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Fire Dynamics and Forensic Analysis of Limited Ventilation Compartment Fires
Volume 2: Modeling

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ABSTRACT

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, two-step combustion model and CO production model in FDS version 5 by simulating limited ventilation, full-scale fire tests in an apartment setting with realistic furniture items and comparing different heat release rate inputs from furniture calorimeter and load cell measurements. The extinction model provides a more accurate representation of the fire behavior in the compartment, but oxygen and temperature results are not satisfactory for severely underventilated fires. Using data from free burn calorimeter tests as input to FDS for fuel items in a compartment where the heat feedback can influence the pyrolysis can be a significant source of non-conservative error and give a poor representation of the burning behavior when ventilation is limited. This must be considered when choosing the heat release rate input to FDS, and the validity of calorimeter data should be evaluated for each case. The CO production model in FDS gives values lower than recorded in the fire tests due to uncertainty about the material data input and simplifications in the model.

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EXECUTIVE SUMMARY

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 underventilated fire conditions.

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 grant, one such test series was conducted in the summer of 2008 to characterize the dynamics of underventilated fires and to evaluate the performance of fire models under these conditions (Wolfe, Mealy and Gottuk 2009).

The full-scale tests were performed inside an instrumented, four room apartment style enclosure measuring 41.8 m^2 (450 ft^2). The apartment structure was built inside the Fire Research Laboratory of the Bureau of Alcohol, Tobacco and Firearms. The fuel and ignition sources aimed to be realistic and reproducible. Furniture items were used as the main fire source, ignited by a cup of alcohol and paper tissue boxes. Tests were conducted using both a sofa and a kitchen cabinet assembly, placed in the living room and kitchen respectively. The fuel item was placed on a load cell which measured the mass loss throughout the test. Five different ventilation conditions were used for the compartment: fully sealed, window half open, window fully open, window removed and open door.

Fifteen full-scale tests were performed, and nine of these were used for the FDS simulations. The compartment was reproduced in the FDS model with a 5 cm (2 in) grid resolution in the fire room and 10 cm (4 in) elsewhere. The simulations were conducted with two different heat release rate inputs. To study the effects of using a heat release rate obtained in well-ventilated conditions when simulating a limited ventilation fire, nine of the simulations used heat release rate data from free burn oxygen-consumption calorimeter tests of identical fuel items. For the second part of the study, the heat release rate input to FDS was extracted from the load cell mass loss rate data and the heat of combustion calculated from the calorimeter tests to give a more accurate estimate of the heat released by the fire inside the compartment. The results

of the simulations using the two heat release rates were compared to evaluate the effects of the limited ventilation and the performance of the FDS model.

Two natural gas burner tests performed in the compartment 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.

In all cases, using the load cell data as input to FDS gave a heat release rate closer to that seen in the tests, and with some exceptions, more accurate temperature and oxygen predictions. The FDS simulations of the sofa test with window open gave temperature measurements with an accuracy around ± 30 % in the living room, which is a larger discrepancy than reported in previous validation studies which usually have more favorable ventilation conditions.

The simulations using cabinets placed both near the ceiling and close to the floor gave oxygen concentration measurements that overall showed good agreement with the test data. In some scenarios the oxygen concentration went to zero in the tests while in FDS it did not go below 5 % by volume, possibly a restriction resulting from the limiting oxygen algorithm in FDS. The temperature in the bedroom also showed good agreement between FDS and the test data, within 10 % for most times analyzed. For the temperatures in the kitchen however, the accuracy of FDS was less clear. For all cases, there were FDS measurements with a discrepancy of up to 30 – 40 % from the test data in some locations, but also more accurate measurements elsewhere. There was some indication that the cabinets in the low configuration gave more accurate results than the elevated cabinets. This may be due to less combustion occurring within the oxygen-poor upper layer.

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, and (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.

Considering the concentrations of CO, FDS showed poor agreement with the test measurements. In the cases were there was reasonable agreement for the oxygen concentrations FDS could predict where spikes in CO concentrations occurred, but the value was always lower in FDS than in the test by a significant amount. This is a result of the way FDS calculated CO yield during underventilated combustion, which in this case does not give an adequate increase in CO yield over the free burn value. Additional sources of uncertainty are the free-burn CO

yield input and the description of the fuel chemistry as well as CO production during pyrolysis which is currently not included in FDS. This study indicates that the added CO produced by FDS in underventilated fire conditions is lower than measured in tests, but further study is required to determine the effect the fuel description input to FDS has on the results.

Four of the simulations were compared for three different settings of the combustion model in FDS, and it was found that the difference between simulations with and without the extinction model was significant. When local flame extinction was modeled, the limited ventilation led to reduced heat release rate and caused the combustion zone to move out of the fire room towards the ventilation opening. Flames outside the fire room were not observed in the test, but overall the extinction model resulted in a fire behavior that better represented that seen in the tests. The extinction model may lead to increased computational costs, but the effects are significant and it is recommended that it is used for compartment fire simulations.

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

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, Boehmer, Alvear 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, Mealy and Gottuk 2009). 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 in a multi-national collaborative effort led 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, Simo Hostikka, Jason Floyd et al. 2008b)

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 any CFD model is an accurate 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 commonly used method in FDS is the 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, termed a Direct Numerical Simulation (DNS). 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 and was used for all simulations conducted for this study. 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.

The Smagorinsky form of LES is used in FDS, where the fluid viscosity depends on an empirical constant given as input to the model by the used. The default value of 0.2 was used for the Smagorinsky constant in this study.

1.3.2   Submodel for Combustion

The submodel treating the process of converting fuel and oxygen to products and heat is what makes FDS able to simulate a fire and its effects on the environment beyond simply the 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 combustion model was expanded from a simple mixed is burned, single-step reaction model 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, Simo Hostikka, Jason Floyd et al. 2008b) and gives a critical mass fraction of oxygen $Y_{O_2 lim}$, as (Mowrer 2008):

$$Y_{O_2 lim} = \frac{\overline{C_p}(T_{f,lim}-T_m)}{\frac{\Delta H}{r_{O_2}}}$$ 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, Simo Hostikka, Jason Floyd et al. 2008b).
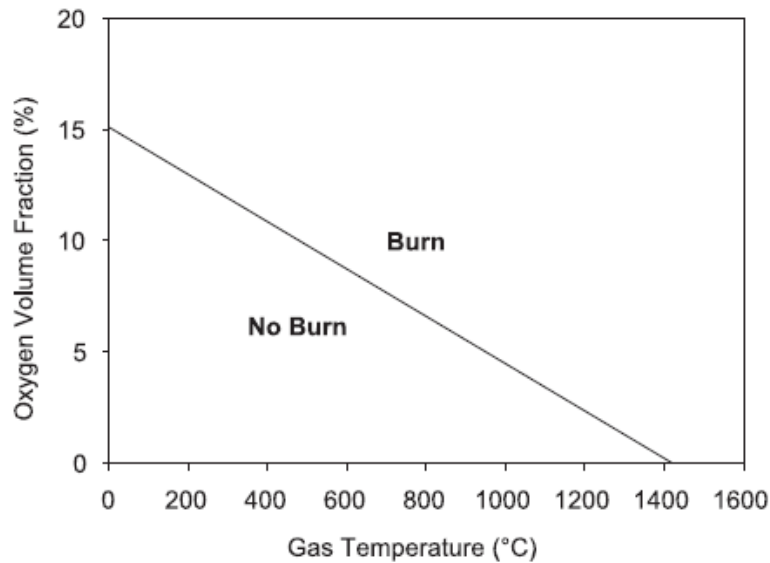
Figure 1-1. Relation between limiting oxygen volume fraction and gas temperature used in the extinction model in FDS to determine whether burning can take place.

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

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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, Bundy and Hamins 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, Simo Hostikka, Jason Floyd et al. 2008b):

$$Z_1 = \frac{Y_F}{Y_F^I}$$

Equation 1-2

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

Equation 1-3

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

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, Simo Hostikka, Jason Floyd et al. 2008b):

$$v_{CO}' \left[CO + \frac{1}{2}O_2 \rightarrow CO_2 \right]$$

Equation 1-5
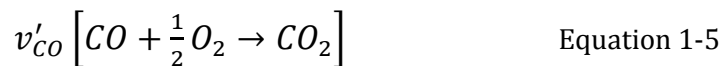
If the fire is well ventilated the yield of CO will be the minimum value prescribed by the user of v_{CO}. However if there is no oxygen to fuel the second step of the reaction the total yield of CO will remain at $(v_{CO} + v_{CO}')$ and no CO_2 will be produced since this always has to go through the CO step. (McGrattan, Simo Hostikka, Jason Floyd et al. 2008b)

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.

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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 coarse 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 is most efficient when the number of cells in the y- and z-direction must be on the form $2^l 3^m 5^n$, 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, Klein, Hostikka et al. 2008). 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, Simo Hostikka, Jason Floyd et al. 2008b) (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, Klein, Hostikka et al. 2008):

$$D^* = \left(\frac{\dot{Q}}{\rho c_p T_\infty \sqrt{g}} \right)^{\frac{2}{5}}$$

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, Floyd, Forney 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, Klein, Hostikka et al. 2008). 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   Flow Conditions, Fire Description and Development

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. In real word applications 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 how to obtain a good approximation for the heat release rate. When modeling fires in residences, 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):

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

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, McGrattan, Hostikka et al. 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, Klein, Hostikka et al. 2008)

1.4.3 CO Production Model

The CO production model implemented in the combustion submodel in FDS will only consider CO formed directly through the combustion process. During pyrolysis of oxygenated fuels such as wood additional CO can be released, which because of this will not be accounted for in FDS. This may result in lower levels of CO produced in the FDS model when comparing the results to real fires with such fuels where CO is produced during pyrolysis.

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 noting 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).

Released together with FDS 5 is the Technical Reference Guide, Volume 2: Verification (McDermott, McGrattan, Hostikka et al. 2008), which contains a description of work that has been carried out in this area so this 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, Simo Hostikka, Jason Floyd et al. 2008b).

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, Simo Hostikka, Jason Floyd et al. 2008b).

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, Simo Hostikka, Jason Floyd et al. 2008b)

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

This 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 performed inside an instrumented, four room apartment style enclosure measuring 41.8 m^2 (450 ft^2). The apartment structure was built inside the FRL Large Burn Room. Fifteen full-scale furniture tests were performed but only nine of these were used for the FDS simulations. The tests evaluated included sofa fires and kitchen cabinet fires.

1.6.2 Simulations

The study was divided into two main parts. First, using heat release rate data for the specific sofas and cabinets from hood calorimeter tests, simulations were performed without including any information about the actual burning behavior inside the compartment. These simulations are referred to as the "calorimeter simulations" in this document. Natural gas burner tests within the apartment enclosure were also included in these simulations.

Second, after the fire tests were completed, the measured fuel mass loss data coupled with the heat of combustion for the items from the calorimeter tests was used to estimate the heat release rate for the fires inside the compartment. This estimated heat release rate 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.

Table 1-1 shows the locations, ventilation conditions and input data for the two 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 calorimeter*	
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
Low Cabinets	Kitchen	Closed
Low Cabinets	Kitchen	Window Half Open
Low 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
Low Cabinets	Kitchen	Closed
Low Cabinets	Kitchen	Window Half Open
Low Cabinets	Kitchen	Door 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:

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

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 from the load cell, and how effectively the extinction and CO production routines in FDS can model the effects of the limited ventilation.

2   FDS METHODS

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 5.2.5 The grid resolution studies were performed before version 5.2.5 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. Examples of FDS input files used are included in Appendix A.

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 is shown in Figure 2-1 (Wolfe, Mealy and Gottuk 2009).
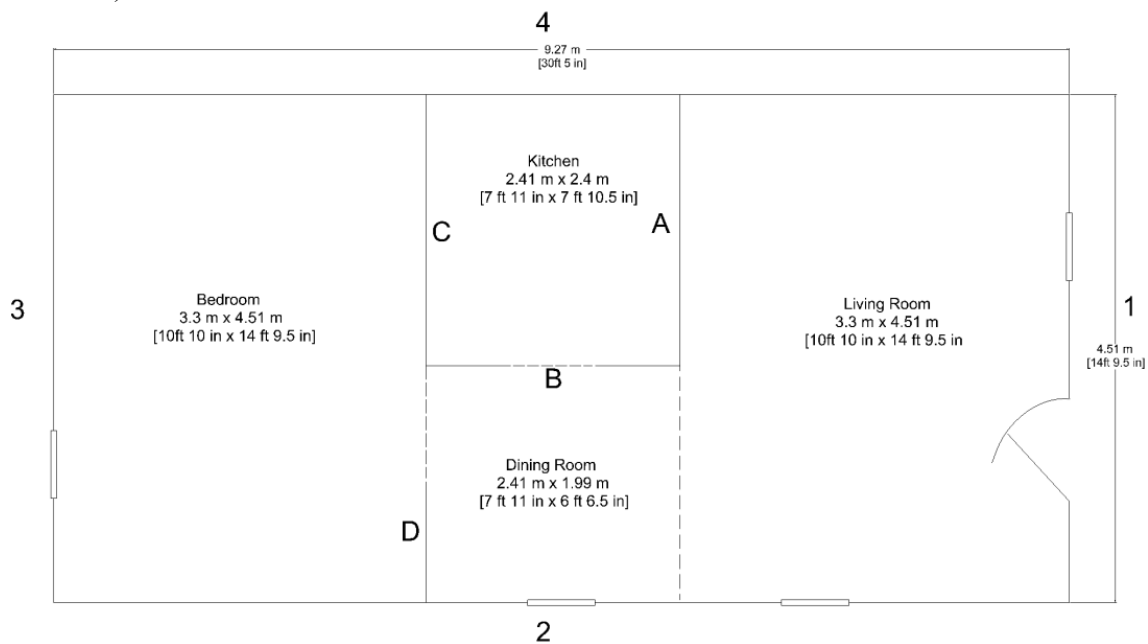
Figure 2-1. Layout of the four-room test compartment.

The compartment measured 9.3 m (30 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 m(15 ft) 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 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 bottom pane of 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 of the wall. 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, Chris Jamieson,
Alan Jeary 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 (Incropera and
DeWitt 2002):

$$D_H = \frac{4A}{P} \hspace{3cm} \text{Equation 2-1}$$

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 was 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 it 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 openings to the
outside closed. This gave an equivalent average 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, Klein, Hostikka et al. 2008):

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

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).
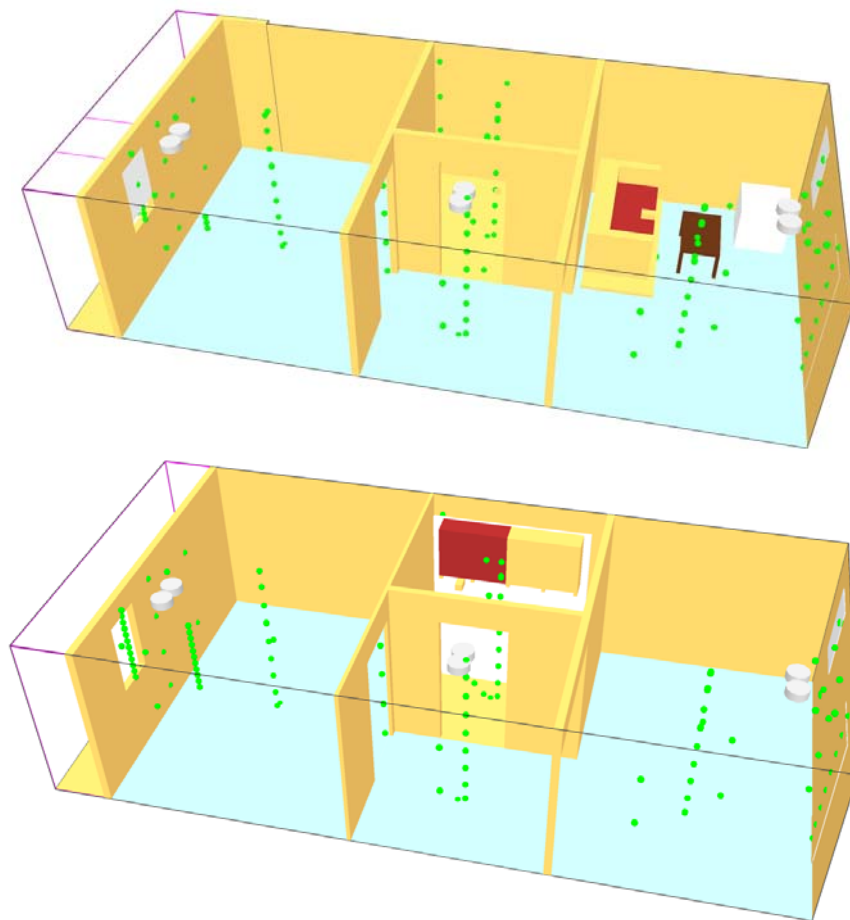

Figure 2-2. Layout in FDS for the load cell heat release rate simulations of the sofa test with the window
half open (top) and the kitchen cabinet test with window removed.

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 smoke alarms. The furniture placed in the compartment during the sofa tests is shown. In addition to the burning sofa, there was a coffee table and a small upholstered chair, 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 horizontal 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 (2 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 et. al. (Wolfe, Mealy and Gottuk 2009). 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 were 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, Mealy and Gottuk 2009). For the FDS simulation, the aspirated thermocouples were 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, Klein, Hostikka et al. 2008). 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 the thermocouple temperature, T_{TC}, iteratively (McGrattan, Klein, Hostikka et al. 2008):

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

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 sofa 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) and at the base of the fire. 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 sampling system was accounted for by shifting the data by the measured ninety percent transport time.

2.3.3 Heat Flux

The simulated heat flux was recorded with the same placement of the gauges as in the fire 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 and 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.
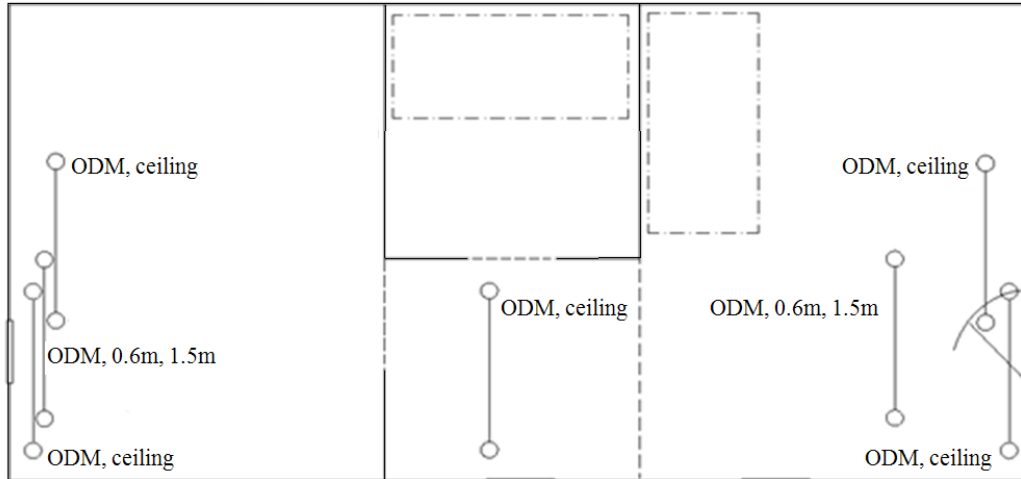
Figure 2-3. Placement of the Optical Density Meters in the compartment.

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, Klein, Hostikka et al. 2008).

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

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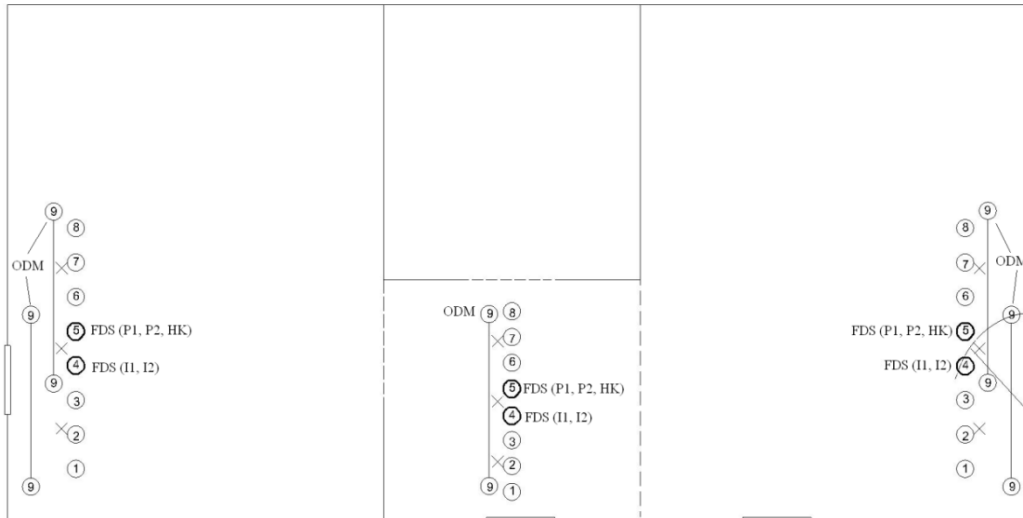
Figure 2-4. Placement of the eight smoke detectors in three locations in the tests and the corresponding placement of the detectors in FDS. Ionization detectors denoted by I1 and I2, photoelectric denoted by P1 and P2 and Heskestad photoelectric model denoted by HK, as per Table 2-1.

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 5cm
5 cm	777,600	100 %
10 cm	97,200	12.5 %
10cm & 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, Klein, Hostikka et al. 2008).

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.
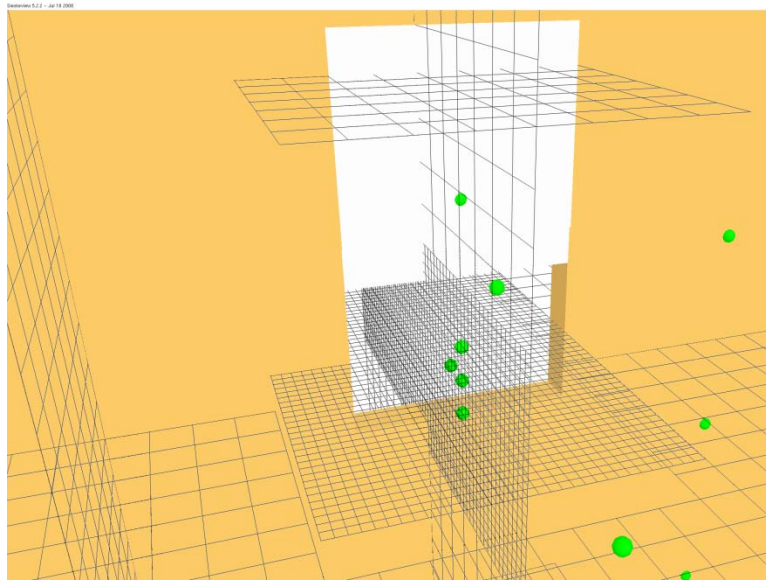

Figure 2-5. Different grid resolutions around the open bedroom window. 2.5 cm (1 in) cells were used for
the opening while 10 cm (4 in) cells were used in the rest of the room.

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, $D^*/\delta x$ 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).

	$D^*/\delta x$	
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, Klein, Hostikka et al. 2008).

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.
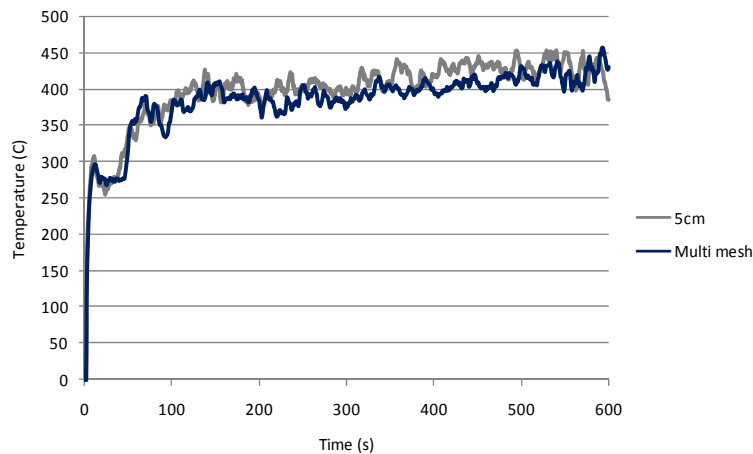

Figure 2-6. Temperature measured at the ceiling in the kitchen using the 5 cm (2 in) and multi mesh configurations.

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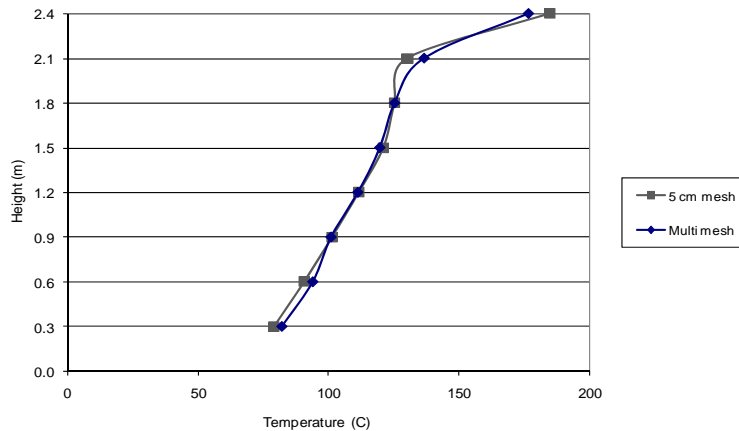
Figure 2-7. Temperature slice in bedroom at 450 s with 5 cm (2 in) and multi mesh configuration.

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 and DeWitt 2002). The thermal conductivity was set to 0.17 W/m-K (Incropera and DeWitt 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

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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 and DeWitt 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   Calorimeter Heat Release Rate Input

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, Klein, Hostikka et al. 2008). 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 is the same.
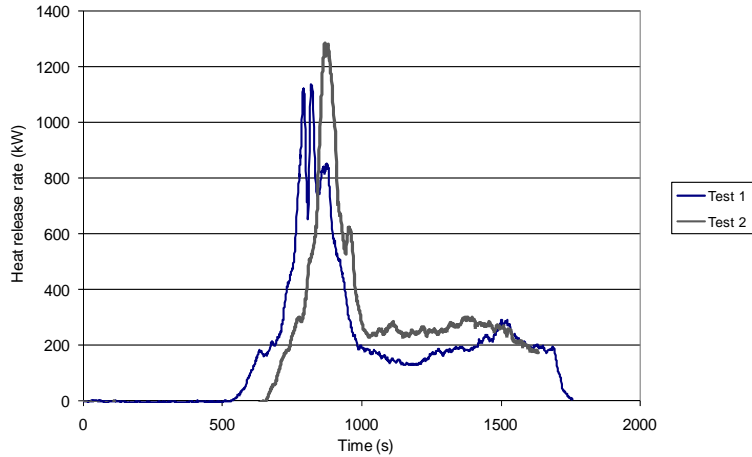
Figure 2-8. Heat release rate from the sofa calorimeter test.

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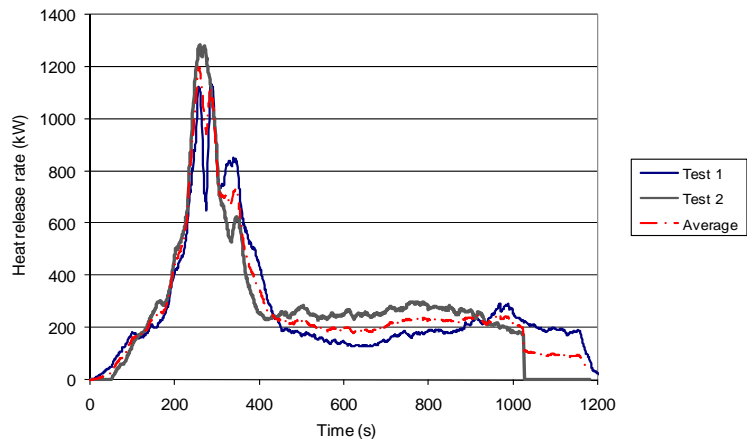
Figure 2-9. Shifted heat release rate curve for the two tests and the average value used as input to FDS.

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

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(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 g CO/g 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 to 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. For this test series the heat of combustion was calculated from the heat release rate measured by the calorimeter and the mass loss rate recorded by the load cell. For the burning sofa the heat of combustion was found to be 14 MJ/kg (Wolfe, Mealy and Gottuk 2009), a lower value than both that found by Mealy and reported in the SFPE handbook.

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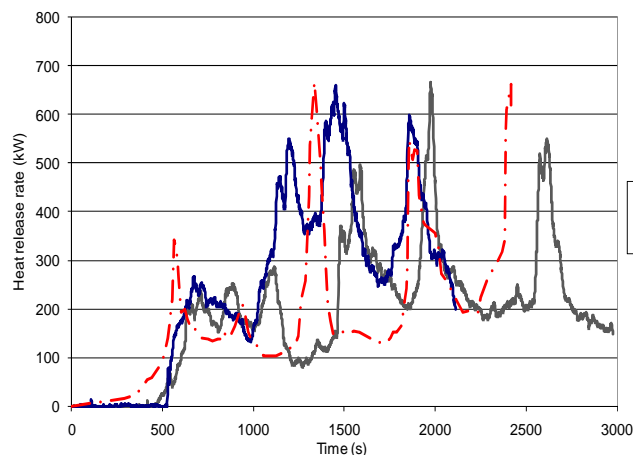
Figure 2-10. Cabinets heat release rate as measured in the calorimeter. Two tests were done for this test series and one calorimeter test was done using the same cabinets by Mealy (Mealy 2007).

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.

In previous tests 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 data from the current calorimeter tests gave the heat of combustion as 12.3 MJ/kg (Wolfe, Mealy and Gottuk 2009), again a value lower than is give by Mealy and the SFPE handbook.

The chemistry of the cabinets was taken as plywood reported by Richie (Richie, Steckler, Hamins 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 to 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.
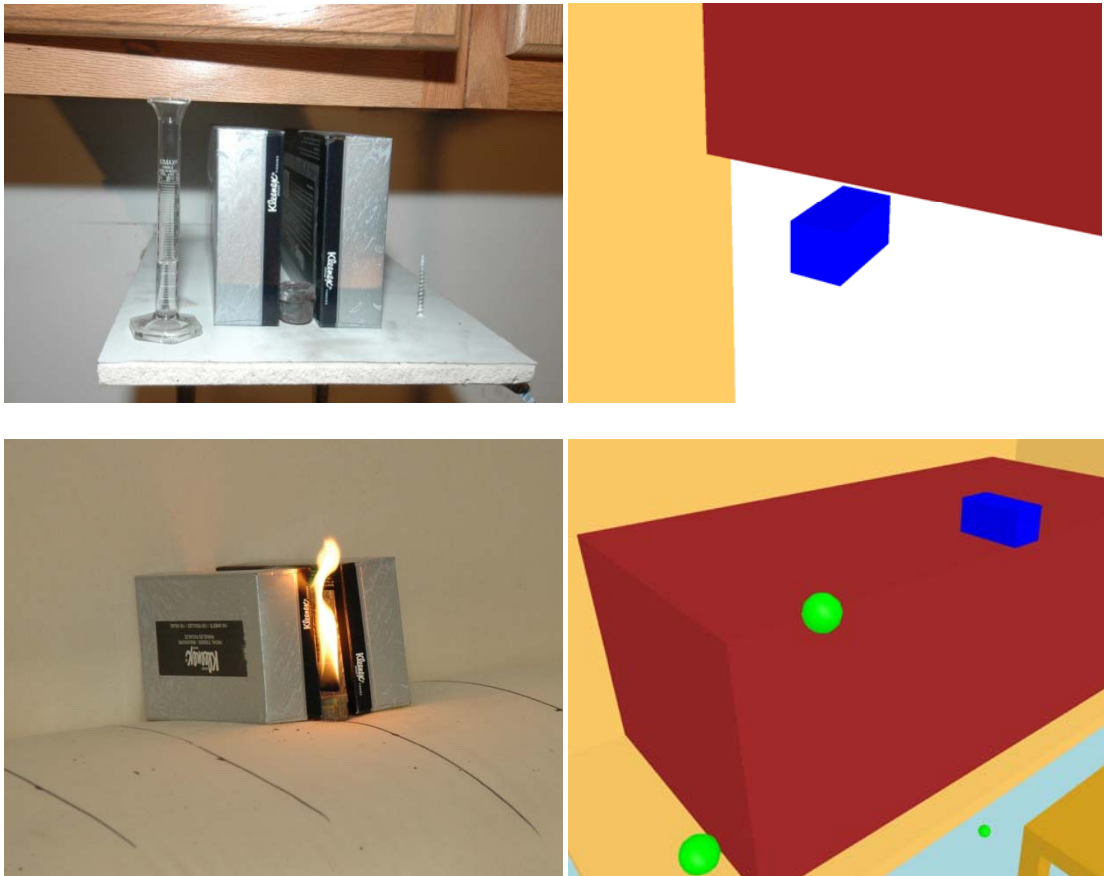
Figure 2-11. Tissue box and cup with 4 ml (0.14 oz) of alcohol ignition souce placed under the cabinets and on sofa seat and the smokeview rendering of the layout in FDS. The tissue boxes are blue and the main fire is red.

2.7   Heat Release Rate Input from Load Cell

The simulations using the load cell data were kept similar to those using the calorimeter data except for the heat release rate and the size of the burner surface. 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):

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

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.

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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 to 9 m (20 to 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.
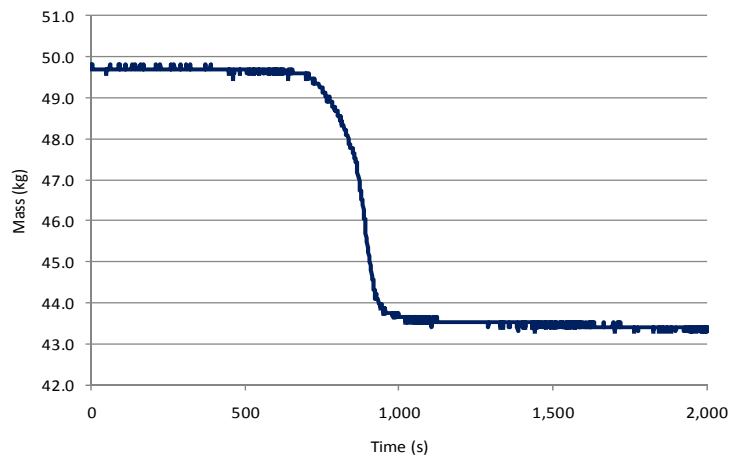
Figure 2-12. Mass of the burning sofa inside the compartment during the first 2,000 s of the test with half open window.

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.

