19. Vertical variations of temperature with the three different simulation configurations at 900 s in the living room (top) and the bedroom (bottom) for sofa test with window half open.

At 900 s there are still only minimal differences between the three simulations. The model with the extinction model and CO production model off show a few degrees less than the two others.

Temperature measured over the height of the room at 1300 s in the living room (top) and bedroom (bottom) are shown in Figure 6-20.



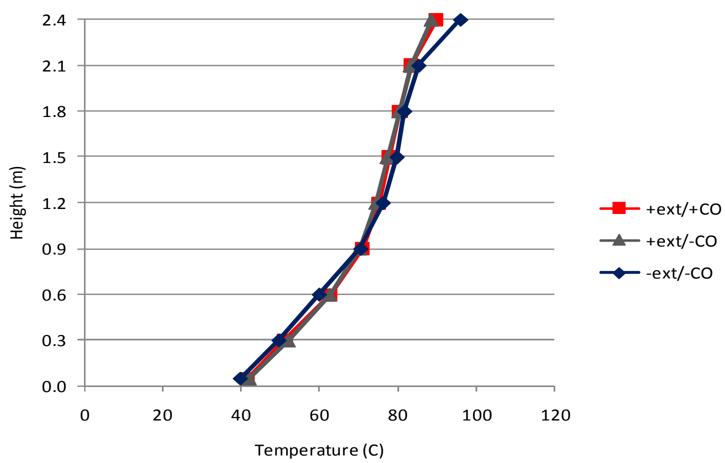


Figure 6-20. Vertical variations of temperature with the three different simulation configurations at 1300 s in the living room (top) and the bedroom (bottom) for sofa test with window half open.

At the end of the fire the two models with extinction on show lower temperatures as would be expected from the heat release rate curve and the oxygen concentration, which indicated lack of oxygen lead to restricted burning in those simulations.

7 DISCUSSION

7.1 Gas Burner Tests

The two 125 kW burner tests in the living room showed that the initial temperature increase occurred more rapidly in both the living room and in the bedroom in the FDS simulation. After 50 s both FDS and the test showed a layer separation starting to become apparent at 1.2 m (4 ft) but with a much higher temperature at the ceiling in FDS. The burner only took about 5 s to ramp up to full heat release rate, compared to 1 s in FDS so this should not have any significant effect. However, later in the test at 200 s and 500 s FDS showed very good agreement with the test data. FDS was within 5% of the measured data at all points in both locations. It is clear that the smoke transport in FDS is faster than in the test, but it is not clear why. It is not know how the gas burner behaves initially, and unsteady flow right after the burner is turned on could be a factor. There did not appear to be any correlation between the accuracy of the temperature measurements and ventilation condition in the two tests. The oxygen levels were never below 15% and the fire showed no signs of being limited by the ventilation. The limiting oxygen index for methane is reported as being 13% by volume. Similarly the limiting oxygen concentration in, which natural gas can burn as a premixed flame is given as 12% (Beyler 2002).

The oxygen concentration results also showed strong agreement between FDS and the test data. In the bedroom, FDS showed a lower concentration in both tests throughout the whole duration. This difference increased with time but only result in just over 1% lower concentration of oxygen in the simulation. In the living room FDS also gave consistently lower oxygen values, up to 18% lower but is not more than a 1% difference in oxygen concentration. Pure methane gas was used as the fuel in FDS whereas in the test natural gas from the public supply was used. The natural gas used in the test burner therefore does not consist of pure methane and contains other gases such as ethane, propane, butane or CO_2 (Coward and Jones 1952), which will result in a lower heat release rate and a reduced oxygen concentration. However, if a less pure methane as is used in FDS this would result in lower oxygen concentrations. A simulation was run using natural gas with the following composition:

C = 1.06084

H = 4.076451

N = 0.015529

O = 0.014848

And a heat of combustion of 48 249 kJ/kg compared to 49 600 kJ/kg for methane. As expected this resulted in a slightly lower oxygen concentration in the living room, but very little change in the bedroom. The mass flow rates to the burner in the tests were decided based on a calculation for heat release rate using the theoretical heat of combustion for natural gas. If the value used was too high this may have resulted in a lower heat release rate than 125 kW and will explain the higher temperatures and lower oxygen concentrations in FDS.

7.2 Effects of Different Heat Release Rate Inputs to FDS on the Accuracy of the Results

The measurement points for the temperature height slices and the deviations from the test data for both the cabinet and sofa tests for both the calorimeter and load cell heat release rate simulations were studied to determine, which simulation gave results closer to that observed in the test. It would be expected that the FDS simulations using the same heat release rate curve would give temperatures closer to the test data. The time point for the temperature slices used were the same as earlier at 50% and of peak, at peak heat release rate and at the end of the simulation time. The absolute value of the difference between the test and the FDS simulations was compared and it was determined that the load cell heat release rate simulation was closer to the test data at 218 of the 324 measurements points or 69%. The number of measurement points where the FDS load cell heat release rate simulation was closer to the test data than the calorimeter heat release rate simulation is show in Table 7-1.

Table 7-1. Location and Ventilation Condition for the Measurement Points Where the Load cell heat release rate Simulation is closer to the Test Data Than the Calorimeter Heat Release Rate Simulation.

Post-test FDS closer to test			
Ventilation	Location	Number	% of total
Closed	Kitchen	12	44%
	Bedroom	13	48%
Open Window	Kitchen	10	37%
	Bedroom	17	63%
No Window	Kitchen	22	81%
	Bedroom	19	70%
Open Door	Kitchen	25	93%
	Bedroom	27	100%
Sofa Closed	Living Room	20	74%
	Bedroom	20	74%
Sofa Window	Living Room	20	74%
	Bedroom	18	67%
	Total	223	69%

The load cell heat release rate simulations were closest to the test data for over 50% of the data points in the open door and window removed tests as well as all the sofa tests. The calorimeter heat release rate simulations were closer at over 50% of the points in the closed compartment test and in the kitchen in the test with half open window. From this it appeared that with less ventilation either the calorimeter heat release rate simulations gave more accurate results or there was less difference between the two simulation inputs. However the larger ventilation openings also gave larger fires. The simulation with open door gave a peak heat release rate twice that of the closed compartment kitchen cabinet test.

7.2.1 Sofa Tests

Different behavior was seen when comparing calorimeter, load cell simulations and the experiment for the sofa tests and the kitchen cabinet test. For the calorimeter heat release rate simulations of the cabinet tests the calorimeter data gave a fire smaller than what was seen in the load cell data from the experiments. The two sofa tests were quite different. The closed compartment test gave a peak heat release rate in the experiment only half of what was seen in the calorimeter. The oxygen concentration in both the living room and the bedroom went down to 16% and remained there for the rest of the fire. The limiting oxygen index for polyurethane is reported as 17% (Tewarson 2002) so the measurements in the test are consistent with reported extinction conditions for the material.

In the sofa test with the bedroom window half open the heat release rate curve followed very closely the input from FDS based on the calorimeter test. The three heat release rates from the calorimeter, load cell and experiment are compared in Figure 7-1, where the shorter ignition time in the calorimeter heat release rate simulation was accounted for to line up the data with respect to time. The heat release rate of the calorimeter heat release rate simulation was averaged over five seconds due to fluctuations

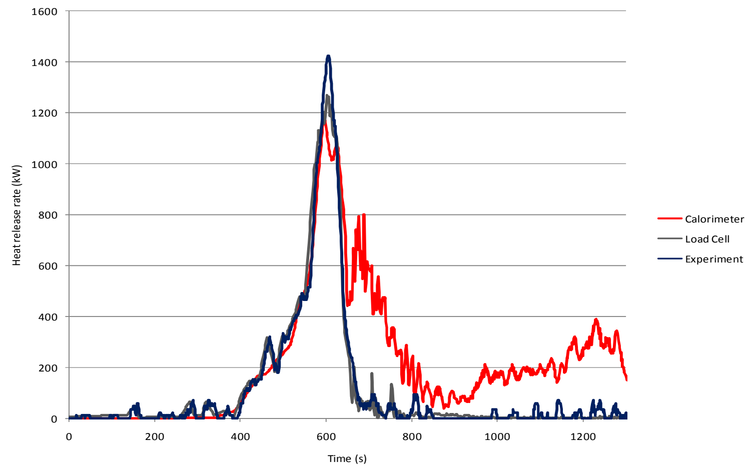


Figure 7-1. Comaprison of heat release rate in the sofa test with half open bedroom window for the calorimeter heat release rate simualtions, load cell heat release rate simualtions and experimental data.

Up until 650 s the three graphs follow the same shape closely. The peak heat release rate in the experiment was about 150 kW higher than the load cell simulations, which was 100 kW higher than the calorimeter data. The calorimeter heat release rate simulations showed a higher heat release rate after 650 s with fluctuations caused by oxygen limitations. This was because the calorimeter input data had a low plateau of steady burning after the peak, which did not occur in the compartment test because of low levels of oxygen. The close similarity of the heat release rate curves in the two simulations led to similar behavior of the gas temperature measurements. The temperature over the height of the room at peak heat release rate in the two simulations and the experiment is shown in Figure 7-2 for the living room (top) and the bedroom on the right (bottom).

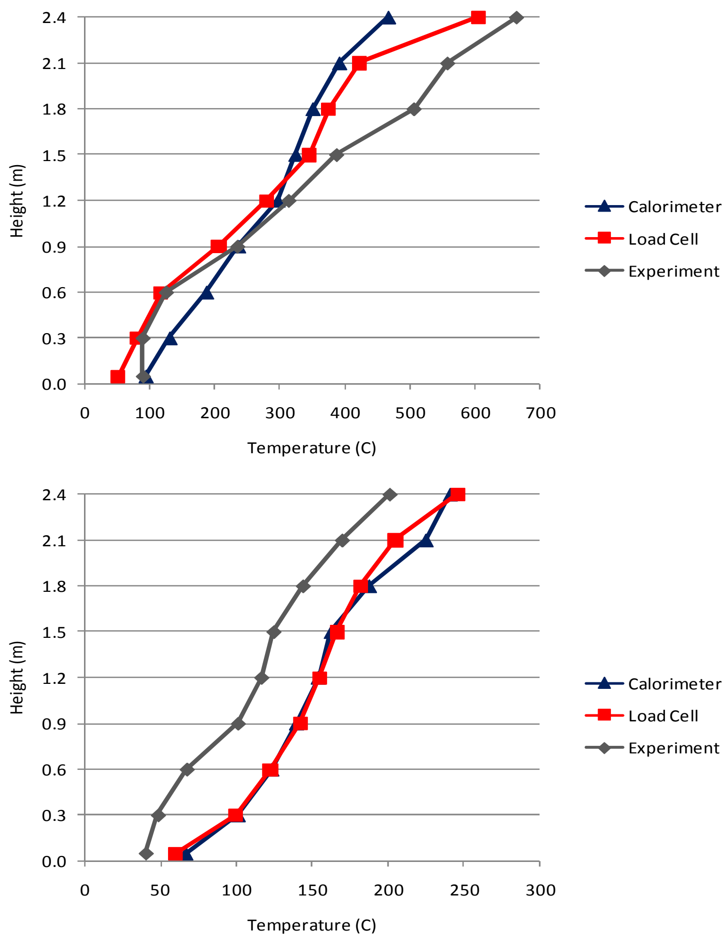


Figure 7-2. Temperature at peak heat releae rate in the living room (top) and bedroom (bottom) in the sofa test with window half open.

The two simulations gave close temperatures but both gave lower than the experiment data in the upper part of the living room. The heat release rate in the test was 250 kW and 150 kW higher than the calorimeter and load cell simulations respectively so this was not unexpected. However in the bedroom both simulations gave temperatures higher than the test for all time steps analyzed. If more combustion products and hot gases were transported to the bedroom in the simulations this could cause higher temperatures than seen in the tests. The horizontal air flow velocity was measured with bi-directional probes at four points in the doorway between the dining room and the bedroom but this data was only available for some of the test and did not give a clear picture of whether the mass flux in FDS was higher than in the tests. The temperature at 2.1 m (6 ft) above the floor in the bedroom in the load cell heat release rate simulation and the experiment are shown in Figure 7-3.

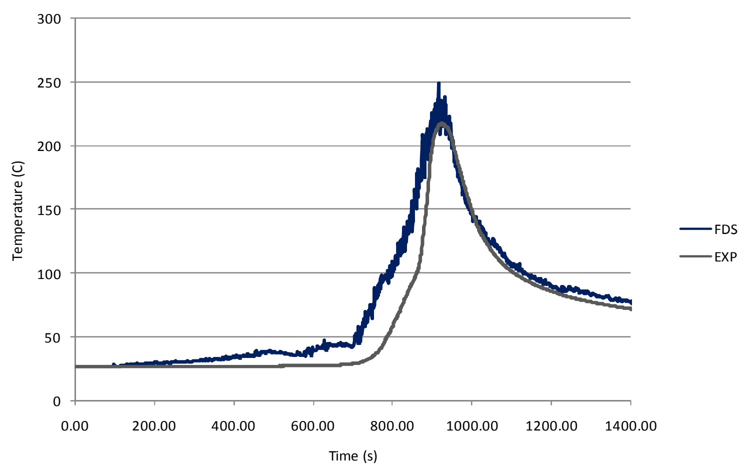


Figure 7-3. Temperature at 2.1 m (6 ft) in the center of the bedroom in the test and in the load cell heat release rate FDS simulation during the sofa test with window half open.

The temperature over time at other heights in the bedroom showed a similar behavior where FDS gave higher temperatures up to the peak and the two graphs show strong agreement as the temperature decrease. Lower down in the room the temperature in the test show a slower growth than FDS and also a lower peak temperature. From this it is clear that in FDS the hot gases are transported to the bedroom faster than in the test even when the heat release rate curve is very close to identical. For comparison the temperature at the same height in the living room is shown in Figure 7-4.

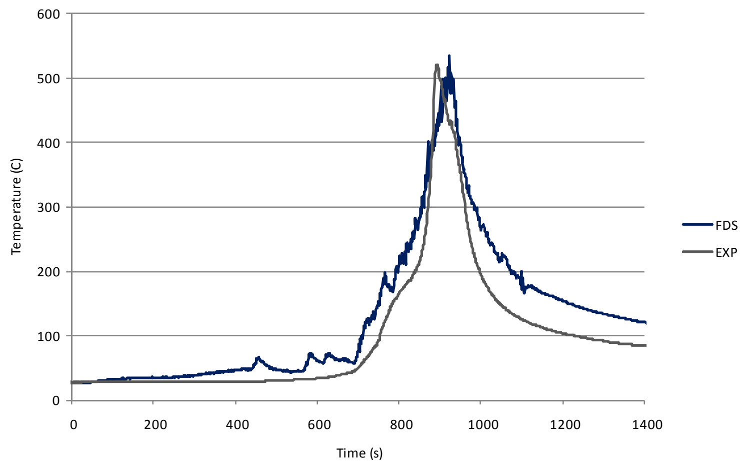


Figure 7-4. Temperature at 2.1 m (6 ft) in the center of the living room in the test and in the load cell heat release rate FDS simulation during the sofa test with window half open.

The temperature rise in FDS shows strong agreement with that seen in the test. The rate of increase in FDS was slower but the peak values were similar and only 30 s apart.

The oxygen concentrations in FDS load cell heat release rate simulations showed good agreement with the test for both the closed and open window tests. The calorimeter heat release rate simulation of the closed compartment test gave the largest deviation in oxygen concentration because of the larger fire size in FDS. In both the load cell heat release rate simulations there was only a difference of a few volume percent between the FDS simulation and the test data in both the living room and the bedroom. The shape of the curve and timing of minimum value from FDS also matched well with the test data.

7.2.2 Cabinet Tests

The four kitchen cabinet tests varied only with respect to the ventilation conditions. The theoretical air flow rate entering an opening in a compartment with a fully developed post-flashover fire can be estimated as (Karlsson and Quintiere 2000):

$$\dot{m}_{air} = \frac{1}{2} A\sqrt{H} \qquad \text{Equation 7-1}$$

Where A and H are the area and height of the ventilation opening respectively. This relation requires that the gas temperature in Kelvin is at least twice that of the ambient air, or around 300 °C, and the enclosure has a uniform temperature throughout its volume (Karlsson and Quintiere 2000). Both of these conditions are usually satisfied in post flashover fires, but for the cabinet test with the window half open it is likely not accurate. The conditions might be satisfied for the cabinet test with the open door and the window removed, but was used here primarily to give an indication of the ventilation conditions since accurate data for the vent flow into the compartment is not available. A theoretical approximation of the maximum fire since that can be sustained inside a compartment can be calculated using the above theoretical vent flow and the value of the heat of combustion per kg of oxygen consumed for common fuels, ${}^{\Delta H_c}/_{r_s}$

$$\dot{Q} = \dot{m}_{air} Y_{O_2 air} \frac{\Delta H_c}{r_s} \qquad \text{Equation 7-2}$$

Where $Y_{O2air} = 0.233$ is the mass fraction of oxygen in air. This was used to produce a comparison of ventilation conditions of the three cabinet test scenarios with ventilation openings seen in Table 7-1.

Table 7-2. Area of Ventilation, Theoretical Vent Flow Rate and Theoretical Maximum Fire Size for the Different Ventilation Conditions.

	A_{vent} (m^2)	$m_{air,th}$ (kg/s)	$Q_{max,th}$ (kW)
Open window	0.12	0.03	81.9
Window removed	0.60	0.30	915.7
Open door	2.00	1.41	4316.6

It is important to remember that the values for air flow rate and fire size are based on assumptions, which are not valid for some of the scenarios and this is only intended as a comparison between the different scenarios. It is interesting to note that the value of the theoretical maximum fire size for the window removed scenario agrees well with the peak heat release rate seen in the test. The large ventilation opening and high temperatures in this scenario may make the estimate for vent flow rate a valid estimate. However the peak heat release rate was only reached for a brief time and this could be a coincidence.

A common way to characterize the ventilation characteristic of a fire is through the dimensionless global equivalence ratio, Φ. It is defined as the average fuel-to-oxygen mass ratio in a compartment divided by the stoichiometric value. For values of $\Phi < 0.3 - 0.5$ the fire is generally regarded as well-ventilated. The combustion is of a high efficiency and the yields of CO and soot are low (Pitts 1994). At higher values as $\Phi > 1$

the fire is considered under-ventilated and the fire may either enter an extinction regime or the combustion zone may move from the fuel source to the vent opening and burn outside the compartment (Lazaro et al. 2008). A correlation between the equivalence ratio and the yield of products, especially CO, in fires has been documented in experimental studies (Beyler 1986) (Gottuk 1992). However, there are shortcomings to these relationships, one of, which is that the equivalence ratio as a global parameter in compartment fire conditions is correlated with the species yields, which depends on local conditions (Wieczorek *et al.* 2004)

The equivalence ratio can be useful as an independent variable to quantify the ventilation conditions in different fire scenario within a test or between different tests as it does not depend on the size of the fire or size and geometry of the compartment.

The global equivalence ratio can be expressed as (Quintiere 2002):

$$\Phi = \frac{r_s \dot{m}_{fuel}}{\dot{m}_{air} y_{O_2 air}} \qquad \text{Equation 7-3}$$

Where:

$$r_s = \frac{y_{O_2} MW_{O_2}}{MW_{fuel}} \qquad \text{Equation 7-4}$$

It can be difficult to calculate the equivalence ratio in real fire scenarios even for instrumented tests. The burning fuel is often heterogeneous and its chemical composition and thus the stoichiometric reaction is unknown. The fuel flow rate can be measured using a load cell but the total air flow rate into the compartment can be difficult to measure accurately, especially during stages with flow both in and out of the same vent. In a compartment with complex geometry there is also uncertainty associated with determining how much of the air entering the vent will reach the combustion zone, and whether the mass fraction of oxygen will have been changed. In FDS the mixture fraction Z is used to track fuel and combustion products and can be measured in a space. In FDS it is, as previously discussed, defined as the fraction of mass that originate in the fuel stream (McGrattan et al. 2008). The value of (1 – Z) is the fraction of mass that originate in the air stream. Thus it is clear that for a volume V:

$$\dot{m}_{fuel} = Z\rho_{mix}V \qquad \text{Equation 7-5}$$

$$\dot{m}_{air} = (1 - Z)\rho_{\infty}V \qquad \text{Equation 7-6}$$

If the density of the mixture is assumed to be approximately that of air it follows that the fuel-to-oxygen ratio can be written as:

$$\mathrm{F/O} = \frac{Z\rho_{\infty}V}{(1-Z)\rho_{\infty}VY_{O2air}} = \frac{Z}{(1-Z)Y_{O2,air}} \qquad \text{Equation 7-7}$$

Dividing by the stoichiometric ratio gives:

$$\Phi = \frac{\frac{Z}{(1-Z)Y_{O2,air}}}{\frac{Z_{stoic}}{(1-Z_{stoic})Y_{O2,air}}} = \frac{\frac{Z}{(1-Z)}}{\frac{Z_{stoic}}{(1-Z_{stoic})}} \qquad \text{Equation 7-8}$$

The value of the stoichiometric mixture fraction for the combustion reaction is given automatically in the output from FDS based on the specified fuel chemistry, i.e, it is dependent on input given by the user. For the cabinet test it was reported as $Z_{stoic} = 0.258$. By measuring the mixture fraction in the kitchen during the cabinet tests an estimate of the equivalence ratio for the fire room can be calculated using the above relation. The equivalence ratio for the four post test simulations of the kitchen cabinet tests are shown in Figure 7-5.

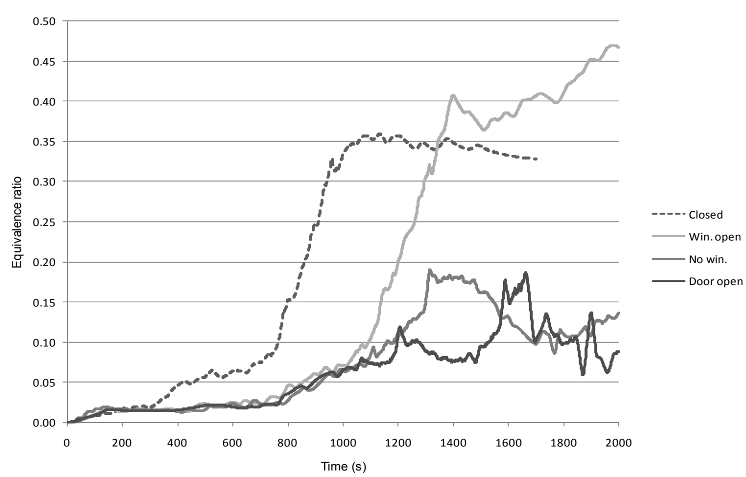


Figure 7-5. The equivalence ratio in the kitchen for the simulations of the four different cabinet tests with closed compartment, window half open, window removed and door open.

None of the four ventilation conditions resulted in a $\Phi > 1$, which would indicate an underventilated fire. Considering that the fires in the test self-extinguished, this seems unreasonable. However two things must be remembered; first this equivalence ratio was calculated for the whole room. The mass fraction of oxygen in the lower half of the room may have been higher than needed for stoichiometric combustion, but the burning cabinets were placed almost at the ceiling and inside the smoke layer. Second, the value of the stoichiometric mixture fraction depends on the chemical composition of the material, which is specified by the user and entails large uncertainties regarding complex fuels consisting of several different materials as in this scenario. The equivalence ratio for these four simulations in Figure 7-5 gives a picture of the ventilation conditions in each scenario relative to the others. As would be expected the equivalence ratio in the simulations with closed compartment and the window half open was higher than in the simulations with larger ventilation openings, about twice the value at the peak. As noted above experiments have indicated that the CO yields reach an asymptotic value when the equivalence ratio in the upper layer reaches 1.5 – 2.0 (Beyler 1986), (Gottuk 1992), (Pitts 1994). It is interesting to note that in the tests performed in the compartment the CO concentration in the test reached a steady value for the closed test and the window open test, around 900 s and 1400 s respectively. In the test with the window removed and the door open the CO concentration reached a peak value but only for a few seconds before it started to decrease. This may indicate that the test with closed compartment and window open reached underventilated conditions with an equivalence ratio over 1.5 but the test with the window removed and the door open did not. However the correlation between asymptotic value of CO and equivalence ratio is demonstrated in special, often reduced scale laboratory conditions and the extrapolation to full scale enclosure conditions is not well demonstrated (Pitts 1994) and as noted above, studies have found it lacking (Wieczorek et al. 2004).

As the ventilation was increased between the cabinet tests, the fire sizes also increased and occurred over a shorter duration while in the simulations using the calorimeter data stayed the same. Within the time it took for the first and part of the second of the four cabinets to burn in the calorimeter tests all of the fires in the compartment either self-extinguished or the cabinets fell down and the fire died down. Since this first cabinet produced less than a 300 kW fire in the calorimeter, when the heat release rate is used as input to FDS the fire is severely underestimated in the compartment. The closed compartment cabinet test, which gave the lowest heat release rate, had a peak value over twice what was produced in FDS at that time. The placement of the fire in the compartment only changed the interaction between the smoke layer and the fire and the ventilation conditions. The reduced ventilation would cause a reduced burning rate. The increased burning rate must therefore be an effect of the smoke layer and increased heat feedback. Harmathy explained (Harmathy 1975), and further expanded on (Harmathy 1978) the opinion that the pyrolysis of wood and cellulosic products does not depend on heat feedback from the flames of the hot gas layer but rather the combustion of the char layer is the driving mechanism. However, as Harmathy also points out the flame sheet and gas layer can act as a “blanket” reducing the heat loss from the fuel and thus increase the pyrolysis. In the small kitchen space it is likely that this served to increase the burning rate. Additionally the radiant and convective heat from the gas layer also serves to heat up unburned wood and thus increasing the spread of the fire. The placement of the cabinets under the ceiling complicated the interaction with the hot smoke layer. The sofa test, which was placed lower in the room showed better correlation between calorimeter and test data.

Despite the smaller fire size the FDS simulations of the cabinet tests with closed compartment and half open window gave higher temperatures in the bedroom for nearly all times analyzed using both the calorimeter and load cell heat release rate. In the cabinet tests with open door and the window removed the opposite was the case where the majority of the temperature profiles showed higher temperatures in the test than in FDS. The FDS simulations also tended to show a more pronounced separation into a lower cold layer and a hot upper layer in the fire room. In the two tests with increased ventilation the test data show a more gradual increase in temperature over the height of the room, which is not seen in FDS. In the two cabinet simulations with only a window or no ventilation the layer separation is more prominent in the test and thus the FDS results are closer to the test data. The temperature in the kitchen (top) and bedroom (bottom) in calorimeter and load cell simulations and the experiment for the kitchen cabinet in the closed compartment are shown in Figure 7-6.

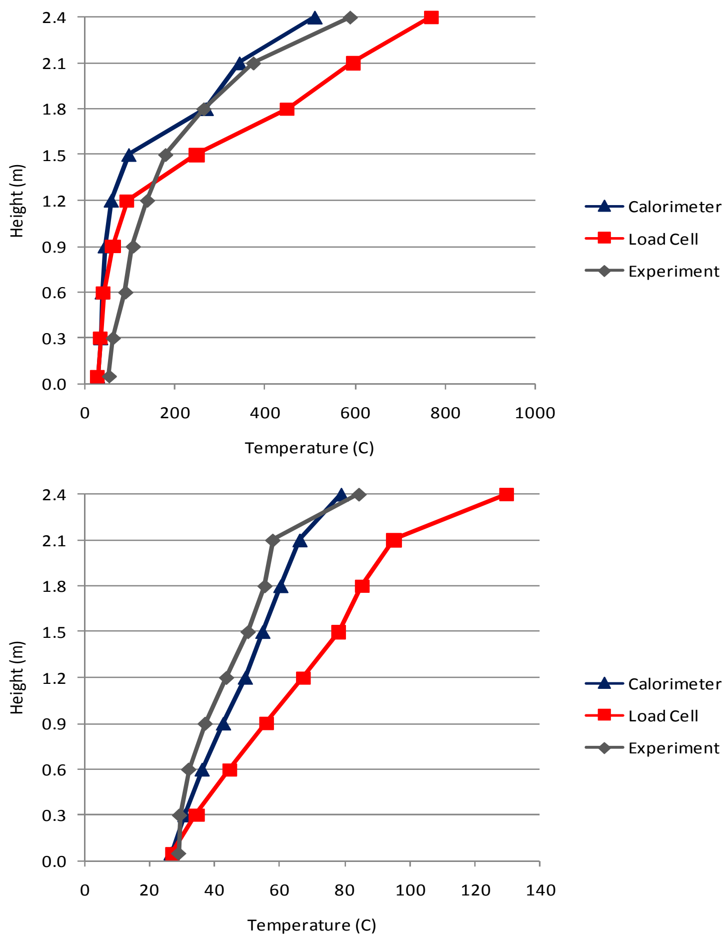


Figure 7-6. Temperature in the kitchen (top) and bedroom (bottom) at peak heat release rate in the calorimeter and load cell simulations and in the experiment for the kitchen cabinet test in the closed compartment.

The graphs in Figure 7-6 are representative of the results seen in both the cabinet test in the closed compartment and with the window half open. In the kitchen FDS showed lower temperatures in the lower layer and a distinct layer separation. In the bedroom the overestimation of the temperature over the whole height of the room by both simulations was typical for the two cabinet tests with only minimal ventilation. For both the test with the compartment closed and the window half open the FDS predictions in both the calorimeter and load cell simulations showed poor accuracy for temperatures in both the kitchen and bedroom. There are points where the temperatures in FDS are within 5-10% of the test data but this occurred in an inconsistent manner both with respect to time and position making predictions unreliable. In the test with open door and window removed the temperature predictions in FDS also show large deviations from the test data. Especially the underpredictions in the fire room are troubling. In engineering applications an underprediction of temperature is considered worse than an overprediction since this can lead to a non-conservative estimate or design. The load cell heat release rate simulations showed better agreement with the temperature data in the bedroom than the calorimeter heat release rate simulations, but the accuracy is still inconsistent and there are several underpredictions.

From the general trends the two different heat release rate inputs appear to have little impact on the accuracy of the simulations for the two tests with the least ventilation, the closed compartment and the open window. For the two tests with larger ventilation openings the post test simulations show better agreement with the test data. The heat feedback effects increased the fire size inside the compartment but the limited ventilation worked to the opposite to reduce the burning rate. With the window removed and the door open the effects of ventilation were smaller and the fire became significantly larger than in the calorimeter, resulting in the load cell heat release rate giving more accurate results but still with significant errors.

The oxygen concentrations are also inaccurate but more consistently. FDS gives a lower value for oxygen concentration for all the cabinet load cell heat release rate simulations and for the closed and window open calorimeter heat release rate simulations, giving a conservative estimate more desirable for life safety considerations, if not for economics.

One of the possible causes of the inaccuracies in the FDS predictions may have been the placement of the cabinets. The bottom edge was positioned from 1.55 m (5 ft) from the floor and the top all the way at 2.3 m (7.5 ft) above the floor, only 10 cm (4 in) from the ceiling. The smoke will accumulate under the ceiling and the combustion zone will quickly be inside the smoke layer with very low oxygen concentrations. Combined with a small ventilation opening this results in a very low supply of oxygen to the fire. Even if the equivalence ratio is low for the whole kitchen the combustion will occur in the part of the room with the lowest oxygen conditions. In the tests with larger ventilation openings more air can flow into the kitchen and up to feed the fire. The oxygen concentration at the ceiling and at the base of the fire at 1.5 m (5 ft) in the cabinet test in the closed compartment is shown in Figure 7-7.

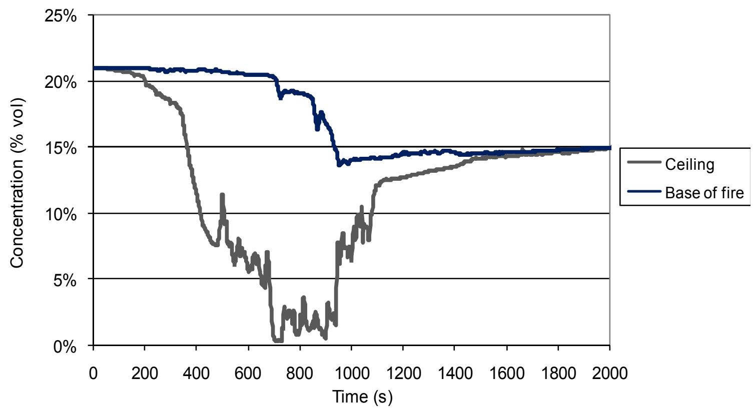


Figure 7-7. Oxygen concentrations at the ceiling and at the base of the fire, 1.5 m (5 ft), in the kitchen in the cabinet test in the closed compartment.

It is clear that the oxygen concentrations drop much faster at the ceiling than it does at the base of the fire. Already at 400 s it is below 10%. Unfortunately, concentrations of unburned hydrocarbon were not measured in the test as this could have been useful for determining the amount of pyrolysed fuel that did not burn. It seems likely that the conditions in the upper layer where the combustion occurred became very complex in the test, conditions, which are difficult to model accurately and recreate in FDS.

7.3 Effects of Changes to the Parameters in the Combustion Model on Results from FDS Simulation

Comparing the four simulations with the three different settings for the extinction model and CO production model gave predictable results for heat release rate and gas concentrations. The extinction model only had an effect on the heat release rate from the fire if there was a lack of oxygen in the combustion zone. The sofa fires, which were placed low in the room and not large enough to use all the available oxygen resulted in only minor differences in the heat release rate between the three simulations. The simulation of the sofa in the closed compartment gave three identical heat release rate curves. The cabinet fires showed more variation where the two simulations with the extinction model gave lower heat release rate than the one with extinction off, which follows the prescribed input.

The changes in heat release rate affected the temperature in the room. Surprisingly, for the cabinet simulations the simulation without the extinction model, and thus a higher heat release rate, showed higher temperatures in the fire room but lower temperature in the bedroom than the two other simulations. This was seen for both of the cabinet simulations. One mechanism that could cause these results is that without extinction most of the combustion occurs in the fire room where the heat is lost to the walls. When local extinction is included more of the combustion moves outside the kitchen towards the vent and the hot gases move to the bedroom where the heat is dissipated. It was confirmed that more hot gases move out of the kitchen by comparing the slice files for the gas temperature for the simulation without extinction to the simulation with extinction and CO production. The two simulations with extinction gave similar temperatures. The resulting temperature distribution in a slice at x = 4.5 m at 1155 s around the time of peak heat release rate is shown in Figure 7-8. The left picture is the simulation with extinction on and the right is with extinction off.

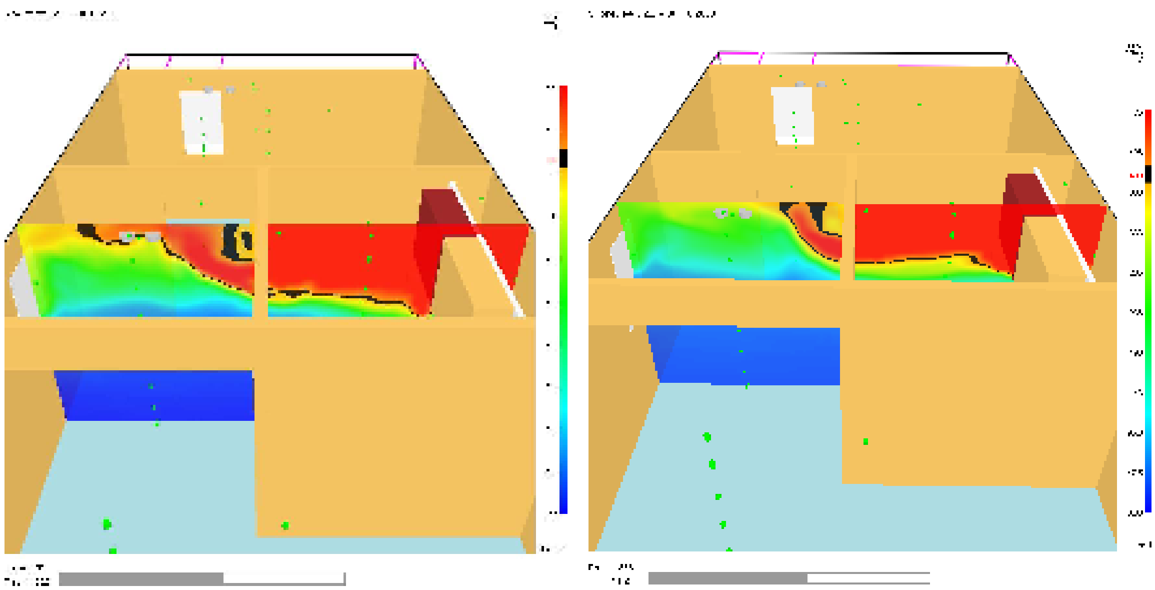


Figure 7-8. Temperature slice at x = 4.5 showing how hot gases are moving out of the kitchen at 1150 s in the simulation with extinction on to the left and extinction off to the right.

The point on the slice where the temperature is 400 °C is marked in black. It is clear that in the model with the extinction model activated more hot gases are moving out of the fire room. In Figure 7-9 the 3D smoke animation of the heat release rate per unit volume is shown.

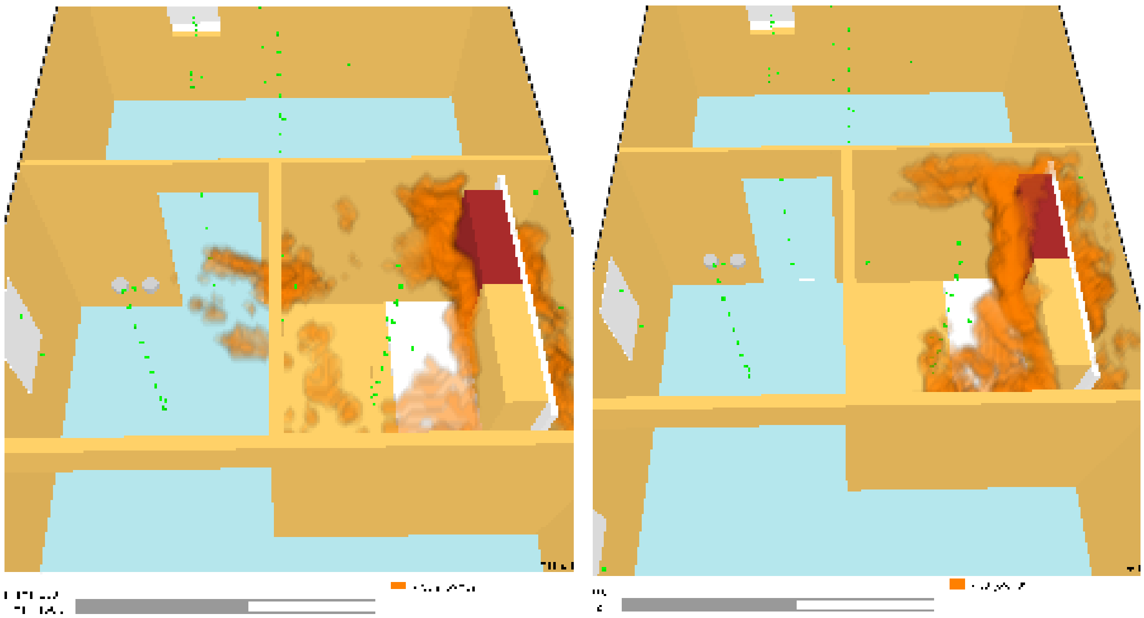


Figure 7-9. Plot 3D rendering of the heat release rate per unit volume where it exceeds 150 kW/m3 in the kitchen cabinet simulations at 1150 s. Left with extinction model active and right without extinction.

In the simulations without extinction the fire is contained around the cabinets whereas in the simulation with extinction, combustion occurs outside the kitchen in the dining room. This will increase the spread of hot gases to the bedroom and result in higher temperatures there. When the fire is limited to inside the kitchen less heat will be transferred to the bedroom and instead dissipate through the wall in the kitchen. Inaccuracies in the description of the material parameters for the gypsum wallboard could potentially affect the temperature rise in the compartment but these effects will be small. The extension of combustion out of the fire room was considered a more plausible explanation for the larger temperature differences observed.

The simulation with both extinction and CO production off gave lower temperatures and was therefore closer to the test data in the bedroom for most of the test but the differences were insignificant compared to that caused by changes in heat release rate. Because of the large and inconsistent deviations it was difficult to decide, which of the three combustion model settings would make the simulation more accurate. No flames were observed outside the kitchen during in the test except when the living room door was open, but combustion may still have occurred.

The three simulations resulted in some differences in the concentrations of CO. For the two models without CO production on, the results were as expected with higher CO concentrations for the model with extinction off. In these two models the CO yield was a constant function of the mass loss rate and when the combustion was reduced due to local extinction the CO yield became lower. The CO production model will have a higher CO yield but will only result in higher concentrations if there is a lack of oxygen preventing CO from being converted to CO_2 in the second step of the combustion process. In well ventilated conditions the CO yield will be the value specified by the user, as it is with the CO production model off (McGrattan et al. 2008). In all the simulations with the CO production model active the CO concentration in both the fire room and the bedroom was lower than in the two other simulations without CO production. According to the description of the two-step CO production model this should not be the case unless the burning rate is different. There were slight differences in the cabinet simulations but in the sofa simulations the heat release rate is identical between the two models with extinction on. It was determined that this anomaly was a result of an error in the execution of the CO production model in version 5.2 of FDS. Running a simulation on the newest version 5.2.2 indicated that the problem has been fixed but further analysis is needed. This made the comparison of the CO concentrations in the test and FDS invalid so they were not included. All the simulations with the CO production model off gave concentrations much lower than seen in the tests because of the effects of limited oxygen on CO yield in the fire compared to that measured in free burning conditions.

The extinction model and the CO production complicate the calculations in FDS as more species and the relationship between oxygen, temperature and the limiting oxygen limit must be tracked. The run times for the simulations with the different settings are shown in Table 7-3. The computational costs are presents as seconds of run time on the computer per second of simulation time, as two of the simulations were run longer than the others with the same scenario.