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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 m² (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.
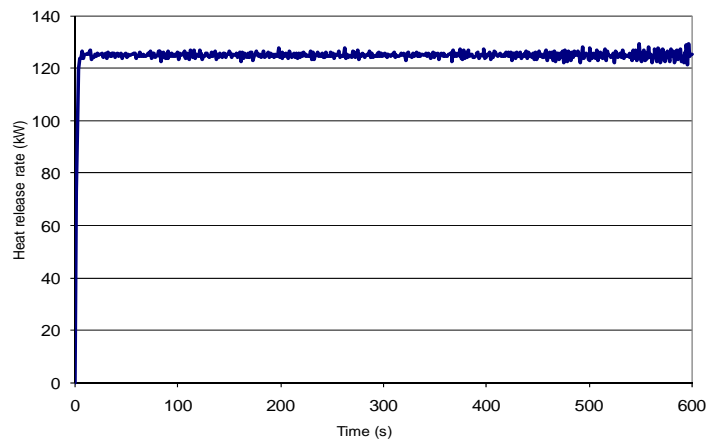
Figure 3-1. Resulting heat release rate from the FDS simulation of the natural gas burner test with closed compartment.

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 at the ceiling, 2.4 m (8 ft), 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.
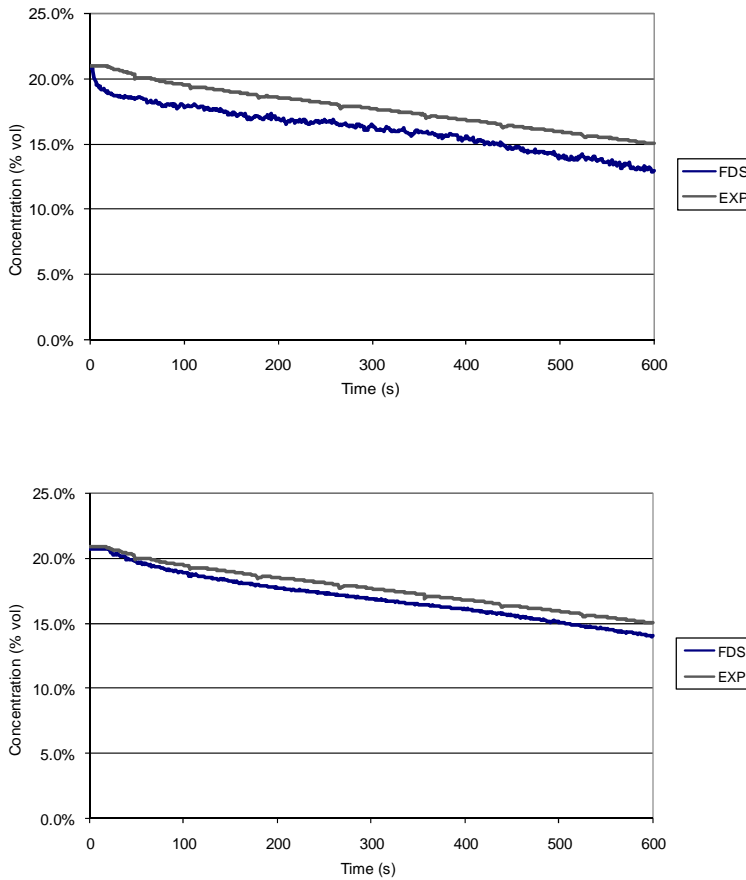
Figure 3-2. Oxygen concentrations at 2.4 m (8 ft) in the living room (top) and bedroom (bottom) for the
burner fire with compartment closed.

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.

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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.

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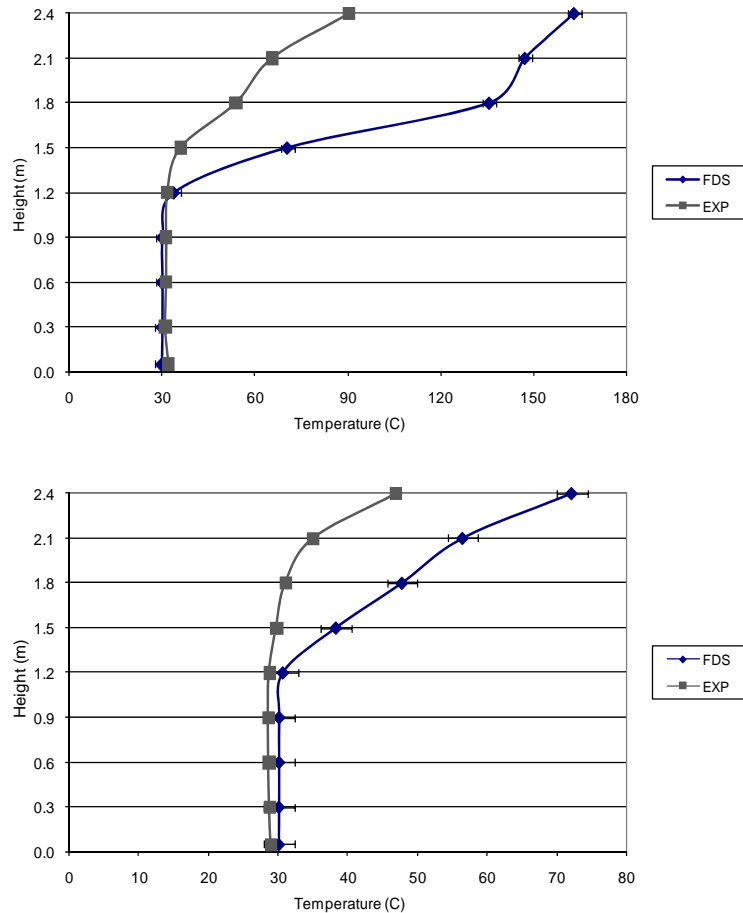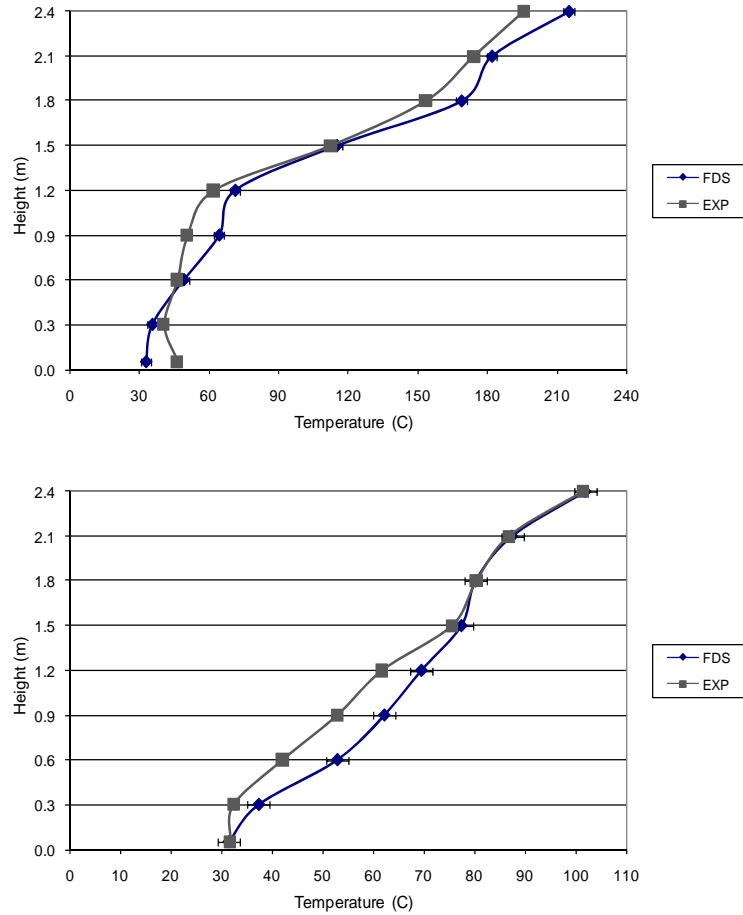
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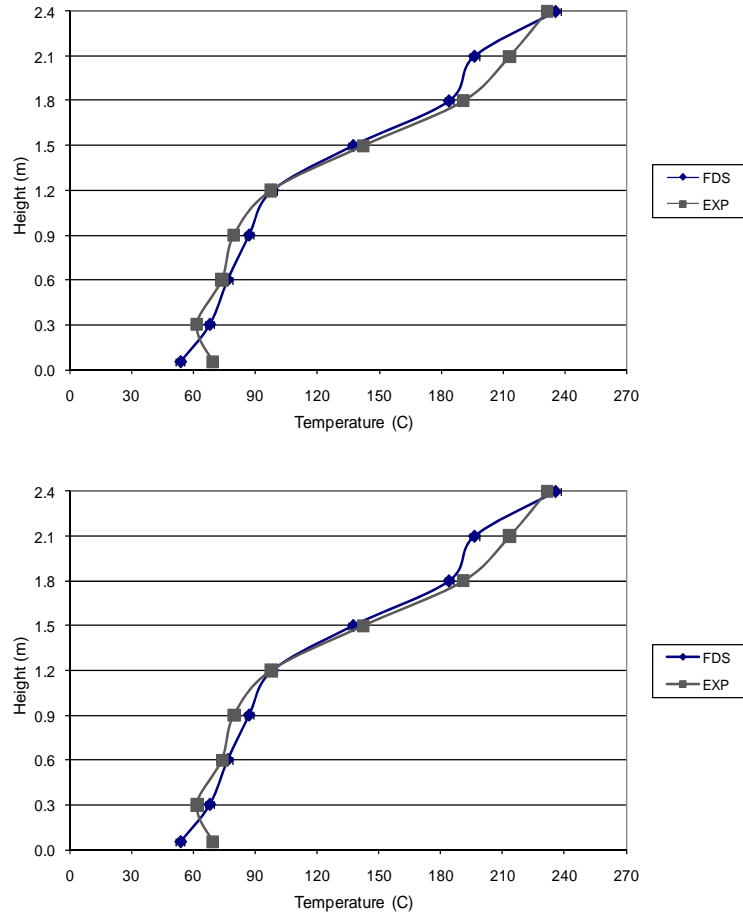
Figure 3-5. Vertical variations of temperature at 500 s in the living room (top) and bedroom (bottom) for the burner fire with compartment closed.

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, Klein, Hostikka et al. 2008).

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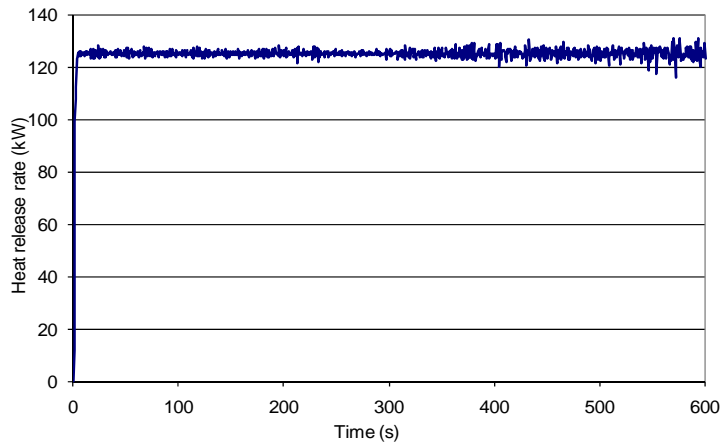
Figure 3-6. Resulting heat release rate from the FDS simulation of the 125 kW natural gas burner test with open window.

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 at the ceiling, 2.4 m (8 ft), 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.
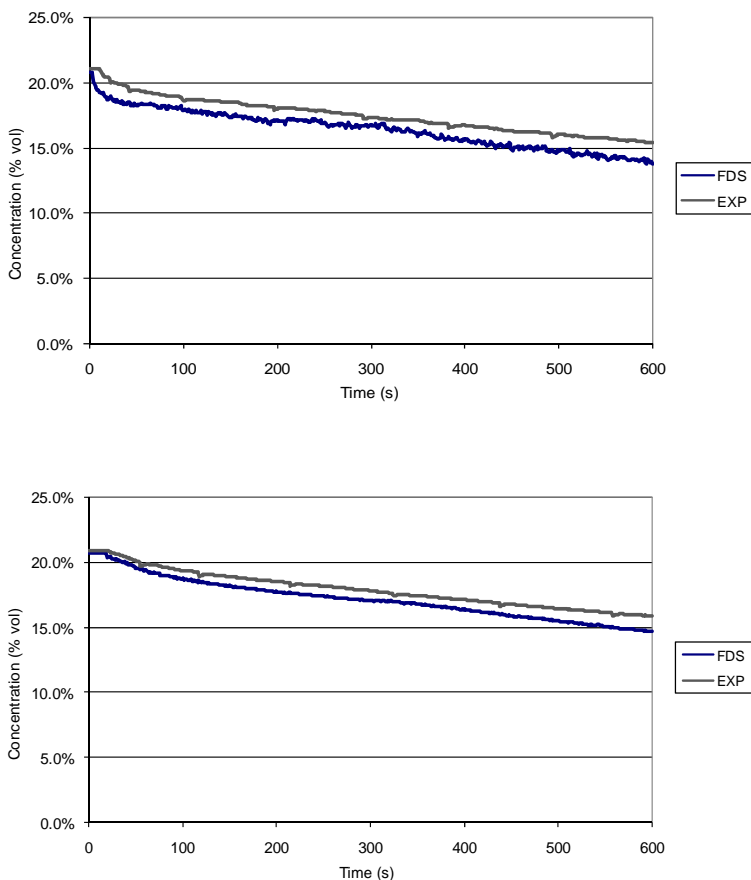
Figure 3-7. Oxygen concentrations at 2.4 m (8 ft) in the living room (top) and bedroom (bottom) for the
natural gas burner test with open window.

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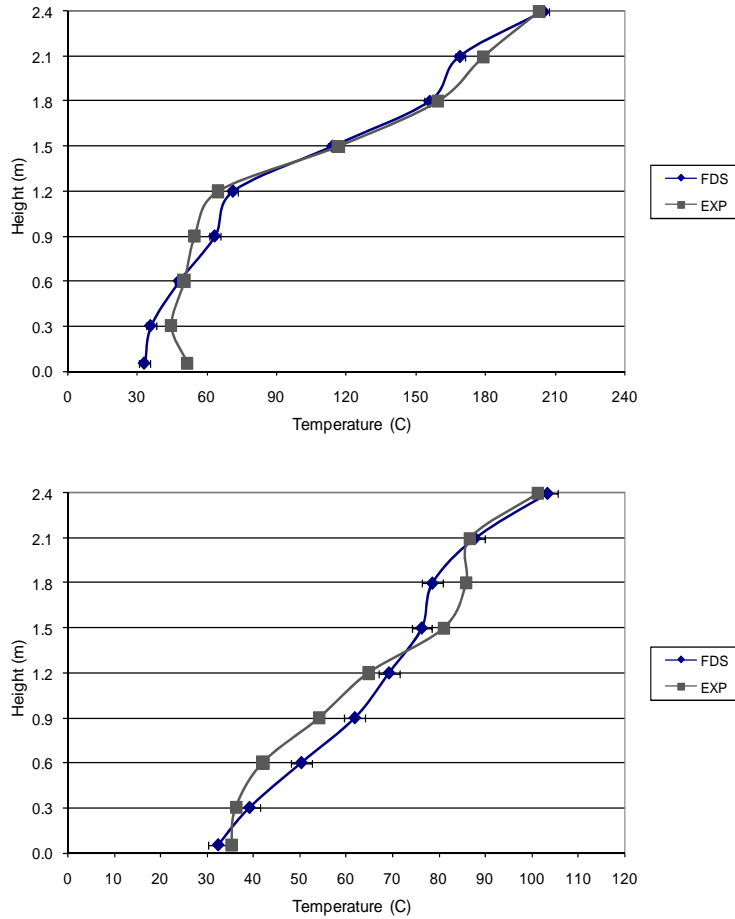
Figure 3-9. Vertical variations of temperature at 200 s in the living room (top) and bedroom (bottom) for the natural gas burner test with open window.

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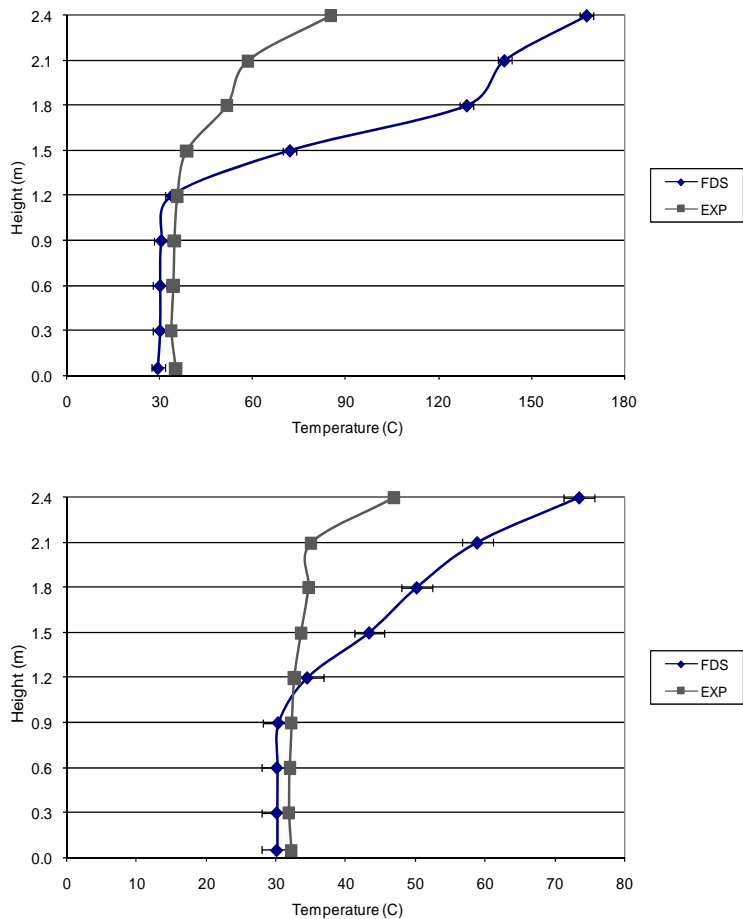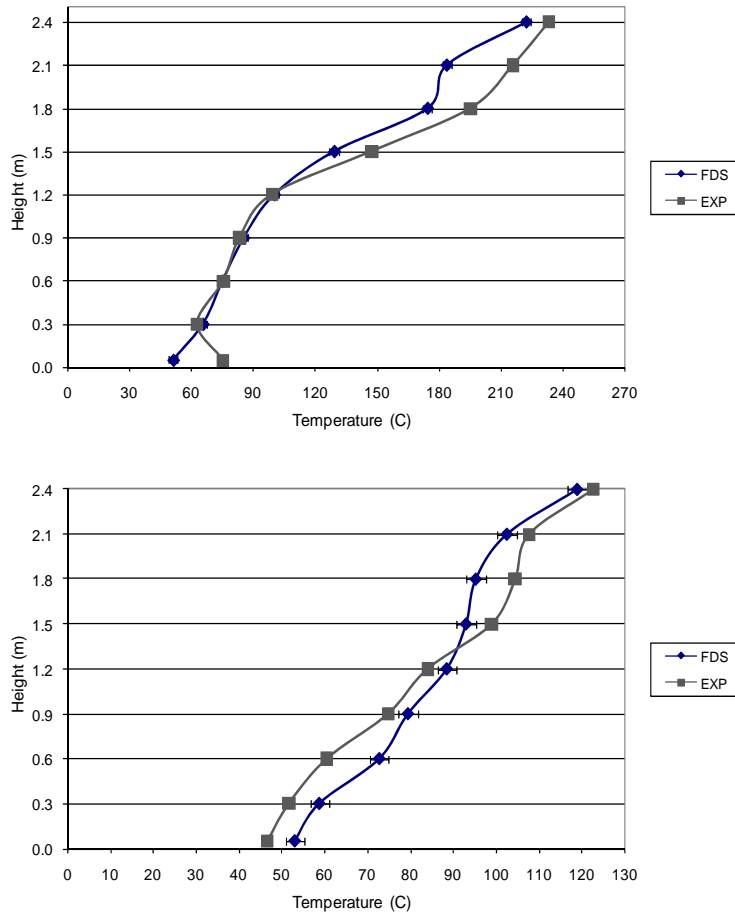
Figure 3-10. Vertical variations of temperature at 500 s in the living room (top) and bedroom (bottom) for the natural gas burner test with open window.

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.

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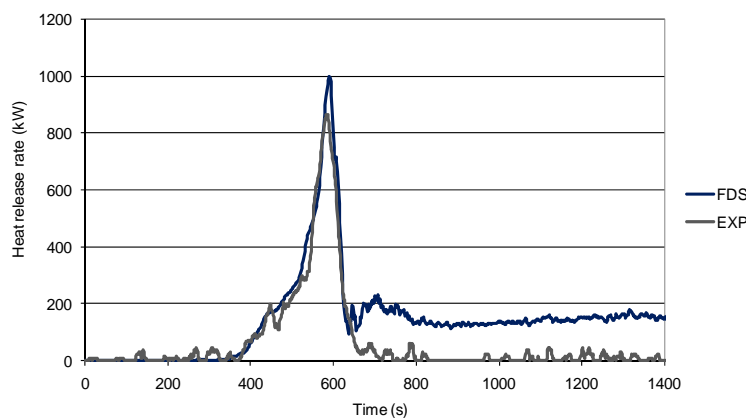
Figure 4-1 Heat release rate curves for the experiment and FDS simulation of the sofa test with half open window. The experiment curve has been shifted 280 s to the left.

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.

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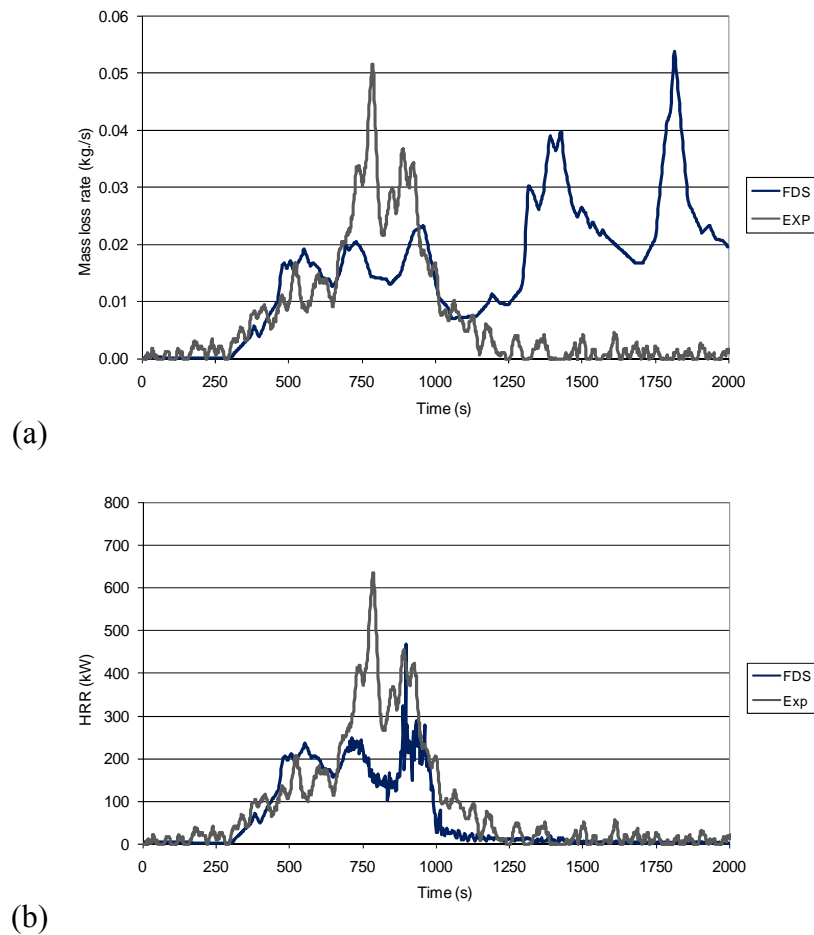
Figure 4-2. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Elevated kitchen cabinets in the closed compartment.

It is clear that the heat released in the experiment is significantly higher than in the FDS simulation. At around 750 s the simulation starts to show fluctuations due to lack of oxygen and the fire dies down at around 1000 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 at the ceiling, 2.4 m (8 ft), 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.
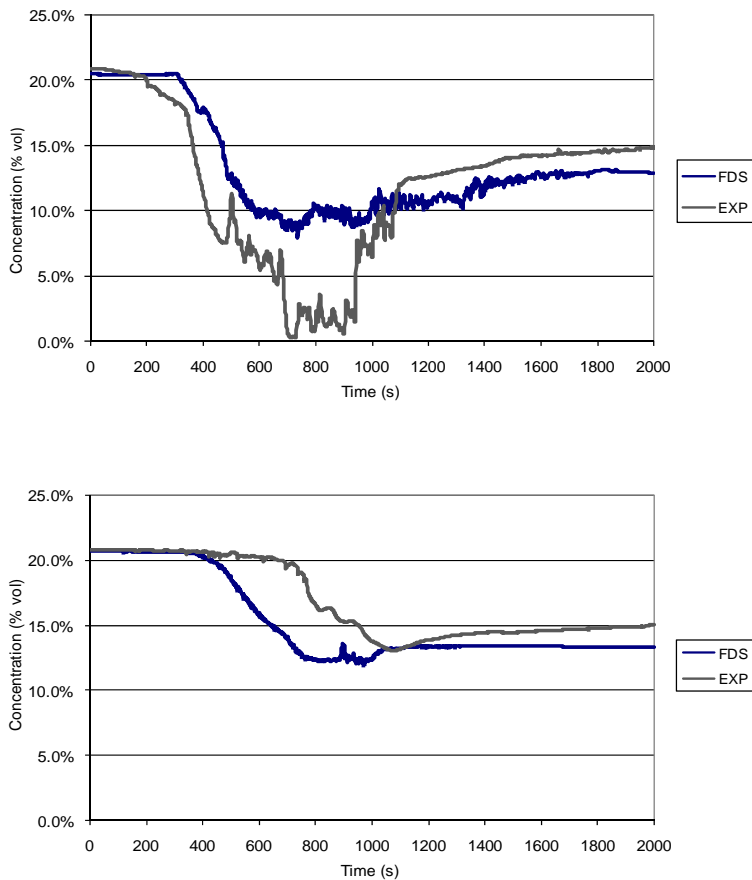
Figure 4-3. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the kitchen cabinet test in the closed compartment.

The test shows a steep drop in oxygen concentration down to zero around 700 s. The FDS data only goes down to just below 10 % where it stabilizes and remains till the end of the test with only a slight increase of a few percent starting around 1400 s. In the bedroom the oxygen concentration starts to decrease in FDS about 300 s earlier than in the experiment but the minimum value reached is close around 13 %.

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.

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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 1.8 m (6 ft) and 2.1 m (8 ft), which show 39 % and 21 % deviation respectively from the experimental data, the largest discrepancy in the kitchen is less than 11 %. In the bedroom FDS predicts a larger temperature rise than was recorded, up to an 12 % 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.
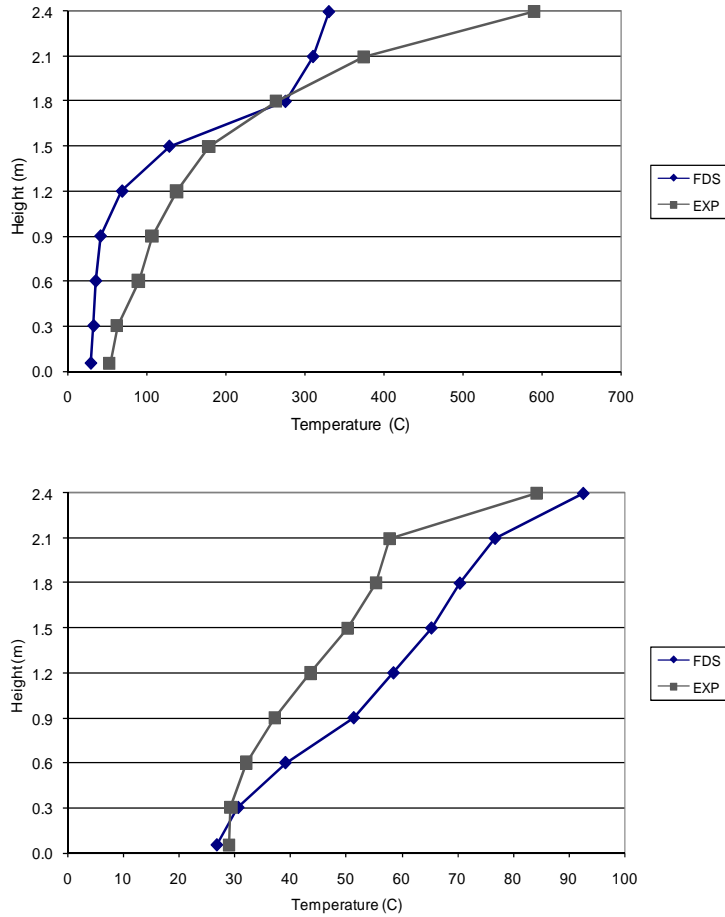
Figure 4-5. Vertical variations of temperature at 800 s. in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with compartment closed

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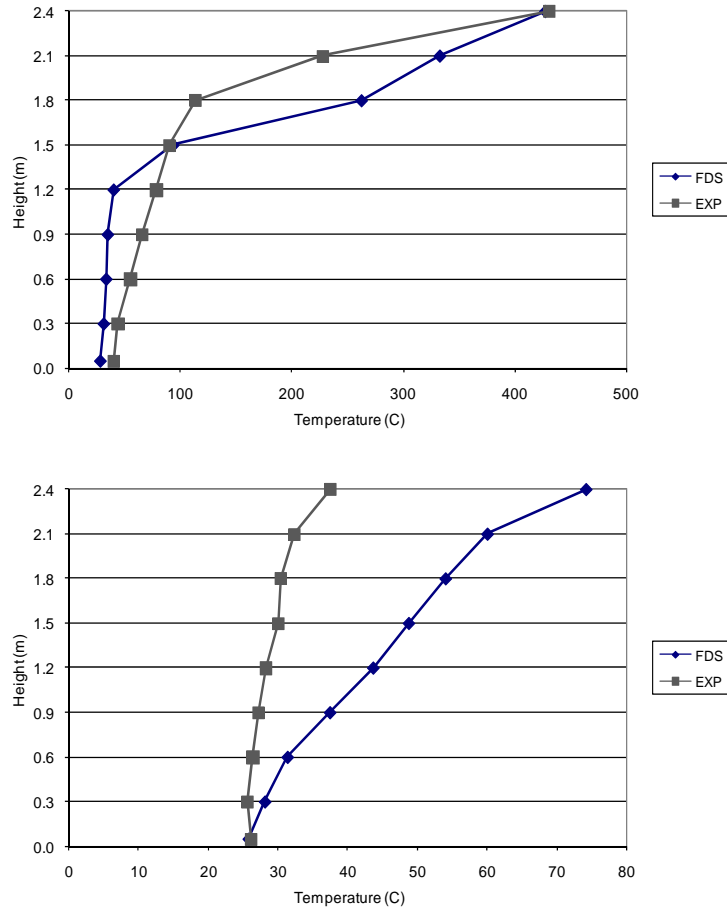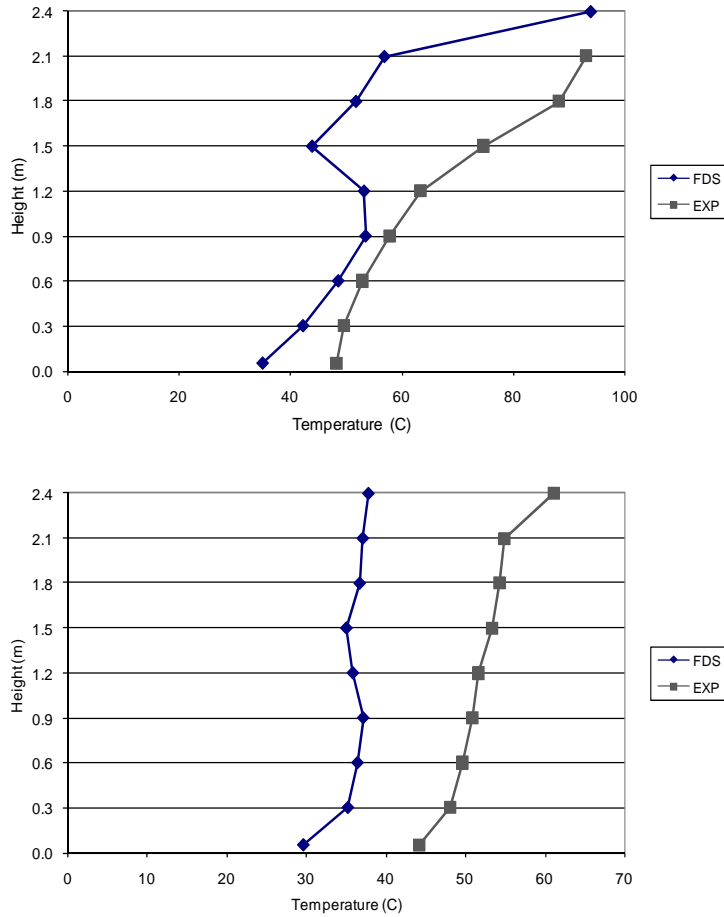
Figure 4-6. Vertical variations of temperature at 2000 s. in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with compartment closed

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.

4.2.4   Carbon Monoxide Concentration

The CO concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-8.

Figure 4-7. Carbon Monoxide concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test in closed compartment.

The CO concentrations are lower in FDS in both locations, only reaching a maximum value less than 1 % by volume in the kitchen and below 0.4 % the bedroom. In the tests the CO concentrations reaches 7 % in the kitchen, but only for a brief period, the rest of the time the maximum value is around 4 %. In the bedroom the maximum value in the test is 2 %.

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 4-8 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.