Table 7-3. Computer run time in seconds per second simulatied in FDS for the three different combustion model settings.

run s/FDS s	+ext/+CO	+ext/-CO	-ext/-CO
Cabinet closed	110	93	62
Cabinet Window	128	129	74
Sofa Closed	111	136	135
Sofa Window	182	181	160

There was little difference in the required computational time between the two simulations with extinction modeling on, except for the sofa in the closed compartment scenario. For the three others the extinction model results in longer run time, but the addition of the CO production model did not increase the computational cost much more. The closed sofa simulation indicates that when there is no CO generated this makes the simulation faster, possibly because the lack of CO to track in the flow reduces the load on the computer. There was also no difference caused by the extinction model in the close sofa scenario as the fire was too small. This explains why the two simulations with CO production have similar computational costs. It is difficult to determine from this data how the CO production model affects the computational load as the heat release rate and CO yields vary, however it is easier to see that the extinction model increases the computational cost.

The simulations were run on a cluster computer system with several different processors, some of, which were newer and faster than others. The processors varied from 3.2 GHz Pentium 4s to 3.0 GHz dual cores. The memory was also shared between several processes, which influence the speed of the computations. The differences were not considered so large that they invalidate the above data, but this must be kept in mind when considering the results. Better control of the available CPU and memory allocation could add insight into the effects of the different models on the computational cost.

8 CONCLUSIONS

Several full scale compartment fire tests were simulated using Fire Dynamics Simulator version 5.2 with different heat release rate inputs and settings for the combustion model. The tests were performed using two different fuel items and locations, a sofa and a kitchen cabinet array. Two small natural gas burner tests were also performed in the compartment. The tests had four different ventilation conditions ranging from completely closed compartment to an open entrance door.

Before the tests in the compartment were conducted simulations were performed using heat release rate data from free burn oxygen-consumption calorimeter tests of identical fuel items. After the tests were over and the data was available, simulations were run again where the heat release rate input to FDS was extracted from mass loss rate data from a load cell placed under the fuel items in the compartment and the heat of combustion for the items from the calorimeter tests.

Four of the simulations were compared for three different settings of the combustion model in FDS. All simulations of the experiments were performed with the extinction model and two-step combustion model with CO production. Additionally, one set of simulations with the CO production model disabled, and one set with both the extinction model and CO production model disabled were run.

The two natural gas burner tests did not show effects of limited ventilation and FDS showed strong agreement with the test data, giving temperature predictions within 5% of the test results at most locations. In the early transient phase FDS showed a more rapid temperature increase than recorded in the tests. The oxygen concentrations recorded in the tests were up to 1% by volume higher than predicted by FDS. These differences are partially explained by uncertainties about the output of the test burner.

The FDS simulations of the sofa test with window open gave temperature measurements with accuracy around the ± 20% reported in previous validation studies for all but a few measurements. The choice of heat release rate input had little effect until the decay phase when oxygen vitiation became apparent. The heat release rate based on load cell data gave better agreement for temperature at 75% of the measurement points. A lower value for the limiting oxygen index in the model resulted in vitiation effects occurring earlier in the test than in FDS. The results from the FDS simulation of the kitchen cabinet tests did not show good agreement with the test data. Calculations of the equivalence ratio showed that the tests with the compartment closed and the window open were more severely underventilated than the two with window removed and door open. In the former simulations the predicted temperatures in the bedroom were higher, which was partially a result of more combustion occurring outside the fire room in FDS. Choice of heat release rate input had little impact on the accuracy for the severely underventilated tests where the error was up to 50% at several measurement points in the upper layer. With increased ventilation the heat release rate based on load cell data gave better results than the calorimeter data, but still with error over 35% for a majority of the measurements in the fire room. In the bedroom away from the fire the cabinet simulations gave results within 10-15% of the test data, but his was partially a result of using absolute temperature to calculate the error.

Two mechanisms affected the fire size inside the compartment in the tests: (1) the heat feedback caused by the accumulation of smoke under the ceiling increases the pyrolysis rate and flame spread. (2) The limited ventilation reduced the burning rate. The heat feedback can only be accounted for in FDS by using load cell data. The reduced burning caused by limited ventilation is included in FDS by way of the extinction function in the combustion model. The extinction model led to more accurate results for the sofa tests and, to a lesser degree, for the two cabinet tests with larger ventilation. But poor results for the most severely underventilated cabinet tests. When the ventilation becomes larger the heat feedback has the dominant effect and the inability of FDS to account for this must be considered. The placement of the cabinets inside the smoke layer and the combined effects of these two mechanisms as well as the more complex geometry are possible explanations for the poor accuracy in the FDS model.

The version of FDS used had an error in the two-step combustion model causing exaggerated post-combustion reductions of CO beyond the free burn limit without an increase in CO_2 yields. This made the CO concentration comparisons invalid. The problem appears to have been corrected in FDS version 5.2.2. The simulations using the one-step combustion reaction produced CO concentrations significantly lower than measured in the test. This is expected since the specified yield in FDS is for well-ventilated conditions.

The difference between simulations with and without the extinction model was significant. The limited ventilation led to reduced heat release rate and the combustion zone moving out of the fire room towards the vent when local flame extinction was modeled. Flames outside the fire room were not observed in the test, but overall the extinction model resulted in a fire behavior that better represents that seen in the tests. Data indicate that the extinction model increases the computational cost but the effects are significant and it is recommended that it is used for compartment fire simulations.

The use of data from free burn calorimeter tests as input to FDS for the fuel item in a compartment where the heat feedback can influence the pyrolysis and fire spread is a significant source of potentially non-conservative error. With the burning item close to the ceiling and smoke layer the burning rate can dramatically change character from that produced in a calorimeter test. This must be considered when choosing the heat release rate input to FDS and calorimeter data should not be used uncritically. There is currently no practical method for dealing with this in FDS.

The simulations should be rerun using the corrected two-step combustion model to determine its effectiveness at predicting the increased CO yield due to limited ventilation conditions. Tests were also run with cabinets on the floor of the kitchen but for modeling purposes elevated cabinets were considered more realistic. Modeling these tests and comparing the results could give insight into the effects of fuel placement in relation to the hot gas layer.

9 APPENDIX 1 - SELCETED FDS INPUT FILES

9.1 Natural Gas Burner Test in Closed Compartment

```
&HEAD CHID='l_burner125UV',TITLE='burner living room 125kW unVentilated'  /


&MESH IJK=64,90,48, XB=5.8,9.0, 0.0,4.5, 0.0,2.4 / 5 cm living room-fire room          276 480
&MESH IJK=60,45,24, XB=0.0,5.8, 0.0,4.5, 0.0,2.4 / 10 cm - rest                          64 800
                                                                               total     341 280


NOTES:


Rooms:
B - bedroom
K - Kitchen
D - dining room
L - living room
Walls
   4
 -------
 !     !
3!     !1
 !     !
 --------
   2


&TIME T_END=600 / 600                          <set

&MISC SURF_DEFAULT='GWB_L',
          TMPA=30 /                            <set

&DUMP   NFRAMES=600,
          PLOT3D_QUANTITY(1:5)='TEMPERATURE','MIXTURE_FRACTION','oxygen','VE
LOCITY','HRRPUV'/    <set




&REAC ID='METHANE'
     FYI='Methane C H_4',
     C=1,
     H=4,
```

```
    SOOT_YIELD=0.01           /From Database4.data


&MATL ID='GWB',
          CONDUCTIVITY = 0.17,
          SPECIFIC_HEAT = 1.1,
          DENSITY = 800. /

&SURF ID='GWB',
          MATL_ID='GWB',
          BACKING='EXPOSED',
          THICKNESS=0.032/

&SURF ID='GWB_L',
          MATL_ID='GWB',
          BACKING='EXPOSED',
          THICKNESS=0.032,
          LEAK_PATH=1,0/

&MATL ID='GLASS',
          CONDUCTIVITY = 1.4,
          SPECIFIC_HEAT = 0.75,
          DENSITY = 2500. /

&SURF ID='GLASS',
          MATL_ID='GLASS',
          BACKING='EXPOSED',
          THICKNESS=0.005,
          COLOR='WHITE'/


&MATL ID = 'CARPET_MATL'
CONDUCTIVITY = 0.1600
SPECIFIC_HEAT = 9.0
DENSITY = 750.0
HEAT_OF_COMBUSTION=22300/


&SURF ID = 'CARPET'
          MATL_ID = 'CARPET_MATL'
          RGB=176, 224, 230
          BACKING = 'INSULATED'
          THICKNESS = 0.006
          HEAT_OF_VAPORIZATION=2000,
          IGNITION_TEMPERATURE= 290.00, / carpet, form FDS 4 database


&MATL ID = 'Plywood',
CONDUCTIVITY = 0.12,
```

```
SPECIFIC_HEAT = 1.3,
DENSITY = 545 /

&SURF ID='WOOD'
        MATL_ID= 'Plywood',
        RGB= 218, 165, 32,
        HRRPUA= 243.36 ,
        THICKNESS= 0.025 ,
        IGNITION_TEMPERATURE= 326.00,
        RAMP_Q= 'RAMP_Q_PS09TG'/

&RAMP ID='RAMP_Q_PS09TG' T=0.00 F=0.00/
&RAMP ID='RAMP_Q_PS09TG' T=30.00 F=0.81/
&RAMP ID='RAMP_Q_PS09TG' T=70.00 F=0.0800/
&RAMP ID='RAMP_Q_PS09TG' T=95.00 F=0.3900/
&RAMP ID='RAMP_Q_PS09TG' T=175.00 F=0.53/
&RAMP ID='RAMP_Q_PS09TG' T=325.00 F=0.2200/
&RAMP ID='RAMP_Q_PS09TG' T=445.00 F=0.2800/
&RAMP ID='RAMP_Q_PS09TG' T=575.00 F=1.00/
&RAMP ID='RAMP_Q_PS09TG' T=700.00 F=0.2100/
&RAMP ID='RAMP_Q_PS09TG' T=1.475000E003 F=0.1400/


&SURF ID='SOFA'
        COLOR='BROWN'
        HRRPUA= 203.7
        RAMP_Q= 'RAMP_Q_SOFA'/   hrrmax=1100kw / 5.4mw = 203.7 kw/m2

&RAMP ID='RAMP_Q_SOFA' T=0.00 F=0.00/
&RAMP ID='RAMP_Q_SOFA' T=360.00 F=0.04/
&RAMP ID='RAMP_Q_SOFA' T=580.00 F=0.22/
&RAMP ID='RAMP_Q_SOFA' T=635.00 F=0.8700/
&RAMP ID='RAMP_Q_SOFA' T=740.00 F=0.55/
&RAMP ID='RAMP_Q_SOFA' T=765.00 F=0.5500/
&RAMP ID='RAMP_Q_SOFA' T=810.00 F=1.00/
&RAMP ID='RAMP_Q_SOFA' T=880.00 F=0.4500/
&RAMP ID='RAMP_Q_SOFA' T=910.00 F=0.4500/
&RAMP ID='RAMP_Q_SOFA' T=1060.0 F=0.2500/
&RAMP ID='RAMP_Q_SOFA' T=1230.00 F=0.2600/
&RAMP ID='RAMP_Q_SOFA' T=1440.00 F=0.16/
&RAMP ID='RAMP_Q_SOFA' T=1700.00 F=0.1500/
&RAMP ID='RAMP_Q_SOFA' T=1860.0 F=0.090/
&RAMP ID='RAMP_Q_SOFA' T=2070.00 F=0.0700/
&RAMP ID='RAMP_Q_SOFA' T=2075.0 F=0/



upholstery (chair)
```

&MATL ID='UPHOLSTERY',
CONDUCTIVITY=0.25,
SPECIFIC_HEAT=1.4
DENSITY=30/ from FDS4 database, Density from IKEA.com

&SURF ID='CHAIR',
MATL_ID='UPHOLSTERY',
COLOR='WHITE',
THICKNESS=0.3,
IGNITION_TEMPERATURE=280,
HEAT_OF_VAPORIZATION=1500/

BURNER

&SURF ID='BURNER',HRRPUA=781.25 , COLOR='RED'/ <<BURNER SIZE

&OBST XB= 6.2,6.6, 3.1,3.5, 0.0,0.5, SURF_IDS='BURNER','INERT',INERT, / Burner on kitchen floor.0.4*0.4M = 0.16m2

LEAK

&ZONE XB=-0.3, 9.0, 0.0, 4.5, 0.0, 2.4, LEAK_AREA(0)=0.0074/ pressure zone - leak area (afrom new tests)

Interior walls
&OBST XB= 3.28, 3.35, 0.0, 4.5, 0.0, 2.4, SURF_ID='GWB' / Wall C
&HOLE XB= 3.25, 3.38, 1.1, 2.0, 0.0, 2.0 / Door in wall C
&OBST XB= 3.35, 5.9, 2.1, 2.2, 0.0, 2.4, SURF_ID='GWB' / Wall B
&HOLE XB= 4.0, 4.9, 2.1, 2.2, 0.0, 2.0 / Door in wall B
&OBST XB= 5.78, 5.92, 0.0, 4.5, 0.0, 2.4, SURF_ID='GWB' / Wall A
&HOLE XB= 5.77, 5.94, 0.0, 2.1, 0.0, 2.0 / Door in wall A

Door and Windows.
&VENT XB= 9.0,9.0, 0.9,1.7, 0.0,2.0, SURF_ID='INERT' / exterior door. Wall 1
&VENT XB= 9.0,9.0, 2.8,3.4, 0.6,2.1, SURF_ID='GLASS' / exterior window. Wall 1
&VENT XB= 4.2,4.8, 0.0,0.0, 0.8,2.1, SURF_ID='GLASS' / exterior window. Wall 2
&VENT XB= 6.5,7.1, 0.0,0.0, 0.8,2.1, SURF_ID='GLASS' / window 2 Wall 2
&VENT XB= -0.3,-0.3, 0.9,1.5, 0.6,2.1, SURF_ID='GLASS' / exterior window. Wall 3

FURNITURE

coffe table

```
&OBST XB= 7.3,7.85, 2.85,3.75, 0.4,0.45, SURF_ID='WOOD'/  surface
&OBST XB= 7.3,7.35, 2.85,2.90, 0.0,0.4, SURF_ID='WOOD'/ leg 1            2   3
&OBST XB= 7.3,7.35, 3.70,3.75, 0.0,0.4, SURF_ID='WOOD'/ leg 2
&OBST XB= 7.8,7.85, 3.70,3.75, 0.0,0.4, SURF_ID='WOOD'/ leg 3
&OBST XB= 7.8,7.85, 2.85,2.90, 0.0,0.4, SURF_ID='WOOD'/ leg 4            1   4


armchair
&OBST XB=8.1,8.8, 3.6,4.3, 0.0,0.7,, SURF_ID='CHAIR' /  chair      <<    change    HRR
curve/HEAT OF VAPO ?

carpet
&VENT XB=0.0,3.3, 0.0,4.5, 0.0,0.0, SURF_ID='CARPET'/BEDROOM
&VENT XB=3.3,5.8, 0.0,2.1, 0.0,0.0, SURF_ID='CARPET'/DINING ROOM
&VENT XB=5.8,9.0, 0.0,4.5, 0.0,0.0, SURF_ID='CARPET'/LIVING ROOM


&BNDF QUANTITY='GAUGE_HEAT_FLUX'/
&BNDF QUANTITY='BURNING_RATE'/

                                                                 Slice files
&SLCF PBY= 1.0, QUANTITY='TEMPERATURE' /
&SLCF PBY= 3.3, QUANTITY='TEMPERATURE' /
&SLCF PBX= 4.5, QUANTITY='TEMPERATURE' /
&SLCF PBX= 6.3, QUANTITY='TEMPERATURE' /

&SLCF PBY= 1.0, QUANTITY='oxygen' /
&SLCF PBY= 3.3, QUANTITY='oxygen' /
&SLCF PBX= 4.5, QUANTITY='oxygen' /
&SLCF PBX= 6.3, QUANTITY='oxygen' /

&SLCF PBY= 3.3, QUANTITY='MIXTURE_FRACTION' /
&SLCF PBX= 4.5, QUANTITY='MIXTURE_FRACTION' /
&SLCF PBX= 6.3, QUANTITY='MIXTURE_FRACTION' /

&SLCF PBY= 1.0, QUANTITY='U-VELOCITY' /


                                                      DEVICES:
```

&DEVC XB=5.9,9, 0.0,4.5, 0.0,2.4, QUANTITY='MIXTURE_FRACTION', STATISTICS='MEAN', ID='Zmean_L'/ MIXTURE FRACTION Living room (mesh mean)
&DEVC XB=0.0,5.8, 0.0,4.5, 0.0,2.4, QUANTITY='MIXTURE_FRACTION', STATISTICS='MEAN', ID='Zmean_KB'/ MIXTURE FRACTION K,D,B (mesh mean)

TEMPERATURE

TC rack 1 - bedroom:
&DEVC XYZ=1.6,2.2, 0.05, QUANTITY='THERMOCOUPLE', ID='B1'/
&DEVC XYZ=1.6,2.2, 0.3, QUANTITY='THERMOCOUPLE', ID='B2'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='THERMOCOUPLE', ID='B3'/
&DEVC XYZ=1.6,2.2, 0.9, QUANTITY='THERMOCOUPLE', ID='B4'/
&DEVC XYZ=1.6,2.2, 1.2, QUANTITY='THERMOCOUPLE', ID='B5'/
&DEVC XYZ=1.6,2.2, 1.5, QUANTITY='THERMOCOUPLE', ID='B6'/
&DEVC XYZ=1.6,2.2, 1.8, QUANTITY='THERMOCOUPLE', ID='B7'/
&DEVC XYZ=1.6,2.2, 2.1, QUANTITY='THERMOCOUPLE', ID='B8'/
&DEVC XYZ=1.6,2.2, 2.35, QUANTITY='THERMOCOUPLE', ID='B9'/

TC rack 2 - kitchen (aspirated TC) +3 Non-aspir
&DEVC XYZ=4.6,2.3, 0.05, QUANTITY='TEMPERATURE', ID='K1'/
&DEVC XYZ=4.6,2.3, 0.3, QUANTITY='TEMPERATURE', ID='K2'/
&DEVC XYZ=4.6,2.3, 0.6, QUANTITY='TEMPERATURE', ID='K3'/
&DEVC XYZ=4.6,2.3, 0.9, QUANTITY='TEMPERATURE', ID='K4'/
&DEVC XYZ=4.6,2.3, 1.2, QUANTITY='TEMPERATURE', ID='K5'/
&DEVC XYZ=4.6,2.3, 1.5, QUANTITY='TEMPERATURE', ID='K6'/
&DEVC XYZ=4.6,2.3, 1.8, QUANTITY='TEMPERATURE', ID='K7'/
&DEVC XYZ=4.6,2.3, 2.1, QUANTITY='TEMPERATURE', ID='K8'/
&DEVC XYZ=4.6,2.3, 2.35, QUANTITY='TEMPERATURE', ID='K9'/
non-aspirated
&DEVC XYZ=4.6,2.3, 0.61, QUANTITY='THERMOCOUPLE', ID='K-N1'/
&DEVC XYZ=4.6,2.3, 1.52, QUANTITY='THERMOCOUPLE', ID='K-N2'/
&DEVC XYZ=4.6,2.3, 2.13, QUANTITY='THERMOCOUPLE', ID='K-N3'/

TC rack 3 - dining room:
&DEVC XYZ=4.6,1.0, 0.05, QUANTITY='THERMOCOUPLE', ID='D1'/
&DEVC XYZ=4.6,1.0, 0.3, QUANTITY='THERMOCOUPLE', ID='D2'/
&DEVC XYZ=4.6,1.0, 0.6, QUANTITY='THERMOCOUPLE', ID='D3'/
&DEVC XYZ=4.6,1.0, 0.9, QUANTITY='THERMOCOUPLE', ID='D4'/
&DEVC XYZ=4.6,1.0, 1.2, QUANTITY='THERMOCOUPLE', ID='D5'/
&DEVC XYZ=4.6,1.0, 1.5, QUANTITY='THERMOCOUPLE', ID='D6'/
&DEVC XYZ=4.6,1.0, 1.8, QUANTITY='THERMOCOUPLE', ID='D7'/
&DEVC XYZ=4.6,1.0, 2.1, QUANTITY='THERMOCOUPLE', ID='D8'/
&DEVC XYZ=4.6,1.0, 2.35, QUANTITY='THERMOCOUPLE', ID='D9'/

TC rack 4 - living room (aspirated TC) +3 Non-aspir

&DEVC XYZ=7.4,1.4, 0.05, QUANTITY='TEMPERATURE', ID='L1'/
&DEVC XYZ=7.4,1.4, 0.3, QUANTITY='TEMPERATURE', ID='L2'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='TEMPERATURE', ID='L3'/
&DEVC XYZ=7.4,1.4, 0.9, QUANTITY='TEMPERATURE', ID='L4'/
&DEVC XYZ=7.4,1.4, 1.2, QUANTITY='TEMPERATURE', ID='L5'/
&DEVC XYZ=7.4,1.4, 1.5, QUANTITY='TEMPERATURE', ID='L6'/
&DEVC XYZ=7.4,1.4, 1.8, QUANTITY='TEMPERATURE', ID='L7'/
&DEVC XYZ=7.4,1.4, 2.1, QUANTITY='TEMPERATURE', ID='L8'/
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='TEMPERATURE', ID='L9'/
non-aspirated
&DEVC XYZ=7.4,1.4, 0.61, QUANTITY='TEMPERATURE', ID='L-N1'/
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='TEMPERATURE', ID='L-N2'/
&DEVC XYZ=7.4,1.4, 2.13, QUANTITY='TEMPERATURE', ID='L-N3'/

TC rack 5 - doorway: DOOR TCs
&DEVC XYZ=4.6,1.0, 0.05, QUANTITY='TEMPERATURE', ID='door1'/
&DEVC XYZ=4.6,1.0, 0.3, QUANTITY='TEMPERATURE', ID='door2'/
&DEVC XYZ=4.6,1.0, 0.6, QUANTITY='TEMPERATURE', ID='door3'/
&DEVC XYZ=4.6,1.0, 0.9, QUANTITY='TEMPERATURE', ID='door4'/
&DEVC XYZ=4.6,1.0, 1.2, QUANTITY='TEMPERATURE', ID='door5'/
&DEVC XYZ=4.6,1.0, 1.5, QUANTITY='TEMPERATURE', ID='door6'/
&DEVC XYZ=4.6,1.0, 1.8, QUANTITY='TEMPERATURE', ID='door7'/
&DEVC XYZ=4.6,1.0, 2.1, QUANTITY='TEMPERATURE', ID='door8'/
Wall TCs

WALL TCs - Inside
living room
&DEVC XYZ=9.0, 3.45, 0.61, QUANTITY='WALL_TEMPERATURE', ID='W1-1-in', IOR=-1/
&DEVC XYZ=9.0, 3.45, 1.83, QUANTITY='WALL_TEMPERATURE', ID='W1-2-in', IOR=-1/
bedroom
&DEVC XYZ=-0.30, 3.1, 0.61, QUANTITY='WALL_TEMPERATURE', ID='W3-1-in', IOR=1/
&DEVC XYZ=-0.30, 3.1, 1.83, QUANTITY='WALL_TEMPERATURE', ID='W3-2-in', IOR=1/
kitchen
&DEVC XYZ=4.5, 4.5, 0.61, QUANTITY='WALL_TEMPERATURE', ID='W4-1-in', IOR=-2/
&DEVC XYZ=4.5, 4.5, 1.83, QUANTITY='WALL_TEMPERATURE', ID='W4-2-in', IOR=-2/

WALL TCs - outside
living room
&DEVC XYZ=9.0, 3.45, 0.61, QUANTITY='BACK_WALL_TEMPERATURE', ID='W1-1-out', IOR=-1/
&DEVC XYZ=9.0, 3.45, 1.83, QUANTITY='BACK_WALL_TEMPERATURE', ID='W1-2-out', IOR=-1/
bedroom
&DEVC XYZ=-0.30, 3.1, 0.61, QUANTITY='BACK_WALL_TEMPERATURE', ID='W3-1-out', IOR=1/
&DEVC XYZ=-0.30, 3.1, 1.83, QUANTITY='BACK_WALL_TEMPERATURE', ID='W3-2-out', IOR=1/

kitchen
&DEVC XYZ=4.5, 4.5, 0.61, QUANTITY='BACK_WALL_TEMPERATURE', ID='W4-1-out', IOR=-2/
&DEVC XYZ=4.5, 4.5, 1.83, QUANTITY='BACK_WALL_TEMPERATURE', ID='W4-2-out', IOR=-2/

Window TCs
&DEVC XYZ=8.95,3.1, 1.0, QUANTITY='THERMOCOUPLE', ID='win1-l'/ window in living room
&DEVC XYZ=8.95,3.1, 1.7, QUANTITY='THERMOCOUPLE', ID='win1-h'/

&DEVC XYZ=4.5,0.05, 1.1, QUANTITY='THERMOCOUPLE', ID='win2-l'/ window on wall 2 - dining room
&DEVC XYZ=4.5,0.05, 1.8, QUANTITY='THERMOCOUPLE', ID='win2-h'/

&DEVC XYZ=6.8,0.05, 1.1, QUANTITY='THERMOCOUPLE', ID='win2.2-l'/ window on wall 2 - living room
&DEVC XYZ=6.8,0.05, 1.8, QUANTITY='THERMOCOUPLE', ID='win2.2-h'/

&DEVC XYZ=0.05,1.2, 1.0, QUANTITY='THERMOCOUPLE', ID='win3-l'/ window in bed room
&DEVC XYZ=0.05,1.2, 1.7, QUANTITY='THERMOCOUPLE', ID='win3-h'/

GAS PROBES

Kitchen
ceiling
&DEVC XYZ=4.6,2.3, 2.35, QUANTITY='carbon monoxide', ID='K-CO-ceil'/
&DEVC XYZ=4.6,2.3, 2.35, QUANTITY='carbon dioxide', ID='K-CO2-ceil'/
&DEVC XYZ=4.6,2.3, 2.35, QUANTITY='oxygen', ID='K-O2-ceil'/
base of fire
&DEVC XYZ=4.6,2.3, 0.05, QUANTITY='carbon monoxide', ID='K-CO-floor'/
&DEVC XYZ=4.6,2.3, 0.05, QUANTITY='carbon dioxide', ID='K-CO2-floor'/
&DEVC XYZ=4.6,2.3, 0.05, QUANTITY='oxygen', ID='K-O2-floor'/

Living room

ceiling
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='carbon monoxide', ID='L-CO-ceil'/
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='carbon dioxide', ID='L-CO2-ceil'/
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='oxygen', ID='L-O2-ceil'/
tree
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='carbon monoxide', ID='L-CO-1.5'/
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='carbon dioxide', ID='L-CO2-1.5'/
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='oxygen', ID='L-O2-1.5'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='carbon monoxide', ID='L-CO-0.6'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='carbon dioxide', ID='L-CO2-0.6'/

```
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='oxygen', ID='L-O2-0.6'/
base of fire
&DEVC XYZ=7.0,3.1, 0.05, QUANTITY='carbon monoxide', ID='L-CO-fire'/
&DEVC XYZ=7.0,3.1, 0.05, QUANTITY='carbon dioxide', ID='L-CO2-fire'/
&DEVC XYZ=7.0,3.1, 0.05, QUANTITY='oxygen', ID='L-O2-fire'/


Bedroom
tree
&DEVC XYZ=1.6,2.2, 2.35, QUANTITY='carbon monoxide', ID='B-CO-ceil'/
&DEVC XYZ=1.6,2.2, 2.35, QUANTITY='carbon dioxide', ID='B-CO2-ceil'/
&DEVC XYZ=1.6,2.3, 2.35, QUANTITY='oxygen', ID='B-O2-ceil'/
tree
&DEVC XYZ=1.6,2.2, 1.52, QUANTITY='carbon monoxide', ID='B-CO-1.5'/
&DEVC XYZ=1.6,2.2, 1.52, QUANTITY='carbon dioxide', ID='B-CO2-1.5'/
&DEVC XYZ=1.6,2.2, 1.52, QUANTITY='oxygen', ID='B-O2-1.5'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='carbon monoxide', ID='B-CO-0.6'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='carbon dioxide', ID='B-CO2-0.6'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='oxygen', ID='B-O2-0.6'/

fuel
&DEVC XYZ=7.4,1.4, 2.375, QUANTITY='fuel', ID='L-fuel'/ LR
&DEVC XYZ=4.6,2.3, 2.375, QUANTITY='fuel', ID='K-fuel'/ K



                                                            HEAT FLUX
&PROP ID='hf1', GAUGE_TEMPERATURE=40 /

Horizontal orientation - floor
&DEVC XYZ=1.6,2.3, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='B-floorHF', PROP_ID='hf1'/
&DEVC XYZ=4.5,3.1, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='K-floorHF', PROP_ID='hf1'/
&DEVC XYZ=7.4,1.4, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='L-floorHF', PROP_ID='hf1'/
&DEVC XYZ=4.5,1.0, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='D-floorHF', PROP_ID='hf1'/

vertical orientation - towards fire
&OBST XB= 4.6,4.7, 2.99,3.0, 0.9,1.0 SURF_ID='INERT' / kitchen
&OBST XB= 7.9,7.91, 3.3,3.4, 0.9,1.0 SURF_ID='INERT' / living room
&DEVC XB=4.6,4.7, 3.0,3.0, 0.9,1.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-fireHF', PROP_ID='hf1' / kitchen
&DEVC XB=7.9,7.9, 3.3,3.4, 0.9,1.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=-1, ID='L-fireHF', PROP_ID='hf1' / living room

wall accross from fire
```

&DEVC XYZ=5.0, 2.2, 0.61, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-wallHF-L', PROP_ID='hf1'/ kitchen wall low
&DEVC XYZ=5.0, 2.2, 1.83, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-wallHF-H', PROP_ID='hf1'/ kitchen wall high
&DEVC XYZ=9.0, 3.5, 0.61, QUANTITY='GAUGE_HEAT_FLUX', IOR=-1, ID='L-wallHF-L', PROP_ID='hf1'/ living room wall low
&DEVC XYZ=9.0, 3.5, 1.83, QUANTITY='GAUGE_HEAT_FLUX', IOR=-1, ID='L-wallHF-H', PROP_ID='hf1'/ living room wall high

VISIBILITY
POINT

living room
&DEVC XYZ=8.59, 1.07, 2.3, QUANTITY='visibility', ID='L-vis-C1'/ Living room - ceiling 1
&DEVC XYZ=8.59, 1.98, 2.3, QUANTITY='visibility', ID='L-vis-C2'/ Living room - ceiling 2

&DEVC XYZ=7.78, 1.22, 0.61, QUANTITY='visibility', ID='L-vis-L'/ Living room - egress low
&DEVC XYZ=7.78, 1.22, 1.54, QUANTITY='visibility', ID='L-vis-H'/ Living room - egress high

dining room
&DEVC XYZ=4.55, 1.07, 2.3, QUANTITY='visibility', ID='D-vis-C'/ Dining room - ceiling

bedroom
&DEVC XYZ=0.2, 1.07, 2.3, QUANTITY='visibility', ID='B-vis-C1'/ Bedroom - ceiling 1
&DEVC XYZ=0.41, 1.98, 2.3, QUANTITY='visibility', ID='B-vis-C2'/ Bedroom - ceiling 2

&DEVC XYZ=0.31, 1.22, 0.61, QUANTITY='visibility', ID='B-vis-L'/ Bedroom - egress low
&DEVC XYZ=0.31, 1.22, 1.54, QUANTITY='visibility', ID='B-vis-H'/ Bedroom - egress high

PATH OBSCURATION

&DEVC XB=8.80, 8.80, 0.31, 1.83, 2.3,2.3, QUANTITY='path obscuration', ID='L-ODM-C1' / Living room ODM ceiling 1
&DEVC XB=8.59, 8.59, 1.22, 2.74, 2.3,2.3, QUANTITY='path obscuration', ID='L-ODM-C2' / Living room ODM ceiling 2

&DEVC XB=7.78, 7.78, 0.46, 1.98, 0.61, QUANTITY='path obscuration', ID='L-ODM-L' / Living room ODM in egress path - low 0.61m
&DEVC XB=7.78, 7.78, 0.46, 1.98, 1.54, QUANTITY='path obscuration', ID='L-ODM-H' / Living room ODM in egress path - high 1.54m

&DEVC XB=0.2, 0.2, 0.31, 1.83, 2.3,2.3, QUANTITY='path obscuration', ID='B-ODM-C1' / bedroom ODM ceiling 1
&DEVC XB=0.41,0.41, 1.22, 2.74, 2.3,2.3, QUANTITY='path obscuration', ID='B-ODM-C2' / bedroom ODM ceiling 2

&DEVC XB=0.31, 0.31, 0.46, 1.98, 0.61, QUANTITY='path obscuration', ID='B-ODM-L' / Bedroom ODM in egress path - low 0.61m
&DEVC XB=0.31, 0.31, 0.46, 1.98, 1.54, QUANTITY='path obscuration', ID='B-ODM-H' / Bedroom ODM in egress path - high 1.54m

&DEVC XB=4.55, 4.55, 0.31, 1.83, 2.3,2.3, QUANTITY='path obscuration', ID='D-ODM-C' / dining room ODM ceiling

BI_DIRECTIONAL PROBEs
(V-velocity)
&DEVC XYZ= 3.4,1.5,0.51, QUANTITY='V-VELOCITY', ID='VEL_0.5'/
&DEVC XYZ= 3.4,1.5,1.02, QUANTITY='V-VELOCITY', ID='VEL_1.0'/
&DEVC XYZ= 3.4,1.5,1.52, QUANTITY='V-VELOCITY', ID='VEL_1.5'/
&DEVC XYZ= 3.4,1.5,2.03, QUANTITY='V-VELOCITY', ID='VEL_2.0'/

Flow measurements
&DEVC XB=4.0,4.9, 2.2,2.2, 0.0,2.0, QUANTITY='MASS FLOW +', ID='mass + kitch' / kitch
&DEVC XB=4.0,4.9, 2.2,2.2, 0.0,2.0, QUANTITY='MASS FLOW -', ID='mass - kitch' /
&DEVC XB=5.9,9.0, 2.1,2.1, 0.0,2.0, QUANTITY='MASS FLOW +', ID='mass + liv' / liv
&DEVC XB=5.9,9.0, 2.1,2.1, 0.0,2.0, QUANTITY='MASS FLOW -', ID='mass - liv' /
&DEVC XB=9.0,9.0, 0.9,1.7, 0.0,2.0, QUANTITY='MASS FLOW +', ID='mass + out' / out
&DEVC XB=9.0,9.0, 0.9,1.7, 0.0,2.0, QUANTITY='MASS FLOW -', ID='mass - out' /

PRESSURE
LIVING ROOM

&DEVC XYZ= 8.9, 1.9, 2.13, QUANTITY='PRESSURE', ID='L-p1' / living room pressure 1
&DEVC XYZ= 8.9, 1.9, 1.52, QUANTITY='PRESSURE', ID='L-p2' / living room pressure 2
&DEVC XYZ= 8.9, 1.9, 0.91, QUANTITY='PRESSURE', ID='L-p3' / living room pressure 3
&DEVC XYZ= 8.9, 1.9, 0.31, QUANTITY='PRESSURE', ID='L-p4' / living room pressure 4
KITCHEN
&DEVC XYZ= 3.5, 4.4, 2.13, QUANTITY='PRESSURE', ID='K-p1' / kitchen pressure 1
&DEVC XYZ= 3.5, 4.4, 1.52, QUANTITY='PRESSURE', ID='K-p2' / kitchen pressure 2
&DEVC XYZ= 3.5, 4.4, 0.91, QUANTITY='PRESSURE', ID='K-p3' / kitchen pressure 3
&DEVC XYZ= 3.5, 4.4, 0.31, QUANTITY='PRESSURE', ID='K-p4' / kitchen pressure 4

BEDROOM
&DEVC XYZ= 0.1, 2.0, 2.13, QUANTITY='PRESSURE', ID='B-p1' / bedroom pressure 1
&DEVC XYZ= 0.1, 2.0, 1.52, QUANTITY='PRESSURE', ID='B-p2' / bedroom pressure 2
&DEVC XYZ= 0.1, 2.0, 0.91, QUANTITY='PRESSURE', ID='B-p3' / bedroom pressure 3
&DEVC XYZ= 0.1, 2.0, 0.31, QUANTITY='PRESSURE', ID='B-p4' / bedroom pressure 4

SMOKE DETECTORS (+TEMP AND VELOCITY)
From User's guide:
&PROP ID='smoke_I1', QUANTITY='spot obscuration', ALPHA_E=2.5, BETA_E=-0.7, ALPHA_C=0.8, BETA_C=-0.9, ACTIVATION_OBSCURATION=3.28 / Cleary ionization I1
&PROP ID='smoke_I2', QUANTITY='spot obscuration', ALPHA_E=1.8, BETA_E=-1.1, ALPHA_C=1.0, BETA_C=-0.8, ACTIVATION_OBSCURATION=3.28 / Cleary ionization I2
&PROP ID='smoke_P1', QUANTITY='spot obscuration', ALPHA_E=1.8, BETA_E=-1.0, ALPHA_C=1.0, BETA_C=-0.8, ACTIVATION_OBSCURATION=3.28 / Cleary photoelectric P1
&PROP ID='smoke_P2', QUANTITY='spot obscuration', ALPHA_E=1.8, BETA_E=-0.8, ALPHA_C=0.8, BETA_C=-0.8, ACTIVATION_OBSCURATION=3.28 / Cleary photoelectric P2
&PROP ID='smoke_H', QUANTITY='spot obscuration', LENGTH=1.8, ACTIVATION_OBSCURATION=3.28 / Heskestad model

LIVING ROOM
&DEVC XYZ=8.39, 1.37, 2.3, PROP_ID='smoke_I1', ID='L-smokeI1' / I1
&DEVC XYZ=8.39, 1.37, 2.3, PROP_ID='smoke_I2', ID='L-smokeI2' / I2
&DEVC XYZ=8.39, 1.37, 2.3, PROP_ID='smoke_H' , ID='L-smokeH' / HESK
&DEVC XYZ=8.39, 1.67, 2.3, PROP_ID='smoke_P1', ID='L-smokeP1' / P1
&DEVC XYZ=8.39, 1.67, 2.3, PROP_ID='smoke_P2', ID='L-smokeP2' / P2
&DEVC XYZ=8.39, 1.67, 2.3, QUANTITY='TEMPERATURE' ID='L-smoke' / TC at smoke detector

BEDROOM
&DEVC XYZ=0.61, 1.37, 2.3, PROP_ID='smoke_I1' , ID='B-smokeI1'/ I1
&DEVC XYZ=0.61, 1.37, 2.3, PROP_ID='smoke_I2' , ID='B-smokeI2'/ I2
&DEVC XYZ=0.61, 1.37, 2.3, PROP_ID='smoke_H' , ID='B-smokeH'/ HESK
&DEVC XYZ=0.61, 1.67, 2.3, PROP_ID='smoke_P1' , ID='B-smokeP1'/ P1
&DEVC XYZ=0.61, 1.67, 2.3, PROP_ID='smoke_P2' , ID='B-smokeP2' / P2
&DEVC XYZ=0.61, 1.67, 2.3, QUANTITY='TEMPERATURE' ID='B-smoke' / TC at smoke detector

DINING ROOM
&DEVC XYZ=4.52, 0.96, 2.3, PROP_ID='smoke_I1', ID='D-smokeI1' / I1
&DEVC XYZ=4.52, 0.96, 2.3, PROP_ID='smoke_I2', ID='D-smokeI2' / I2
&DEVC XYZ=4.52, 0.96, 2.3, PROP_ID='smoke_H' , ID='D-smokeH' / HESK
&DEVC XYZ=4.52, 1.19, 2.3, PROP_ID='smoke_P1', ID='D-smokeP1' / P1
&DEVC XYZ=4.52, 1.19, 2.3, PROP_ID='smoke_P2', ID='D-smokeP2' / P2

```
&DEVC XYZ=4.52, 1.19, 2.3, QUANTITY='TEMPERATURE' ID='D-smoke' / TC at smoke detector
```

```
&TAIL/
```