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(a)

(b)
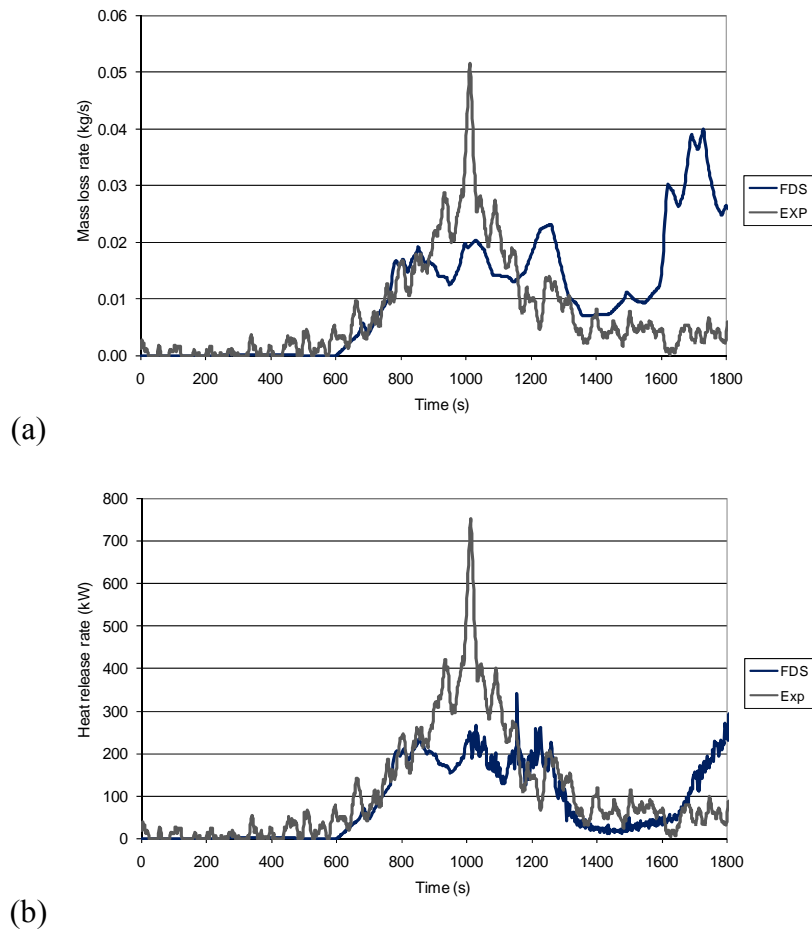
Figure 4-8. Mass loss rate (a) and heat release rate (b) in the FDS pre-test simulation compared to the test data. Kitchen cabinets with window half open

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 at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-9. The FDS data was averaged over five seconds because of fluctuations in the data.
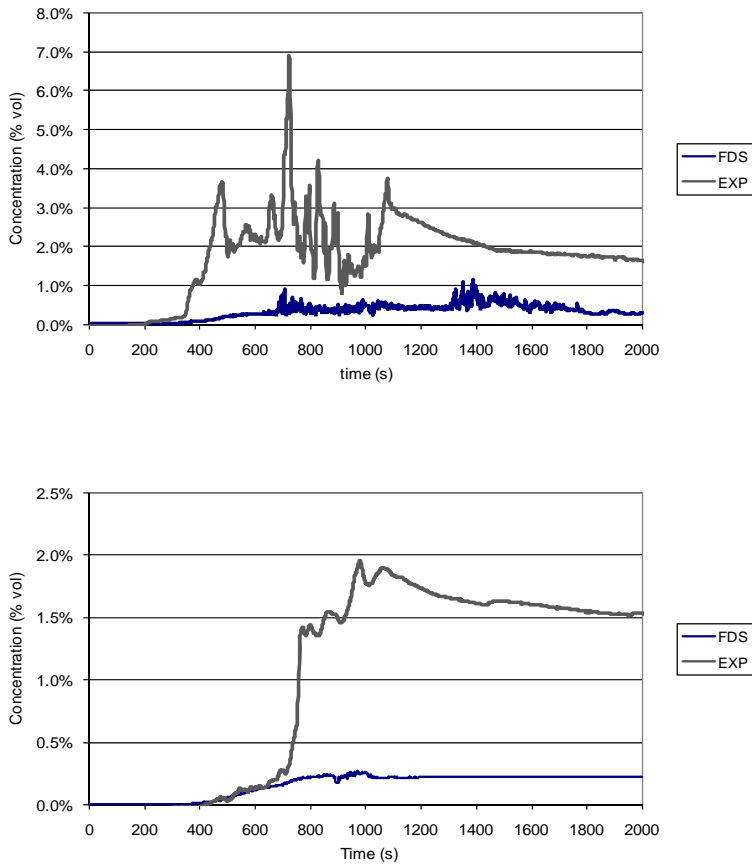
47
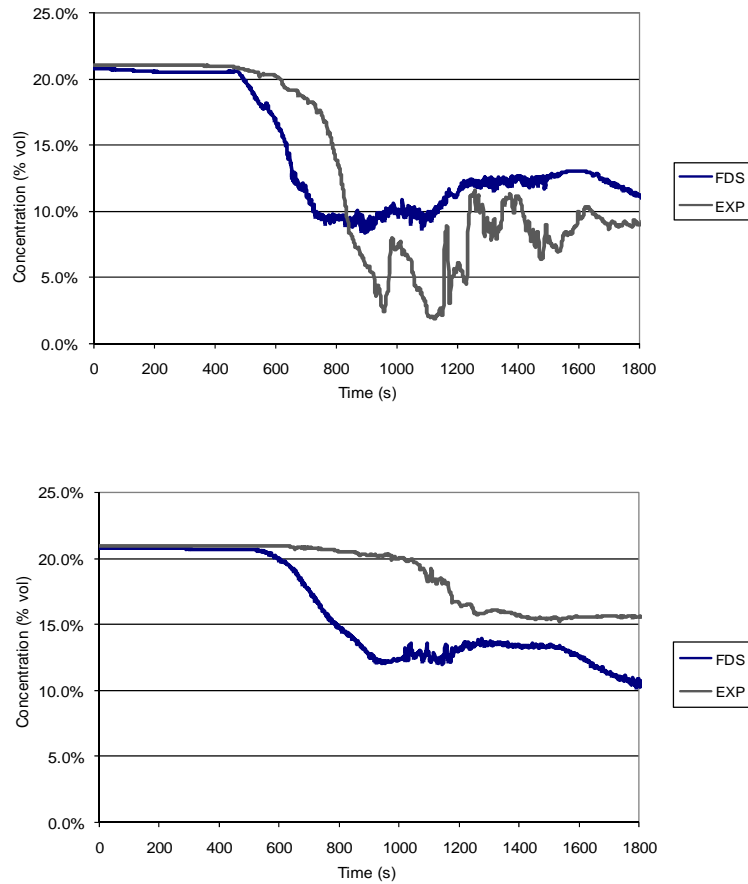
Figure 4-9. Oxygen concentrations 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test with window half open.

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, but a higher minimum value in the kitchen. The tests show a minimum value below 5 % by volume where FDS stabilize around 10 % and increase later in the simulation. In the bedroom the same trend can be seen; FDS predicts that concentrations start to decrease about 500 s earlier than the experimental data shows. Here FDS predicts a minimum value down to 12 % 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 4-10.

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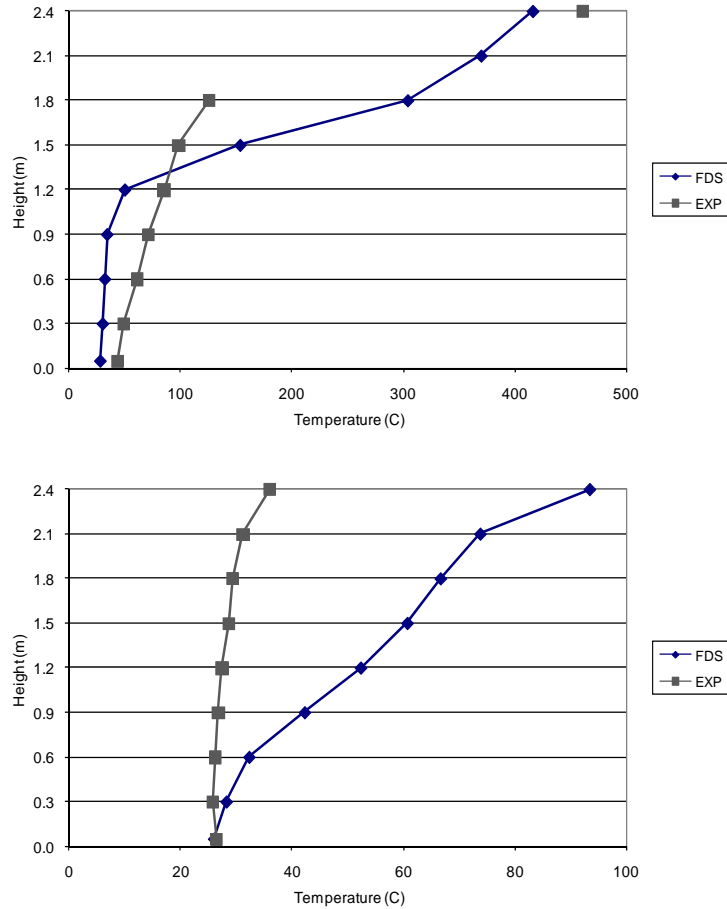
Figure 4-10. Vertical variations of temperature at 900 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window half open.

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 4-11.
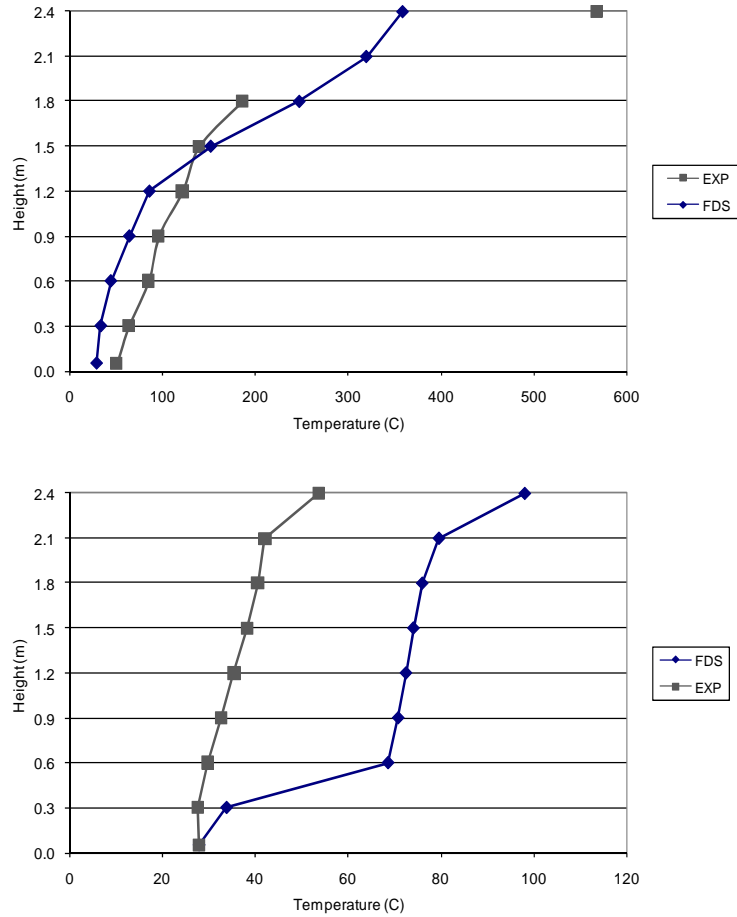
Figure 4-11 Vertical variations of temperature at 1000 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window half open.

At 1000 s the temperature profile in the kitchen shows the same shape. The overprediction in the upper layer in is lower at about 20 % and the underprediction below 1.5 m (5 ft) is between 7 – 12 %. In the bedroom FDS overpredicts the temperatures by 11 % to 14 % above 0.6 m (2 ft). It is clear that in FDS the layer interface in the bedroom is at 0.6 m, but less prominent around 2.1 m (7 ft) in the experiment.

Temperature measured over the height of the room at 1800 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-12.
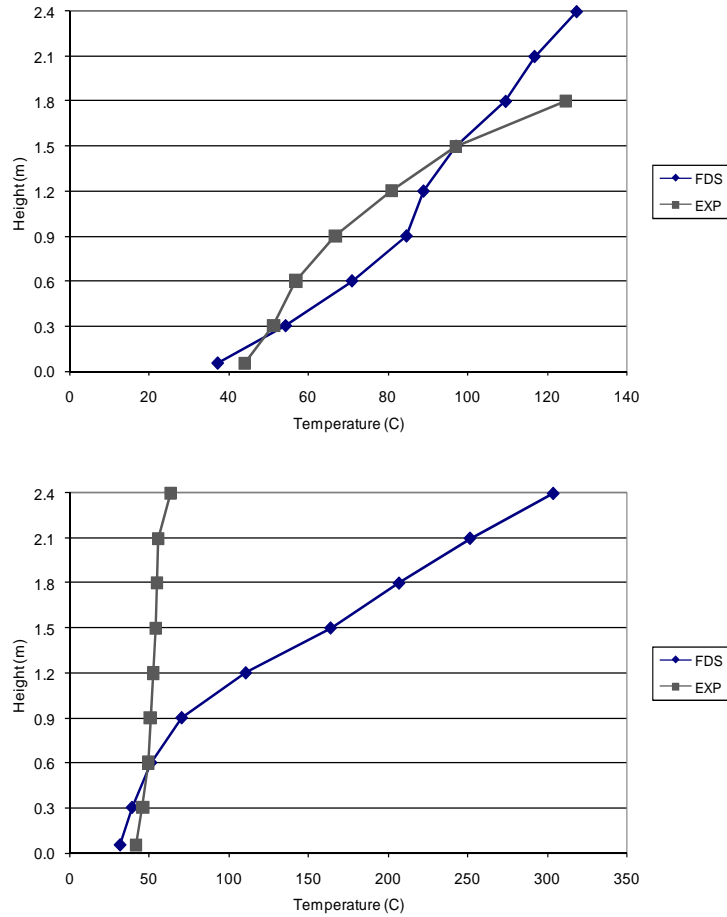
Figure 4-12. Vertical variations of temperature at 1800 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window half open.

At 1800 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.

4.3.4   Carbon Monoxide Concentration

The CO concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-13.

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Figure 4-13. Carbon Monoxide concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test in with window half open.

The CO concentrations in FDS increases and then stabilizes at 0.5 % and 0.2 % respectively in the kitchen and bedroom, while the test data shows a more fluctuating behavior in the kitchen with concentrations from 0.5 % to 4.5 %. in the bedroom FDS starts to increase around 200 s earlier than the test, but as in the earlier simulations reaches a much lower value.

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 4-14 shows the mass loss rate in FDS and the test (a) and the resulting heat release rates (b).

(a)

(b)
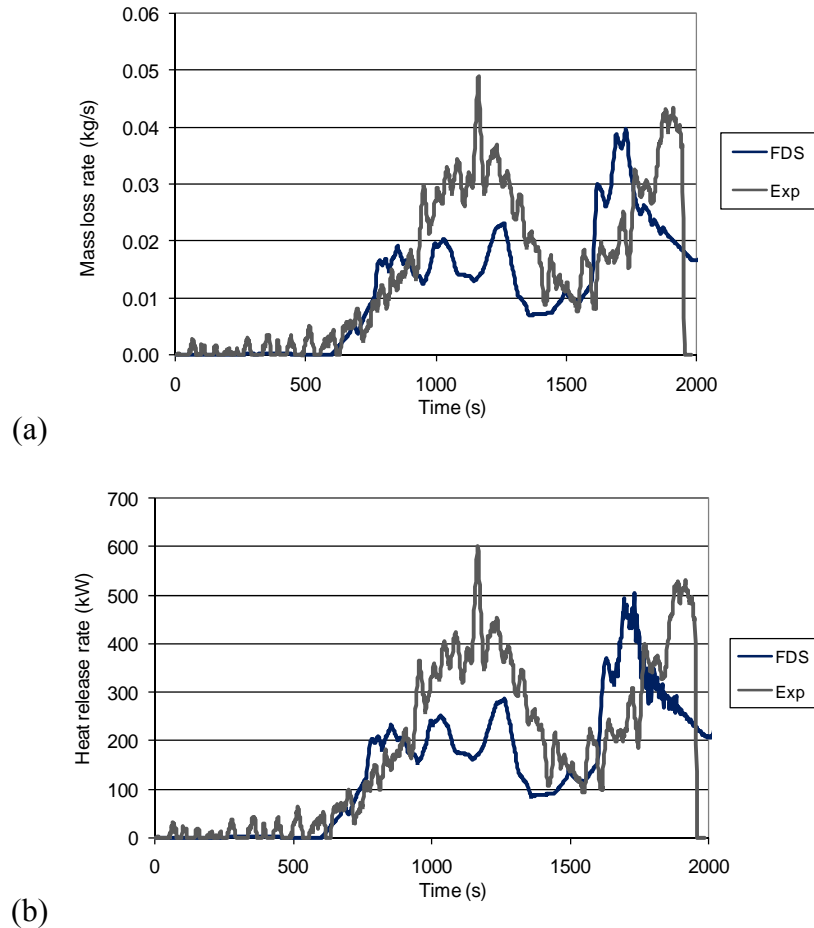
Figure 4-14. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Elevated kitchen cabinets with window removed.

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 at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-15. The FDS data in the kitchen has been averaged over 5 s to reduce effects of fluctuations. The test data in the kitchen

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also shows strange behavior between 1300 s and 1550 s, which most likely is due to issues with the measurement equipment.

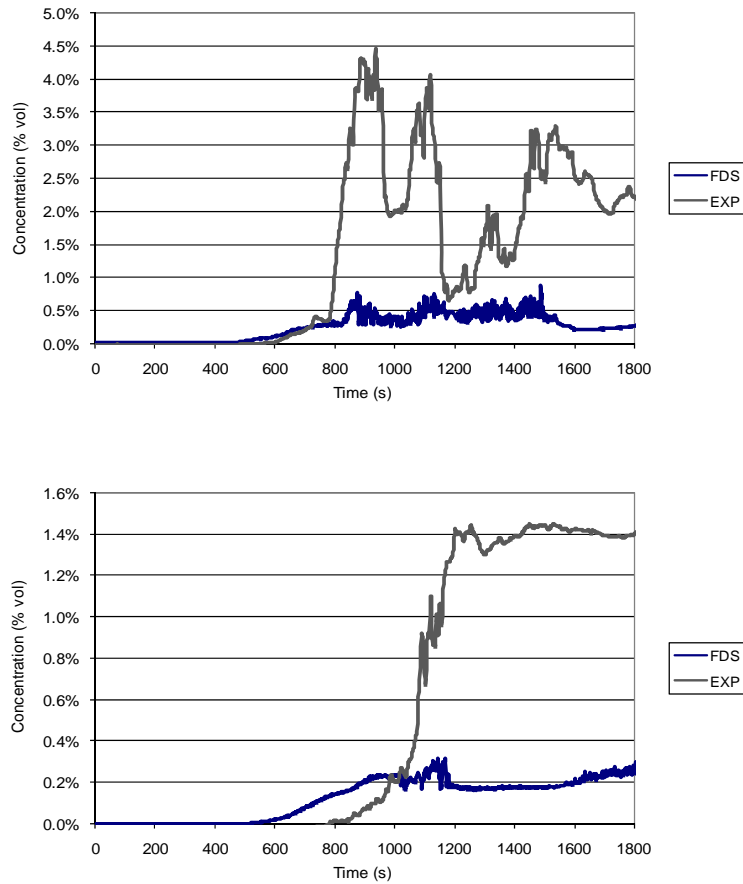

Figure 4-15. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the kitchen cabinet test with window removed.

The larger ventilation opening results in oxygen concentration not being reduced as low as in the other tests, but the behavior is similar. In the kitchen the test data starts to decrease later than FDS but reaches a lower value close to zero percent. The FDS data does not decrease below 7 %. In the bedroom the FDS data indicates a quicker movement of combustion gases from the kitchen as oxygen concentrations starts to decrease 200 s – 400 s earlier than in the test. The minimum value in the test and in FDS is similar, but do not occur at the same time.

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 4-16.
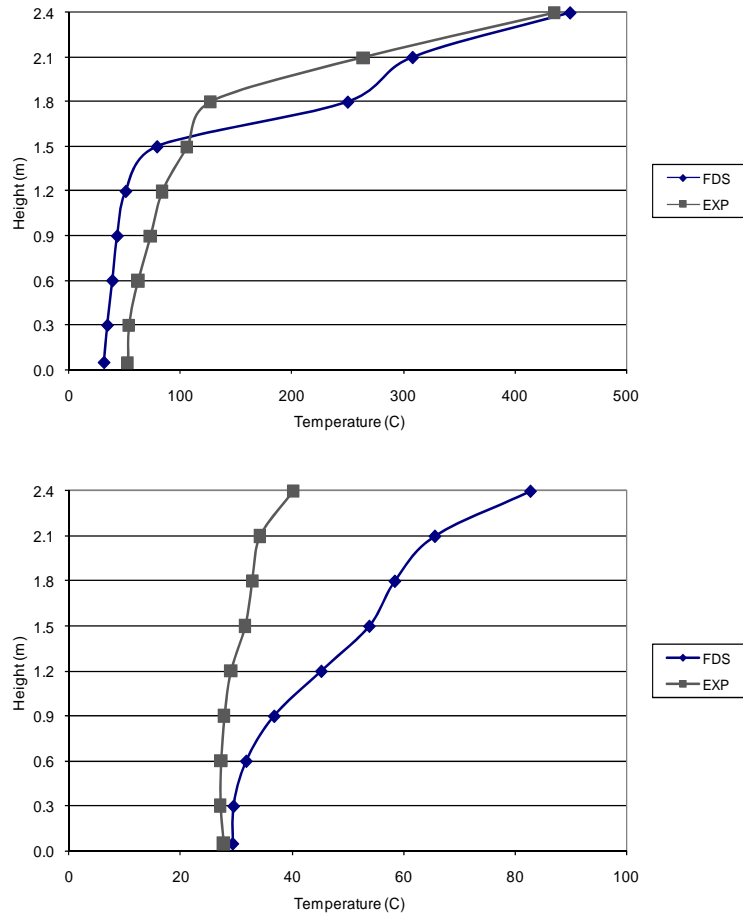
Figure 4-16. Vertical variations of temperature at 900 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

In the kitchen FDS shows a slight 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 to 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 14 % 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 4-17.
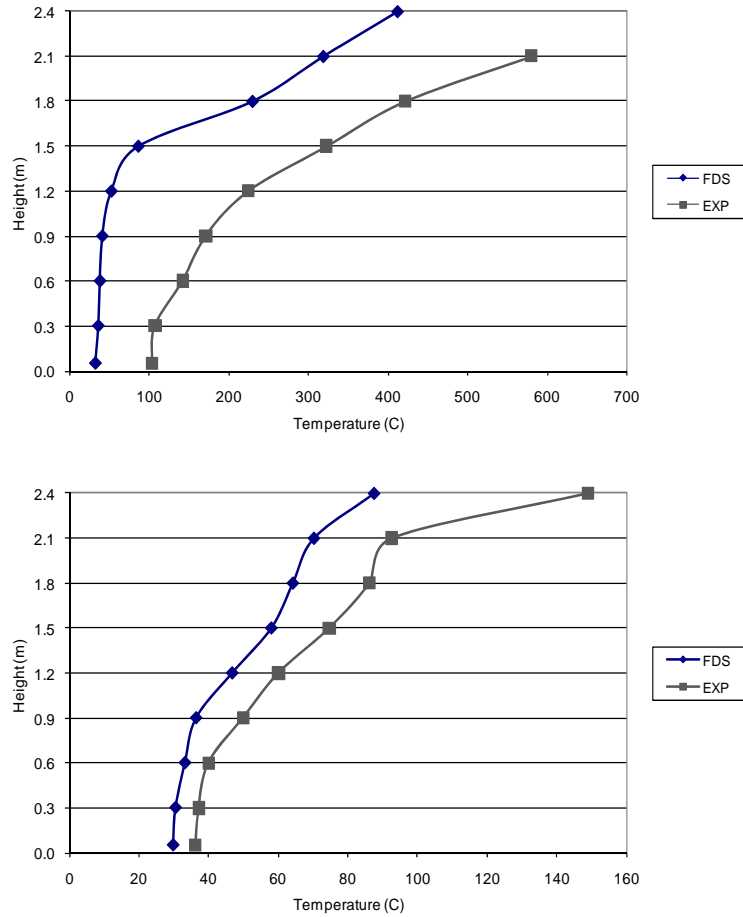
Figure 4-17. Vertical variations of temperature at 1200 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

At 1200 s FDS appears to show the same general shape of the curve for temperature in the kitchen but with a value 20 to 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 1900 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-18.

Figure 4-18. Vertical variations of temperature at 1900 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

After 1900 s the thermocouple at the ceiling in the kitchen was destroyed by the fire so is not included in Figure 4-18. The fire in FDS 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 % to 17 % lower than recorded in the test.

4.4.4   Carbon Monoxide Concentration

The CO concentrations measured at the ceiling, 2.4 m (8 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-19. A spike in the test data in the bedroom around 1325 s has been removed as it appeared to be equipment related. The FDS data in the kitchen has been averaged over 5 s due to fluctuations in the data.
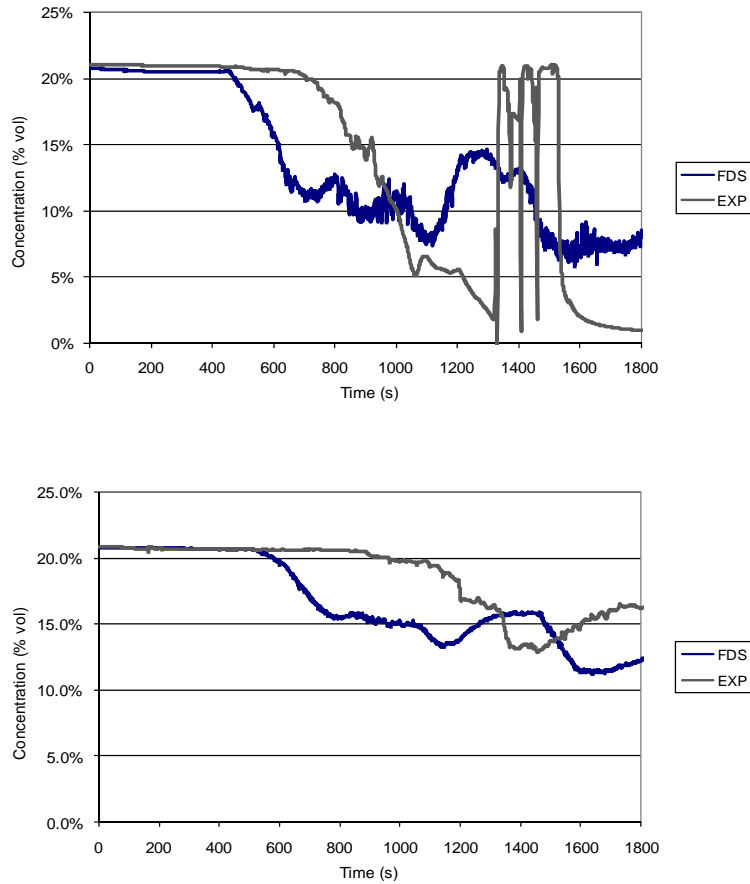
57
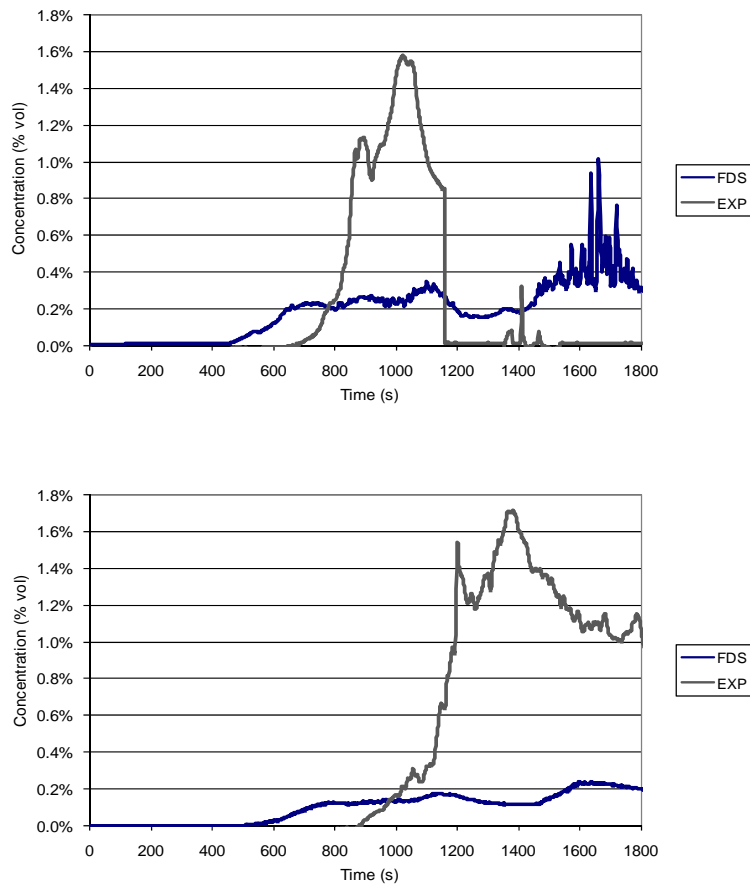
Figure 4-19. Carbon Monoxide concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test in with window removed.

The CO concentrations are lower in FDS than in the tests in both locations. In the kitchen the CO concentration in FDS plateau around 0.3 % until the last 300 s where it shows fluctuations. In the tests the CO concentrations reaches a maximum of 1.6 % by volume in both locations. In the kitchen the test results show a drop to zero around 1200 s.

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 4-20 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)
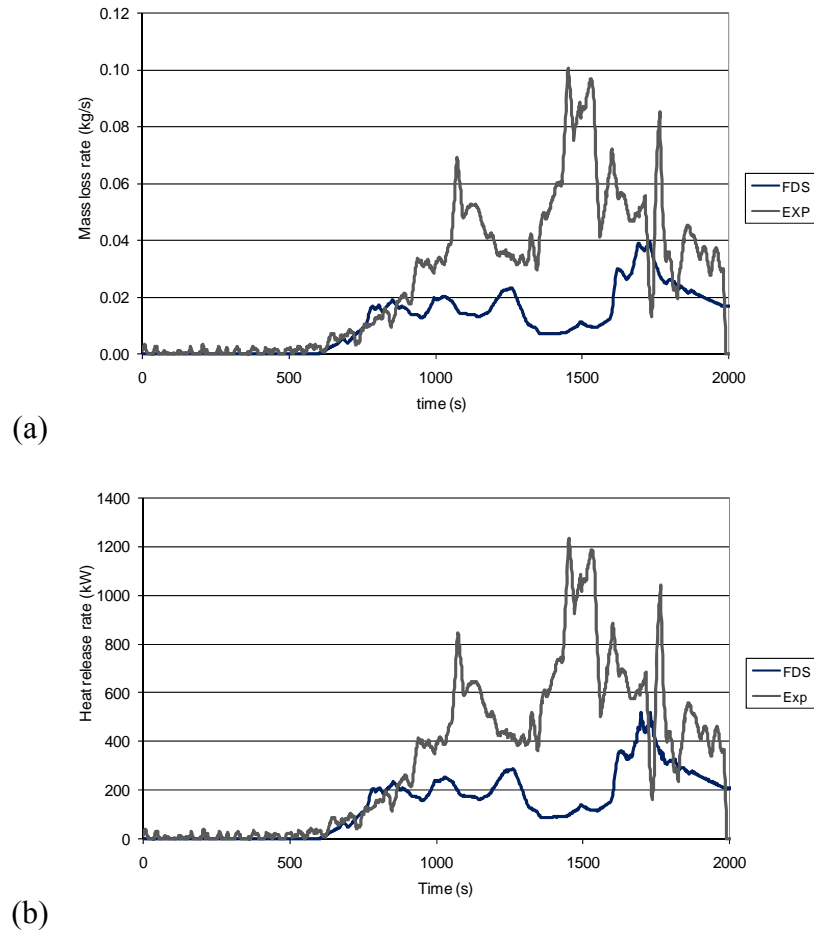
Figure 4-20. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Kitchen cabinets with door open.

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 1200 kW, almost 800 kW higher than was reached in FDS in the same time period. In the free burning 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.

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4.5.2 Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-21.

Figure 4-21. Oxygen concentrations at 2.4 m (8 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 oxygen concentration in the kitchen only decreasing to around 7 %, compared to the test where the concentration goes down to 0 %. The timings of the reduction in concentrations differ somewhat but the shape of the FDS and test data curves show some similarities. In the bedroom the decrease in oxygen starts earlier then in the test, as it does in all the other cases above, but except for a short drop, the minimum values agree well around 12 to 13 %.

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.

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Temperature measured over the height of the room at 1050 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-22.
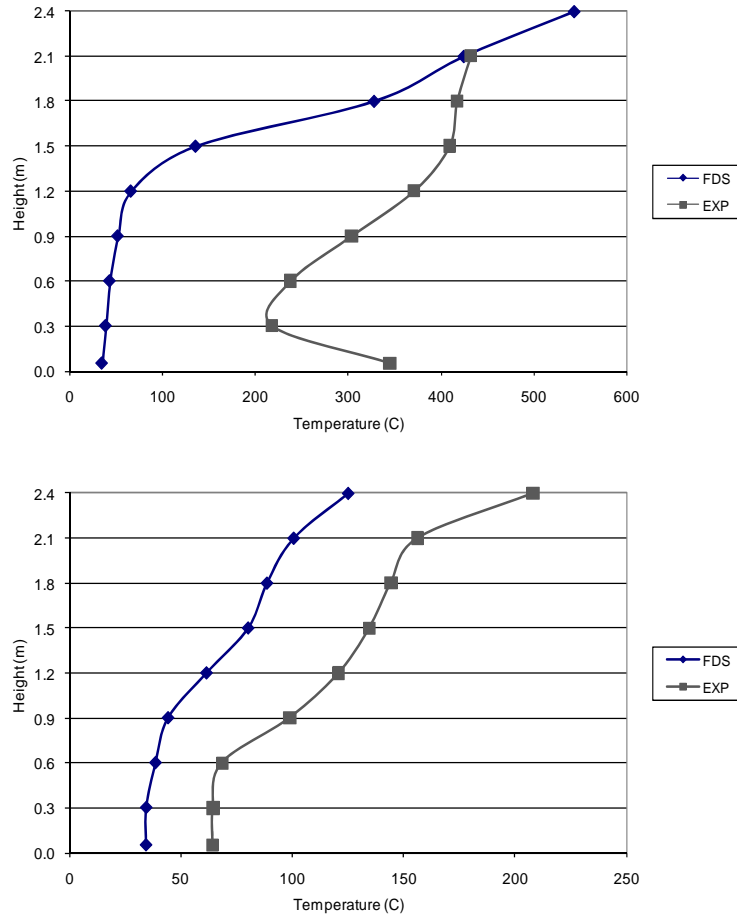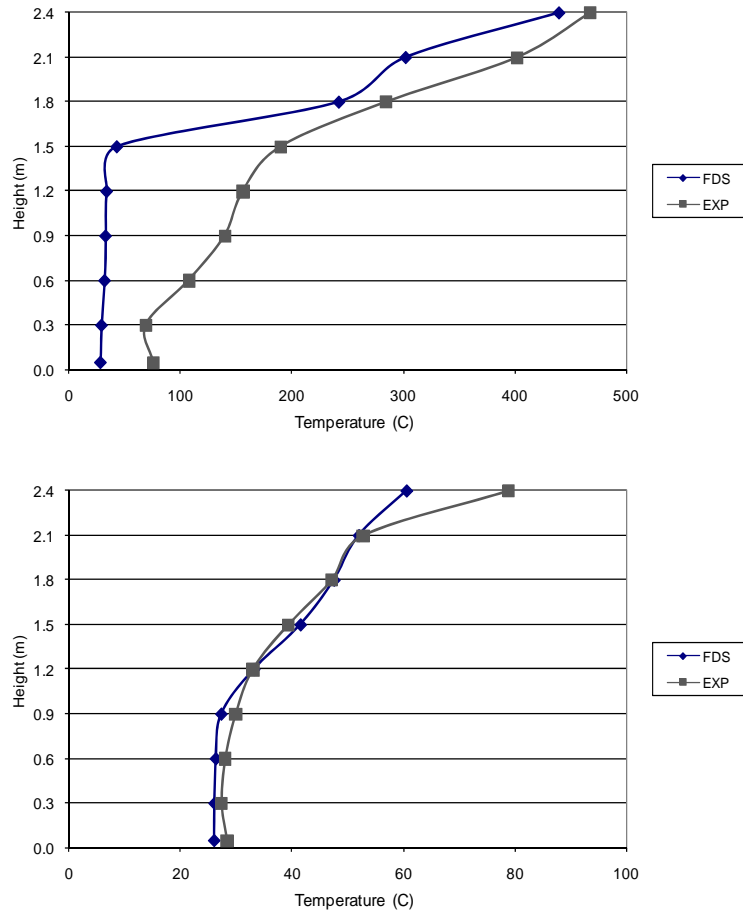

Figure 4-22. Vertical variations of temperature at 1050 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

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 4-23.