9.2 Cabinet Test with Window Half Open Using Calorimeter Heat Release Rate

```
&HEAD CHID='cab_H',TITLE='kitchen cabinets high window half open'  /


&MESH IJK=50,90,48, XB=3.3,5.8, 0.0,4.5, 0.0,2.4 / 5 cm - DIN. + KITCH              216 000
&MESH IJK=60,32,16, XB=-0.7,0.8, 0.7,1.5, 1.0,1.4 / 2.5cm - window vent              30 720
&MESH IJK=15,7,24,  XB=-0.7,0.8, 0.0,0.7, 0.0,2.4 / 10cm - LEFT OF window    2520
&MESH IJK=15,30,24, XB=-0.7,0.8, 1.5,4.5, 0.0,2.4 / 10cm - RIGHT OF window           10 800
&MESH IJK=15,8,10,  XB=-0.7,0.8, 0.7,1.5, 0.0,1.0 / 10cm - UNDER window               1200
&MESH IJK=15,8,10,  XB=-0.7,0.8, 0.7,1.5, 1.4,2.4 / 10cm - OVER window                1200

&MESH IJK=25,45,24, XB=0.8,3.3, 0.0,4.5, 0.0,2.4 / 10 cm - BEDROOM
&MESH IJK=32,45,24, XB=5.8,9.0, 0.0,4.5, 0.0,2.4 / 10 cm - LIV                       22 680
                                                                    total      285 120
```

```
Rooms:
B - bedroom
K - Kitchen
D - dining room
L - living room
Walls:
   4
 ---------
 !  !  !  !
3! C!__!A !1
 !   B    !
 ---------
   2
```

```
&TIME T_END=2500 / 2500                         <set
```

```
&MISC SURF_DEFAULT='GWB',
          TMPA=25 ,
          CO_PRODUCTION=.TRUE/                                    <set

&DUMP   DT_DEVC=1,
          DT_SLCF=1,
          DT_PL3D=90,
          PLOT3D_QUANTITY(1:5)='TEMPERATURE','carbon
monoxide','oxygen','VELOCITY','HRRPUV'/     <set


&REAC ID='WOOD'
     FYI='Ritchie, et al., 5th IAFSS, C_3.4 H_6.2 O_2.5'
     SOOT_YIELD = 0.253
          C=3.4,
          H=6.2,
          O=2.5,
          CO_YIELD=0.021
          HEAT_OF_COMBUSTION=14600 / Soot yield, CO yield from chris's old test data.
HOC from new hood


&MATL ID='GWB',
          CONDUCTIVITY = 0.17,
          SPECIFIC_HEAT = 1.1,
          DENSITY = 800. /

&SURF ID='GWB',
          MATL_ID='GWB',
          BACKING='EXPOSED',
          THICKNESS=0.032/

SURF ID='GWB_L',
          MATL_ID='GWB',
          BACKING='EXPOSED',
          THICKNESS=0.032,
          LEAK_PATH=1,0


&MATL ID='GLASS',
          CONDUCTIVITY = 1.4,
          SPECIFIC_HEAT = 0.75,
          DENSITY = 2500. /

&SURF ID='GLASS',
          MATL_ID='GLASS',
          BACKING='EXPOSED',
          THICKNESS=0.005,
```

```
      COLOR='WHITE'/


&MATL ID = 'CARPET_MATL'
CONDUCTIVITY = 0.1600
SPECIFIC_HEAT = 9.0
DENSITY = 750.0
HEAT_OF_COMBUSTION=22300/


&SURF ID = 'CARPET'
      MATL_ID = 'CARPET_MATL'
      RGB=176, 224, 230
      BACKING = 'INSULATED'
      THICKNESS = 0.006
      HEAT_OF_VAPORIZATION=2000,
      IGNITION_TEMPERATURE= 290.00, / carpet, form FDS 4 database


&MATL ID = 'Plywood',
CONDUCTIVITY = 0.12,
SPECIFIC_HEAT = 1.3,
DENSITY = 545 /

&SURF ID='WOOD'
      MATL_ID= 'Plywood',
      RGB= 218, 165, 32,
      HRRPUA= 243.36 ,
      THICKNESS= 0.025 ,
      IGNITION_TEMPERATURE= 326.00,
      RAMP_Q= 'RAMP_Q_PS09TG'/

&RAMP ID='RAMP_Q_PS09TG' T=0.00 F=0.00/
&RAMP ID='RAMP_Q_PS09TG' T=30.00 F=0.81/
&RAMP ID='RAMP_Q_PS09TG' T=70.00 F=0.0800/
&RAMP ID='RAMP_Q_PS09TG' T=95.00 F=0.3900/
&RAMP ID='RAMP_Q_PS09TG' T=175.00 F=0.53/
&RAMP ID='RAMP_Q_PS09TG' T=325.00 F=0.2200/
&RAMP ID='RAMP_Q_PS09TG' T=445.00 F=0.2800/
&RAMP ID='RAMP_Q_PS09TG' T=575.00 F=1.00/
&RAMP ID='RAMP_Q_PS09TG' T=700.00 F=0.2100/
&RAMP ID='RAMP_Q_PS09TG' T=1.475000E003 F=0.1400/


&SURF ID='TISSUE_BOX'
      COLOR='BLUE'
      HRRPUA= 40.92
      RAMP_Q= 'RAMP_Q_TISSUE'/   hrrmax=3.06kw / A=0.0748M2
```

```
&RAMP ID='RAMP_Q_TISSUE',	T=	0.00	,F=	0.000	/
&RAMP ID='RAMP_Q_TISSUE',	T=	8.28	,F=	0.027	/
&RAMP ID='RAMP_Q_TISSUE',	T=	40.56	,F=	0.041	/
&RAMP ID='RAMP_Q_TISSUE',	T=	105.13	,F=	0.048	/
&RAMP ID='RAMP_Q_TISSUE',	T=	139.56	,F=	0.038	/
&RAMP ID='RAMP_Q_TISSUE',	T=	148.17	,F=	0.014	/
&RAMP ID='RAMP_Q_TISSUE',	T=	163.23	,F=	0.082	/
&RAMP ID='RAMP_Q_TISSUE',	T=	199.81	,F=	0.167	/
&RAMP ID='RAMP_Q_TISSUE',	T=	227.79	,F=	0.246	/
&RAMP ID='RAMP_Q_TISSUE',	T=	240.70	,F=	0.263	/
&RAMP ID='RAMP_Q_TISSUE',	T=	249.31	,F=	0.341	/
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&SURF ID='CABINET'
          COLOR='BROWN'
          HRRPUA= 221.08
          RAMP_Q= 'RAMP_Q_CABINET'/   hrrmax=666.55 kw / 3.015m = 221.08 kw/m2

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&RAMP ID='RAMP_Q_CABINET',    T=    2258.08,F=    0.384   /
&RAMP ID='RAMP_Q_CABINET',    T=    2283.85,F=    0.380   /
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&RAMP ID='RAMP_Q_CABINET',     T=       3061.34,F=       0.244    /
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FIRES

&OBST XB= 3.85,3.95, 3.65,3.85, 1.40,1.50, SURF_IDS='TISSUE_BOX','TISSUE_BOX','INERT'/ Tissue box fire 0.12 x 0.22 x 0.10 cm

&OBST XB= 3.6,5.5, 3.75,4.05, 1.55,2.3, SURF_ID6='CABINET','CABINET' ,'CABINET','INERT','CABINET','CABINET'/ A=3.015

&OBST XB= 3.45,5.65, 4.05,4.10, 0.2,2.3, SURF_ID='GWB', COLOR='WHITE'/ wall behind cabinets

&OBST XB= 3.45,5.65, 3.30,4.4, 0.15,0.2, SURF_ID='GWB', COLOR='WHITE'/ Load cell platform

LEAK

ZONE XB=-0.3, 9.0, 0.0, 4.5, 0.0, 2.4, LEAK_AREA(0)=0.0074 pressure zone - leak area (as measured in NEW tests (0.015/2))

Interior walls

&OBST XB= 3.28, 3.35, 0.0, 4.5, 0.0, 2.4, SURF_ID='GWB' / Wall C (K and B)

&HOLE XB= 3.25, 3.38, 1.1, 2.0, 0.0, 2.0 / Door in wall C

&OBST XB= 3.35, 5.9, 2.1, 2.2, 0.0, 2.4, SURF_ID='GWB' / Wall B (K and D)

```
&HOLE XB= 4.0, 4.9, 2.1, 2.2, 0.0, 2.0 / Door in wall B
&OBST XB= 5.78, 5.92, 0.0, 4.5, 0.0, 2.4, SURF_ID='GWB' / Wall A (K and L)
&HOLE XB= 5.77, 5.94, 0.0, 2.1, 0.0, 2.0 / Door in wall A

&OBST XB= 0.0,0.1, 0.0,4.5, 0.0,2.4, SURF_ID='GWB'/ BR WALL
&HOLE XB= 0.0,0.1, 0.9,1.5, 1.1,1.3/ OPEN WINDOW


        Door and Windows.
&VENT XB= 9.0,9.0, 0.9,1.7, 0.0,2.0, SURF_ID='INERT' / exterior door. Wall 1
&VENT XB= 9.0,9.0, 3.3,3.9, 1.1,2.1, SURF_ID='GLASS' / window. Wall 1
&VENT XB= 4.3,4.9, 0.0,0.0, 1.1,2.1, SURF_ID='GLASS' / window. Wall 2
&VENT XB= 6.4,7.0, 0.0,0.0, 1.1,2.1, SURF_ID='GLASS' / window 2 Wall 2

&VENT XB= 0.10,0.10, 0.9,1.5, 1.3,2.1, SURF_ID='GLASS' / window. Wall 3


                                                          OPEN          VENTS
OUTSIDE WINDOW
&VENT MB=XMIN, SURF_ID='OPEN'/
&VENT XB= -0.7,0.0, 0.0,4.5, 2.4,2.4, SURF_ID='OPEN'/ CEILING
&VENT XB= -0.7,0.0, 0.0,0.0, 0.0,2.4, SURF_ID='OPEN'/ Y MIN
&VENT XB= -0.7,0.0, 4.5,4.5, 0.0,2.4, SURF_ID='OPEN'/ Y MAX


                                                          FURNITURE
carpet
&VENT XB=0.0,3.3, 0.0,4.5, 0.0,0.0, SURF_ID='CARPET'/BEDROOM
&VENT XB=3.3,5.8, 0.0,2.1, 0.0,0.0, SURF_ID='CARPET'/DINING ROOM
&VENT XB=5.8,9.0, 0.0,4.5, 0.0,0.0, SURF_ID='CARPET'/LIVING ROOM


&BNDF QUANTITY='GAUGE_HEAT_FLUX'/
&BNDF QUANTITY='BURNING_RATE'/
&BNDF QUANTITY='ADIABATIC_SURFACE_TEMPERATURE'/

                                                          Slice files
&SLCF PBY= 1.0, QUANTITY='TEMPERATURE' /
&SLCF PBY= 2.3, QUANTITY='TEMPERATURE' /
&SLCF PBX= 4.5, QUANTITY='TEMPERATURE' /
&SLCF PBX= 6.3, QUANTITY='TEMPERATURE' /

&SLCF PBY= 1.0, QUANTITY='oxygen' /
&SLCF PBY= 2.3, QUANTITY='oxygen' /
&SLCF PBX= 4.5, QUANTITY='oxygen' /
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&SLCF PBX= 6.3, QUANTITY='oxygen' /

&SLCF PBY= 2.3, QUANTITY='MIXTURE_FRACTION' /
&SLCF PBX= 4.5, QUANTITY='MIXTURE_FRACTION' /
&SLCF PBX= 6.3, QUANTITY='MIXTURE_FRACTION' /

&SLCF PBY= 1.5, QUANTITY='U-VELOCITY' /

DEVICES:

&DEVC XB=5.9,9, 0.0,4.5, 0.0,2.4, QUANTITY='MIXTURE_FRACTION', STATISTICS='MEAN', ID='Zmean_L'/ MIXTURE FRACTION Living room (mesh mean)
&DEVC XB=0.0,5.8, 0.0,4.5, 0.0,2.4, QUANTITY='MIXTURE_FRACTION', STATISTICS='MEAN', ID='Zmean_KB'/ MIXTURE FRACTION K,D,B (mesh mean)

TEMPERATURE

TC rack 1 - bedroom:
&DEVC XYZ=1.6,2.2, 0.05, QUANTITY='THERMOCOUPLE', ID='B1'/
&DEVC XYZ=1.6,2.2, 0.3, QUANTITY='THERMOCOUPLE', ID='B2'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='THERMOCOUPLE', ID='B3'/
&DEVC XYZ=1.6,2.2, 0.9, QUANTITY='THERMOCOUPLE', ID='B4'/
&DEVC XYZ=1.6,2.2, 1.2, QUANTITY='THERMOCOUPLE', ID='B5'/
&DEVC XYZ=1.6,2.2, 1.5, QUANTITY='THERMOCOUPLE', ID='B6'/
&DEVC XYZ=1.6,2.2, 1.8, QUANTITY='THERMOCOUPLE', ID='B7'/
&DEVC XYZ=1.6,2.2, 2.1, QUANTITY='THERMOCOUPLE', ID='B8'/
&DEVC XYZ=1.6,2.2, 2.35, QUANTITY='THERMOCOUPLE', ID='B9'/

TC rack 2 - kitchen (aspirated TC) +3 Non-aspir
&DEVC XYZ=4.6,3.1, 0.05, QUANTITY='TEMPERATURE', ID='K1'/
&DEVC XYZ=4.6,3.1, 0.3, QUANTITY='TEMPERATURE', ID='K2'/
&DEVC XYZ=4.6,3.1, 0.6, QUANTITY='TEMPERATURE', ID='K3'/
&DEVC XYZ=4.6,3.1, 0.9, QUANTITY='TEMPERATURE', ID='K4'/
&DEVC XYZ=4.6,3.1, 1.2, QUANTITY='TEMPERATURE', ID='K5'/
&DEVC XYZ=4.6,3.1, 1.5, QUANTITY='TEMPERATURE', ID='K6'/
&DEVC XYZ=4.6,3.1, 1.8, QUANTITY='TEMPERATURE', ID='K7'/
&DEVC XYZ=4.6,3.1, 2.1, QUANTITY='TEMPERATURE', ID='K8'/
&DEVC XYZ=4.6,3.1, 2.35, QUANTITY='TEMPERATURE', ID='K9'/
non-aspirated
&DEVC XYZ=4.6,3.1, 0.61, QUANTITY='THERMOCOUPLE', ID='K-N1'/
&DEVC XYZ=4.6,3.1, 1.52, QUANTITY='THERMOCOUPLE', ID='K-N2'/
&DEVC XYZ=4.6,3.1, 2.13, QUANTITY='THERMOCOUPLE', ID='K-N3'/

TC rack 3 - dining room:
&DEVC XYZ=4.6,1.0, 0.05, QUANTITY='THERMOCOUPLE', ID='D1'/
&DEVC XYZ=4.6,1.0, 0.3, QUANTITY='THERMOCOUPLE', ID='D2'/
&DEVC XYZ=4.6,1.0, 0.6, QUANTITY='THERMOCOUPLE', ID='D3'/
&DEVC XYZ=4.6,1.0, 0.9, QUANTITY='THERMOCOUPLE', ID='D4'/
&DEVC XYZ=4.6,1.0, 1.2, QUANTITY='THERMOCOUPLE', ID='D5'/
&DEVC XYZ=4.6,1.0, 1.5, QUANTITY='THERMOCOUPLE', ID='D6'/
&DEVC XYZ=4.6,1.0, 1.8, QUANTITY='THERMOCOUPLE', ID='D7'/
&DEVC XYZ=4.6,1.0, 2.1, QUANTITY='THERMOCOUPLE', ID='D8'/
&DEVC XYZ=4.6,1.0, 2.35, QUANTITY='THERMOCOUPLE', ID='D9'/

TC rack 4 - living room (aspirated TC) +3 Non-aspir
&DEVC XYZ=7.4,1.4, 0.05, QUANTITY='TEMPERATURE', ID='L1'/
&DEVC XYZ=7.4,1.4, 0.3, QUANTITY='TEMPERATURE', ID='L2'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='TEMPERATURE', ID='L3'/
&DEVC XYZ=7.4,1.4, 0.9, QUANTITY='TEMPERATURE', ID='L4'/
&DEVC XYZ=7.4,1.4, 1.2, QUANTITY='TEMPERATURE', ID='L5'/
&DEVC XYZ=7.4,1.4, 1.5, QUANTITY='TEMPERATURE', ID='L6'/
&DEVC XYZ=7.4,1.4, 1.8, QUANTITY='TEMPERATURE', ID='L7'/
&DEVC XYZ=7.4,1.4, 2.1, QUANTITY='TEMPERATURE', ID='L8'/
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='TEMPERATURE', ID='L9'/
non-aspirated
&DEVC XYZ=7.4,1.4, 0.61, QUANTITY='TEMPERATURE', ID='L-N1'/
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='TEMPERATURE', ID='L-N2'/
&DEVC XYZ=7.4,1.4, 2.13, QUANTITY='TEMPERATURE', ID='L-N3'/

TC rack 5 - doorway: DOOR TCs

&DEVC XYZ=9.0,1.3, 0.05, QUANTITY='TEMPERATURE', ID='door1'/
&DEVC XYZ=9.0,1.3, 0.3, QUANTITY='TEMPERATURE', ID='door2'/
&DEVC XYZ=9.0,1.3, 0.6, QUANTITY='TEMPERATURE', ID='door3'/
&DEVC XYZ=9.0,1.3, 0.9, QUANTITY='TEMPERATURE', ID='door4'/
&DEVC XYZ=9.0,1.3, 1.2, QUANTITY='TEMPERATURE', ID='door5'/
&DEVC XYZ=9.0,1.3, 1.5, QUANTITY='TEMPERATURE', ID='door6'/
&DEVC XYZ=9.0,1.3, 1.8, QUANTITY='TEMPERATURE', ID='door7'/
&DEVC XYZ=9.0,1.3, 2.1, QUANTITY='TEMPERATURE', ID='door8'/

WINDOW FLOW TCs
at window
&DEVC XYZ=0.1, 1.2, 1.1, QUANTITY='TEMPERATURE', ID='win1'/
&DEVC XYZ=0.1, 1.2, 1.2, QUANTITY='TEMPERATURE', ID='win2'/
&DEVC XYZ=0.1, 1.2, 1.3, QUANTITY='TEMPERATURE', ID='win3'/
2.5 lengths from window
&DEVC XYZ=1.0, 1.2, 1.1, QUANTITY='TEMPERATURE', ID='winBR1'/
&DEVC XYZ=1.0, 1.2, 1.2, QUANTITY='TEMPERATURE', ID='winBR2'/

&DEVC XYZ=1.0, 1.2, 1.3, QUANTITY='TEMPERATURE', ID='winBR3'/

Wall TCs

WALL TCs - Inside

living room

&DEVC XYZ=9.0, 3.45, 0.61, QUANTITY='WALL_TEMPERATURE', ID='W1-1-in', IOR=-1/
&DEVC XYZ=9.0, 3.45, 1.83, QUANTITY='WALL_TEMPERATURE', ID='W1-2-in', IOR=-1/

bedroom

&DEVC XYZ=0.1, 3.1, 0.61, QUANTITY='WALL_TEMPERATURE', ID='W3-1-in', IOR=1/
&DEVC XYZ=0.1, 3.1, 1.83, QUANTITY='WALL_TEMPERATURE', ID='W3-2-in', IOR=1/

kitchen

&DEVC XYZ=4.5, 4.5, 0.61, QUANTITY='WALL_TEMPERATURE', ID='W4-1-in', IOR=-2/
&DEVC XYZ=4.5, 4.5, 1.83, QUANTITY='WALL_TEMPERATURE', ID='W4-2-in', IOR=-2/

WALL TCs - outside

living room

&DEVC XYZ=9.0, 3.45, 0.61, QUANTITY='BACK_WALL_TEMPERATURE', ID='W1-1-out', IOR=-1/
&DEVC XYZ=9.0, 3.45, 1.83, QUANTITY='BACK_WALL_TEMPERATURE', ID='W1-2-out', IOR=-1/

bedroom

&DEVC XYZ=0.0, 3.1, 0.61, QUANTITY='BACK_WALL_TEMPERATURE', ID='W3-1-out', IOR=1/
&DEVC XYZ=0.0, 3.1, 1.83, QUANTITY='BACK_WALL_TEMPERATURE', ID='W3-2-out', IOR=1/

kitchen

&DEVC XYZ=4.5, 4.5, 0.61, QUANTITY='BACK_WALL_TEMPERATURE', ID='W4-1-out', IOR=-2/
&DEVC XYZ=4.5, 4.5, 1.83, QUANTITY='BACK_WALL_TEMPERATURE', ID='W4-2-out', IOR=-2/

Window TCs

&DEVC XYZ=8.95,3.1, 1.0, QUANTITY='THERMOCOUPLE', ID='win1-l'/ window in living room
&DEVC XYZ=8.95,3.1, 1.7, QUANTITY='THERMOCOUPLE', ID='win1-h'/

&DEVC XYZ=4.5,0.05, 1.1, QUANTITY='THERMOCOUPLE', ID='win2-l'/ window on wall 2 - dining room
&DEVC XYZ=4.5,0.05, 1.8, QUANTITY='THERMOCOUPLE', ID='win2-h'/

&DEVC XYZ=6.8,0.05, 1.1, QUANTITY='THERMOCOUPLE', ID='win2.2-l'/ window on wall 2 - living room
&DEVC XYZ=6.8,0.05, 1.8, QUANTITY='THERMOCOUPLE', ID='win2.2-h'/

&DEVC XYZ=0.1,1.2, 1.2, QUANTITY='THERMOCOUPLE', ID='win3-l'/ window in bed room
&DEVC XYZ=0.1,1.2, 1.7, QUANTITY='THERMOCOUPLE', ID='win3-h'/

Kitchen
ceiling
&DEVC XYZ=4.4,3.1, 2.35, QUANTITY='carbon monoxide', ID='K-CO-ceil'/
&DEVC XYZ=4.4,3.1, 2.35, QUANTITY='carbon dioxide', ID='K-CO2-ceil'/
&DEVC XYZ=4.4,3.1, 2.35, QUANTITY='oxygen', ID='K-O2-ceil'/
base of fire
&DEVC XYZ=4.4,3.1, 0.05, QUANTITY='carbon monoxide', ID='K-CO-floor'/
&DEVC XYZ=4.4,3.1, 0.05, QUANTITY='carbon dioxide', ID='K-CO2-floor'/
&DEVC XYZ=4.4,3.1, 0.05, QUANTITY='oxygen', ID='K-O2-floor'/
base of fire
&DEVC XYZ=4.4,3.1, 1.5, QUANTITY='carbon monoxide', ID='K-CO-fire'/
&DEVC XYZ=4.4,3.1, 1.5, QUANTITY='carbon dioxide', ID='K-CO2-fire'/
&DEVC XYZ=4.4,3.1, 1.5, QUANTITY='oxygen', ID='K-O2-fire'/

Living room

ceiling
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='carbon monoxide', ID='L-CO-ceil'/
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='carbon dioxide', ID='L-CO2-ceil'/
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='oxygen', ID='L-O2-ceil'/
tree
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='carbon monoxide', ID='L-CO-1.5'/
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='carbon dioxide', ID='L-CO2-1.5'/
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='oxygen', ID='L-O2-1.5'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='carbon monoxide', ID='L-CO-0.6'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='carbon dioxide', ID='L-CO2-0.6'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='oxygen', ID='L-O2-0.6'/