Figure 4-23. 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 4-24.
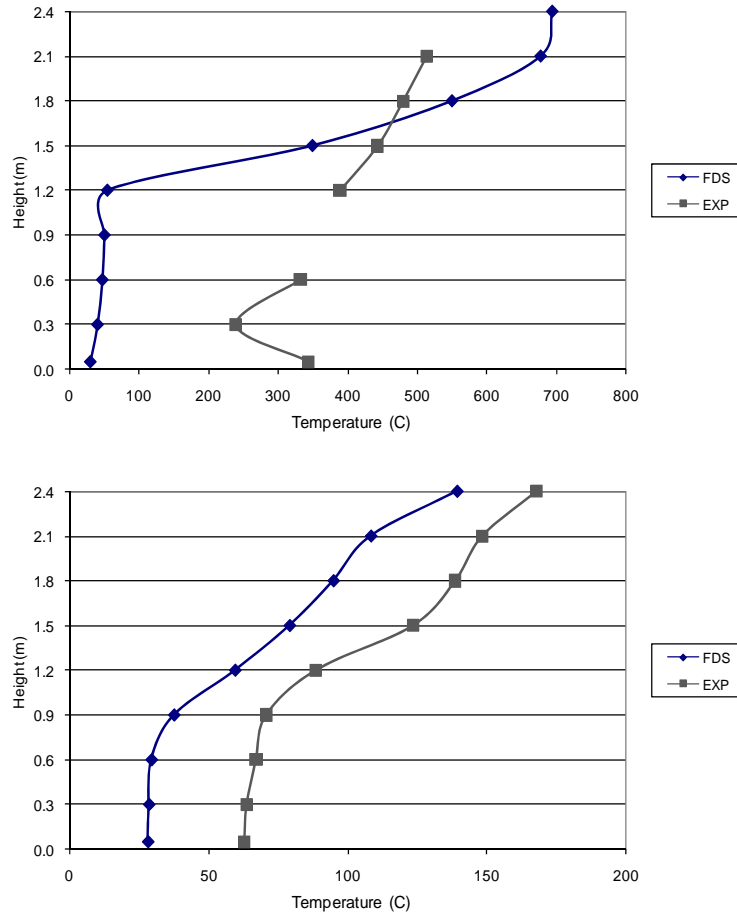
Figure 4-24. Vertical variations of temperature at 2000 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

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.

4.5.4   Carbon Monoxide Concentration

The CO concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-44.
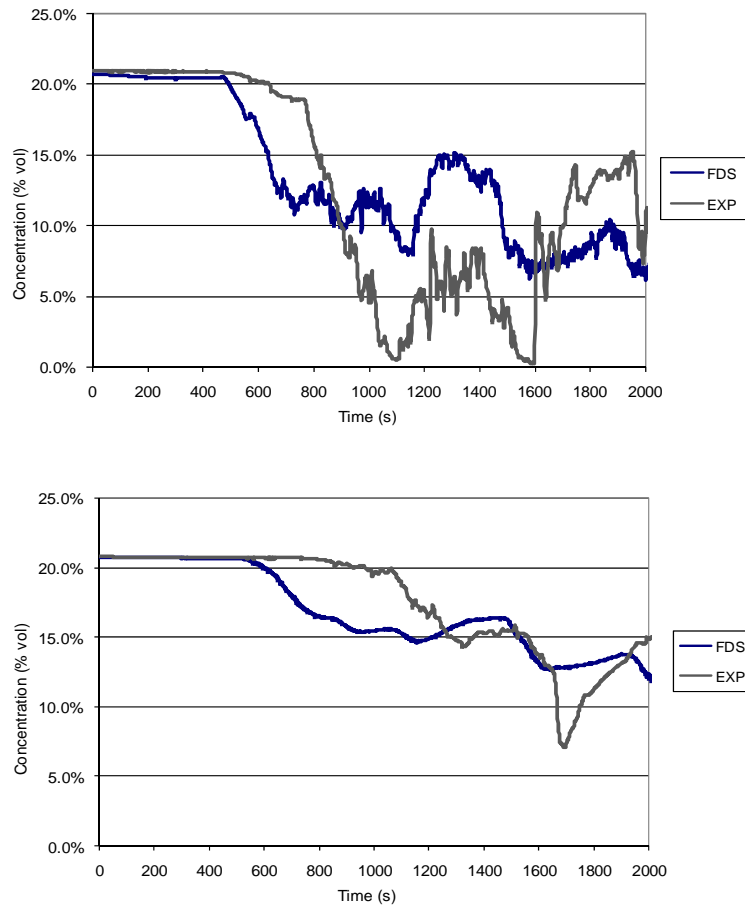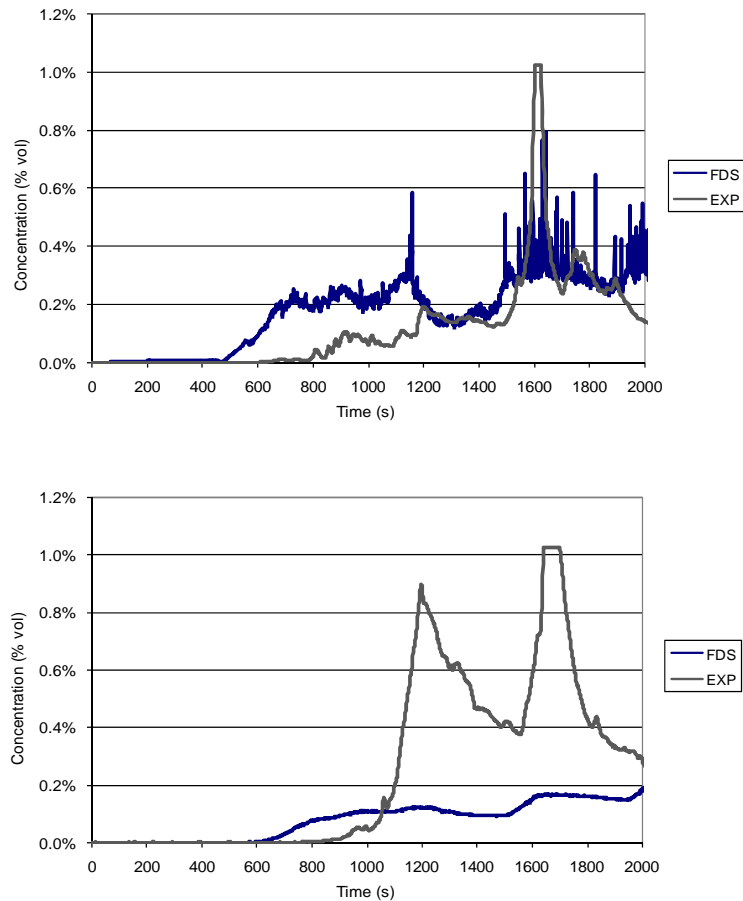
Figure 4-25. Carbon Monoxide concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test in with door open.

In the kitchen the FDS and test data shows very good agreement after 1200 s, except for at the peak where FDS only reaches 0.8 % and the test goes up to 1 % CO by volume. However the large difference in heat release rate and oxygen concentrations indicates that the fire behavior in FDS and the test is quite different so this might be a coincidence.

The CO concentrations in the bedroom are as in the other cases much lower in FDS than in the test, barely reaching 0. 2 % compared to 1.0 % measured in the compartment.

4.6   Low Kitchen Cabinet in Closed Compartment

The low kitchen cabinet simulations used the same heat release rate input from the calorimeter hood tests as the elevated cabinet simulations, only the vertical position of the cabinets was changed.

4.6.1   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

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free burning hood. Figure 4-2 shows the mass loss rate in FDS and the test (a) and the resulting
heat release rates (b).

(a)

(b)

Figure 4-26 Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation
compared to the test data. Low kitchen cabinets in the closed compartment.

The heat release rate shows better agreement between FDS and the test than was seen for
the elevated cabinet test. The test still reaches a heat release rate of 600 kW compared to a
maximum of 250 kW in FDS. However this is only a brief spike and the rest of the simulation
time the test heat release rate is at the most around 100 kW higher than seen in FDS. Around
1250 s the FDS heat release rate starts to show fluctuations indicating incomplete burning due to
lack of oxygen.

4.6.2   Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft) above the floor in the
center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-27.

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Figure 4-27. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the low 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 minimum value around 10 % by volume at 1000 s. FDS reaches this value about 200 s later. In the bedroom the oxygen concentration starts to decrease earlier in the experiment but FDS reaches a lower minimum value around 12 % by volume compared to 15 % in the test. It is not clear what caused the spiked drop around 1700 s in the experimental data.

4.6.3 Temperature

The temperature profiles across the height of the compartment were analyzed at 950 s, 1050 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 24 °C in the simulation and 27 °C in the test.

Temperature measured over the height of the room at 950 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-28.
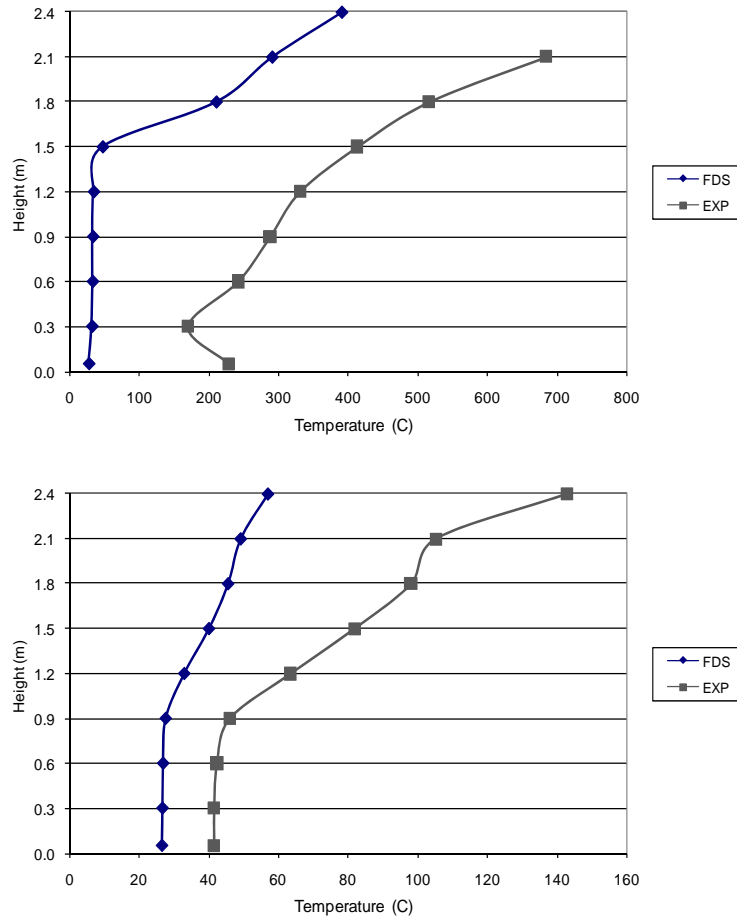
66

Figure 4-28. Vertical variations of temperature at 950 s. in the kitchen (top) and the bedroom (bottom) for the low cabinet test with compartment closed

After 950 s the upper layer in the test shows up to 25 % higher temperatures than in FDS. Below 1.5 m (5 ft) FDS is shows a lower temperature of 5 % or less. In the bedroom FDS also shows lower temperatures throughout the height by 5 % or less. These results are not surprising as the test data shows a higher heat release rate at this point.

Temperature measured over the height of the room at 1050 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-30 Figure 4-5.

Figure 4-29. Vertical variations of temperature at 1050 s. in the kitchen (top) and the bedroom (bottom) for the low cabinet test with compartment closed

In both the kitchen and the bedroom FDS underpredicts the temperatures at all heights at 1050 s. Again this is predictable when considering the higher heat release rate of fire in the test. The differences are up to 42 % in the kitchen and 14 % in the bedroom.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-30.

Figure 4-30. Vertical variations of temperature at 2000 s. in the kitchen (top) and the bedroom (bottom) for the low cabinet test with compartment closed

The fires in both the experiment and in the FDS simulation had self-extinguished due to lack of oxygen by 2000 s. In the kitchen the FDS results show good agreement with temperatures within 5 % of the test data below 1.8 m (6 ft), but overestimate the temperatures higher up. In the bedroom FDS is within 4 % of the test data

4.6.4   Carbon Monoxide Concentration

The CO concentrations measured 2.4 m (8 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-31.

Figure 4-31. Carbon Monoxide concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test in closed compartment.

The CO concentrations in both rooms show similar behavior to that seen in the other scenarios with the FDS results only reaching around 0.2 % while the test data give higher values, up to 1 %

4.7   Low Kitchen Cabinet with window half open

The window was open half way as in the elevated cabinet test, giving a ventilation opening of 20 cm (8 in) high by 60 cm (24 in) wide.

4.7.1   Heat Release Rate

Figure 4-2 shows the mass loss rate from the FDS simulation and the test data (a) and the resulting heat release rates (b).
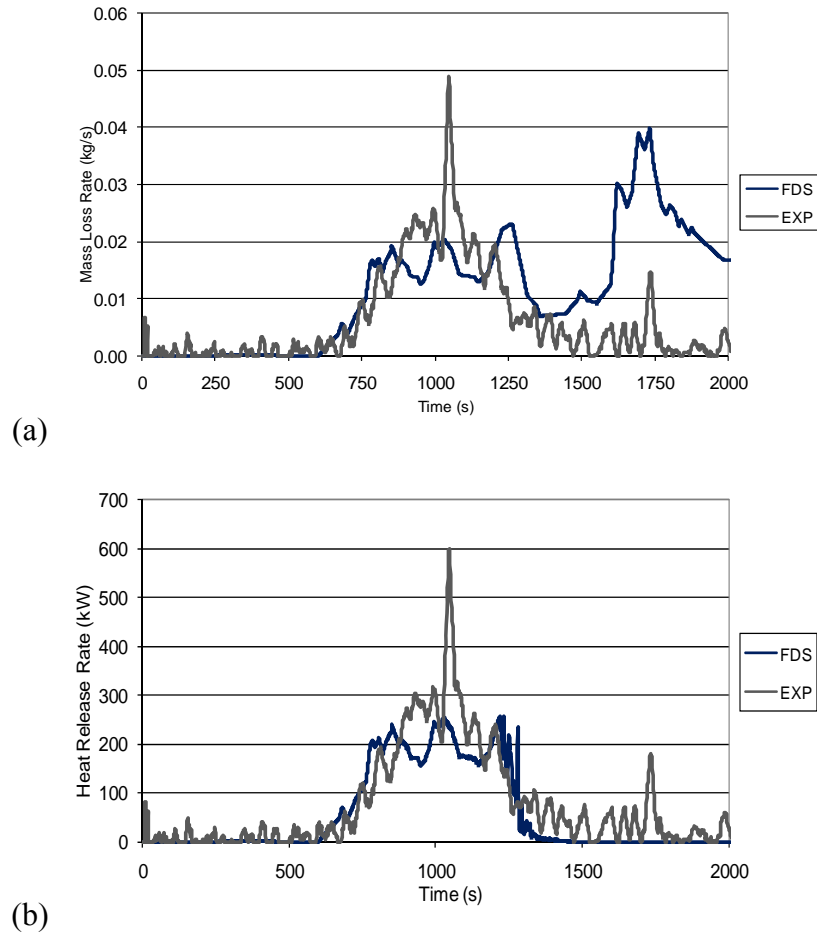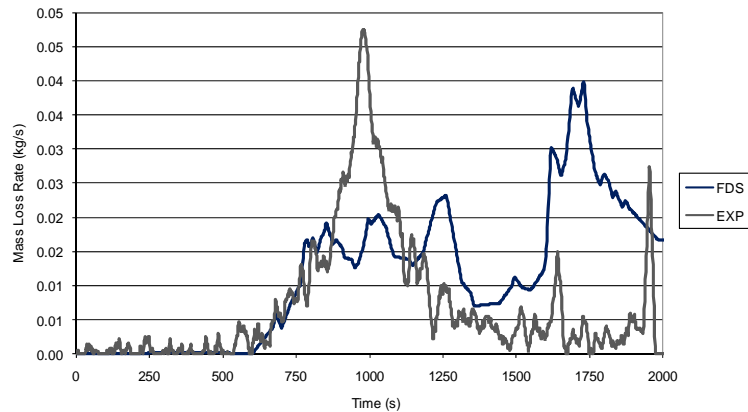
(a)
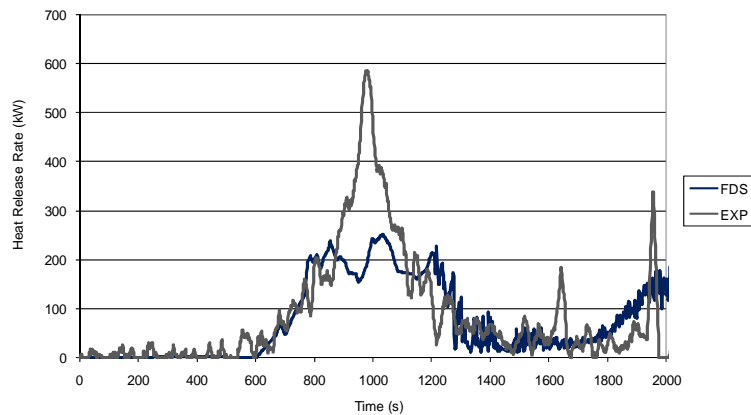
(b)

Figure 4-32 Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation
compared to the test data. Low kitchen cabinet test with window half open

The agreement between FDS and the tests is not as good with the window open as it was
in the closed configuration. The test reached a maximum heat release rate of close to 600 kW
while FDS stop around 250 kW as in the calorimeter tests. The FDS data starts to show
fluctuations at the same time as seen in the closed compartment simulation, around 1200 s.

4.7.2   Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft) above the floor in the
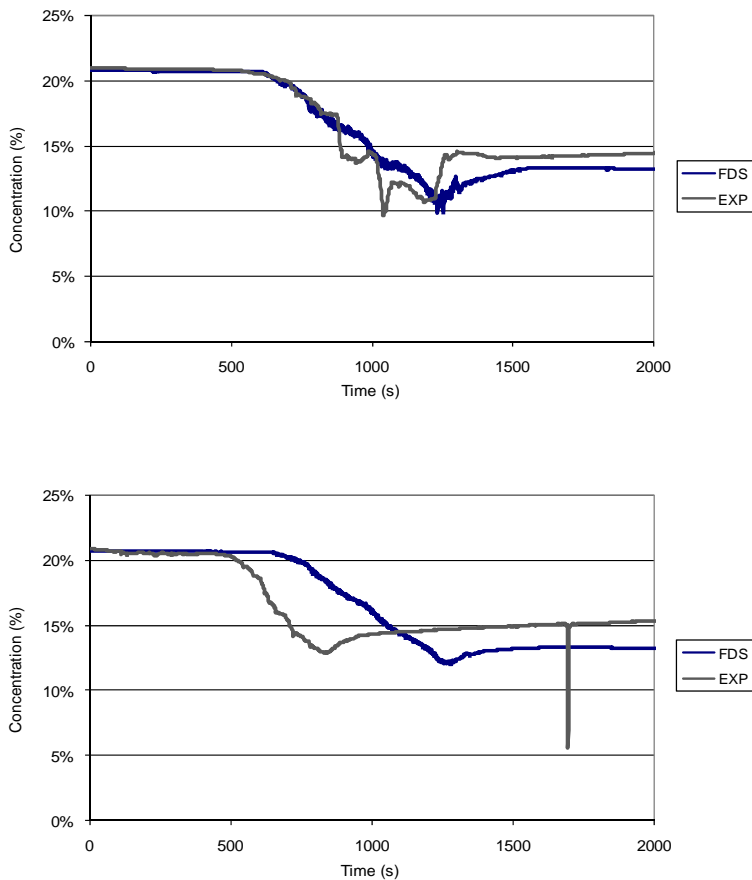center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-33.

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Figure 4-33. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the low kitchen cabinet test with window half open

In the kitchen the graphs show good agreement between the simulation and test results. However, the test reaches a lower minimum value of 8 % compared to 12 % in FDS. In the bedroom FDS predict that the decrease in oxygen starts earlier than seen in the test data, but the minimum values of 12 – 13 % show good agreement.

4.7.3   Temperature

The temperature profiles across the height of the compartment were analyzed at 1000 s, 1100 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 25 °C.

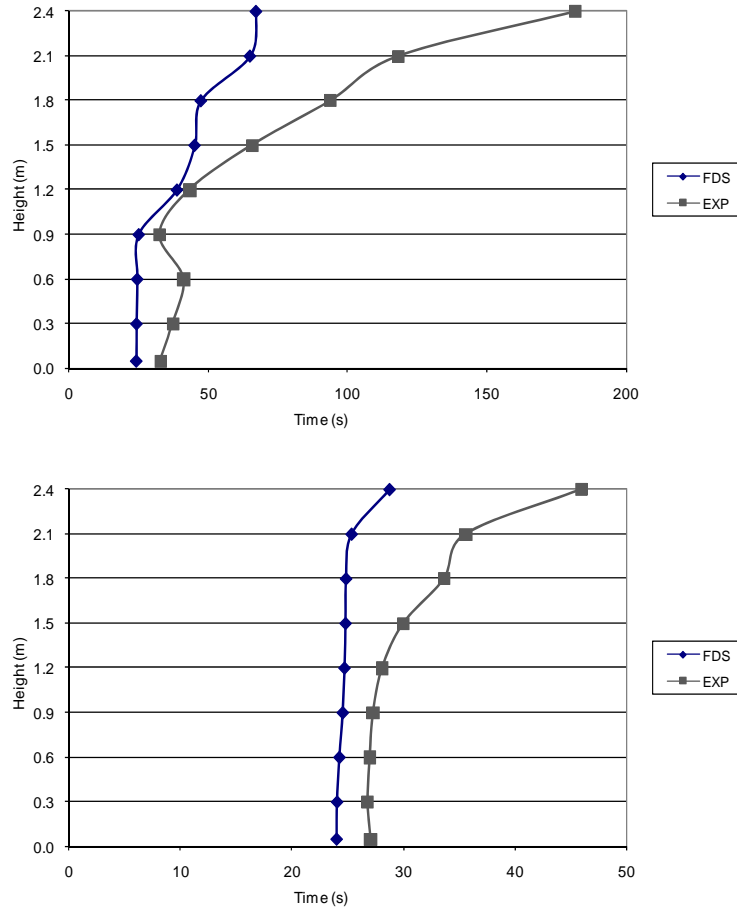Temperature measured over the height of the room at 1000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-34.

Figure 4-34 Vertical variations of temperature at 950 s. in the kitchen (top) and the bedroom (bottom) for the low cabinet test with window half open

The temperature in the kitchen shows good agreement between FDS and the test data. At 1.2 m (4 ft) and 2.4 m (8 ft) there is a 20 % differences but otherwise FDS is within 8 % of the temperature recorded in the test. In the bedroom FDS consistently shows lower temperatures than seen in the test by up to 15 %.

Temperature measured over the height of the room at 1050 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-35.

Figure 4-35. Vertical variations of temperature at 1050 s. in the kitchen (top) and the bedroom (bottom) for the low cabinet test with window half open

The test had a higher peak heat release rate than FDS so predictably the temperatures in the fire room are higher. Around 20 % higher in the lower layer up to 1.2 m (4 ft) and 30 % higher in the upper layer. In the bedroom the results are more mixed with FDS giving lower temperatures in the lower layer and higher in the upper layer. However , the FDS results are within 10 % 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 4-36.
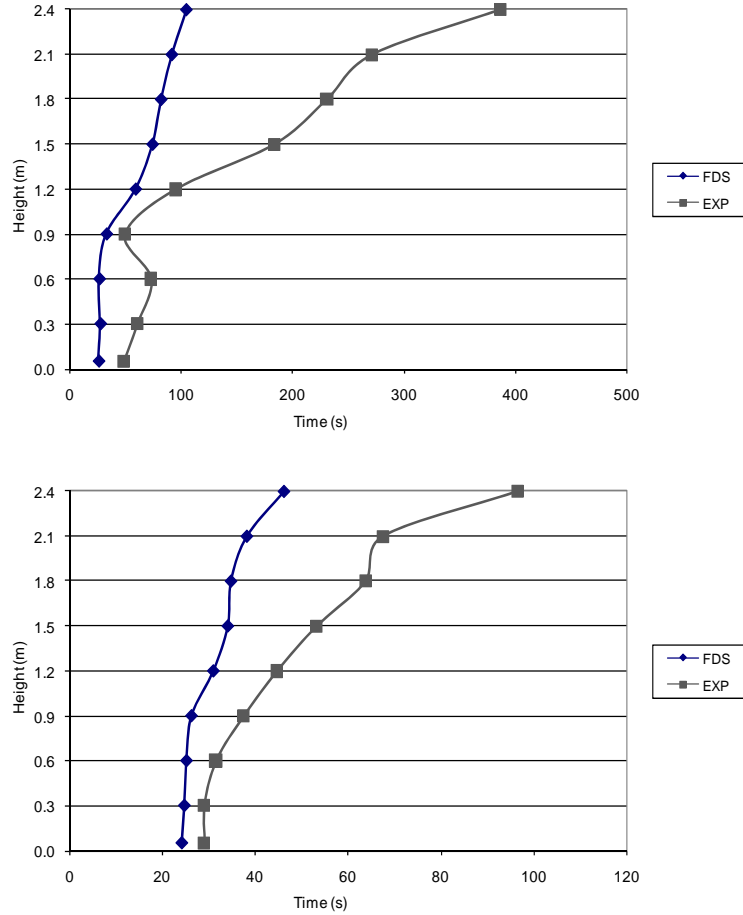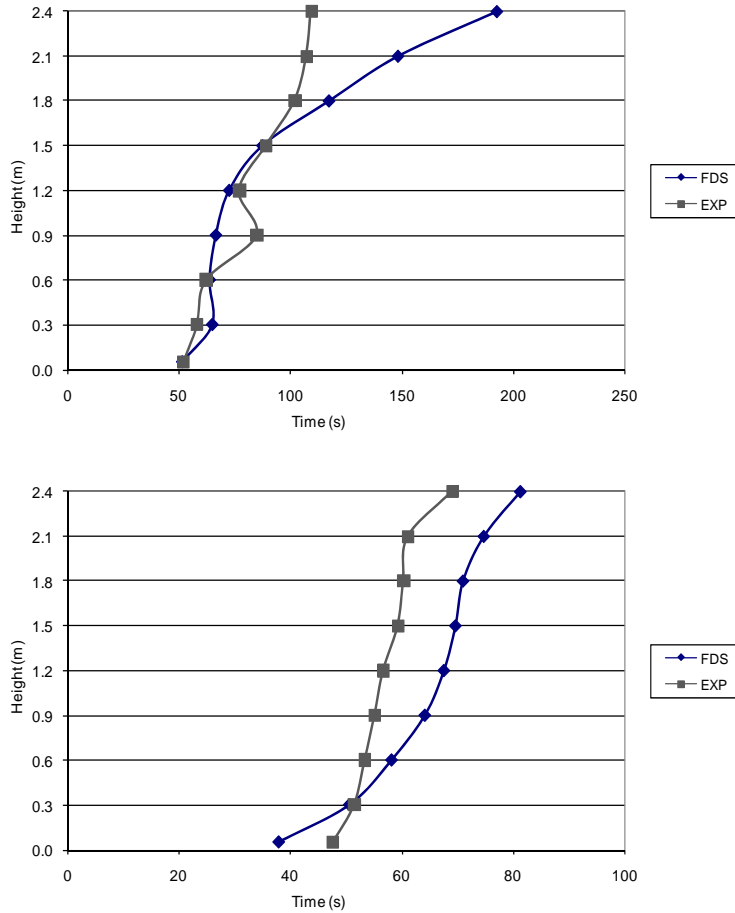
74

Figure 4-36. Vertical variations of temperature at 2000 s. in the kitchen (top) and the bedroom (bottom) for the low cabinet test with window half open

At the end of the fire the FDS results in the kitchen are lower than recorded in the test but within 7 % at all heights. Because of the increase in heat release rate late in the simulations, which was not seen in the test data FDS gives higher temperatures near the ceiling in the bedroom.

4.7.4   Carbon Monoxide Concentration

The CO concentrations measured 2.4 m (8 ft) above the floor in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-37.
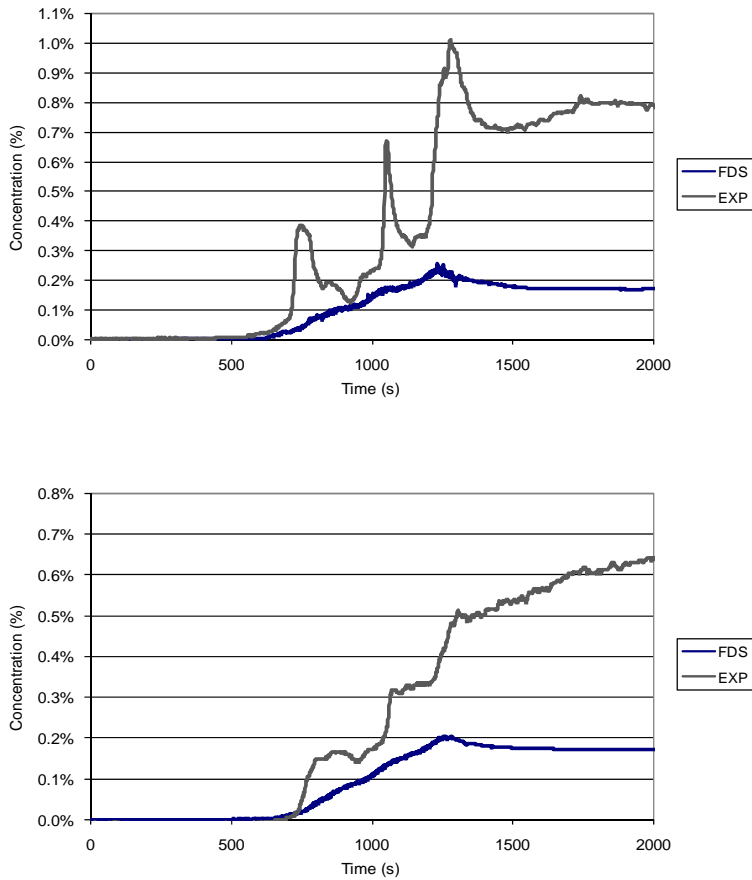
Figure 4-37. Carbon Monoxide concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the low cabinet test with window half open.

The CO concentrations in the kitchen show FDS reaching a maximum value around 0.3 %. The test data rises up to 0.9 % at 1300 s. In the bedroom the behavior in FDS is similar to that seen in the kitchen with a steady rise starting around 500 s to a maximum value of 0.2 % at 1200 s, which is lower than the 0.6 % seen in the test data.

4.8   Low Kitchen Cabinet with door open

The entrance door was fully opened and the window closed, giving a ventilation opening into the living room of 2 m (6.5 ft) high by 1 m (3 ft) wide. A window broke at 1822 s after ignition and the fire was extinguished.

4.8.1   Heat Release Rate

Figure 4-38 shows the mass loss rate from the FDS simulation and the test data (a) and the resulting heat release rates (b).

76

(a)

(b)

Figure 4-38 Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation
compared to the test data. Low kitchen cabinet test with door open

As was seen for the elevated cabinet tests, with larger ventilation the difference increases
between the heat release rate from the calorimeter as input to FDS and the actual heat release rate
achieved in the compartment in the test. The FDS data does not go above 500 kW but the load
cell data from the test indicates a heat release rate of over 1000 kW at several points, and a
maximum sustained value over 600 kW.

4.8.2   Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft) above the floor in the
center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-39.
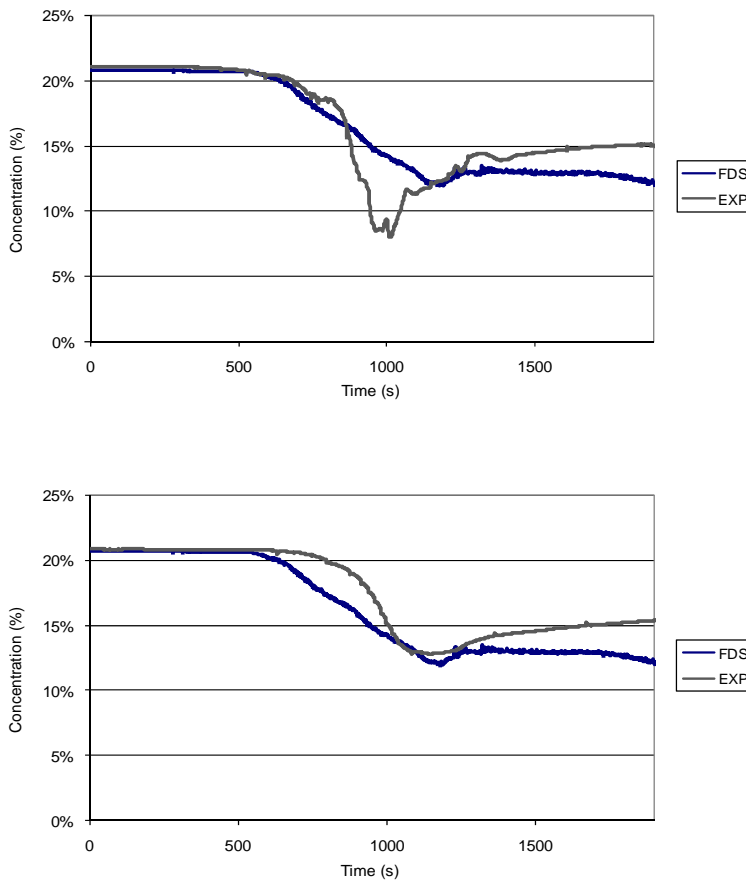
77
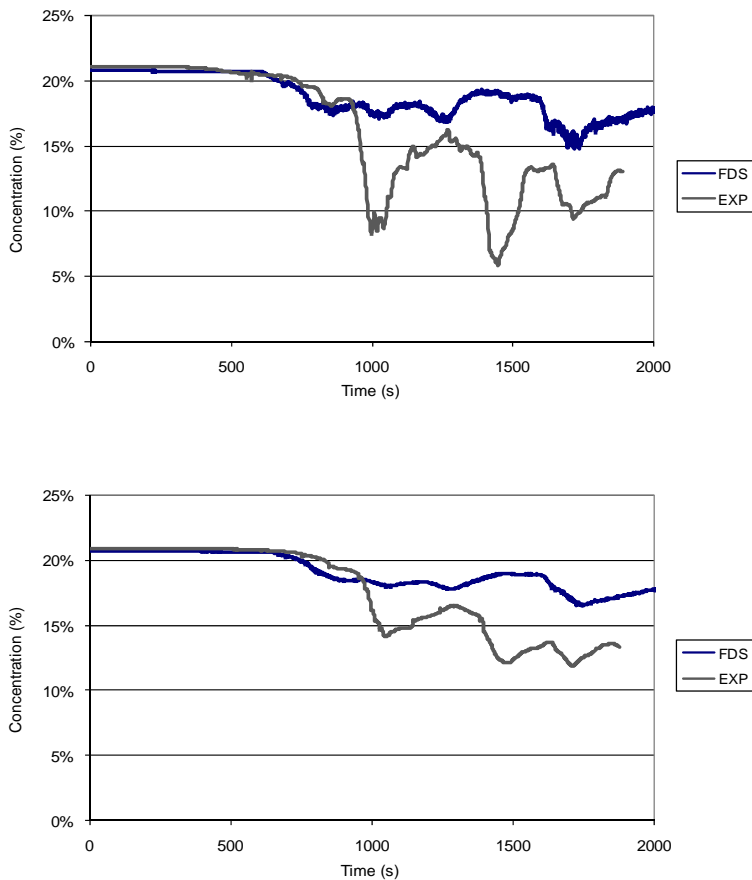
Figure 4-39. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the low kitchen cabinet test with window half open

The larger heat release rate of the fire in the test results in a reduction in oxygen concentrations larger than that seen in the FDS simulations in both the kitchen and in the bedroom. The FDS simulation does not give oxygen concentrations below 15 % by volume in either room, whereas in the test the concentration drops close to 5 % in the kitchen and 12 % in the bedroom.

4.8.3   Temperature

The temperature profiles across the height of the compartment were analyzed at 1150 s, 1650 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 25 °C.

Temperature measured over the height of the room at 1150 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-40.
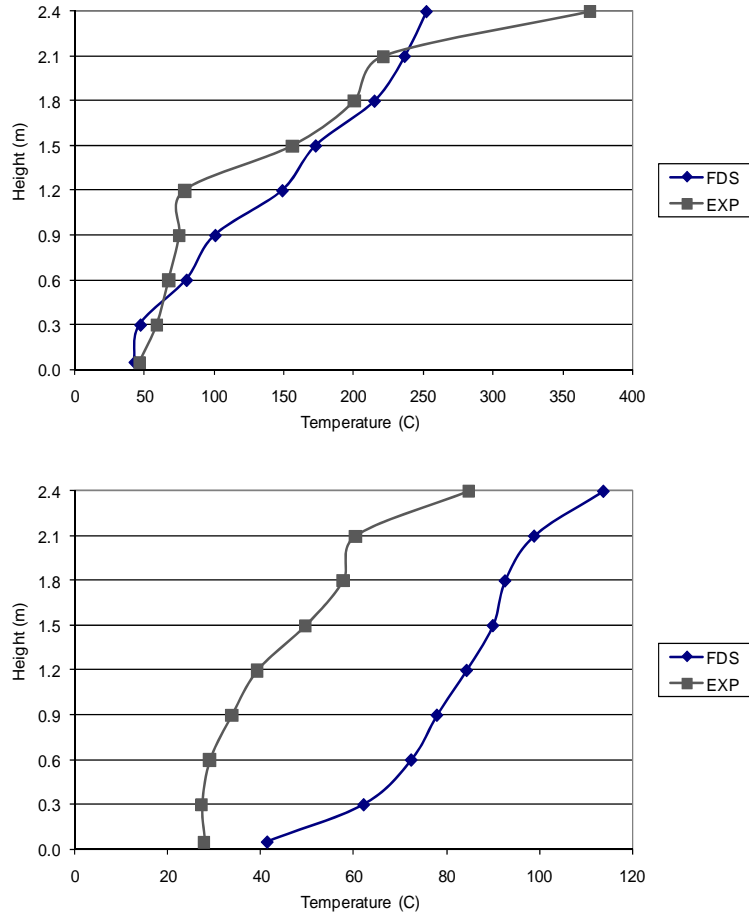
Figure 4-40 Vertical variations of temperature at 1150 s. in the kitchen (top) and the bedroom (bottom) for the low cabinet test with door open

The much smaller fire size in FDS predictably results in a lower temperature in both rooms. The temperature in the test is up to 40 % higher in the kitchen. In the bedroom the top three thermocouples show strange behavior indicating that the data might not be valid. Looking at the temperature versus time graphs shows that the thermocouples at 2.4 m (8 ft) and 1.8 m (6 ft) barely report temperatures above ambient, while the one at 2.1 m (7 ft) shows large fluctuations throughout the test. Excluding these, FDS gives temperatures up to 15 % below that recorded in the test.

Temperature measured over the height of the room at 1050 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-41.
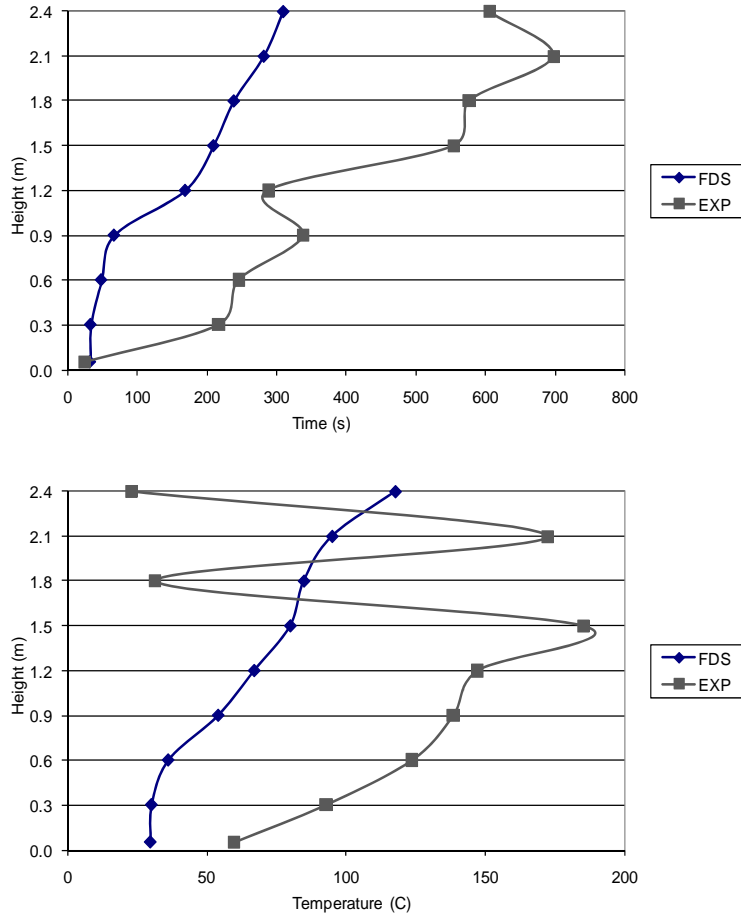
Figure 4-41. Vertical variations of temperature at 1650 s. in the kitchen (top) and the bedroom (bottom) for the low cabinet test with window half open

At peak heat release rate the underestimation of the temperatures in FDS has increased at all heights. The test data is now over 30 % higher everywhere except at the floor, and 43 % higher at 2.1 m (7 ft). The same is the case in the bedroom where if the top three thermocouples are excluded FDS gives temperatures up to 23 % lower than the test data.

Temperature measured over the height of the room at 1900 s in the kitchen (top) and bedroom (bottom) are shown in Figure 4-42.
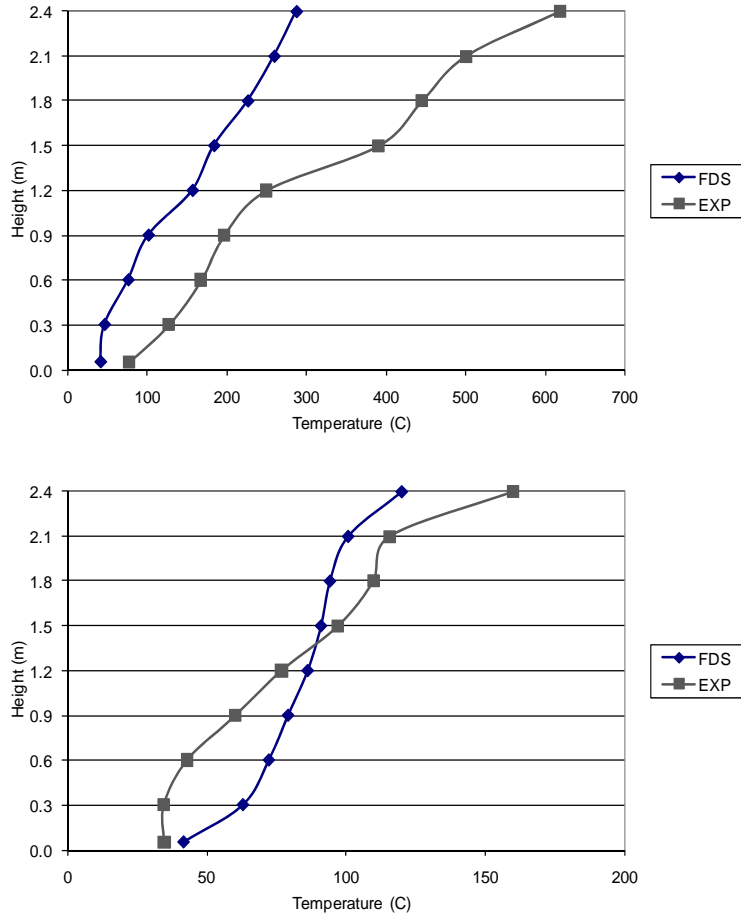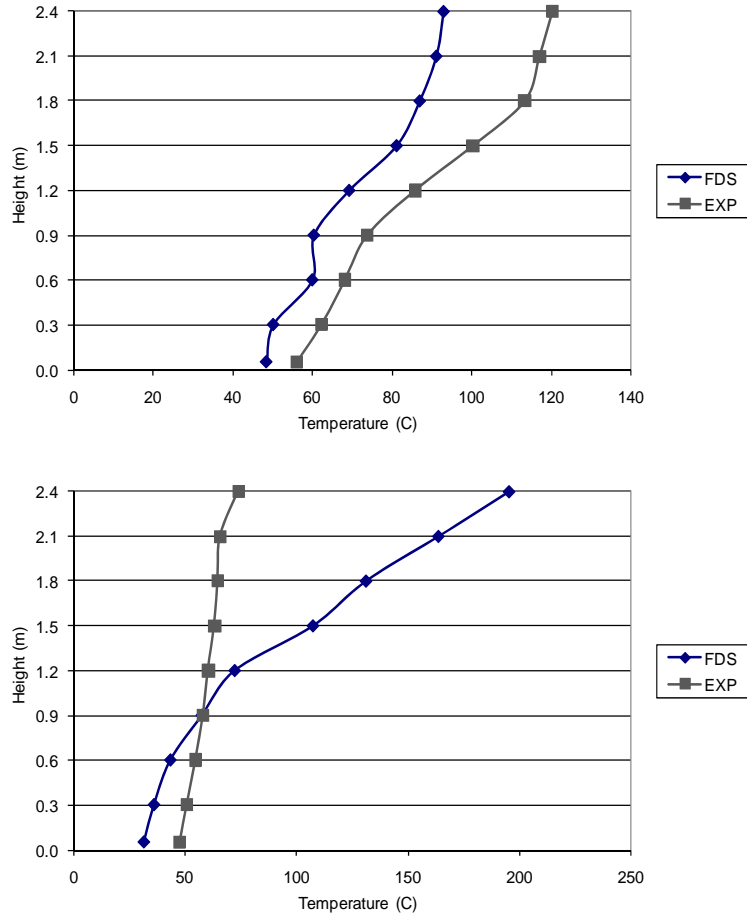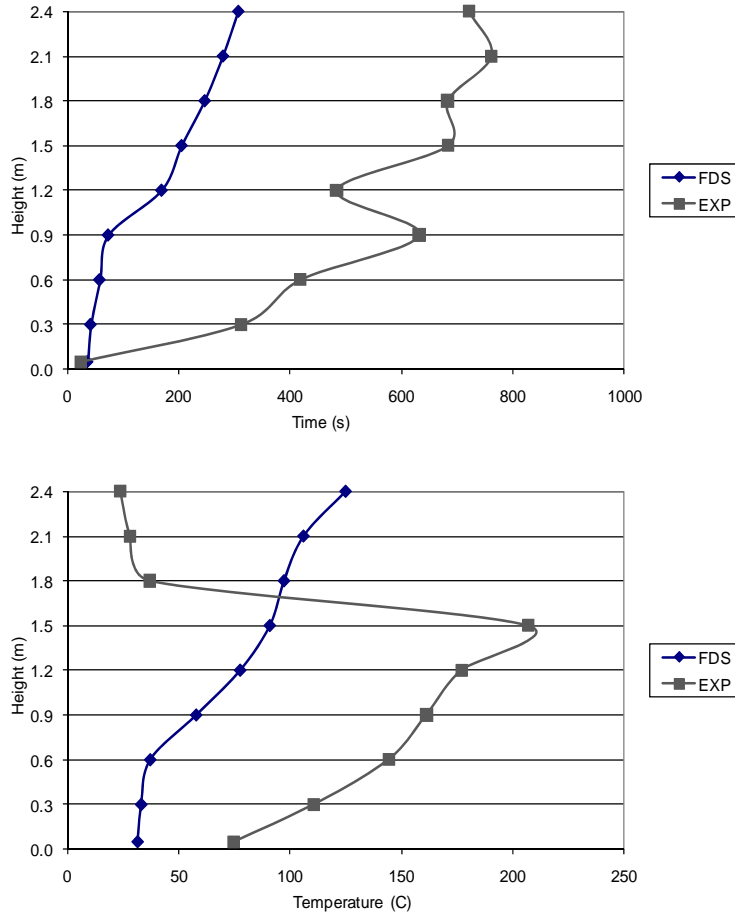
Figure 4-42. Vertical variations of temperature at 2000 s. in the kitchen (top) and the bedroom (bottom)
for the low cabinet test with window half open

At the end of the fire the temperature results from the test is over 40 % higher than in
FDS everywhere in the kitchen except at the floor, and at the most 60 % higher. In the bedroom
the results are about the same as seen at peak heat release rate at 1650 s, with the differences a
few percent higher.

4.8.4   Carbon Monoxide Concentration

The CO concentrations measured 2.4 m (8 ft) above the floor in the center of the room in
the kitchen (top) and in the bedroom (bottom) are shown in Figure 4-43.
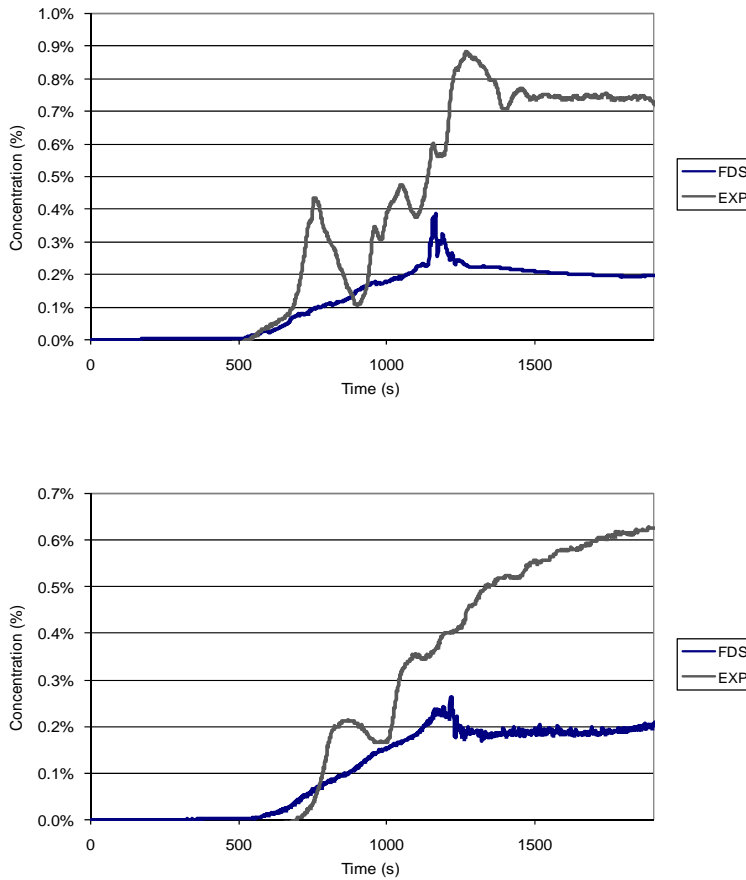
81
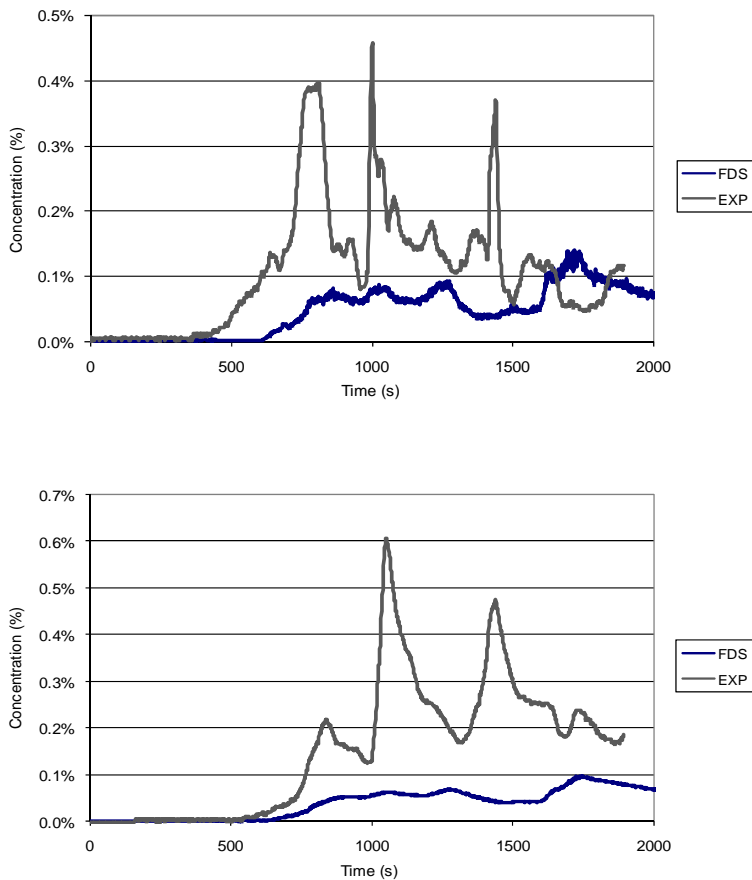
Figure 4-43. Carbon Monoxide concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the low cabinet test with window half open.

The CO concentrations in both rooms were low in this configuration compared to the other tests, only exceeding 0.5 % by volume for a brief time at one point in the bedroom. The test data shows a earlier increase in CO concentration and a higher value throughout the test in both rooms, except after 1600 s in the kitchen.

4.9 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.

4.9.1 Heat Release Rate

The mass loss rate from the test data and FDS is shown in Figure 4-44 (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 4-44 (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.
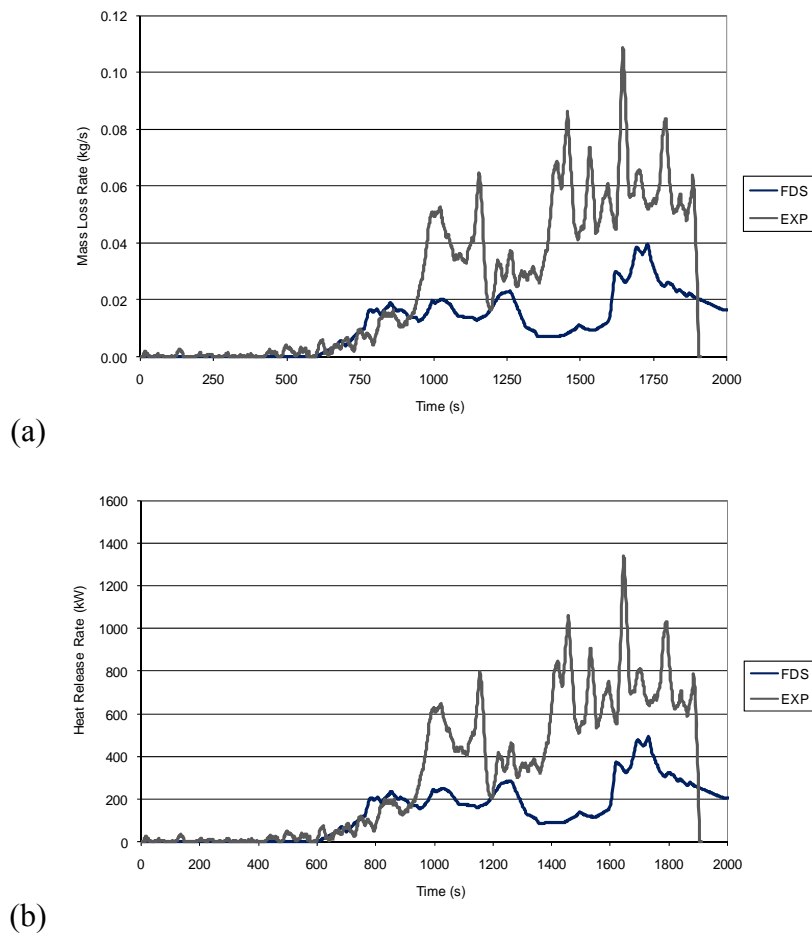
82

(a)

(b)
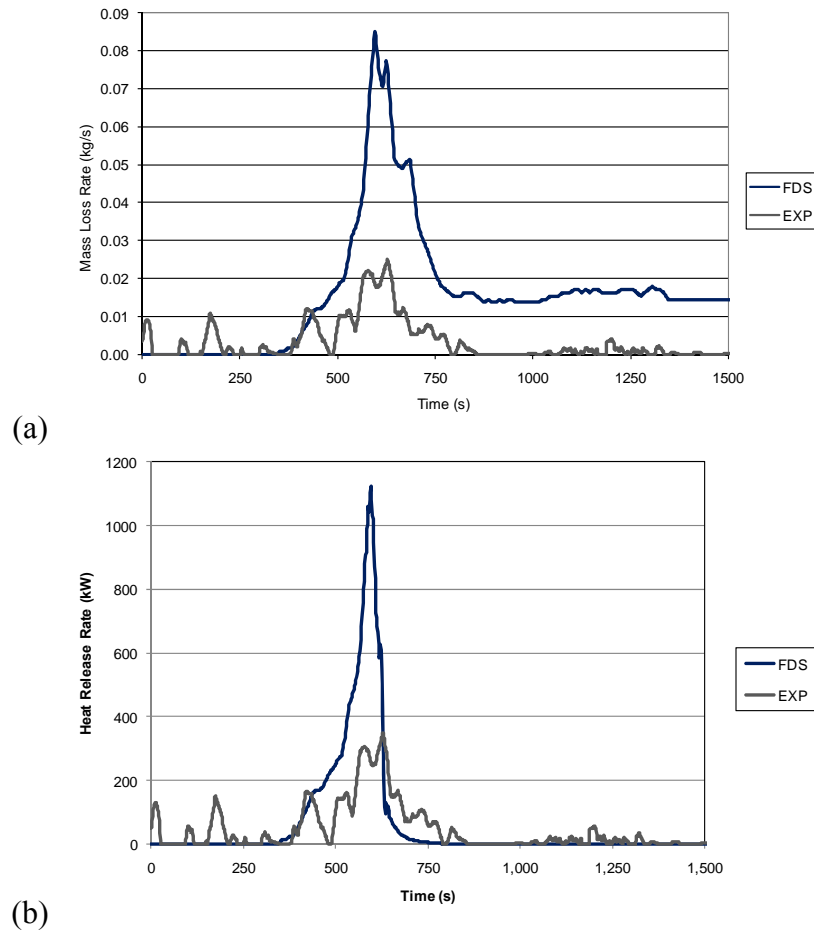
Figure 4-44. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Sofa in the closed compartment.

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.

4.9.2   Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 4-45.

83
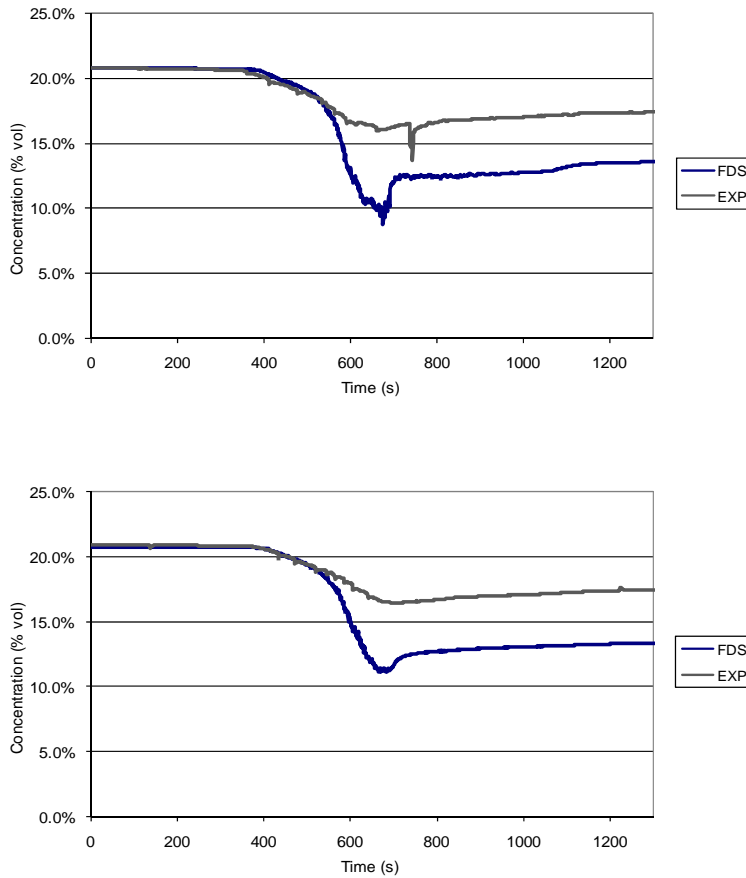
Figure 4-45. Oxygen concentrations at 2.4 m (8 ft) in the living room (top) and bedroom (bottom) for the sofa test in the closed compartment.

Possible because 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 indicates that it was not a lack of oxygen in the compartment that caused the reduced heat release rate in the experiment. FDS shows a lower oxygen concentration with a minimum of 10 % before it settle around 13 % but still does not show 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.

4.9.3   Temperature

The temperature profiles across the height of the compartment were analyzed at 500 s, 650 s and 1500 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.

84

Temperature measured over the height of the room at 500 s in the living room (top) and bedroom (bottom) are shown in Figure 4-46.

Figure 4-46. 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 up to 7 %.

Temperature measured over the height of the room at 650 s in the living room (top) and bedroom (bottom) are shown in Figure 4-47.

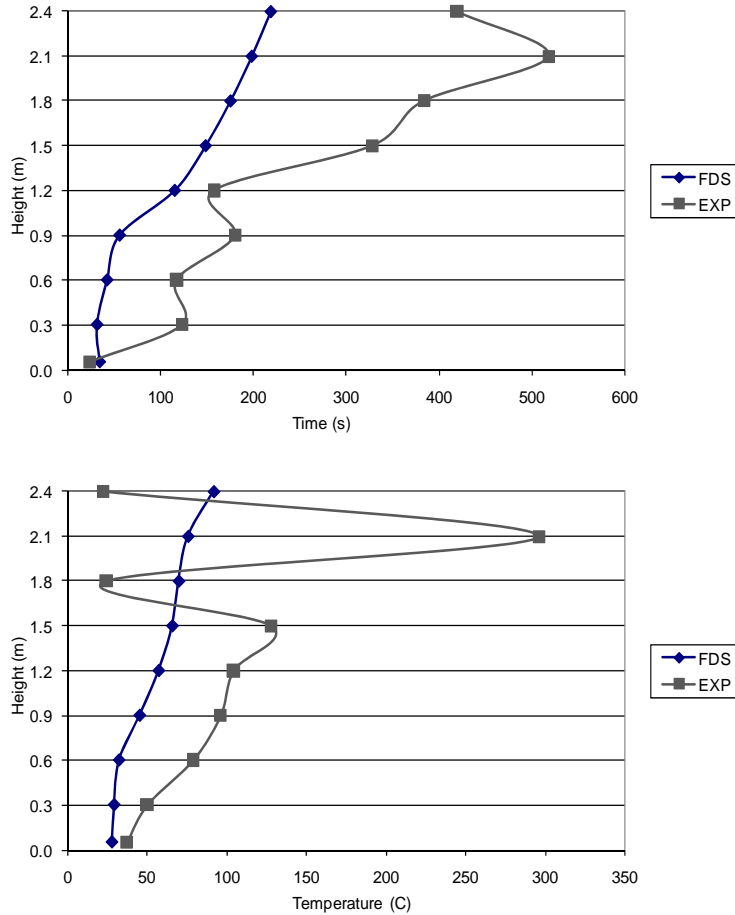Figure 4-47. Vertical variations of temperature at 650 s in the living room (top) and the bedroom (bottom) for the sofa test in the closed compartment.

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 1500 s in the living room (top) and bedroom (bottom) are shown in Figure 4-47.

86
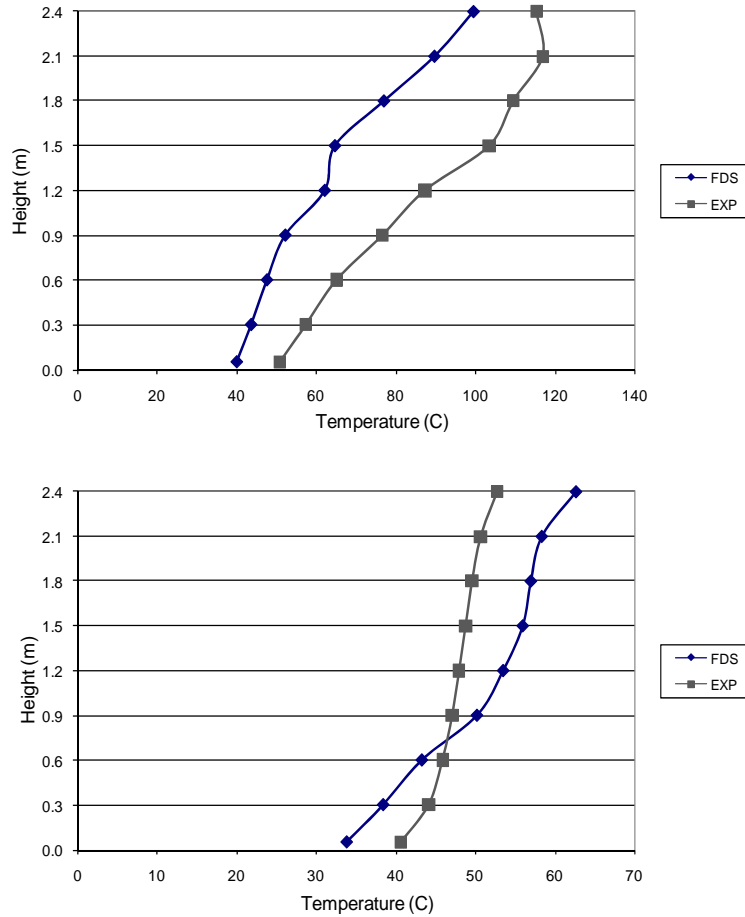
Figure 4-48. Vertical variations of temperature at 1500 s in the living room (top) and the bedroom (bottom) for the sofa test in the closed compartment.

At 1500 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.

4.9.4   Carbon Monoxide Concentrations

The CO concentrations measured 2.4 m (8 ft) above the floor in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 4-49
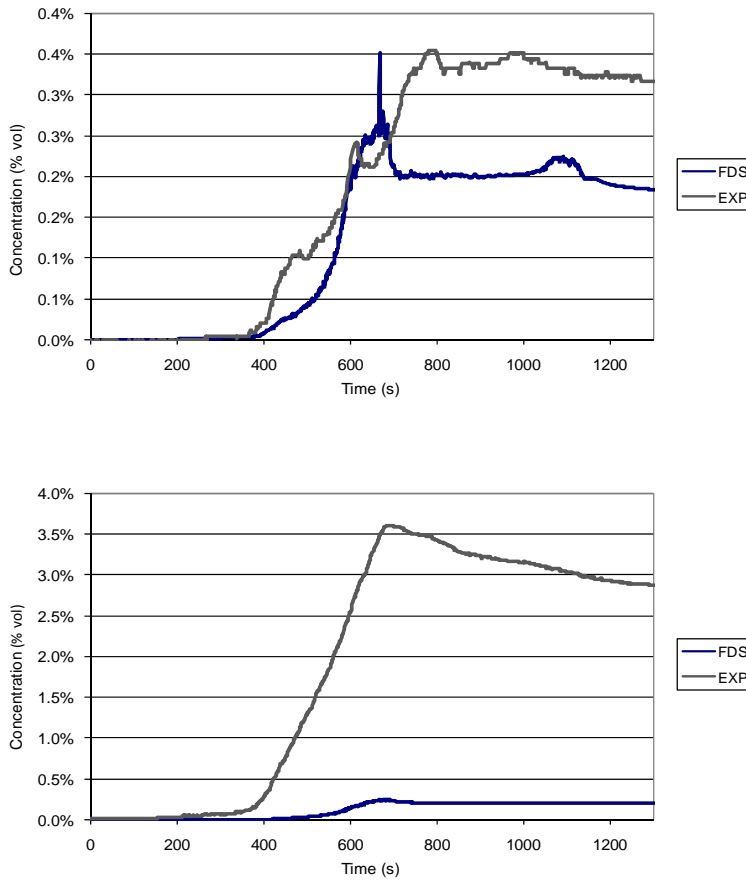
Figure 4-49. Carbon Monoxide concentrations at 2.4 m (8 ft) in the living room (top) and bedroom (bottom) for the sofa test in the closed compartment.