Bedroom
ceiling
&DEVC XYZ=1.6,2.2, 2.35, QUANTITY='carbon monoxide', ID='B-CO-ceil'/
&DEVC XYZ=1.6,2.2, 2.35, QUANTITY='carbon dioxide', ID='B-CO2-ceil'/
&DEVC XYZ=7.4,2.3, 2.35, QUANTITY='oxygen', ID='B-O2-ceil'/
tree
&DEVC XYZ=1.6,2.2, 1.52, QUANTITY='carbon monoxide', ID='B-CO-1.5'/
&DEVC XYZ=1.6,2.2, 1.52, QUANTITY='carbon dioxide', ID='B-CO2-1.5'/
&DEVC XYZ=1.6,2.2, 1.52, QUANTITY='oxygen', ID='B-O2-1.5'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='carbon monoxide', ID='B-CO-0.6'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='carbon dioxide', ID='B-CO2-0.6'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='oxygen', ID='B-O2-0.6'/

fuel
&DEVC XYZ=7.4,1.4, 2.375, QUANTITY='fuel', ID='L-fuel'/ LR

&DEVC XYZ=4.6,2.3, 2.375, QUANTITY='fuel', ID='K-fuel'/ K

HEAT FLUX

&PROP ID='hf1', GAUGE_TEMPERATURE=40 /

Horizontal orientation - floor
&DEVC XYZ=1.6,2.3, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='B-floorHF', PROP_ID='hf1'/
&DEVC XYZ=4.5,3.1, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='K-floorHF', PROP_ID='hf1'/
&DEVC XYZ=7.4,1.4, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='L-floorHF', PROP_ID='hf1'/
&DEVC XYZ=4.5,1.0, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='D-floorHF', PROP_ID='hf1'/

vertical orientation - towards fire
&OBST XB= 4.6,4.7, 2.99,3.0, 0.9,1.01 SURF_ID='INERT' / kitchen
&OBST XB= 7.9,7.91, 3.3,3.4, 0.9,1.0 SURF_ID='INERT' / living room
&DEVC XYZ=4.61, 3.0, 0.95, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-fireHF', PROP_ID='hf1' /kitchen
&DEVC XYZ=7.9, 3.35, 0.95, QUANTITY='GAUGE_HEAT_FLUX', IOR=-1, ID='L-fireHF', PROP_ID='hf1' / living room

wall accross from fire
&DEVC XYZ=3.91, 2.2, 0.6, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-wallHF-L', PROP_ID='hf1'/ kitchen wall low
&DEVC XYZ=3.91, 2.2, 1.8, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-wallHF-H', PROP_ID='hf1'/ kitchen wall high
&DEVC XYZ=9.0, 3.5, 0.61, QUANTITY='GAUGE_HEAT_FLUX', IOR=-1, ID='L-wallHF-L', PROP_ID='hf1'/ living room wall low
&DEVC XYZ=9.0, 3.5, 1.83, QUANTITY='GAUGE_HEAT_FLUX', IOR=-1, ID='L-wallHF-H', PROP_ID='hf1'/ living room wall high

VISIBILITY
POINT

living room
&DEVC XYZ=8.59, 1.07, 2.3, QUANTITY='visibility', ID='L-vis-C1'/ Living room - ceiling 1
&DEVC XYZ=8.59, 1.98, 2.3, QUANTITY='visibility', ID='L-vis-C2'/ Living room - ceiling 2

&DEVC XYZ=7.78, 1.22, 0.61, QUANTITY='visibility', ID='L-vis-L'/ Living room - egress low
&DEVC XYZ=7.78, 1.22, 1.54, QUANTITY='visibility', ID='L-vis-H'/ Living room - egress high

dining room

&DEVC XYZ=4.55, 1.07, 2.3, QUANTITY='visibility', ID='D-vis-C'/ Dining room - ceiling

bedroom
&DEVC XYZ=0.2, 1.07, 2.3, QUANTITY='visibility', ID='B-vis-C1'/ Bedroom - ceiling 1
&DEVC XYZ=0.41, 1.98, 2.3, QUANTITY='visibility', ID='B-vis-C2'/ Bedroom - ceiling 2

&DEVC XYZ=0.31, 1.22, 0.61, QUANTITY='visibility', ID='B-vis-L'/ Bedroom - egress low
&DEVC XYZ=0.31, 1.22, 1.54, QUANTITY='visibility', ID='B-vis-H'/ Bedroom - egress high

PATH OBSCURATION
&DEVC XB=8.80, 8.80, 0.31, 1.83, 2.3,2.3, QUANTITY='path obscuration', ID='L-ODM-C1' / Living room ODM ceiling 1
&DEVC XB=8.59, 8.59, 1.22, 2.74, 2.3,2.3, QUANTITY='path obscuration', ID='L-ODM-C2' / Living room ODM ceiling 2

&DEVC XB=7.78, 7.78, 0.46, 1.98, 0.61, QUANTITY='path obscuration', ID='L-ODM-L' / Living room ODM in egress path - low 0.61m
&DEVC XB=7.78, 7.78, 0.46, 1.98, 1.54, QUANTITY='path obscuration', ID='L-ODM-H' / Living room ODM in egress path - high 1.54m

&DEVC XB=0.2, 0.2, 0.31, 1.83, 2.3,2.3, QUANTITY='path obscuration', ID='B-ODM-C1' / bedroom ODM ceiling 1
&DEVC XB=0.41,0.41, 1.22, 2.74, 2.3,2.3, QUANTITY='path obscuration', ID='B-ODM-C2' / bedroom ODM ceiling 2

&DEVC XB=0.31, 0.31, 0.46, 1.98, 0.61, QUANTITY='path obscuration', ID='B-ODM-L' / Bedroom ODM in egress path - low 0.61m
&DEVC XB=0.31, 0.31, 0.46, 1.98, 1.54, QUANTITY='path obscuration', ID='B-ODM-H' / Bedroom ODM in egress path - high 1.54m

&DEVC XB=4.55, 4.55, 0.31, 1.83, 2.3,2.3, QUANTITY='path obscuration', ID='D-ODM-C' / dining room ODM ceiling

BI_DIRECTIONAL PROBEs
(V-velocity)
&DEVC XYZ= 3.4,1.5,0.51, QUANTITY='V-VELOCITY', ID='VEL_0.5'/
&DEVC XYZ= 3.4,1.5,1.02, QUANTITY='V-VELOCITY', ID='VEL_1.0'/
&DEVC XYZ= 3.4,1.5,1.52, QUANTITY='V-VELOCITY', ID='VEL_1.5'/
&DEVC XYZ= 3.4,1.5,2.03, QUANTITY='V-VELOCITY', ID='VEL_2.0'/

&DEVC XYZ= 0.1,1.2,1.2, QUANTITY='V-VELOCITY', ID='VEL_B-Win'/ at beedroom window

Flow measurements
&DEVC XB=4.0,4.9, 2.2,2.2, 0.0,2.0, QUANTITY='MASS FLOW +', ID='mass + kitch' / kitch
&DEVC XB=4.0,4.9, 2.2,2.2, 0.0,2.0, QUANTITY='MASS FLOW -', ID='mass - kitch' /
&DEVC XB=5.9,9.0, 2.1,2.1, 0.0,2.0, QUANTITY='MASS FLOW +', ID='mass + liv' / liv
&DEVC XB=5.9,9.0, 2.1,2.1, 0.0,2.0, QUANTITY='MASS FLOW -', ID='mass - liv' /
&DEVC XB=0.0,0.0, 0.9,1.5, 1.1,1.3, QUANTITY='MASS FLOW +', ID='mass + BRwin' / out
&DEVC XB=0.0,0.0, 0.9,1.5, 1.1,1.3, QUANTITY='MASS FLOW -', ID='mass - BRwin' /

PRESSURE
LIVING ROOM

&DEVC XYZ= 8.9, 1.9, 2.13, QUANTITY='PRESSURE', ID='L-p1' / living room pressure 1
&DEVC XYZ= 8.9, 1.9, 1.52, QUANTITY='PRESSURE', ID='L-p2' / living room pressure 2
&DEVC XYZ= 8.9, 1.9, 0.91, QUANTITY='PRESSURE', ID='L-p3' / living room pressure 3
&DEVC XYZ= 8.9, 1.9, 0.31, QUANTITY='PRESSURE', ID='L-p4' / living room pressure 4
KITCHEN
&DEVC XYZ= 3.5, 4.4, 2.13, QUANTITY='PRESSURE', ID='K-p1' / kitchen pressure 1
&DEVC XYZ= 3.5, 4.4, 1.52, QUANTITY='PRESSURE', ID='K-p2' / kitchen pressure 2
&DEVC XYZ= 3.5, 4.4, 0.91, QUANTITY='PRESSURE', ID='K-p3' / kitchen pressure 3
&DEVC XYZ= 3.5, 4.4, 0.31, QUANTITY='PRESSURE', ID='K-p4' / kitchen pressure 4
BEDROOM
&DEVC XYZ= 0.1, 2.0, 2.13, QUANTITY='PRESSURE', ID='B-p1' / bedroom pressure 1
&DEVC XYZ= 0.1, 2.0, 1.52, QUANTITY='PRESSURE', ID='B-p2' / bedroom pressure 2
&DEVC XYZ= 0.1, 2.0, 0.91, QUANTITY='PRESSURE', ID='B-p3' / bedroom pressure 3
&DEVC XYZ= 0.1, 2.0, 0.31, QUANTITY='PRESSURE', ID='B-p4' / bedroom pressure 4

SMOKE DETECTORS (+TEMP AND VELOCITY)
From User's guide:
&PROP ID='smoke_I1', QUANTITY='spot obscuration', ALPHA_E=2.5, BETA_E=-0.7, ALPHA_C=0.8, BETA_C=-0.9, ACTIVATION_OBSCURATION=3.28 / Cleary ionization I1
&PROP ID='smoke_I2', QUANTITY='spot obscuration', ALPHA_E=1.8, BETA_E=-1.1, ALPHA_C=1.0, BETA_C=-0.8, ACTIVATION_OBSCURATION=3.28 / Cleary ionization I2
&PROP ID='smoke_P1', QUANTITY='spot obscuration', ALPHA_E=1.8, BETA_E=-1.0, ALPHA_C=1.0, BETA_C=-0.8, ACTIVATION_OBSCURATION=3.28 / Cleary photoelectric P1
&PROP ID='smoke_P2', QUANTITY='spot obscuration', ALPHA_E=1.8, BETA_E=-0.8, ALPHA_C=0.8, BETA_C=-0.8, ACTIVATION_OBSCURATION=3.28 / Cleary photoelectric P2
&PROP ID='smoke_H', QUANTITY='spot obscuration', LENGTH=1.8, ACTIVATION_OBSCURATION=3.28 / Heskestad model

LIVING ROOM
&DEVC XYZ=8.39, 1.37, 2.3, PROP_ID='smoke_I1', ID='L-smokeI1' / I1
&DEVC XYZ=8.39, 1.37, 2.3, PROP_ID='smoke_I2', ID='L-smokeI2' / I2
&DEVC XYZ=8.39, 1.37, 2.3, PROP_ID='smoke_H' , ID='L-smokeH' / HESK
&DEVC XYZ=8.39, 1.67, 2.3, PROP_ID='smoke_P1', ID='L-smokeP1' / P1
&DEVC XYZ=8.39, 1.67, 2.3, PROP_ID='smoke_P2', ID='L-smokeP2' / P2
&DEVC XYZ=8.39, 1.67, 2.3, QUANTITY='TEMPERATURE' ID='L-smoke' / TC at smoke detector

BEDROOM
&DEVC XYZ=0.61, 1.37, 2.3, PROP_ID='smoke_I1' , ID='B-smokeI1'/ I1
&DEVC XYZ=0.61, 1.37, 2.3, PROP_ID='smoke_I2' , ID='B-smokeI2'/ I2
&DEVC XYZ=0.61, 1.37, 2.3, PROP_ID='smoke_H' , ID='B-smokeH'/ HESK
&DEVC XYZ=0.61, 1.67, 2.3, PROP_ID='smoke_P1' , ID='B-smokeP1'/ P1
&DEVC XYZ=0.61, 1.67, 2.3, PROP_ID='smoke_P2' , ID='B-smokeP2' / P2
&DEVC XYZ=0.61, 1.67, 2.3, QUANTITY='TEMPERATURE' ID='B-smoke' / TC at smoke detector

DINING ROOM
&DEVC XYZ=4.52, 0.96, 2.3, PROP_ID='smoke_I1', ID='D-smokeI1' / I1
&DEVC XYZ=4.52, 0.96, 2.3, PROP_ID='smoke_I2', ID='D-smokeI2' / I2
&DEVC XYZ=4.52, 0.96, 2.3, PROP_ID='smoke_H' , ID='D-smokeH' / HESK
&DEVC XYZ=4.52, 1.19, 2.3, PROP_ID='smoke_P1', ID='D-smokeP1' / P1
&DEVC XYZ=4.52, 1.19, 2.3, PROP_ID='smoke_P2', ID='D-smokeP2' / P2
&DEVC XYZ=4.52, 1.19, 2.3, QUANTITY='TEMPERATURE' ID='D-smoke' / TC at smoke detector

&TAIL/

9.3 Sofa Test with Window Half Open Using Load Cell Heat Release Rate

```
&HEAD CHID='sofaV',TITLE='Sofa in apt ventilated - half opening (20cm) - POST TEST'  /


&MESH IJK=64,90,48, XB=5.8,9.0, 0.0,4.5, 0.0,2.4 / 5 cm living room-fire room          276 480
&MESH IJK=50,45,24, XB=0.8,5.8, 0.0,4.5, 0.0,2.4 / 10 cm - rest                          54 000
&MESH IJK=60,32,16, XB=-0.7,0.8, 0.7,1.5, 1.0,1.4 / 2.5cm - window vent                  30 720
&MESH IJK=15,7,24,  XB=-0.7,0.8, 0.0,0.7, 0.0,2.4 / 10cm - LEFT OF window    2520
&MESH IJK=15,30,24, XB=-0.7,0.8, 1.5,4.5, 0.0,2.4 / 10cm - RIGHT OF window             10 800
&MESH IJK=15,8,10,  XB=-0.7,0.8, 0.7,1.5, 0.0,1.0 / 10cm - UNDER window                  1200
&MESH IJK=15,8,10,  XB=-0.7,0.8, 0.7,1.5, 1.4,2.4 / 10cm - OVER window                   1200
                                                                    total      378 920



NOTES:          CO from Chris's old test data
          New leak measurements
          HOC from new hood tests
          HRR from Test



Rooms:
B - bedroom
K - Kitchen
D - dining room
L - living room

Walls:
   4
 ---------
 !  !  !  !
3! C!__!A !1
 !   B    !
 ---------
   2


&TIME T_END=1800 / 1800                        <set
```

```
&MISC SURF_DEFAULT='GWB',
        TMPA=27,
        CO_PRODUCTION=.TRUE. /                     <set

&DUMP   DT_DEVC=1,
        DT_SLCF=1,
        DT_BNDF=5,
        DT_PL3D=90,
        PLOT3D_QUANTITY(1:5)='TEMPERATURE','carbon
monoxide','oxygen','VELOCITY','HRRPUV'/     <set


&REAC ID='POLYURETHANE'
        FYI='C_6.3 H_7.1 N O_2.1, NFPA Handbook, Babrauskas'
        SOOT_YIELD=0.215
        C= 6.3
        H= 7.1
        N= 1
        O= 2.1
        CO_YIELD=0.030,
        HEAT_OF_COMBUSTION=23080/   mw=130.3. Soot yield, CO yield from chris's old
test data. .



&MATL ID='GWB',
        CONDUCTIVITY = 0.17,
        SPECIFIC_HEAT = 1.1,
        DENSITY = 800. /

&SURF ID='GWB',
        MATL_ID='GWB',
        BACKING='EXPOSED',
        THICKNESS=0.032/

SURF ID='GWB_L',
        MATL_ID='GWB',
        BACKING='EXPOSED',
        THICKNESS=0.032,
        LEAK_PATH=1,0                <not used


&MATL ID='GLASS',
        CONDUCTIVITY = 1.4,
        SPECIFIC_HEAT = 0.75,
        DENSITY = 2500. /
```

```
&SURF ID='GLASS',
        MATL_ID='GLASS',
        BACKING='EXPOSED',
        THICKNESS=0.005,
        COLOR='WHITE'/


&MATL ID = 'CARPET_MATL'
CONDUCTIVITY = 0.1600
SPECIFIC_HEAT = 9.0
DENSITY = 750.0
HEAT_OF_COMBUSTION=22300/


&SURF ID = 'CARPET'
        MATL_ID = 'CARPET_MATL'
        RGB=176, 224, 230
        BACKING = 'INSULATED'
        THICKNESS = 0.006
        HEAT_OF_VAPORIZATION=2000,
        IGNITION_TEMPERATURE= 290.00, / carpet, form FDS 4 database


&MATL ID = 'Plywood',
CONDUCTIVITY = 0.12,
SPECIFIC_HEAT = 1.3,
DENSITY = 545 /

&SURF ID='WOOD'
        MATL_ID= 'Plywood',
        RGB= 218, 165, 32,
        HRRPUA= 243.36 ,
        THICKNESS= 0.025 ,
        IGNITION_TEMPERATURE= 326.00,
        RAMP_Q= 'RAMP_Q_PS09TG'/

&RAMP ID='RAMP_Q_PS09TG' T=0.00 F=0.00/
&RAMP ID='RAMP_Q_PS09TG' T=30.00 F=0.81/
&RAMP ID='RAMP_Q_PS09TG' T=70.00 F=0.0800/
&RAMP ID='RAMP_Q_PS09TG' T=95.00 F=0.3900/
&RAMP ID='RAMP_Q_PS09TG' T=175.00 F=0.53/
&RAMP ID='RAMP_Q_PS09TG' T=325.00 F=0.2200/
&RAMP ID='RAMP_Q_PS09TG' T=445.00 F=0.2800/
&RAMP ID='RAMP_Q_PS09TG' T=575.00 F=1.00/
&RAMP ID='RAMP_Q_PS09TG' T=700.00 F=0.2100/
&RAMP ID='RAMP_Q_PS09TG' T=1.475000E003 F=0.1400/
```

```
&SURF ID='SOFA'
        COLOR='BROWN'
        HRRPUA=  1053.9,
        RAMP_Q= 'RAMP_Q_SOFA'/   hrrmax=1150 kw / 1.35 m2 = 851.85 kw/m2

&RAMP ID='RAMP_Q_SOFA',     T=    0.00    ,F=    0.000    /
&RAMP ID='RAMP_Q_SOFA',     T=    81.00   ,F=    0.003    /
&RAMP ID='RAMP_Q_SOFA',     T=    227.41  ,F=    0.003    /
&RAMP ID='RAMP_Q_SOFA',     T=    401.87  ,F=    0.010    /
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&RAMP ID='RAMP_Q_SOFA',     T=    448.60  ,F=    0.038    /
&RAMP ID='RAMP_Q_SOFA',     T=    457.94  ,F=    0.003    /
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&RAMP ID='RAMP_Q_SOFA',     T=    604.36  ,F=    0.010    /
&RAMP ID='RAMP_Q_SOFA',     T=    613.71  ,F=    0.048    /
&RAMP ID='RAMP_Q_SOFA',     T=    632.40  ,F=    0.010    /
&RAMP ID='RAMP_Q_SOFA',     T=    657.32  ,F=    0.022    /
&RAMP ID='RAMP_Q_SOFA',     T=    679.13  ,F=    0.003    /
&RAMP ID='RAMP_Q_SOFA',     T=    697.82  ,F=    0.070    /
&RAMP ID='RAMP_Q_SOFA',     T=    716.51  ,F=    0.105    /
&RAMP ID='RAMP_Q_SOFA',     T=    725.86  ,F=    0.096    /
&RAMP ID='RAMP_Q_SOFA',     T=    738.32  ,F=    0.115    /
&RAMP ID='RAMP_Q_SOFA',     T=    757.01  ,F=    0.227    /
&RAMP ID='RAMP_Q_SOFA',     T=    775.70  ,F=    0.125    /
&RAMP ID='RAMP_Q_SOFA',     T=    791.28  ,F=    0.230    /
&RAMP ID='RAMP_Q_SOFA',     T=    800.62  ,F=    0.227    /
&RAMP ID='RAMP_Q_SOFA',     T=    825.55  ,F=    0.304    /
&RAMP ID='RAMP_Q_SOFA',     T=    831.78  ,F=    0.339    /
&RAMP ID='RAMP_Q_SOFA',     T=    844.24  ,F=    0.329    /
&RAMP ID='RAMP_Q_SOFA',     T=    866.04  ,F=    0.690    /
&RAMP ID='RAMP_Q_SOFA',     T=    894.08  ,F=    1.000    /
&RAMP ID='RAMP_Q_SOFA',     T=    919.00  ,F=    0.671    /
&RAMP ID='RAMP_Q_SOFA',     T=    934.58  ,F=    0.259    /
&RAMP ID='RAMP_Q_SOFA',     T=    962.62  ,F=    0.064    /
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&RAMP ID='RAMP_Q_SOFA',     T=    1024.92,F=    0.010    /
&RAMP ID='RAMP_Q_SOFA',     T=    1040.50,F=    0.042    /
&RAMP ID='RAMP_Q_SOFA',     T=    1077.88,F=    0.006    /
&RAMP ID='RAMP_Q_SOFA',     T=    1096.57,F=    0.061    /
&RAMP ID='RAMP_Q_SOFA',     T=    1105.92,F=    0.010    /
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&RAMP ID='RAMP_Q_SOFA',    T=   1121.50,F=   0.029   /
&RAMP ID='RAMP_Q_SOFA',    T=   1130.84,F=   0.016   /
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&RAMP ID='RAMP_Q_SOFA',    T=   1283.49,F=   0.022   /
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&RAMP ID='RAMP_Q_SOFA',    T=   1327.10,F=   0.019   /
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&RAMP ID='RAMP_Q_SOFA',    T=   1404.98,F=   0.006   /
&RAMP ID='RAMP_Q_SOFA',    T=   1423.68,F=   0.003   /
&RAMP ID='RAMP_Q_SOFA',    T=   1429.91,F=   0.048   /
&RAMP ID='RAMP_Q_SOFA',    T=   1442.37,F=   0.003   /
&RAMP ID='RAMP_Q_SOFA',    T=   1479.75,F=   0.029   /
&RAMP ID='RAMP_Q_SOFA',    T=   1485.98,F=   0.006   /
&RAMP ID='RAMP_Q_SOFA',    T=   1514.02,F=   0.006   /
&RAMP ID='RAMP_Q_SOFA',    T=   1523.36,F=   0.048   /
&RAMP ID='RAMP_Q_SOFA',    T=   1535.83,F=   0.006   /
&RAMP ID='RAMP_Q_SOFA',    T=   1563.86,F=   0.038   /
&RAMP ID='RAMP_Q_SOFA',    T=   1591.90,F=   0.006   /
&RAMP ID='RAMP_Q_SOFA',    T=   1607.48,F=   0.013   /
&RAMP ID='RAMP_Q_SOFA',    T=   1635.51,F=   0.029   /
&RAMP ID='RAMP_Q_SOFA',    T=   1647.98,F=   0.006   /
&RAMP ID='RAMP_Q_SOFA',    T=   1676.01,F=   0.006   /
&RAMP ID='RAMP_Q_SOFA',    T=   1691.59,F=   0.026   /
&RAMP ID='RAMP_Q_SOFA',    T=   1697.82,F=   0.010   /
&RAMP ID='RAMP_Q_SOFA',    T=   1719.63,F=   0.010   /
&RAMP ID='RAMP_Q_SOFA',    T=   1722.74,F=   0.022   /
&RAMP ID='RAMP_Q_SOFA',    T=   1753.89,F=   0.016   /
&RAMP ID='RAMP_Q_SOFA',    T=   1834.89,F=   0.010   /
&RAMP ID='RAMP_Q_SOFA',    T=   1841.12,F=   0.026   /
&RAMP ID='RAMP_Q_SOFA',    T=   1847.35,F=   0.013   /
&RAMP ID='RAMP_Q_SOFA',    T=   1925.23,F=   0.013   /
&RAMP ID='RAMP_Q_SOFA',    T=   1996.88,F=   0.010   /
```

upholstery (chair)

```
&MATL ID='UPHOLSTERY',
      CONDUCTIVITY=0.25,
      SPECIFIC_HEAT=1.4
```

DENSITY=30/ from FDS4 database, Density from IKEA.com

&SURF ID='CHAIR',
MATL_ID='UPHOLSTERY',
COLOR='WHITE',
THICKNESS=0.3,
IGNITION_TEMPERATURE=280,
HEAT_OF_VAPORIZATION=1500/ << change HRR curve/HEAT OF VAPO ?

&OBST XB= 6.68,6.9, 3.25,3.35, 0.6,0.70, SURF_ID='INERT'/ Tissue box 0.12 x 0.22 x 0.10 cm

SOFA A=1.35M2
&OBST XB= 6.3,6.9, 2.55,4.05, 0.2,0.6, SURF_IDS='SOFA','INERT','INERT'/ A= 0.9 m2 sofa fire
&OBST XB= 6.0,6.3, 2.55,4.05, 0.6,0.9, SURF_ID6='INERT', 'SOFA','INERT','INERT','INERT','INERT'/ A= 0.45m2 sofa fire
&OBST XB= 6.0,6.9, 2.4,2.55, 0.2,0.9, SURF_ID='INERT'/ R ARM
&OBST XB= 6.0,6.9, 4.05,4.2, 0.2,0.9, SURF_ID='INERT' /L ARM

&OBST XB= 6.0,7.0, 2.1,4.3, 0.15,0.2, SURF_ID='GWB'/ LOAD CELL PLATFORM

LEAK

ZONE XB=-0.3, 9.0, 0.0, 4.5, 0.0, 2.4, LEAK_AREA(0)=0.0074 pressure zone - leak area (as measured in NEW tests (0.16/2)) <Not used

Interior walls
&OBST XB= 3.28, 3.35, 0.0, 4.5, 0.0, 2.4, SURF_ID='GWB' / Wall C
&HOLE XB= 3.25, 3.38, 1.1, 2.0, 0.0, 2.0 / Door in wall C
&OBST XB= 3.35, 5.9, 2.1, 2.2, 0.0, 2.4, SURF_ID='GWB' / Wall B
&HOLE XB= 4.0, 4.9, 2.1, 2.2, 0.0, 2.0 / Door in wall B
&OBST XB= 5.78, 5.92, 0.0, 4.5, 0.0, 2.4, SURF_ID='GWB' / Wall A
&HOLE XB= 5.77, 5.94, 0.0, 2.1, 0.0, 2.0 / Door in wall A

&OBST XB= 0.0,0.1, 0.0,4.5, 0.0,2.4, SURF_ID='GWB'/ BR WALL
&HOLE XB= 0.0,0.1, 0.9,1.5, 1.1,1.3/ OPEN WINDOW

Door and Windows.
&VENT XB= 9.0,9.0, 0.9,1.7, 0.0,2.0, SURF_ID='INERT' / exterior door. Wall 1
&VENT XB= 9.0,9.0, 3.3,3.9, 1.1,2.1, SURF_ID='GLASS' / window. Wall 1
&VENT XB= 4.3,4.9, 0.0,0.0, 1.1,2.1, SURF_ID='GLASS' / window. Wall 2
&VENT XB= 6.4,7.0, 0.0,0.0, 1.1,2.1, SURF_ID='GLASS' / window 2 Wall 2
&VENT XB= 0.1,0.1, 0.9,1.5, 1.3,2.1, SURF_ID='GLASS' / window. Wall 3

OPEN VENTS
OUTSIDE WINDOW

```
&VENT MB=XMIN, SURF_ID='OPEN'/
&VENT XB= -0.7,0.0, 0.0,4.5, 2.4,2.4, SURF_ID='OPEN'/ CEILING
&VENT XB= -0.7,0.0, 0.0,0.0, 0.0,2.4, SURF_ID='OPEN'/ Y MIN
&VENT XB= -0.7,0.0, 4.5,4.5, 0.0,2.4, SURF_ID='OPEN'/ Y MAX
```

FURNITURE
coffe table

```
&OBST XB= 7.3,7.85, 2.85,3.75, 0.4,0.45, SURF_ID='INERT', RGB=95, 48, 20/  surface
&OBST XB= 7.3,7.35, 2.85,2.90, 0.0,0.4, SURF_ID='INERT', RGB=95, 48, 20/  leg 1
          2   3
&OBST XB= 7.3,7.35, 3.70,3.75, 0.0,0.4, SURF_ID='INERT', RGB=95, 48, 20/leg 2
&OBST XB= 7.8,7.85, 3.70,3.75, 0.0,0.4, SURF_ID='INERT', RGB=95, 48, 20/leg 3
&OBST XB= 7.8,7.85, 2.85,2.90, 0.0,0.4, SURF_ID='INERT', RGB=95, 48, 20/ leg 4
          1   4
```

armchair

```
&OBST XB=8.1,8.8, 3.6,4.3, 0.0,0.7,, SURF_ID='INERT', COLOR='WHITE' /  chair
```

carpet

```
&VENT XB=0.0,3.3, 0.0,4.5, 0.0,0.0, SURF_ID='CARPET'/BEDROOM
&VENT XB=3.3,5.8, 0.0,2.1, 0.0,0.0, SURF_ID='CARPET'/DINING ROOM
&VENT XB=5.8,9.0, 0.0,4.5, 0.0,0.0, SURF_ID='CARPET'/LIVING ROOM
```

```
&BNDF QUANTITY='GAUGE_HEAT_FLUX'/
&BNDF QUANTITY='BURNING_RATE'/
&BNDF QUANTITY='ADIABATIC_SURFACE_TEMPERATURE'/
```

Slice files

```
&SLCF PBY= 1.0, QUANTITY='TEMPERATURE' /
&SLCF PBY= 2.3, QUANTITY='TEMPERATURE' /
&SLCF PBX= 4.5, QUANTITY='TEMPERATURE' /
&SLCF PBX= 6.3, QUANTITY='TEMPERATURE' /

&SLCF PBY= 1.0, QUANTITY='oxygen' /
&SLCF PBY= 2.3, QUANTITY='oxygen' /
&SLCF PBX= 4.5, QUANTITY='oxygen' /
&SLCF PBX= 6.3, QUANTITY='oxygen' /

&SLCF PBY= 2.3, QUANTITY='MIXTURE_FRACTION' /
```

&SLCF PBX= 4.5, QUANTITY='MIXTURE_FRACTION' /
&SLCF PBX= 6.3, QUANTITY='MIXTURE_FRACTION' /

&SLCF PBY= 1.5, QUANTITY='U-VELOCITY' /

DEVICES:

&DEVC XB=5.9,9, 0.0,4.5, 0.0,2.4, QUANTITY='MIXTURE_FRACTION', STATISTICS='MASS MEAN', ID='Zmean_L'/ MIXTURE FRACTION Living room (mesh mean)
&DEVC XB=0.0,5.8, 0.0,4.5, 0.0,2.4, QUANTITY='MIXTURE_FRACTION', STATISTICS='MASS MEAN', ID='Zmean_KB'/ MIXTURE FRACTION K,D,B (mesh mean)

TEMPERATURE

TC rack 1 - bedroom:
&DEVC XYZ=1.6,2.2, 0.05, QUANTITY='THERMOCOUPLE', ID='B1'/
&DEVC XYZ=1.6,2.2, 0.3, QUANTITY='THERMOCOUPLE', ID='B2'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='THERMOCOUPLE', ID='B3'/
&DEVC XYZ=1.6,2.2, 0.9, QUANTITY='THERMOCOUPLE', ID='B4'/
&DEVC XYZ=1.6,2.2, 1.2, QUANTITY='THERMOCOUPLE', ID='B5'/
&DEVC XYZ=1.6,2.2, 1.5, QUANTITY='THERMOCOUPLE', ID='B6'/
&DEVC XYZ=1.6,2.2, 1.8, QUANTITY='THERMOCOUPLE', ID='B7'/
&DEVC XYZ=1.6,2.2, 2.1, QUANTITY='THERMOCOUPLE', ID='B8'/
&DEVC XYZ=1.6,2.2, 2.35, QUANTITY='THERMOCOUPLE', ID='B9'/

TC rack 2 - kitchen (aspirated TC) +3 Non-aspir
&DEVC XYZ=4.6,3.1, 0.05, QUANTITY='TEMPERATURE', ID='K1'/
&DEVC XYZ=4.6,3.1, 0.3, QUANTITY='TEMPERATURE', ID='K2'/
&DEVC XYZ=4.6,3.1, 0.6, QUANTITY='TEMPERATURE', ID='K3'/
&DEVC XYZ=4.6,3.1, 0.9, QUANTITY='TEMPERATURE', ID='K4'/
&DEVC XYZ=4.6,3.1, 1.2, QUANTITY='TEMPERATURE', ID='K5'/
&DEVC XYZ=4.6,3.1, 1.5, QUANTITY='TEMPERATURE', ID='K6'/
&DEVC XYZ=4.6,3.1, 1.8, QUANTITY='TEMPERATURE', ID='K7'/
&DEVC XYZ=4.6,3.1, 2.1, QUANTITY='TEMPERATURE', ID='K8'/
&DEVC XYZ=4.6,3.1, 2.35, QUANTITY='TEMPERATURE', ID='K9'/
non-aspirated
&DEVC XYZ=4.6,3.1, 0.61, QUANTITY='THERMOCOUPLE', ID='K-N1'/
&DEVC XYZ=4.6,3.1, 1.52, QUANTITY='THERMOCOUPLE', ID='K-N2'/
&DEVC XYZ=4.6,3.1, 2.13, QUANTITY='THERMOCOUPLE', ID='K-N3'/

TC rack 3 - dining room:
&DEVC XYZ=4.6,1.0, 0.05, QUANTITY='THERMOCOUPLE', ID='D1'/

&DEVC XYZ=4.6,1.0, 0.3, QUANTITY='THERMOCOUPLE', ID='D2'/
&DEVC XYZ=4.6,1.0, 0.6, QUANTITY='THERMOCOUPLE', ID='D3'/
&DEVC XYZ=4.6,1.0, 0.9, QUANTITY='THERMOCOUPLE', ID='D4'/
&DEVC XYZ=4.6,1.0, 1.2, QUANTITY='THERMOCOUPLE', ID='D5'/
&DEVC XYZ=4.6,1.0, 1.5, QUANTITY='THERMOCOUPLE', ID='D6'/
&DEVC XYZ=4.6,1.0, 1.8, QUANTITY='THERMOCOUPLE', ID='D7'/
&DEVC XYZ=4.6,1.0, 2.1, QUANTITY='THERMOCOUPLE', ID='D8'/
&DEVC XYZ=4.6,1.0, 2.35, QUANTITY='THERMOCOUPLE', ID='D9'/

TC rack 4 - living room (aspirated TC) +3 Non-aspir
&DEVC XYZ=7.4,1.4, 0.05, QUANTITY='TEMPERATURE', ID='L1'/
&DEVC XYZ=7.4,1.4, 0.3, QUANTITY='TEMPERATURE', ID='L2'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='TEMPERATURE', ID='L3'/
&DEVC XYZ=7.4,1.4, 0.9, QUANTITY='TEMPERATURE', ID='L4'/
&DEVC XYZ=7.4,1.4, 1.2, QUANTITY='TEMPERATURE', ID='L5'/
&DEVC XYZ=7.4,1.4, 1.5, QUANTITY='TEMPERATURE', ID='L6'/
&DEVC XYZ=7.4,1.4, 1.8, QUANTITY='TEMPERATURE', ID='L7'/
&DEVC XYZ=7.4,1.4, 2.1, QUANTITY='TEMPERATURE', ID='L8'/
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='TEMPERATURE', ID='L9'/
non-aspirated
&DEVC XYZ=7.4,1.4, 0.61, QUANTITY='TEMPERATURE', ID='L-N1'/
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='TEMPERATURE', ID='L-N2'/
&DEVC XYZ=7.4,1.4, 2.13, QUANTITY='TEMPERATURE', ID='L-N3'/

TC rack 5 - doorway: DOOR TCs

&DEVC XYZ=9.0,1.3, 0.05, QUANTITY='TEMPERATURE', ID='door1'/
&DEVC XYZ=9.0,1.3, 0.3, QUANTITY='TEMPERATURE', ID='door2'/
&DEVC XYZ=9.0,1.3, 0.6, QUANTITY='TEMPERATURE', ID='door3'/
&DEVC XYZ=9.0,1.3, 0.9, QUANTITY='TEMPERATURE', ID='door4'/
&DEVC XYZ=9.0,1.3, 1.2, QUANTITY='TEMPERATURE', ID='door5'/
&DEVC XYZ=9.0,1.3, 1.5, QUANTITY='TEMPERATURE', ID='door6'/
&DEVC XYZ=9.0,1.3, 1.8, QUANTITY='TEMPERATURE', ID='door7'/
&DEVC XYZ=9.0,1.3, 2.1, QUANTITY='TEMPERATURE', ID='door8'/

WINDOW FLOW TCs
at window
&DEVC XYZ=0.1, 1.2, 1.1, QUANTITY='TEMPERATURE', ID='win1'/
&DEVC XYZ=0.1, 1.2, 1.2, QUANTITY='TEMPERATURE', ID='win2'/
&DEVC XYZ=0.1, 1.2, 1.3, QUANTITY='TEMPERATURE', ID='win3'/
2.5 lengths from window
&DEVC XYZ=1.0, 1.2, 1.1, QUANTITY='TEMPERATURE', ID='winBR1'/
&DEVC XYZ=1.0, 1.2, 1.2, QUANTITY='TEMPERATURE', ID='winBR2'/
&DEVC XYZ=1.0, 1.2, 1.3, QUANTITY='TEMPERATURE', ID='winBR3'/
Wall TCs

WALL TCs - Inside

living room

&DEVC XYZ=9.0, 3.45, 0.61, QUANTITY='WALL_TEMPERATURE', ID='W1-1-in', IOR=-1/
&DEVC XYZ=9.0, 3.45, 1.83, QUANTITY='WALL_TEMPERATURE', ID='W1-2-in', IOR=-1/

bedroom

&DEVC XYZ=0.1, 3.1, 0.61, QUANTITY='WALL_TEMPERATURE', ID='W3-1-in', IOR=1/
&DEVC XYZ=0.1, 3.1, 1.83, QUANTITY='WALL_TEMPERATURE', ID='W3-2-in', IOR=1/

kitchen

&DEVC XYZ=4.5, 4.5, 0.61, QUANTITY='WALL_TEMPERATURE', ID='W4-1-in', IOR=-2/
&DEVC XYZ=4.5, 4.5, 1.83, QUANTITY='WALL_TEMPERATURE', ID='W4-2-in', IOR=-2/

WALL TCs - outside

living room

&DEVC XYZ=9.0, 3.45, 0.61, QUANTITY='BACK_WALL_TEMPERATURE', ID='W1-1-out', IOR=-1/
&DEVC XYZ=9.0, 3.45, 1.83, QUANTITY='BACK_WALL_TEMPERATURE', ID='W1-2-out', IOR=-1/

bedroom

&DEVC XYZ=0.0, 3.1, 0.61, QUANTITY='BACK_WALL_TEMPERATURE', ID='W3-1-out', IOR=1/
&DEVC XYZ=0.0, 3.1, 1.83, QUANTITY='BACK_WALL_TEMPERATURE', ID='W3-2-out', IOR=1/

kitchen

&DEVC XYZ=4.5, 4.5, 0.61, QUANTITY='BACK_WALL_TEMPERATURE', ID='W4-1-out', IOR=-2/
&DEVC XYZ=4.5, 4.5, 1.83, QUANTITY='BACK_WALL_TEMPERATURE', ID='W4-2-out', IOR=-2/

Window TCs

&DEVC XYZ=8.95,3.1, 1.0, QUANTITY='THERMOCOUPLE', ID='win1-l'/ window in living room
&DEVC XYZ=8.95,3.1, 1.7, QUANTITY='THERMOCOUPLE', ID='win1-h'/

&DEVC XYZ=4.5,0.05, 1.1, QUANTITY='THERMOCOUPLE', ID='win2-l'/ window on wall 2 - dining room
&DEVC XYZ=4.5,0.05, 1.8, QUANTITY='THERMOCOUPLE', ID='win2-h'/

&DEVC XYZ=6.8,0.05, 1.1, QUANTITY='THERMOCOUPLE', ID='win2.2-l'/ window on wall 2 - living room
&DEVC XYZ=6.8,0.05, 1.8, QUANTITY='THERMOCOUPLE', ID='win2.2-h'/

&DEVC XYZ=0.1,1.2, 1.2, QUANTITY='THERMOCOUPLE', ID='win3-l'/ window in bed room
&DEVC XYZ=0.1,1.2, 1.7, QUANTITY='THERMOCOUPLE', ID='win3-h'/

GAS PROBES

Kitchen
ceiling
&DEVC XYZ=4.6,2.3, 2.35, QUANTITY='carbon monoxide', ID='K-CO-ceil'/
&DEVC XYZ=4.6,2.3, 2.35, QUANTITY='carbon dioxide', ID='K-CO2-ceil'/
&DEVC XYZ=4.6,2.3, 2.35, QUANTITY='oxygen', ID='K-O2-ceil'/
base of fire
&DEVC XYZ=4.6,2.3, 0.05, QUANTITY='carbon monoxide', ID='K-CO-floor'/
&DEVC XYZ=4.6,2.3, 0.05, QUANTITY='carbon dioxide', ID='K-CO2-floor'/
&DEVC XYZ=4.6,2.3, 0.05, QUANTITY='oxygen', ID='K-O2-floor'/