In the kitchen the FDS data follows the test closely up until around 700 s when it drops down and settles at 0.2 % and the test data continue to rise to 0.4 %. In the bedroom FDS only give a minimal increase in CO concentrations compared to the test which reaches 3.5 %, indicating significantly underventilated burning.

4.10 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.

4.10.1 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 4-50 shows the mass loss rate in FDS and the test (a) and the resulting heat release rates (b).

88
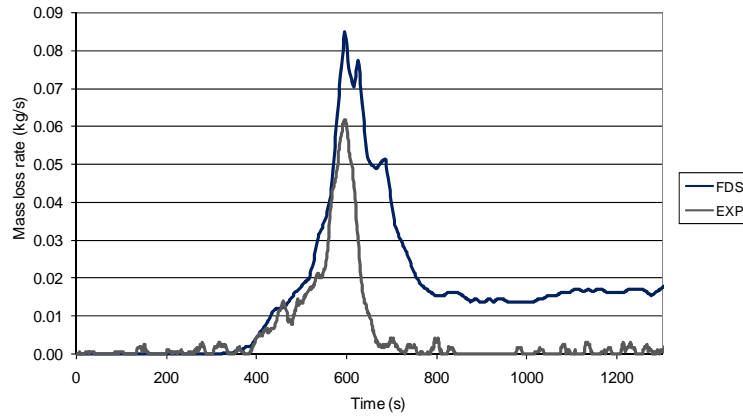
(a)
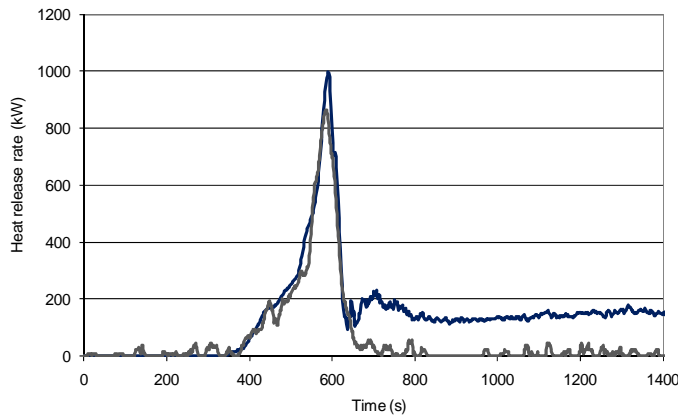
(b)

Figure 4-50. Mass loss rate (a) and heat release rate (b) in the FDS calorimeter heat release rate simulation compared to the test data. Sofa test 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, even though the mass loss rate is lower. The higher mass loss rate in FDS which gives a similar heat release rate indicates that the heat of combustion used in FDS is lower that was the case in the test. Comparing the two curves it is clear that in FDS at around 600 s a lack of oxygen restricts the burning. Mass is being released which does not burn.

4.10.2 Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 4-51.
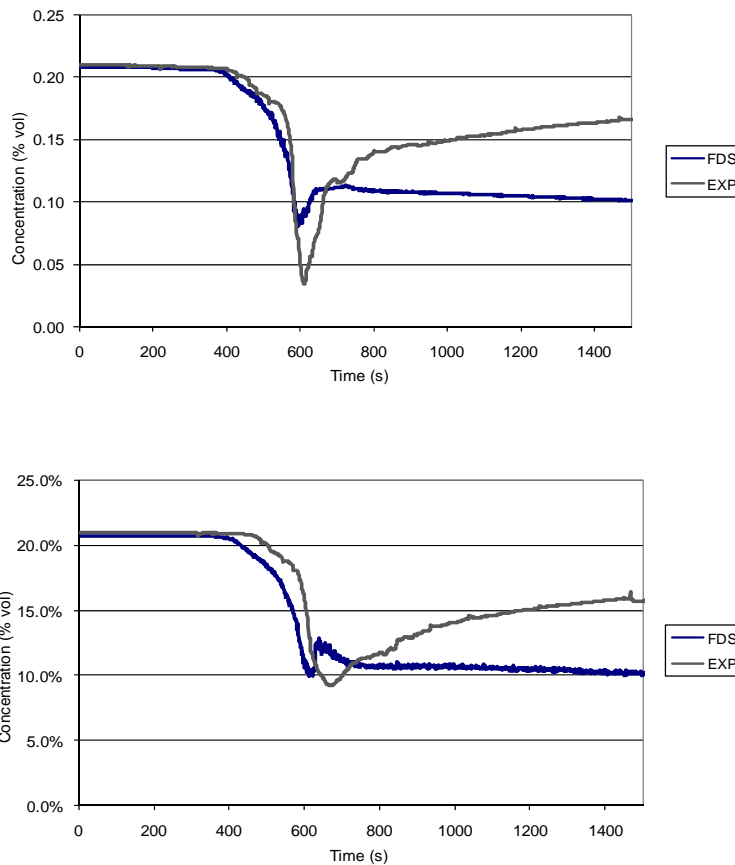
Figure 4-51. Oxygen concentrations at 2.4 m (8 ft) in the living room (top) and bedroom (bottom) for the sofa test with window half open.

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. This is also the point where the heat release rate indicates incomplete combustion starts. 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.

4.10.3 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 4-52.

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Figure 4-52. 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 between 10 – 15 % at all heights.

Temperature measured over the height of the room at 600 s in the living room (top) and bedroom (bottom) are shown in Figure 4-53.
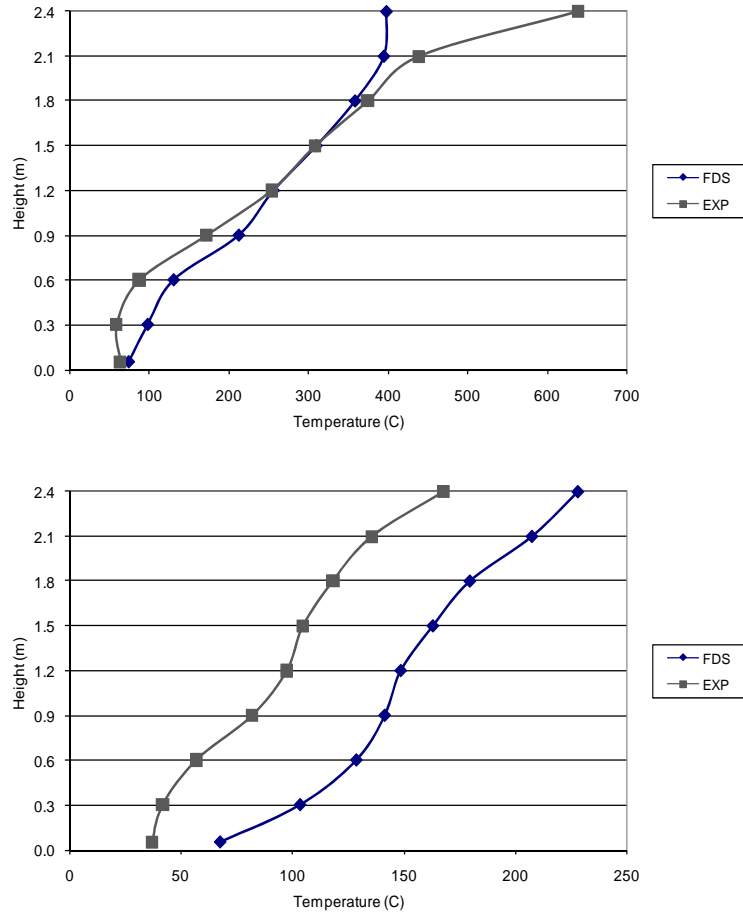
Figure 4-53 Vertical variations of temperature at 600 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open.

After 600 s the predictions in the living room are closer, being within 12 % of the test data for all the thermocouples, except at the ceiling. In the bedroom FDS gives temperatures at least 10 % 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 living room (top) and bedroom (bottom) are shown in Figure 4-54.
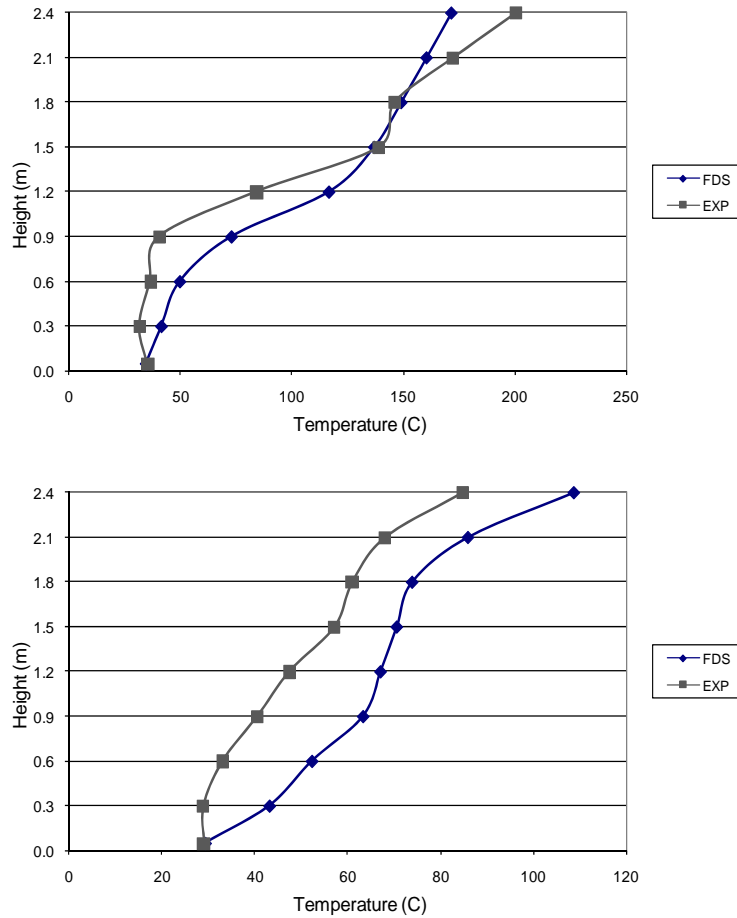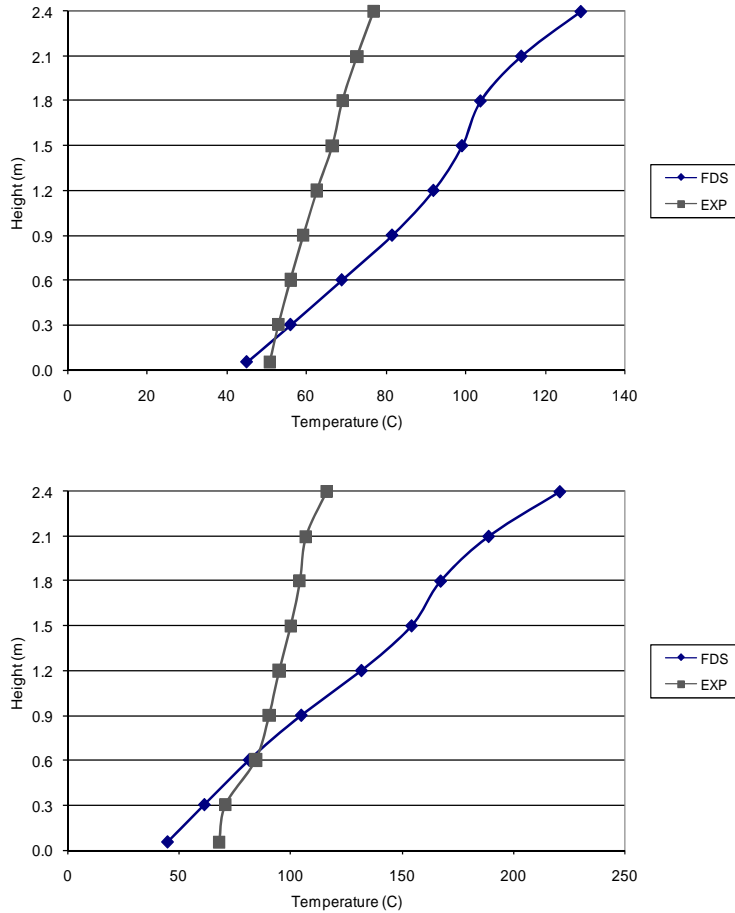
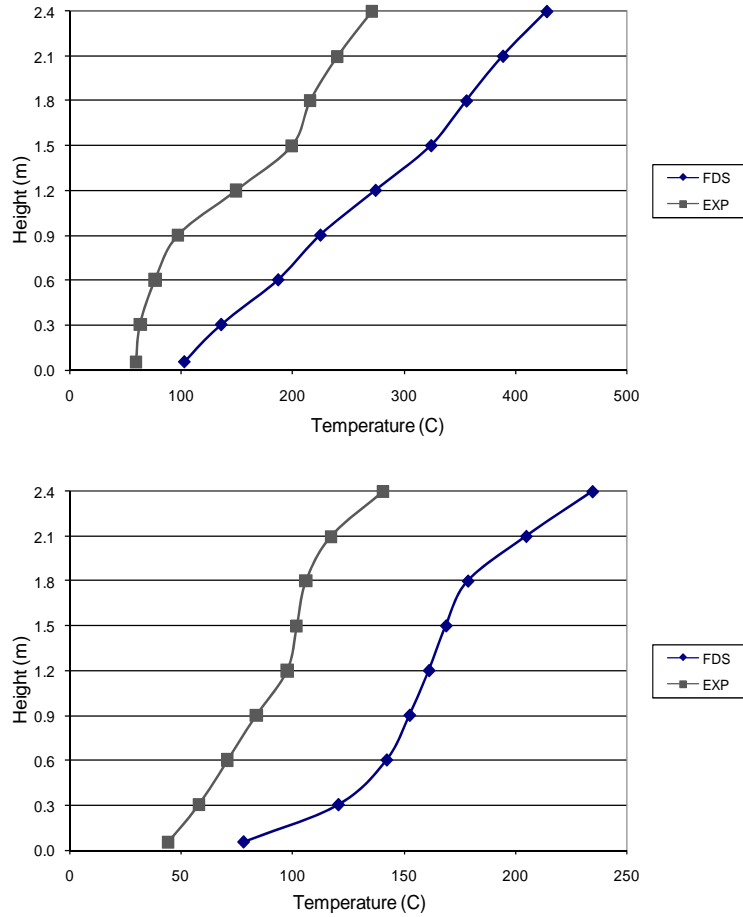Figure 4-54. Vertical variations of temperature at 1300 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open.

At this time the test 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 and the higher heat release rate later in the fire. The difference is up to 15 % in the living room and up to 27 % in the bedroom.

4.10.4 Carbon Monoxide Concentrations

The CO concentrations measured 2.4 m (8 ft) above the floor in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 4-55.
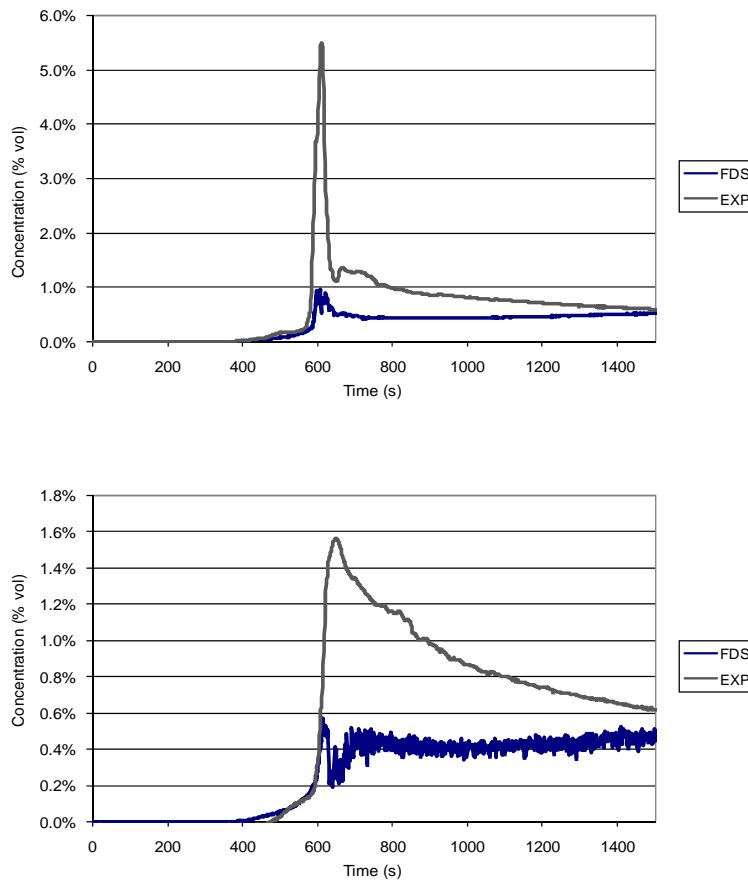
Figure 4-55. Carbon Monoxide concentrations at 2.4 m (8 ft) in the living room (top) and bedroom (bottom) for the sofa test with window half open.

As with the cabinet simulations the CO concentrations are lower in FDS than in the tests, even when it is clear from the heat release rate curve that incomplete combustion occurs. The FDS results reach a maximum value of 1 % in the living room and 0.6 % in the bedroom, whereas the test data show a concentration over 5 % in the living room.

5   COMPARISON OF LOAD CELL HEAT RELEASE RATE SIMULATIONS AND EXPERIMENTS

5.1   Elevated 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 2000 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.
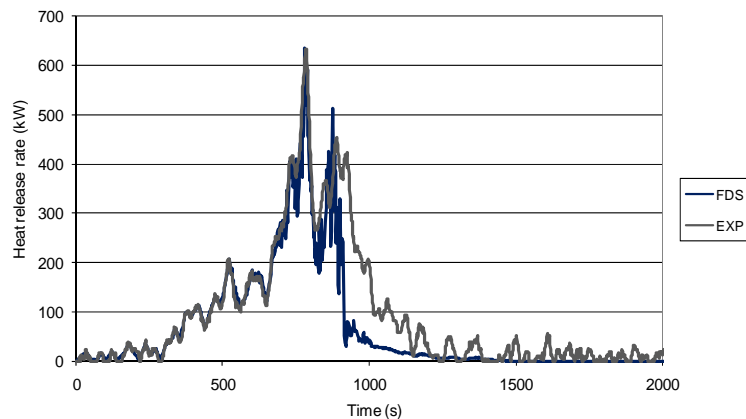
Figure 5-1. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Elevated kitchen cabinets in the closed compartment.

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 follow the test data past the second peak.

5.1.2   Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft), 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.
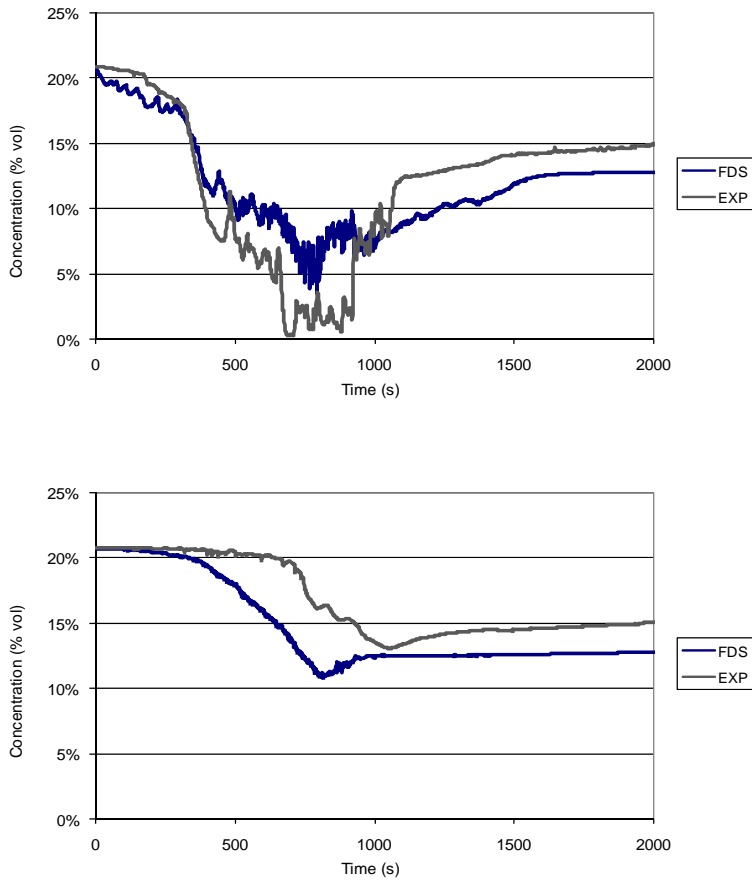
Figure 5-2. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the load
cell heat release rate simulation of the elevated cabinet test in the closed compartment.

During the initial decrease the oxygen concentration in the kitchen show agreement
between FDS and the experiment but after about 500 s the oxygen concentration in the test
continues to decrease down to zero whereas the minimum value reached in FDS is 5 %. In the
bedroom the opposite occurs where the simulation shows a lower oxygen concentration
throughout the test.

5.1.3 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. 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.

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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 elevated 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 14 % 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 5-4.

97
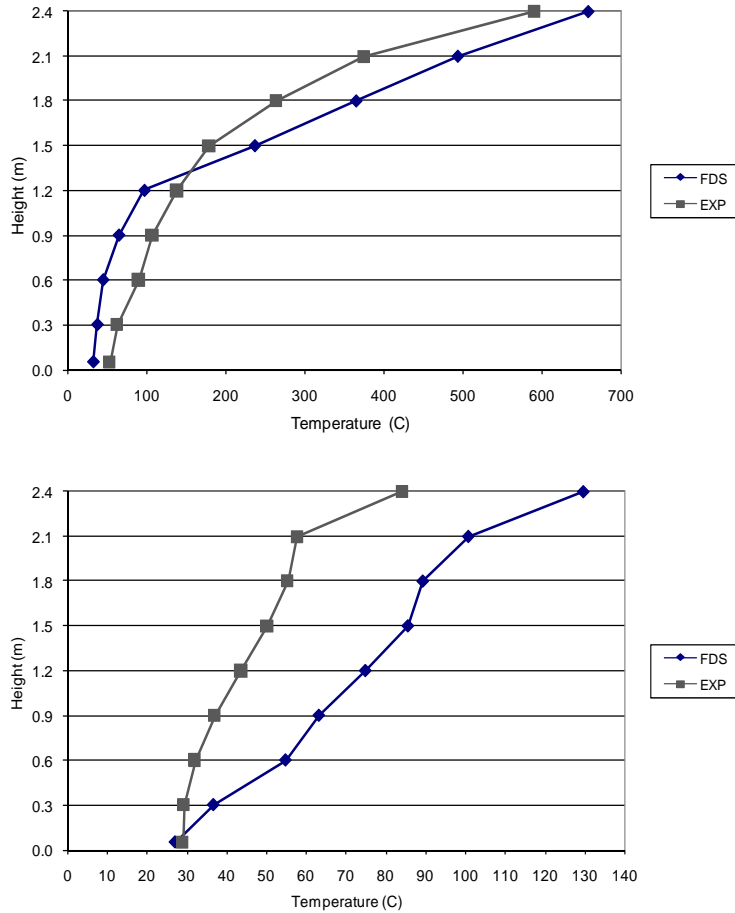
Figure 5-4. Vertical variations of temperature at 800 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test in the closed compartment.

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 13 % lower than recorded and in the upper layer a value up to 19 % 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 20000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-5.
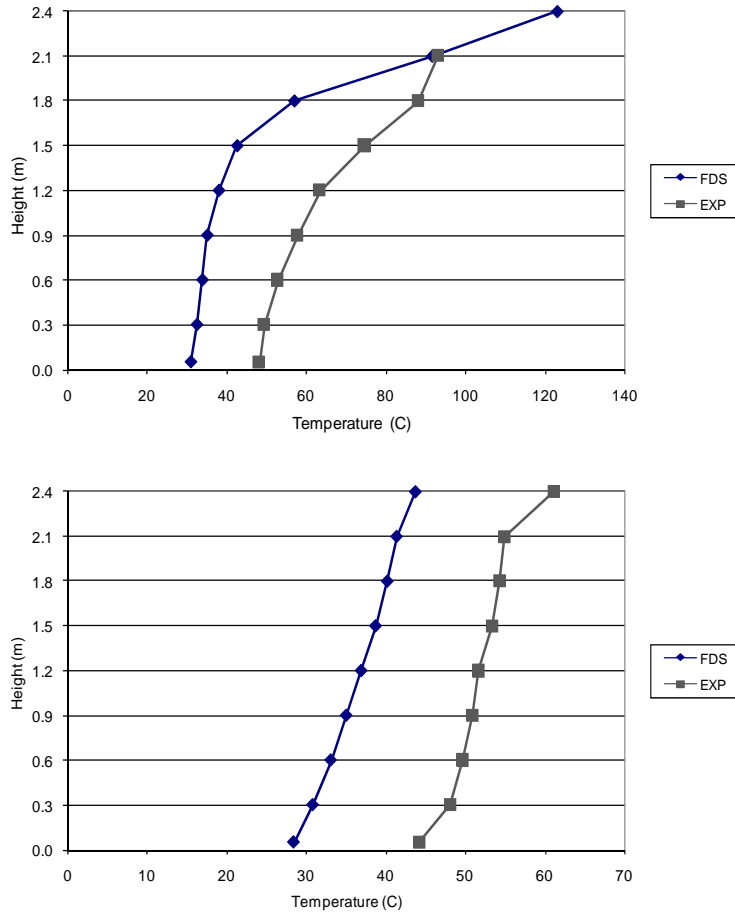
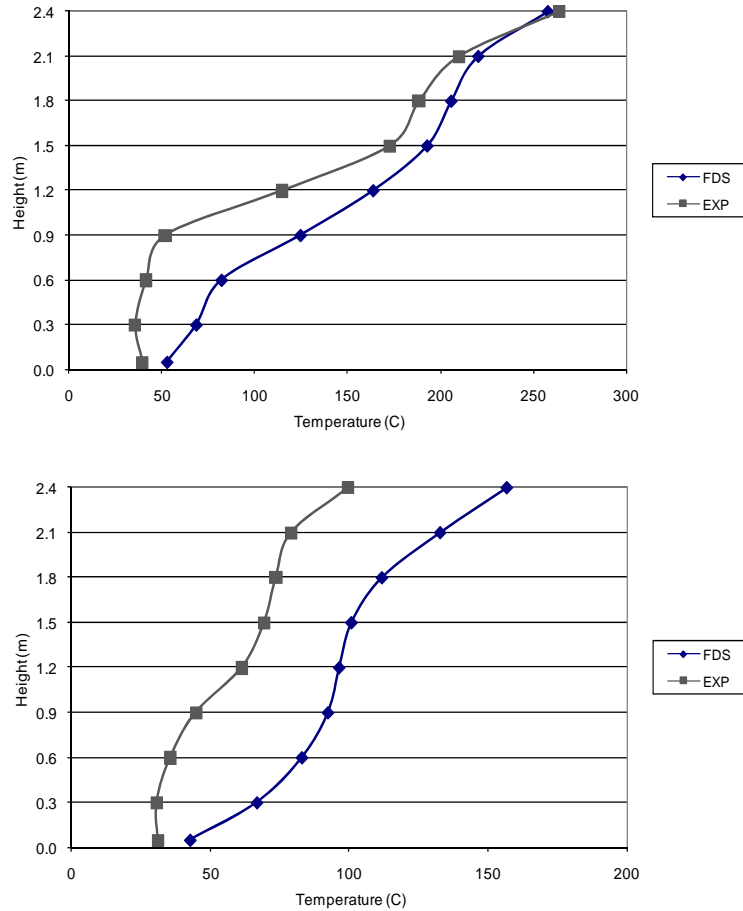Figure 5-5. Vertical variations of temperature at 1700 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test in closed compartment.

The thermocouple 2.5 cm (1 in) from the ceiling was destroyed by the heat so is not included in the profile at 2000 s. At the end of the simulation FDS also shows a temperature in the lower layer in the kitchen up to 9 % 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.

5.1.4   Carbon Monoxide Concentration

The concentration of CO in volume percent at the ceiling is shown in Figure 5-6 for the kitchen (top) and bedroom (bottom).

99
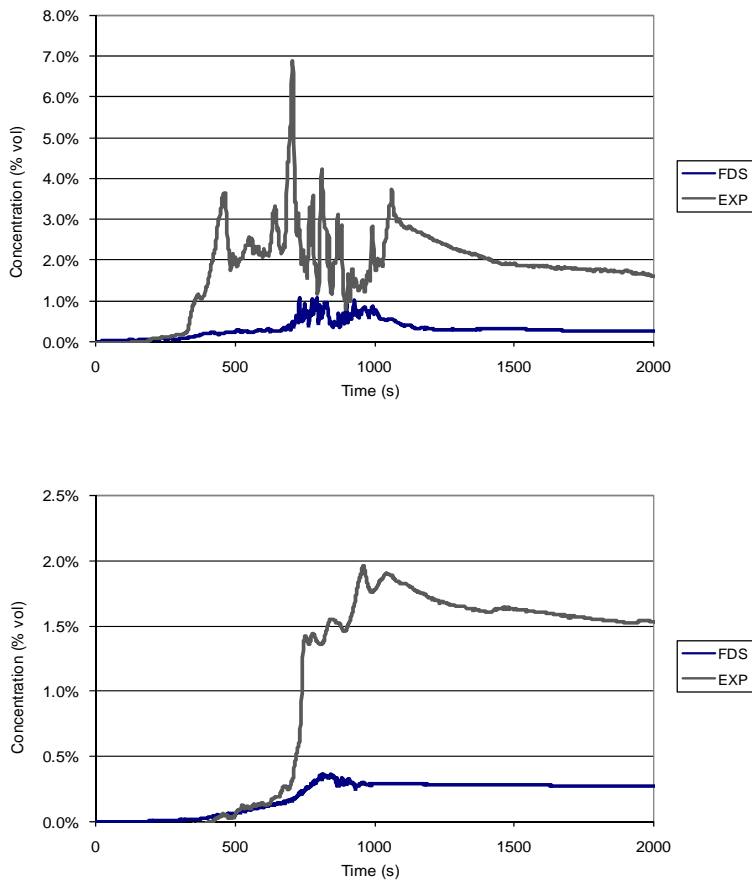
Figure 5-6 Concentration in volume percent of carbon monoxide at the ceiling in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test in closed compartment.

Even though the heat release rate and oxygen concentrations in this simulation shows better agreement between FDS and the test the CO concentration is still higher in the tests as was the case for the simulations with the, less accurate calorimeter heat release rate as input. At the ceiling in the kitchen FDS shows a maximum value around 1 %, but in the test this value is almost 7 %. The CO concentrations recorded in the test are higher than in FDS at all times at both measurement points.

5.2   Elevated 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 5-7.
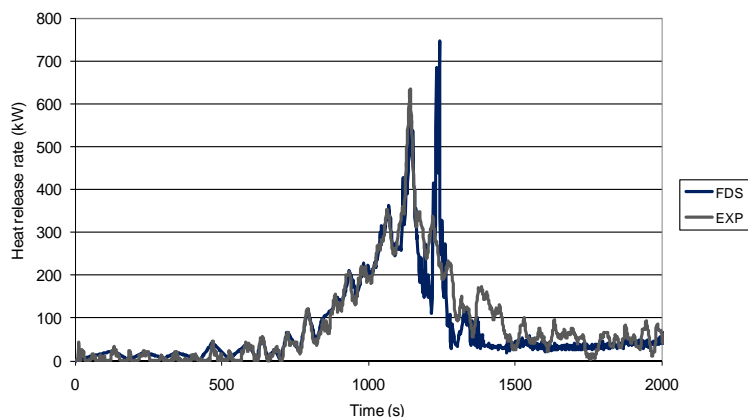
Figure 5-7. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the mass loss data from the test. Elevated kitchen cabinets with half open window.

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 at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-8. The oxygen concentration data from FDS in the kitchen has been averaged over five seconds because of fluctuations in the data.
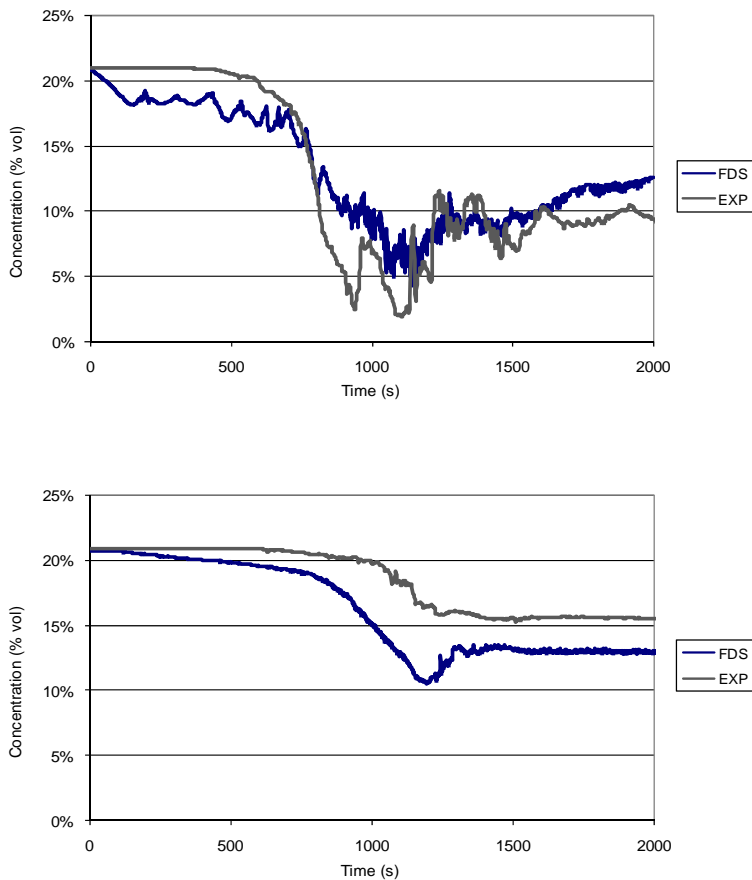
Figure 5-8. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with window half open.