Living room

ceiling
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='carbon monoxide', ID='L-CO-ceil'/
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='carbon dioxide', ID='L-CO2-ceil'/
&DEVC XYZ=7.4,1.4, 2.35, QUANTITY='oxygen', ID='L-O2-ceil'/
tree
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='carbon monoxide', ID='L-CO-1.5'/
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='carbon dioxide', ID='L-CO2-1.5'/
&DEVC XYZ=7.4,1.4, 1.52, QUANTITY='oxygen', ID='L-O2-1.5'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='carbon monoxide', ID='L-CO-0.6'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='carbon dioxide', ID='L-CO2-0.6'/
&DEVC XYZ=7.4,1.4, 0.6, QUANTITY='oxygen', ID='L-O2-0.6'/
base of fire
&DEVC XYZ=7.0,3.1, 0.05, QUANTITY='carbon monoxide', ID='L-CO-fire'/
&DEVC XYZ=7.0,3.1, 0.05, QUANTITY='carbon dioxide', ID='L-CO2-fire'/
&DEVC XYZ=7.0,3.1, 0.05, QUANTITY='oxygen', ID='L-O2-fire'/

Bedroom
ceiling
&DEVC XYZ=1.6,2.2, 2.35, QUANTITY='carbon monoxide', ID='B-CO-ceil'/
&DEVC XYZ=1.6,2.2, 2.35, QUANTITY='carbon dioxide', ID='B-CO2-ceil'/
&DEVC XYZ=1.6,2.3, 2.35, QUANTITY='oxygen', ID='B-O2-ceil'/
tree
&DEVC XYZ=1.6,2.2, 1.52, QUANTITY='carbon monoxide', ID='B-CO-1.5'/
&DEVC XYZ=1.6,2.2, 1.52, QUANTITY='carbon dioxide', ID='B-CO2-1.5'/
&DEVC XYZ=1.6,2.2, 1.52, QUANTITY='oxygen', ID='B-O2-1.5'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='carbon monoxide', ID='B-CO-0.6'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='carbon dioxide', ID='B-CO2-0.6'/
&DEVC XYZ=1.6,2.2, 0.6, QUANTITY='oxygen', ID='B-O2-0.6'/

fuel
&DEVC XYZ=7.4,1.4, 2.375, QUANTITY='fuel', ID='L-fuel'/ LR
&DEVC XYZ=4.6,2.3, 2.375, QUANTITY='fuel', ID='K-fuel'/ K

HEAT FLUX

&PROP ID='hf1', GAUGE_TEMPERATURE=40 /

Horizontal orientation - floor
&DEVC XYZ=1.6,2.3, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='B-floorHF', PROP_ID='hf1'/
&DEVC XYZ=4.5,3.1, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='K-floorHF', PROP_ID='hf1'/
&DEVC XYZ=7.4,1.4, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='L-floorHF', PROP_ID='hf1'/
&DEVC XYZ=4.5,1.0, 0.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='D-floorHF', PROP_ID='hf1'/

vertical orientation - towards fire
&OBST XB= 4.6,4.7, 2.99,3.0, 0.9,1.0 SURF_ID='INERT' / kitchen
&OBST XB= 7.9,7.91, 3.3,3.4, 0.9,1.0 SURF_ID='INERT' / living room
DEVC XYZ=4.6, 3.0, 1.0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-fireHF', PROP_ID='hf1' kitchen
&DEVC XYZ=7.9, 3.35, 0.95, QUANTITY='GAUGE_HEAT_FLUX', IOR=-1, ID='L-fireHF', PROP_ID='hf1' / living room

wall accross from fire
&DEVC XYZ=5.0, 2.2, 0.61, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-wallHF-L', PROP_ID='hf1'/ kitchen wall low
&DEVC XYZ=5.0, 2.2, 1.83, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-wallHF-H', PROP_ID='hf1'/ kitchen wall high
&DEVC XYZ=9.0, 3.5, 0.61, QUANTITY='GAUGE_HEAT_FLUX', IOR=-1, ID='L-wallHF-L', PROP_ID='hf1'/ living room wall low
&DEVC XYZ=9.0, 3.5, 1.83, QUANTITY='GAUGE_HEAT_FLUX', IOR=-1, ID='L-wallHF-H', PROP_ID='hf1'/ living room wall high

VISIBILITY
POINT

living room
&DEVC XYZ=8.59, 1.07, 2.3, QUANTITY='visibility', ID='L-vis-C1'/ Living room - ceiling 1
&DEVC XYZ=8.59, 1.98, 2.3, QUANTITY='visibility', ID='L-vis-C2'/ Living room - ceiling 2

&DEVC XYZ=7.78, 1.22, 0.61, QUANTITY='visibility', ID='L-vis-L'/ Living room - egress low
&DEVC XYZ=7.78, 1.22, 1.54, QUANTITY='visibility', ID='L-vis-H'/ Living room - egress high

dining room
&DEVC XYZ=4.55, 1.07, 2.3, QUANTITY='visibility', ID='D-vis-C'/ Dining room - ceiling

bedroom

&DEVC XYZ=0.2, 1.07, 2.3, QUANTITY='visibility', ID='B-vis-C1'/ Bedroom - ceiling 1
&DEVC XYZ=0.41, 1.98, 2.3, QUANTITY='visibility', ID='B-vis-C2'/ Bedroom - ceiling 2

&DEVC XYZ=0.31, 1.22, 0.61, QUANTITY='visibility', ID='B-vis-L'/ Bedroom - egress low
&DEVC XYZ=0.31, 1.22, 1.54, QUANTITY='visibility', ID='B-vis-H'/ Bedroom - egress high

PATH OBSCURATION
&DEVC XB=8.80, 8.80, 0.31, 1.83, 2.3,2.3, QUANTITY='path obscuration', ID='L-ODM-C1' / Living room ODM ceiling 1
&DEVC XB=8.59, 8.59, 1.22, 2.74, 2.3,2.3, QUANTITY='path obscuration', ID='L-ODM-C2' / Living room ODM ceiling 2

&DEVC XB=7.78, 7.78, 0.46, 1.98, 0.61, QUANTITY='path obscuration', ID='L-ODM-L' / Living room ODM in egress path - low 0.61m
&DEVC XB=7.78, 7.78, 0.46, 1.98, 1.54, QUANTITY='path obscuration', ID='L-ODM-H' / Living room ODM in egress path - high 1.54m

&DEVC XB=0.2, 0.2, 0.31, 1.83, 2.3,2.3, QUANTITY='path obscuration', ID='B-ODM-C1' / bedroom ODM ceiling 1
&DEVC XB=0.41,0.41, 1.22, 2.74, 2.3,2.3, QUANTITY='path obscuration', ID='B-ODM-C2' / bedroom ODM ceiling 2

&DEVC XB=0.31, 0.31, 0.46, 1.98, 0.61, QUANTITY='path obscuration', ID='B-ODM-L' / Bedroom ODM in egress path - low 0.61m
&DEVC XB=0.31, 0.31, 0.46, 1.98, 1.54, QUANTITY='path obscuration', ID='B-ODM-H' / Bedroom ODM in egress path - high 1.54m

&DEVC XB=4.55, 4.55, 0.31, 1.83, 2.3,2.3, QUANTITY='path obscuration', ID='D-ODM-C' / dining room ODM ceiling

BI_DIRECTIONAL PROBEs
(V-velocity)
&DEVC XYZ= 3.4,1.5,0.51, QUANTITY='V-VELOCITY', ID='VEL_0.5'/
&DEVC XYZ= 3.4,1.5,1.02, QUANTITY='V-VELOCITY', ID='VEL_1.0'/
&DEVC XYZ= 3.4,1.5,1.52, QUANTITY='V-VELOCITY', ID='VEL_1.5'/
&DEVC XYZ= 3.4,1.5,2.03, QUANTITY='V-VELOCITY', ID='VEL_2.0'/

&DEVC XYZ= 0.1,1.2,1.2, QUANTITY='V-VELOCITY', ID='VEL_B-Win'/ at beedroom window

Flow measurements
&DEVC XB=4.0,4.9, 2.2,2.2, 0.0,2.0, QUANTITY='MASS FLOW +', ID='mass + kitch' / kitch
&DEVC XB=4.0,4.9, 2.2,2.2, 0.0,2.0, QUANTITY='MASS FLOW -', ID='mass - kitch' /
&DEVC XB=5.9,9.0, 2.1,2.1, 0.0,2.0, QUANTITY='MASS FLOW +', ID='mass + liv' / liv
&DEVC XB=5.9,9.0, 2.1,2.1, 0.0,2.0, QUANTITY='MASS FLOW -', ID='mass - liv' /
&DEVC XB=0.0,0.0, 0.9,1.5, 1.1,1.3, QUANTITY='MASS FLOW +', ID='mass + BRwin' / out
&DEVC XB=0.0,0.0, 0.9,1.5, 1.1,1.3, QUANTITY='MASS FLOW -', ID='mass - BRwin' /

PRESSURE
LIVING ROOM

&DEVC XYZ= 8.9, 1.9, 2.13, QUANTITY='PRESSURE', ID='L-p1' / living room pressure 1
&DEVC XYZ= 8.9, 1.9, 1.52, QUANTITY='PRESSURE', ID='L-p2' / living room pressure 2
&DEVC XYZ= 8.9, 1.9, 0.91, QUANTITY='PRESSURE', ID='L-p3' / living room pressure 3
&DEVC XYZ= 8.9, 1.9, 0.31, QUANTITY='PRESSURE', ID='L-p4' / living room pressure 4
KITCHEN
&DEVC XYZ= 3.5, 4.4, 2.13, QUANTITY='PRESSURE', ID='K-p1' / kitchen pressure 1
&DEVC XYZ= 3.5, 4.4, 1.52, QUANTITY='PRESSURE', ID='K-p2' / kitchen pressure 2
&DEVC XYZ= 3.5, 4.4, 0.91, QUANTITY='PRESSURE', ID='K-p3' / kitchen pressure 3
&DEVC XYZ= 3.5, 4.4, 0.31, QUANTITY='PRESSURE', ID='K-p4' / kitchen pressure 4
BEDROOM
&DEVC XYZ= 0.1, 2.0, 2.13, QUANTITY='PRESSURE', ID='B-p1' / bedroom pressure 1
&DEVC XYZ= 0.1, 2.0, 1.52, QUANTITY='PRESSURE', ID='B-p2' / bedroom pressure 2
&DEVC XYZ= 0.1, 2.0, 0.91, QUANTITY='PRESSURE', ID='B-p3' / bedroom pressure 3
&DEVC XYZ= 0.1, 2.0, 0.31, QUANTITY='PRESSURE', ID='B-p4' / bedroom pressure 4

SMOKE DETECTORS (+TEMP AND VELOCITY)
From User's guide:
&PROP ID='smoke_I1', QUANTITY='spot obscuration', ALPHA_E=2.5, BETA_E=-0.7, ALPHA_C=0.8, BETA_C=-0.9, ACTIVATION_OBSCURATION=3.28 / Cleary ionization I1
&PROP ID='smoke_I2', QUANTITY='spot obscuration', ALPHA_E=1.8, BETA_E=-1.1, ALPHA_C=1.0, BETA_C=-0.8, ACTIVATION_OBSCURATION=3.28 / Cleary ionization I2
&PROP ID='smoke_P1', QUANTITY='spot obscuration', ALPHA_E=1.8, BETA_E=-1.0, ALPHA_C=1.0, BETA_C=-0.8, ACTIVATION_OBSCURATION=3.28 / Cleary photoelectric P1
&PROP ID='smoke_P2', QUANTITY='spot obscuration', ALPHA_E=1.8, BETA_E=-0.8, ALPHA_C=0.8, BETA_C=-0.8, ACTIVATION_OBSCURATION=3.28 / Cleary photoelectric P2
&PROP ID='smoke_H', QUANTITY='spot obscuration', LENGTH=1.8, ACTIVATION_OBSCURATION=3.28 / Heskestad model

LIVING ROOM

&DEVC XYZ=8.39, 1.37, 2.3, PROP_ID='smoke_I1', ID='L-smokeI1' / I1
&DEVC XYZ=8.39, 1.37, 2.3, PROP_ID='smoke_I2', ID='L-smokeI2' / I2
&DEVC XYZ=8.39, 1.37, 2.3, PROP_ID='smoke_H' , ID='L-smokeH' / HESK
&DEVC XYZ=8.39, 1.67, 2.3, PROP_ID='smoke_P1', ID='L-smokeP1' / P1
&DEVC XYZ=8.39, 1.67, 2.3, PROP_ID='smoke_P2', ID='L-smokeP2' / P2
&DEVC XYZ=8.39, 1.67, 2.3, QUANTITY='TEMPERATURE' ID='L-smoke' / TC at smoke detector

BEDROOM
&DEVC XYZ=0.61, 1.37, 2.3, PROP_ID='smoke_I1' , ID='B-smokeI1'/ I1
&DEVC XYZ=0.61, 1.37, 2.3, PROP_ID='smoke_I2' , ID='B-smokeI2'/ I2
&DEVC XYZ=0.61, 1.37, 2.3, PROP_ID='smoke_H' , ID='B-smokeH'/ HESK
&DEVC XYZ=0.61, 1.67, 2.3, PROP_ID='smoke_P1' , ID='B-smokeP1'/ P1
&DEVC XYZ=0.61, 1.67, 2.3, PROP_ID='smoke_P2' , ID='B-smokeP2' / P2
&DEVC XYZ=0.61, 1.67, 2.3, QUANTITY='TEMPERATURE' ID='B-smoke' / TC at smoke detector

DINING ROOM
&DEVC XYZ=4.52, 0.96, 2.3, PROP_ID='smoke_I1', ID='D-smokeI1' / I1
&DEVC XYZ=4.52, 0.96, 2.3, PROP_ID='smoke_I2', ID='D-smokeI2' / I2
&DEVC XYZ=4.52, 0.96, 2.3, PROP_ID='smoke_H' , ID='D-smokeH' / HESK
&DEVC XYZ=4.52, 1.19, 2.3, PROP_ID='smoke_P1', ID='D-smokeP1' / P1
&DEVC XYZ=4.52, 1.19, 2.3, PROP_ID='smoke_P2', ID='D-smokeP2' / P2
&DEVC XYZ=4.52, 1.19, 2.3, QUANTITY='TEMPERATURE' ID='D-smoke' / TC at smoke detector

&TAIL/

10 REFERENCES

Babrauskas, V. (2003). Upholstered Furniture and Mattresses. NFPA Fire protection handbook, Section 8/Chapter 17. A. E. Cote. Quincy, MA. **1**.

Babrauskas, V., Peacock, R. D. (1992). "Heat Release Rate: The Single Most Important Variable in Fire Hazard." Fire Safety Journal **18**: 255-272.

Beyler, C. (2002). Flammability Limits of Premixed and Diffusion Flames. SFPE Handbook of Fire Protection Engineering. P. DiNenno.

Beyler, C. L. (1986). "Major species production by diffusion flames in a two-layer compartment fire environment." Fire Safety Journal **10**(1).

Coward, H. F. and G. W. Jones (1952). "Limits of Flammability of Gases and Vapors". Washington DC, United States Department of the Interior, Bureau of Mines.

Cox, G., Kumar, S. (2002). Modeling Enclosure Fires Using CFD. SFPE Handbook of Fire Protection Engineering. P. DiNenno.

Drysdale, D. D. (2002). Thermochemistry. SFPE Handbook of Fire Protection Engineering. P. DiNenno.

Floyd, J. and K. McGrattan (2008). "Validation of A CFD Fire Model Using Two Step Combustion Chemistry Using the NIST Reduced-Scale Ventilation-Limited Compartment Data". Fire Safety Science, Proceedings of the Ninth International Symposium. Karlsruhe, Germany, International Association for Fire Safety Science.

Floyd, J. E. (2002). "Comparison of CFAST and FDS for Fire Simulation with the HDR T51 and T52 Tests", Fire Research Division, Building and Fire Research Laboratory, National Institute of Standards and Technology.

Floyd, J. E., McGrattan, K.B., Hostikka, S., Baum, H.R. (2003). "CFD Fire Simulation Using Mixture Fraction Combustion and Finite Volume Radiative Heat Transfer." Journal of Fire Protection Engineering **13**.

Friday, P. A. and F. W. Mowrer (2001). "Comparison of FDS Model Predictions With FM,SNL Fire Test Data." Department of Fire Protection Engineering, University of Maryland at College Park, National Institute of Standards and Technology.

Gottuk, D. T. (1992). "The Generation of Carbon Monoxide in Compartment Fires". Department of Mechanical Engineering. Blacksburg, VA, Virginia Polytechnic Institute and State University.

Gottuk, D. T. and B. Y. Lattimer (2002). Effect of Combustion Conditions on Species Production. SFPE Handbook of Fire Protection Engineering. P. DiNenno.

Gypsum Association (2005). "Gypsum board typical mechanical and physical properties."

Harmathy, T. Z. (1975). "The Role of Thermal Feedback in Compartment Fires." Fire Technology **11**(1).

Harmathy, T. Z. (1978). "Mechanism of Burning of Fully-Developed Compartment Fires." Combustion and Flame **31**(1): 265-273.

Huggett, C. (1980). "Estimation of the Rate of Heat Release by Means of Oxygen Consumption." Fire and Materials **12**.

ikea.com. (2008). "Ikea Furniture." Retrieved 06.05.2008, from http://www.ikea.com/us/en/.

Incropera, F. P., DeWitt, D. P. (2002). Fundamentals of Heat and Mass Transfer, Wiley.

Johnsson, E. L., M. F. Bundy and A. Hamins (2007). "Reduced-Scale Ventilation-Limited Enclosure Fires - Heat and Combustion Product Measurements ". Interflam 2007. London, England, International Interflam Conference, 11th Proceedings.

Jones, W. W. e. a. (2005). "CFAST - Consolidated Model of Fire Growth and Smoke Transport (Version 6) Technical Reference Guide", NIST.

Karlsson, B. and J. Quintiere, G. (2000). Enclosure Fire Dynamics.

Lazaro, M., H. Boehmer, D. Alvear, J. A. Capote and A. Trouve (2008). "Numerical Simulation of Fire Growth, Transition to Flashover, and Post-Flashover Dynamics in the Dalmarnock Fire Test". Fire Safety Science, Proceedings of the Ninth International Symposium. Karlsruhe, Germany, International Association for Fire Safety Science.

matweb.com. (2008). "Overview of materials for Acrylic, General Purpose." Retrieved 06.05.2008, from http://www.matweb.com/search/DataSheet.aspx?MatGUID=632572aeef2a4224b5ac8fbd4f1b6f77.

McGrattan, K., J. Floyd, G. Forney, H. Baum and S. Hostikka (2003). "Improved Radiation and Combustion Routines for a Large Eddy Simulation Fire Model". Fire Safety Science, Proceedings of the Seventh International Symposium. Boston, MA, International Association for Fire Safety Science.

McGrattan, K., B. Klein, S. Hostikka and J. Floyd (2008b). "Fire Dynamics Simulator (Version 5) User`s Guide", NIST.

McGrattan, K., Simo Hostikka, Jason Floyd, Howard Baum and R. Rehm (2008). "Fire Dynamics Simulator (Version 5) Technical Reference Guide", NIST.

Mealy, C. L. (2007). "A Study of Unventilated Enclosure Fires". Department of Fire Protection Engineering. College Park MD, University of Maryland. Master of Science.

Mowrer, F. W. (2008). A Simple Model of Flame Extinction. FDS 5 Technical reference guide, Appendix C.

NIST. (2008). "FDS-SMV Official Website." Retrieved 03.15, 2008, from http://www.fire.nist.gov/fds/.

NIST. (2008b). "FDS Release Notes." Retrieved 10.08.2008, from http://code.google.com/p/fds-smv/wiki/FDSReleaseNotes.

Novozhilov, V. (2001). "Computational Fluid Dynamics Modeling of Compartment Fires." Progress in Energy and Combustion Science **27**: 611-666.

Omega (2002). "The OMEGA Made in the USA Handbook, Volume 1". Stamford CT, USA, Omega Engineering**:** Page: Z - 204.

Pitts, W. M. (1994). "The Global Equivalence Ratio Concept and the Prediction of Carbon Monoxide Formation in Enclosure Fires", NIST Monograph 179, National Institute of Standards and Technology.

Quintiere, J. G. (2002). Compartment Fire Modeling. SFPE Handbook of Fire Protection Engineering. P. DiNenno. **3**.

Richie, S. J., K. D. Steckler, A. Hamins, T. G. Cleary, J. C. Yang and T. Kashiwagi (1997). "The effect of sample size on the heat release rate of charring materials. " Fire safety science, Proceedings of the Fifth International Symposium. Melbourne Australia, International Association for Fire Safety Science.

Salley, M. (2007). "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications". Rockville, MD, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research. Electric Power Research Institute. 7 - Fire Dynamics Simulator - FDS.

Tewarson, A. (2002). Generation of Heat and Chemical Compounds in Fires. SFPE Handbook of Fire Protection Engineering. P. DiNenno.

Wieczorek, C. J., U. Vandsburger and J. Floyd (2004). "Evaluating the Global Equivalence Ratio Concept for Compartment Fires: Part II–Limitations for Correlating Species Yields." Journal of Fire Protection Engineering **14**.

Wolfe, A. (2008). "Underventilated Full Scale Fire Tests". College Park, MD, USA, University of Maryland.

Yaping He, Chris Jamieson, Alan Jeary and Jian Wang (2008). "Effect of Computational Domain on Simulation of Small Comapartment Fires". Fire Safety Science, Proceedings of the Ninth International Symposium. Karlsruhe, Germany, International Association for Fire Safety Science.