In the kitchen FDS shows an immediate reduction in oxygen concentration down to 18 % where it stays until around 700 s when it drops down to the minimum of 5 % at 1100 s. The test data stays at ambient concentrations longer but the reduction is close to that seen in FDS. The concentration in the tests drops down lower to 2 % by volume. 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 5-9.

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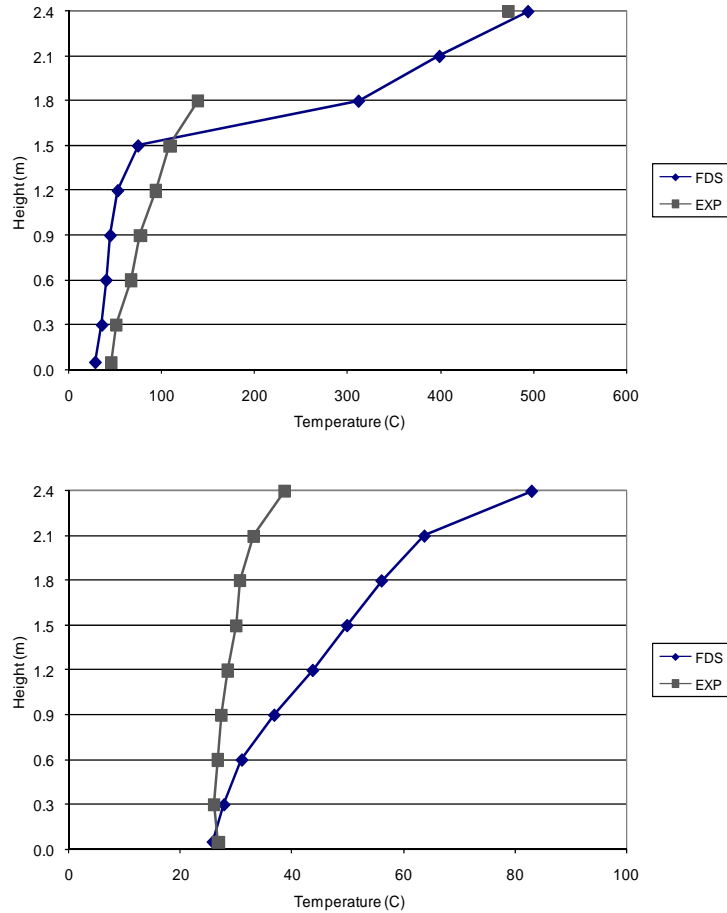
Figure 5-9. Vertical variations of temperature at 1050 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with window half open.

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 higher temperature. 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 44 °C higher giving a value 14 % 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 5-10
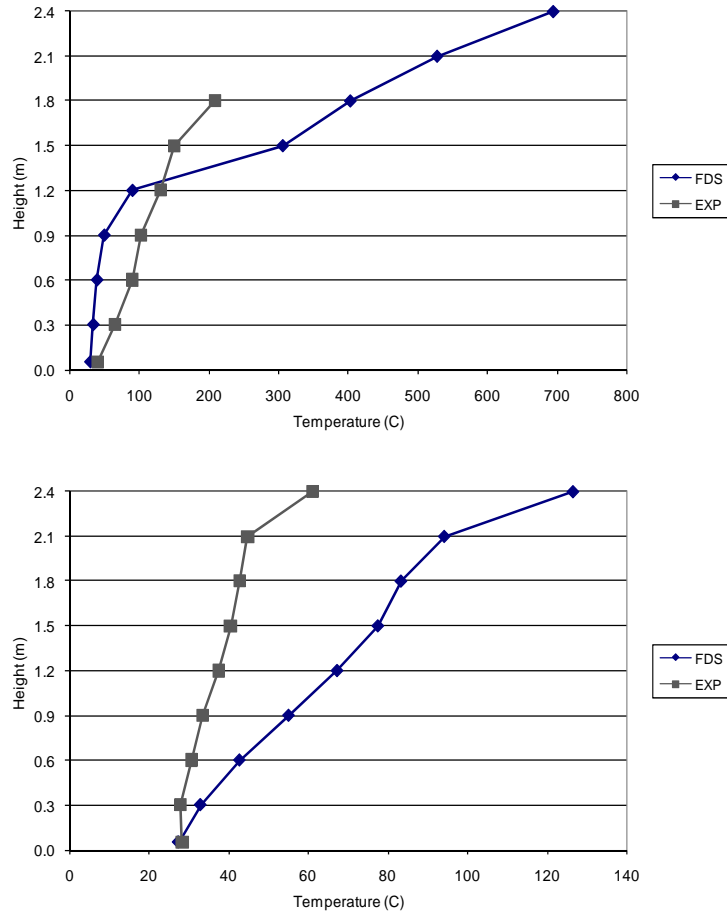
Figure 5-10. Vertical variations of temperature at 1150 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with window half open.

The top two thermocouples in the test gave zero or negative values at this time so were not included. FDS show the same tendencies in the kitchen as seen in Figure 5-9 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 130 °C compared to only 60 °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 5-11.
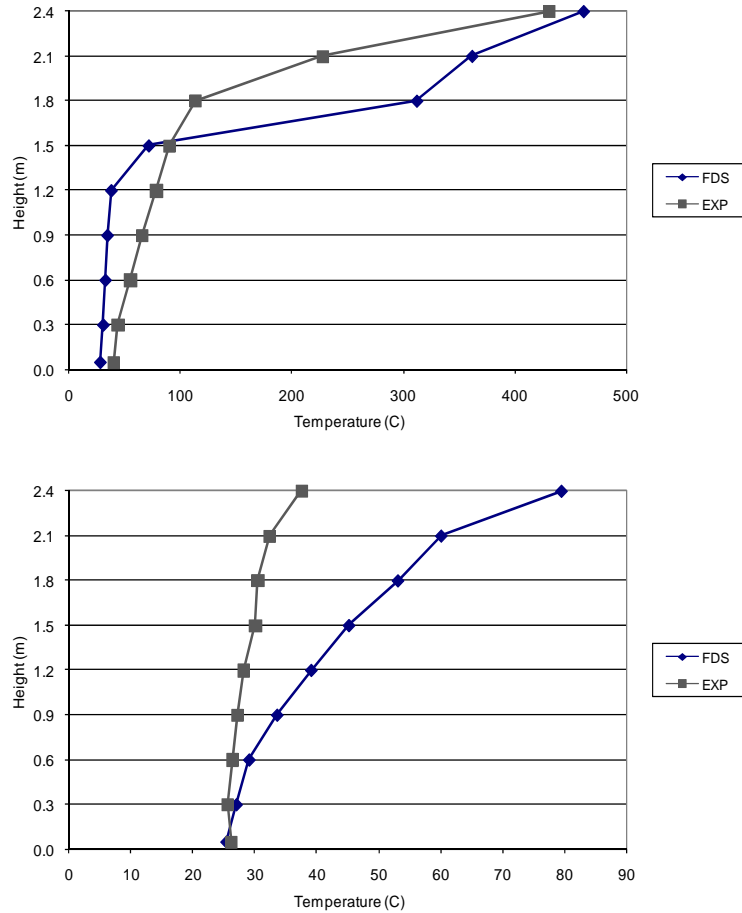
Figure 5-11. Vertical variations of temperature at 2000 s in the kitchen (top) and bedroom (bottom) for
the load cell heat release rate simulation of the elevated cabinet test with window half open.

In the kitchen the top two thermocouples from the test are not included. FDS shows lower
temperatures than the test data in the kitchen throughout the height. 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).

5.2.4   Carbon Monoxide Concentration

The concentration of CO in volume percent at the ceiling is shown in Figure 5-12 for the
kitchen (top) and bedroom (bottom).
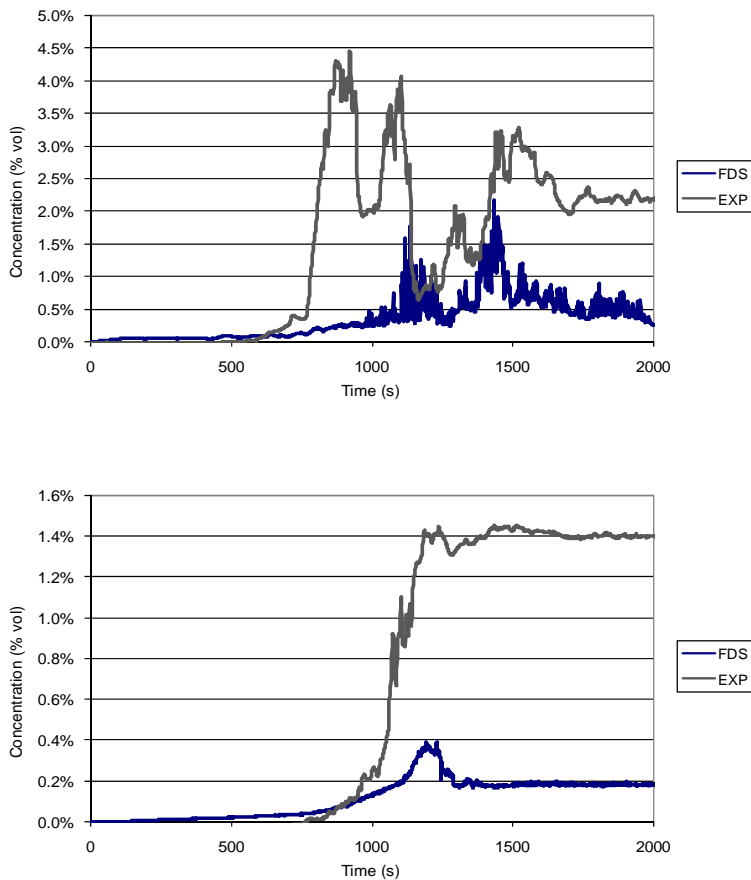
Figure 5-12 Concentration in volume percent of carbon monoxide at the ceiling in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with window half open.

The test data shows several spikes in the CO concentrations in the kitchen which are not seen in the FDS curve. In FDS there are two spikes but they are lower than the maximum in the test and occur at different times. In the bedroom FDS and the test data both show a rise to a plateau but the test gives a value higher than FDS, 1.4 % compared to 0.2 %.

5.3 Elevated 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 5-13.
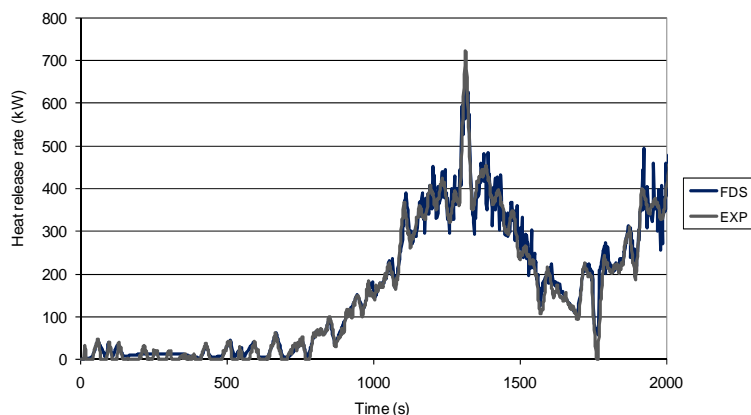
Figure 5-13. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Elevated kitchen cabinets with window removed.

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 at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-13. Because of fluctuations in the data from FDS the oxygen concentration in the kitchen was taken as the average over five seconds.
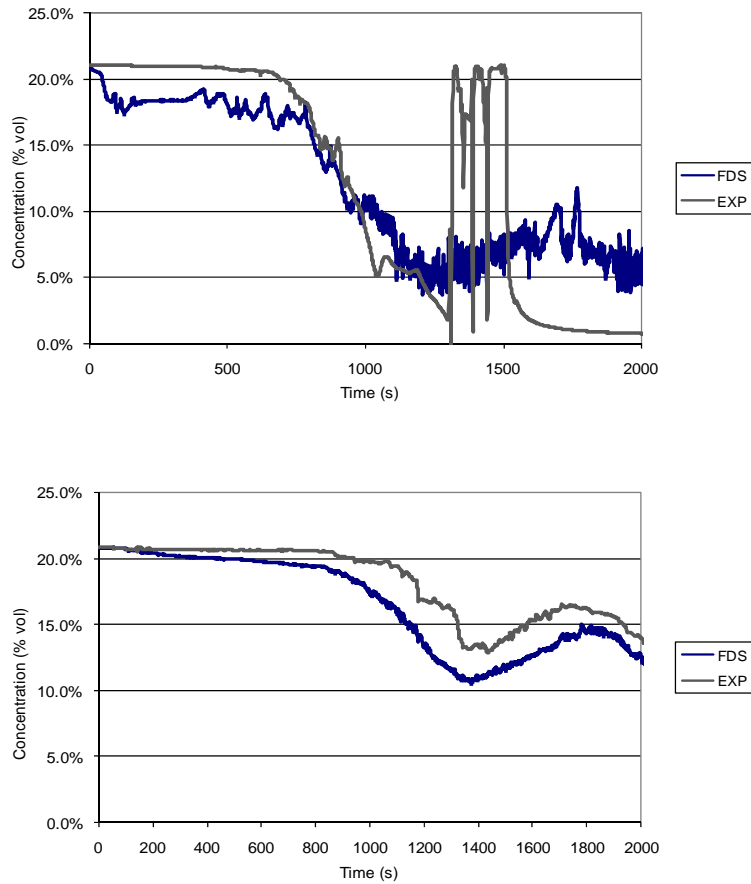
Figure 5-14. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the elevated kitchen cabinet test with window removed.

The oxygen concentration in the kitchen shows good agreement between the test and FDS. The graphs decrease at the same time and rata, but the test reaches a slightly lower value. 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 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 FDS.

Temperature measured over the height of the room at 1100 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-15.
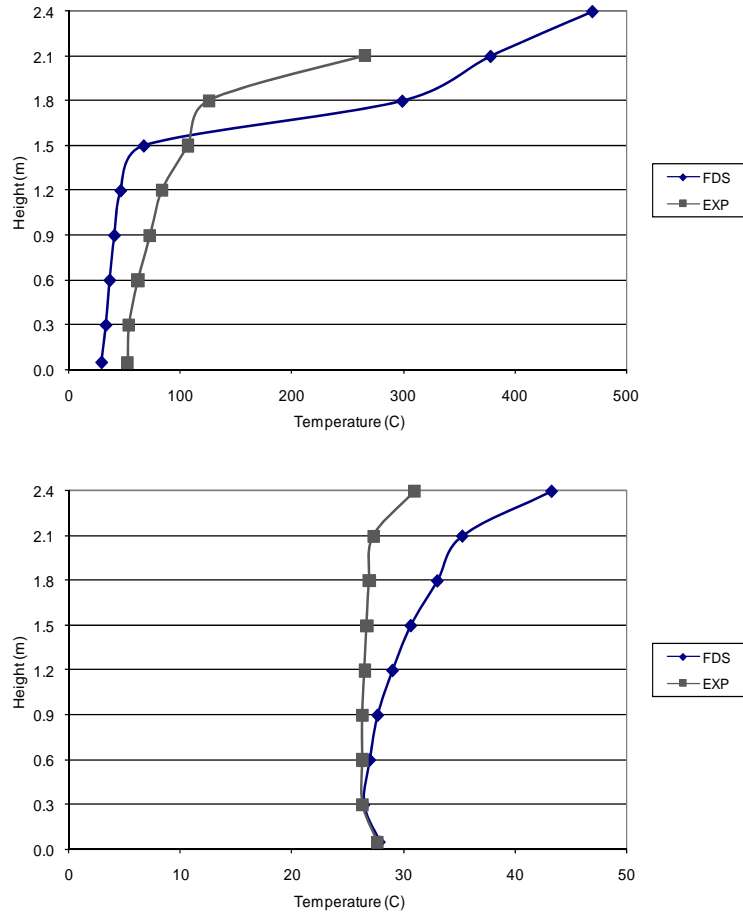
Figure 5-15. Vertical variations of temperature at 1100 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with window removed.

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 5 % 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 5-16.

Figure 5-16. 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 5-17.

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Figure 5-17. 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.

5.3.4   Carbon Monoxide Concentration

The concentration of CO in volume percent at the ceiling is shown in Figure 5-18 in the kitchen (top) and bedroom (bottom). The FDS data for the kitchen has been averaged over 5 s because of large fluctuations in the data.
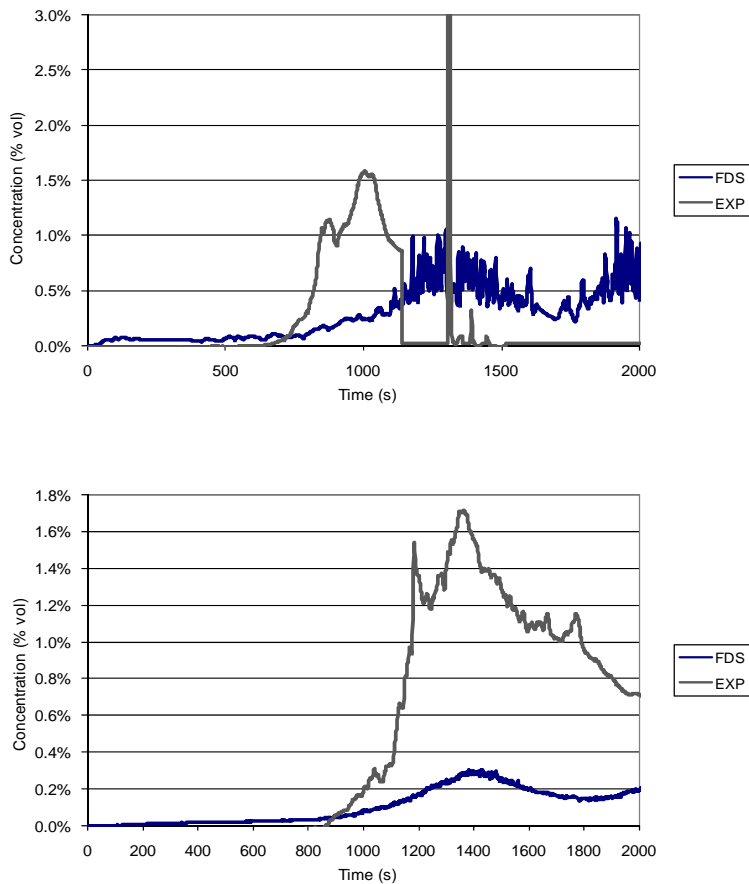
Figure 5-18 Concentration in volume percent of carbon monoxide at the ceiling in the kitchen (top) and
bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with window
removed.

When the cabinets fall off the wall there is an abrupt drop in CO concentration, indicating
a possible error in the data. Before this the test data gave a concentration up to 1.5 % by volume,
compared to less than 1 % in FDS. In the bedroom FDS gives a slow increase up to around 0.3 %
which is much lower than the 1.6 % maximum in the test.

5.4   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 (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 5-19.

Figure 5-19. 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 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 at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-20. The FDS data in the kitchen was averaged over five seconds because of fluctuations in the data.
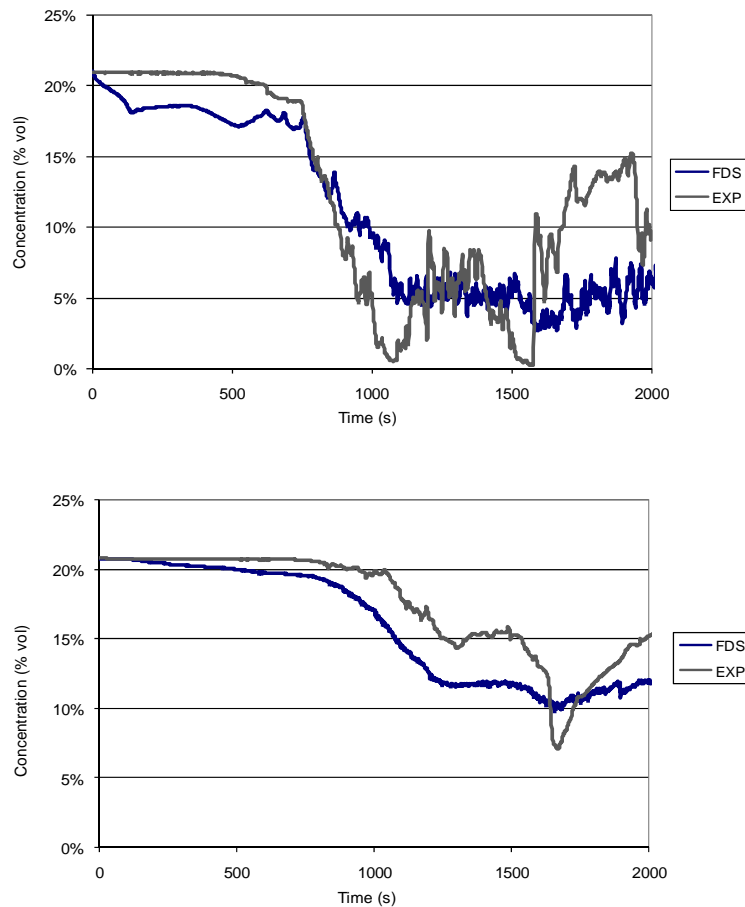
Figure 5-20. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the elevated cabinet test with door open.

The oxygen concentration in the kitchen predicted by FDS show some fluctuating behavior similar to what was seen for the test with window removed. But also in this scenario the FDS predictions match well with the test data in the kitchen. The time to when the oxygen concentration starts to decrease is identical; however the rate of decrease in the tests was steeper than predicted by FDS. The minimum value was also a few percent lower. 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.

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Temperature measured over the height of the room at 1200 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-21.
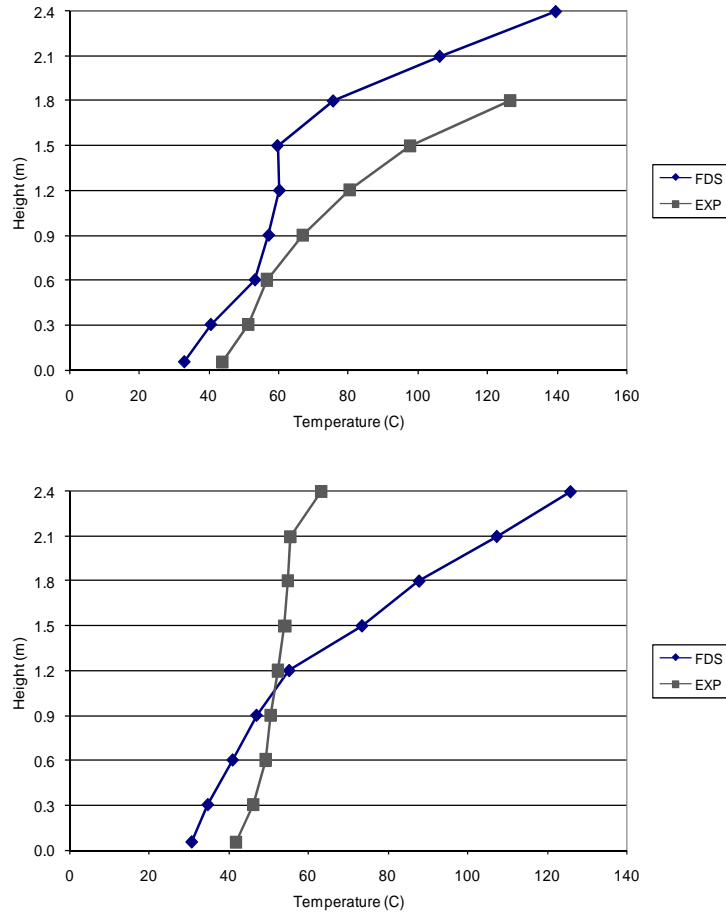

Figure 5-21. Vertical variations of temperature at 1200 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

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 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 12 % 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 5-22.

115

Figure 5-22. 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 13 % of the test data. In the bedroom FDS shows good agreement and is within 6 % of the test 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 5-23.

116
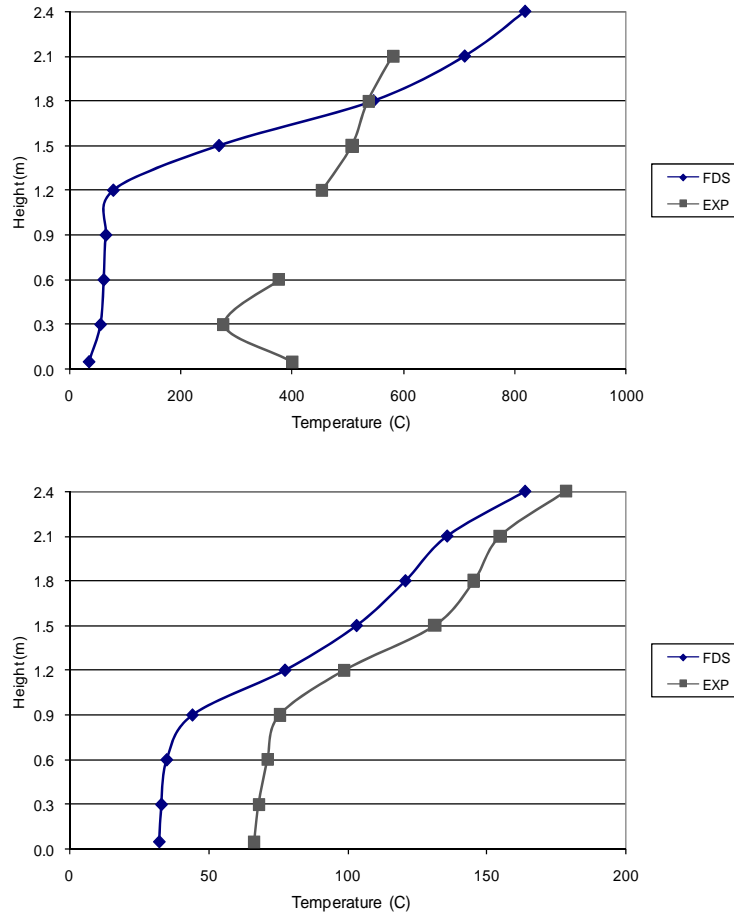
Figure 5-23. Vertical variations of temperature at 2000 s in the kitchen (top) and the bedroom (bottom) for the elevated cabinet test with door open.

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 lower at all heights, but within 10 % of the test data.

5.4.4   Carbon Monoxide Concentration

The concentration of CO in volume percent at the ceiling is shown in Figure 5-24Figure 5-6 for the kitchen (top) and bedroom (bottom). The FDS data in the kitchen has been averaged over 5 s because of fluctuations on the data.

117
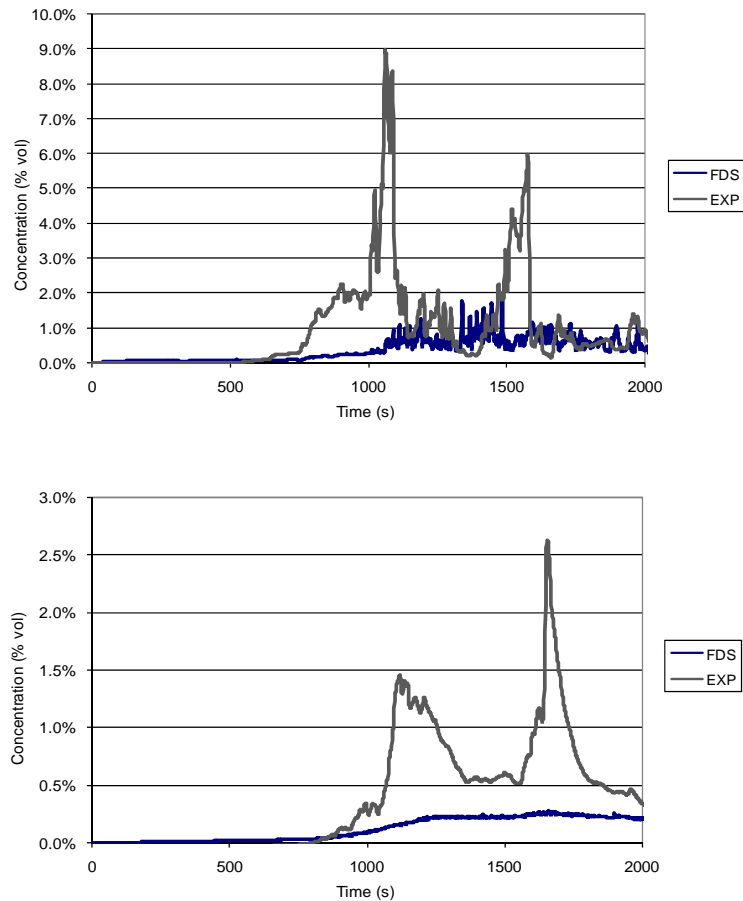
Figure 5-24 Concentration in volume percent of carbon monoxide at the ceiling in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the elevated cabinet test with open door.

Even with the large ventilation opening the CO concentrations measured in the test are higher than any seen in FDS, up to 9 % by volume in the kitchen. The maximum measured at the ceiling in FDS is less than 2 %. In the bedroom FDS only show minimal concentrations around 0.3 %, whereas the test gives concentrations as high as 2.5 %.

5.5   Low Kitchen Cabinet in Closed Compartment

Similar to the elevated cabinet simulations the heat release rate used as input for 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 was also here reduced to only the two first cabinets. The simulation was run for 2000 s.

5.5.1   Heat Release Rate

The resulting heat release rates from the FDS simulation and the test are shown in Figure 5-25. The FDS data was averaged over five seconds because of fluctuations.

118
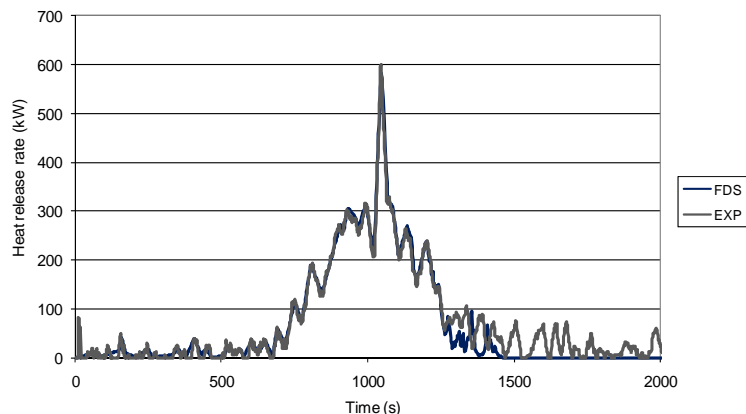
Figure 5-25. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Low kitchen cabinets in the closed compartment.

The two graphs show almost perfect agreement until about 1250 s where the FDS simulations show signs of ventilation limited burning. After this the smaller spikes seen in the test data are not seen in FDS.

5.5.2   Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-44.
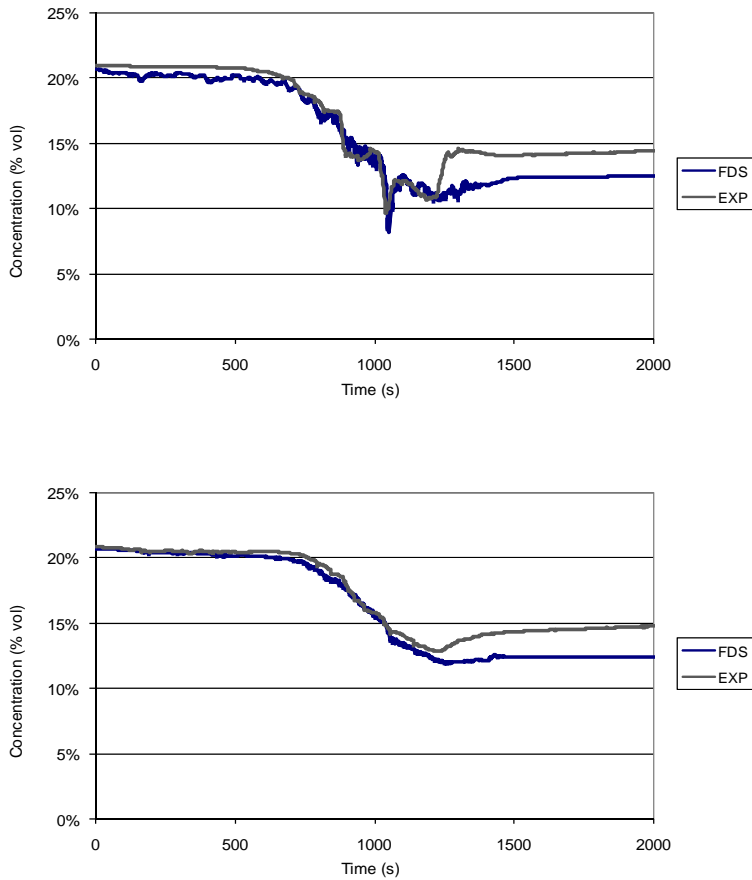
Figure 5-26. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the load
cell heat release rate simulation of the low cabinet test in the closed compartment.

Like the heat release rate the oxygen concentration at the ceiling in both the kitchen and
the bedroom show good agreement between FDS and test data until about 1250 s. After this the
test gives a higher oxygen concentration than FDS. Oxygen concentrations do no drop below
10 % by volume in either room

5.5.3   Temperature

The temperature profiles across the height of the compartment were analyzed at 950 s,
1050 s and 2000 s in the kitchen and bedroom. The ambient temperature was 27 °C.

Temperature measured over the height of the room at 950 s in the kitchen (top) and
bedroom (bottom) are shown in Figure 5-27.

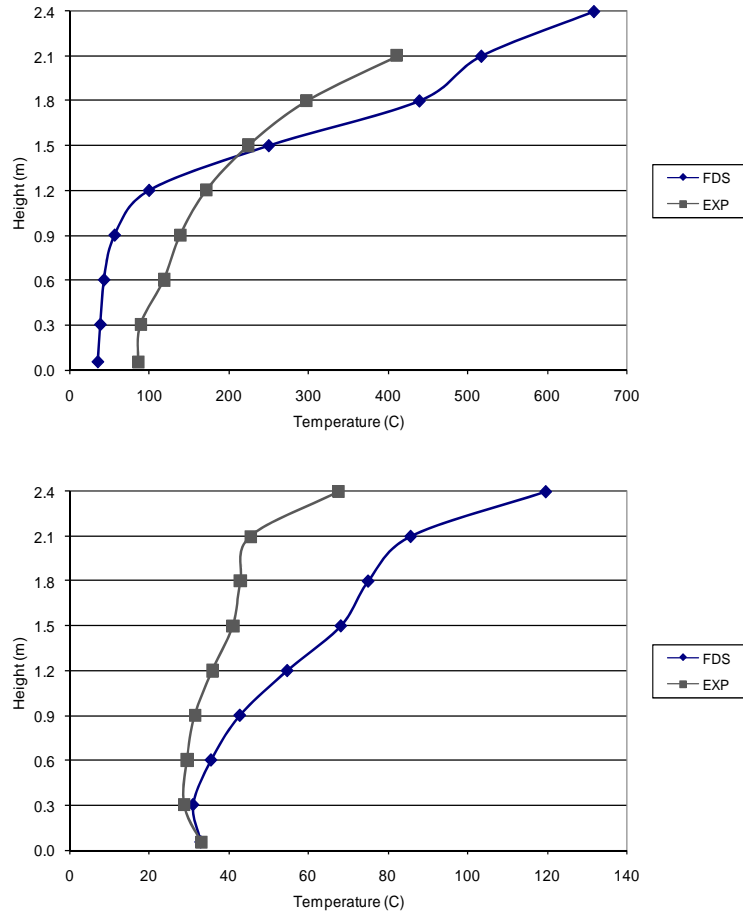Figure 5-27 Vertical variations of temperature at 950 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test in closed compartment.

Temperature data show very good agreement in the kitchen at this time, with FDS giving values within 8 % of the test results. In the bedroom FDS gives consistently higher temperatures at all heights, but is within 10 %

Temperature measured over the height of the room at 1050 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-46

121
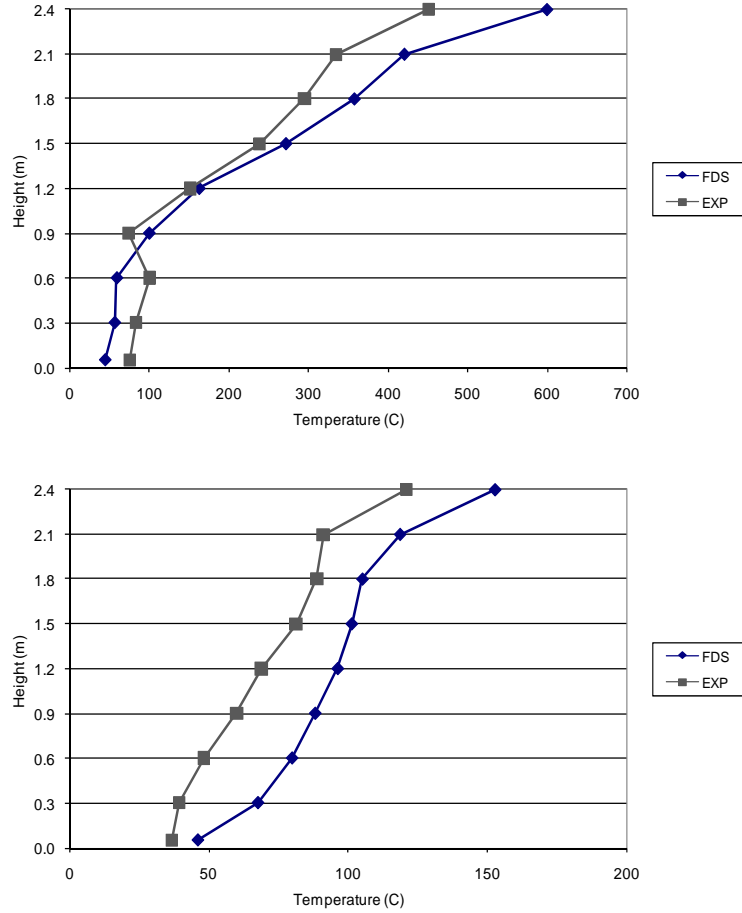
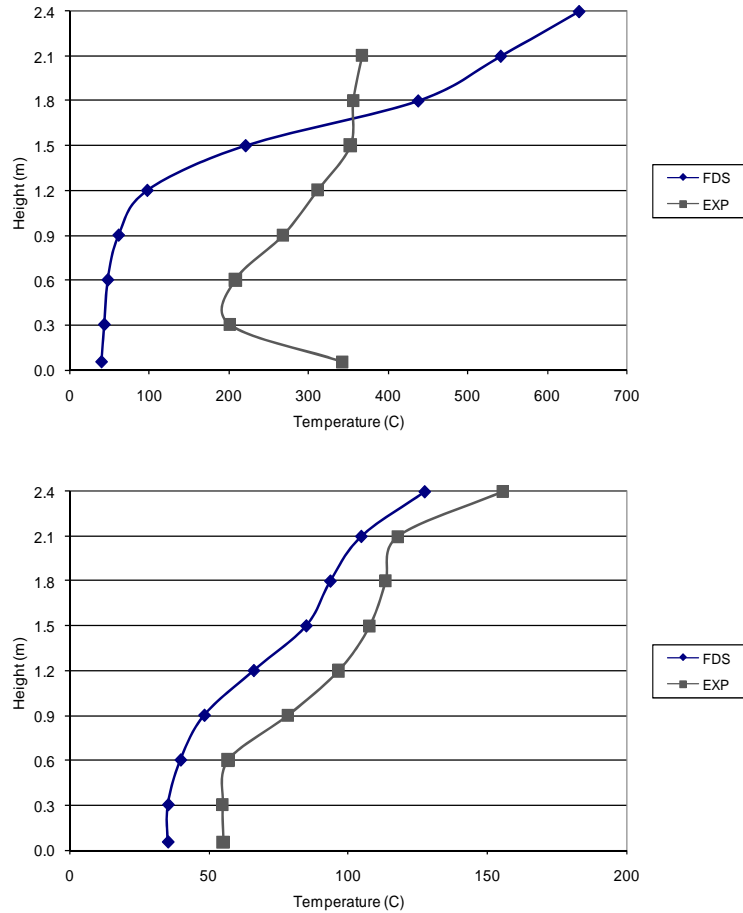Figure 5-28. Vertical variations of temperature at 1050 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the cabinet test in the closed compartment.

The temperature measured across the height of the room remains similar at 1050 s, with FDS giving temperatures in the top three thermocouples which are 11 – 20 % higher than in the test. In the bedroom the temperatures reported by FDS are still up to 11 % higher than the test measurements.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-47.
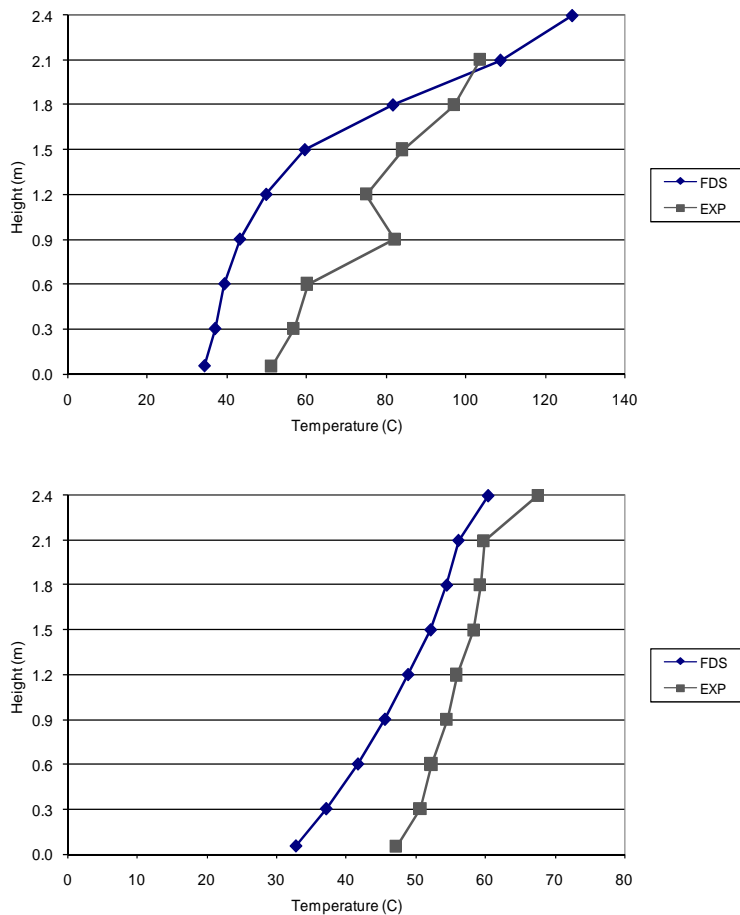
Figure 5-29. Vertical variations of temperature at 2000 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test in the closed compartment.

The thermocouple at the ceiling in the kitchen was destroyed by the heat so is not included at 2000 s. At the end of the simulation temperatures have cooled down, but the test data show higher temperatures in the lower layer than FDS, but about 10 %. In the bedroom FDS is within 4 %

5.5.4   Carbon Monoxide Concentration

The concentration of CO in volume percent at the ceiling is shown in Figure 5-31 for the kitchen (top) and bedroom (bottom).
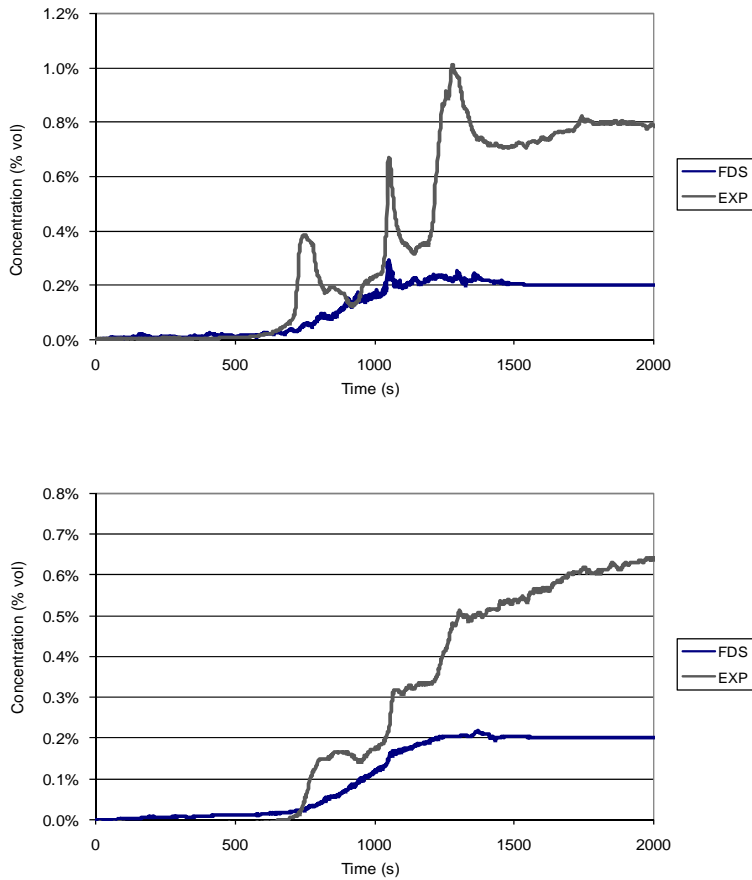
Figure 5-30 Concentration in volume percent of carbon monoxide at the ceiling in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test in closed compartment.

The CO concentrations remain low in the FDS simulation in both rooms never going above 0.2 % by volume. This is most likely a result of the relatively high oxygen concentrations. In the test CO concentrations up to 0.8 % are measured.

5.6   Low Kitchen Cabinet with Half Open Window

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

5.6.1   Heat Release Rate

The resulting heat release rates from the FDS simulation and the test are shown in Figure 5-43. The FDS data was averaged over five seconds because of fluctuations.

124
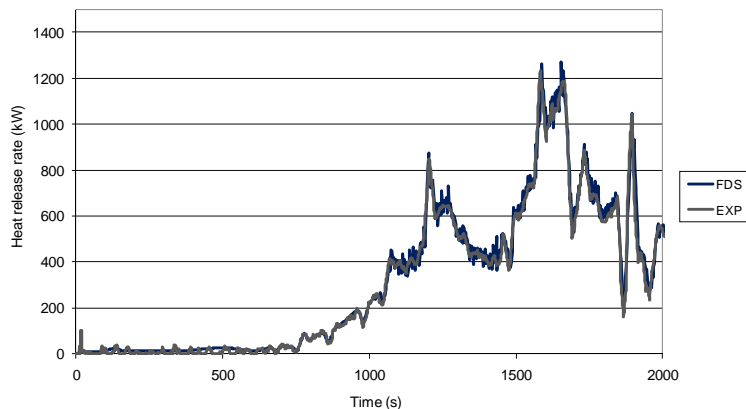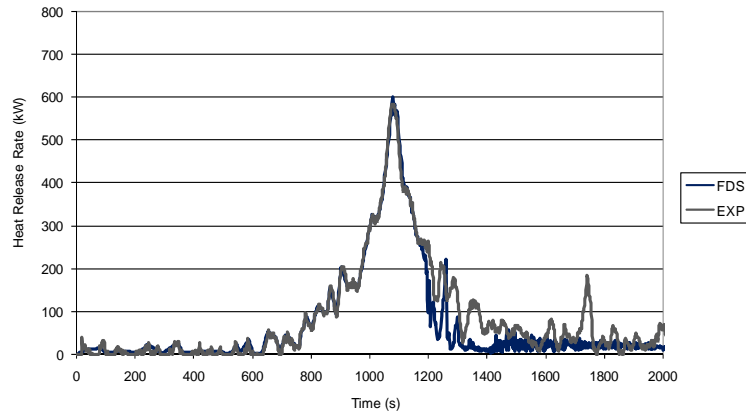
Figure 5-31. Heat release rate in the FDS load cell heat release rate simulation compared to the one
calculated from the test mass loss data. Low kitchen cabinets with half open window.

The ventilation opening has little impact on the heat release rate and the graphs show
good agreement until about 1200 s where the FDS simulations show signs of ventilation limited
burning as in the closed compartment simulation.

5.6.2   Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room
in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-32.
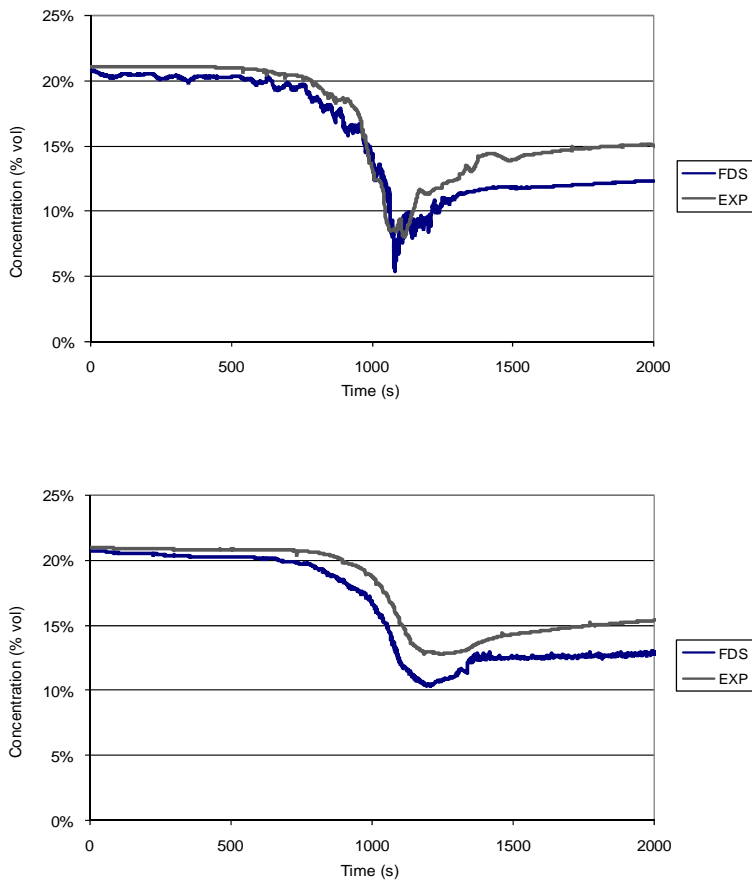
Figure 5-32. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the load
cell heat release rate simulation of the low cabinet test with half open window.

The FDS prediction of oxygen concentrations in the kitchen are similar to that measured
in the test. FDS gives a minimum value a few percent lower and up to 3 % by volume lower later
in the test. In the bedroom FDS is consistently lower than the test throughout the simulation by
around 3 % by volume.

5.6.3   Temperature

The temperature profiles across the height of the compartment were analyzed at 1000 s,
1100 s and 2000 s in the kitchen and bedroom, corresponding to 50 % and 100 % of maximum
heat release rate and the end of the simulation. The ambient temperature was 25 °C.

Temperature measured over the height of the room at 1000 s in the kitchen (top) and
bedroom (bottom) are shown in Figure 5-45.

126
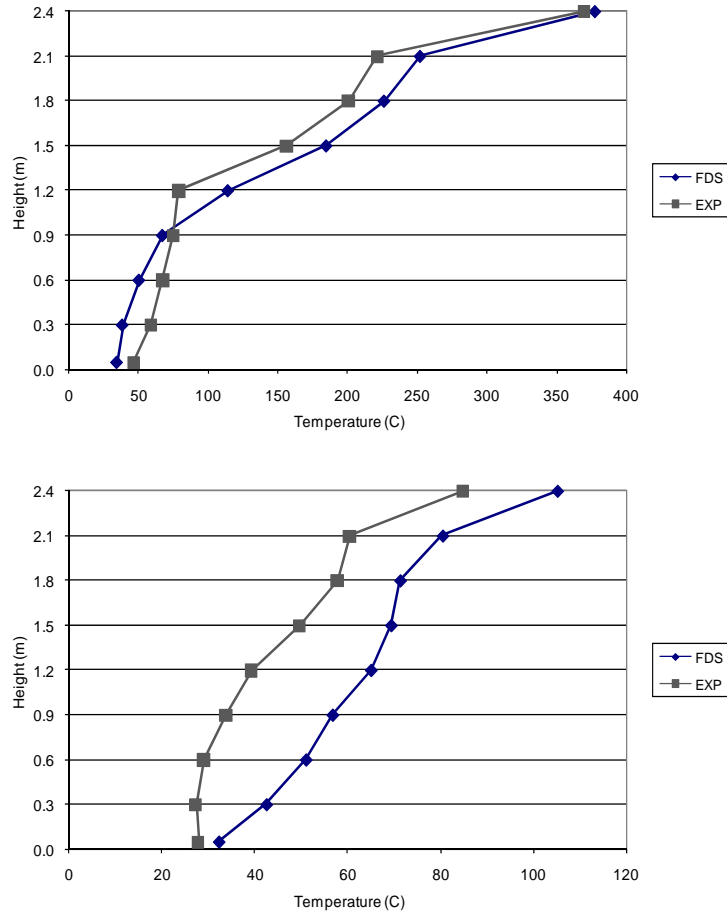
Figure 5-33 Vertical variations of temperature at 1000 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test with half open window.

The temperature predicted by FDS in the kitchen follows closely that measured in the test with deviations of no more than 10 %. In the bedroom FDS predicts higher temperatures at all heights but all are within 8 % of the test data.

Temperature measured over the height of the room at 1100 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-34
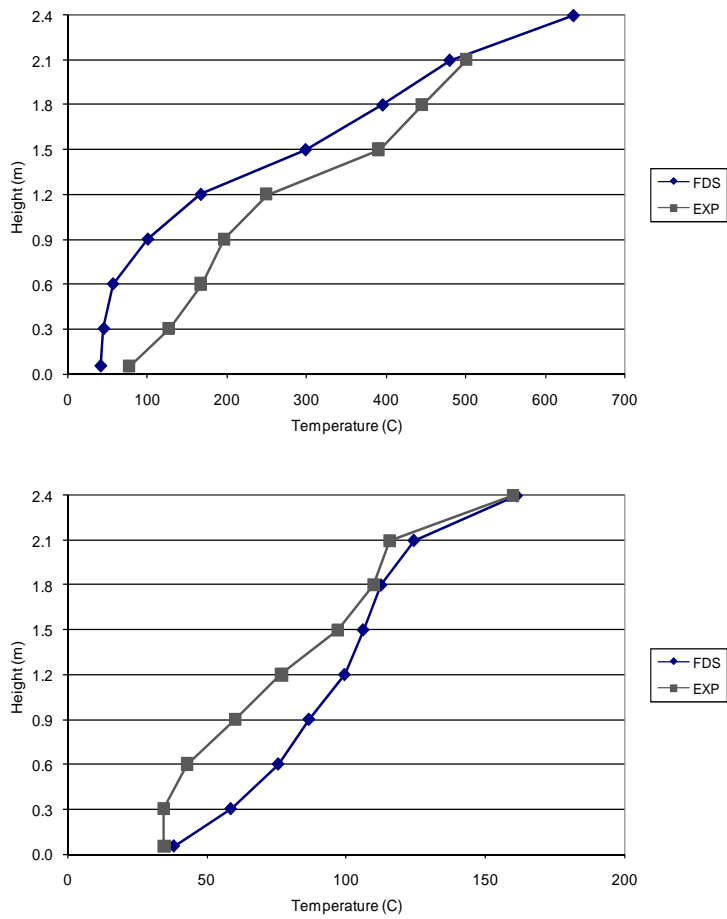
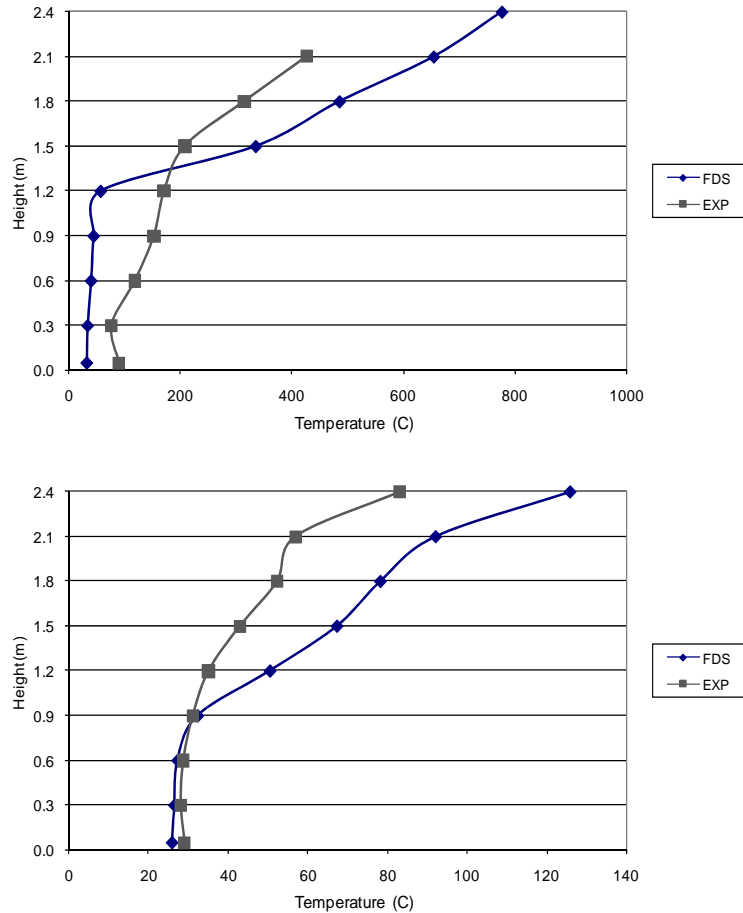Figure 5-34. Vertical variations of temperature at 1100 s in the kitchen (top) and bedroom (bottom) for
the load cell heat release rate simulation of the cabinet test with half open window.

After 1100 s the temperatures in the test are higher than predicted by FDS in the kitchen,
but lower in the bedroom, at all heights. The top thermocouple in the kitchen was not functional
at this time so is not included. FDS gives temperatures is up to 25 % lower in the kitchen but is
within 10 % in the bedroom.

Temperature measured over the height of the room at 2000 s in the kitchen (top) and
bedroom (bottom) are shown in Figure 5-35
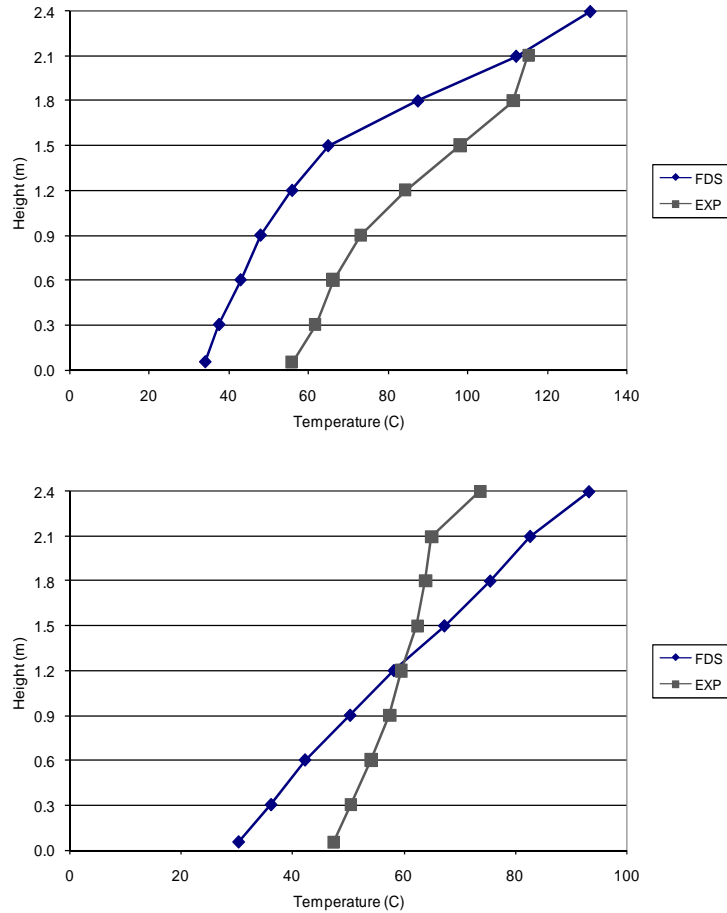
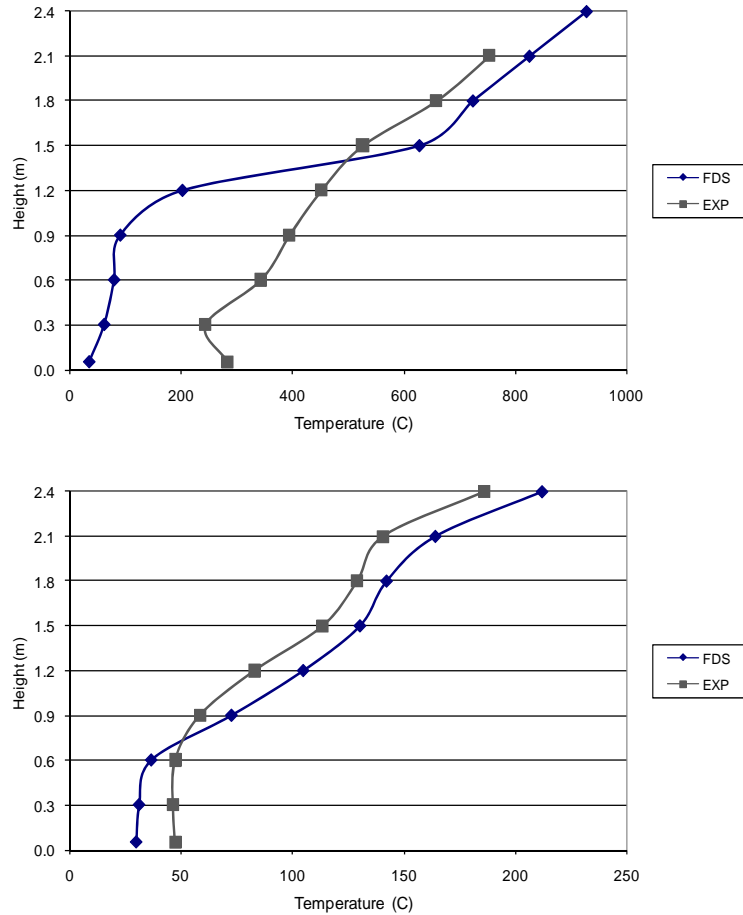Figure 5-35. Vertical variations of temperature at 2000 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test with half open window.

The test data remains higher than predicted by FDS in the kitchen at the end of the simulation, but only by about 8 % at this time. In the bedroom temperatures in FDS is lower at the floor and higher at the ceiling, by up to 20 % at both extremes.

5.6.4   Carbon Monoxide Concentration

The concentration of CO in volume percent at the ceiling is shown in Figure 5-36 for the kitchen (top) and bedroom (bottom).
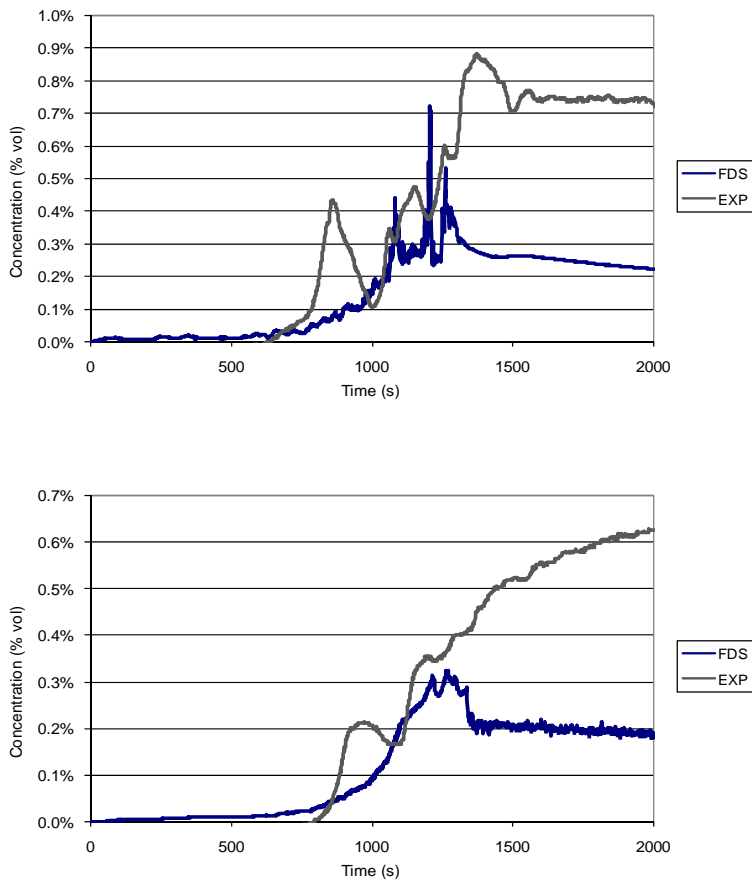
Figure 5-36 Concentration in volume percent of carbon monoxide at the ceiling in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test with half open window.

The CO concentrations in FDS reach a plateau of 0.3 % and 0.2 % in the kitchen and bedroom respectively. This is as in the other configurations lower than that measured in the test in both locations.

5.7   Low Kitchen Cabinet with Door Open

The cabinet configuration was kept the same as the two previous simulations but the window was closed and 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 fire in the test was extinguished at approximately 1900 s.

5.7.1   Heat Release Rate

The resulting heat release rates from the FDS simulation and the test are shown in Figure 5-37. The FDS data was averaged over five seconds because of fluctuations.
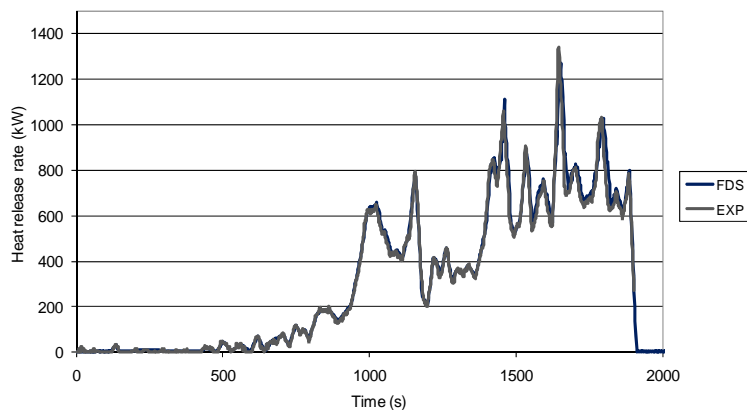
Figure 5-37. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Low kitchen cabinets with door open.

The heat release rate curve in FDS follows perfectly that measured in the test, indicating no incomplete combustion occurred in the simulation.

5.7.2 Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the kitchen (top) and in the bedroom (bottom) are shown in Figure 5-38. The FDS data from the kitchen has been averaged over 5 s because of fluctuations.
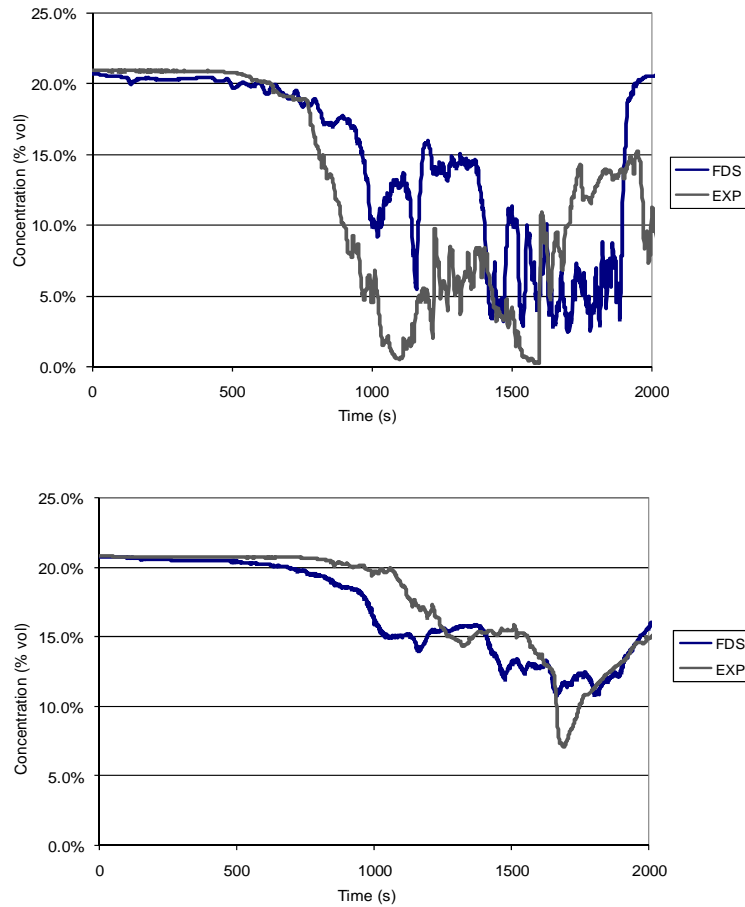
Figure 5-38. Oxygen concentrations at 2.4 m (8 ft) in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test with door open.

The oxygen concentrations in the kitchen show a steep drop in both FDS and the test data, but FDS is approximately 100 s slower. FDS also shows a higher value for most of the test. In the bedroom FDS gives lower concentrations early in the simulations but otherwise shows good agreement with the test data.

5.7.3   Temperature

The temperature profiles across the height of the compartment were analyzed at 1150 s, 1650 s and 1900 s in the kitchen and bedroom, corresponding to 50 % and 100 % of maximum heat release rate and the end of the simulation. The ambient temperature was 24 °C.

Temperature measured over the height of the room at 1150 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-39.

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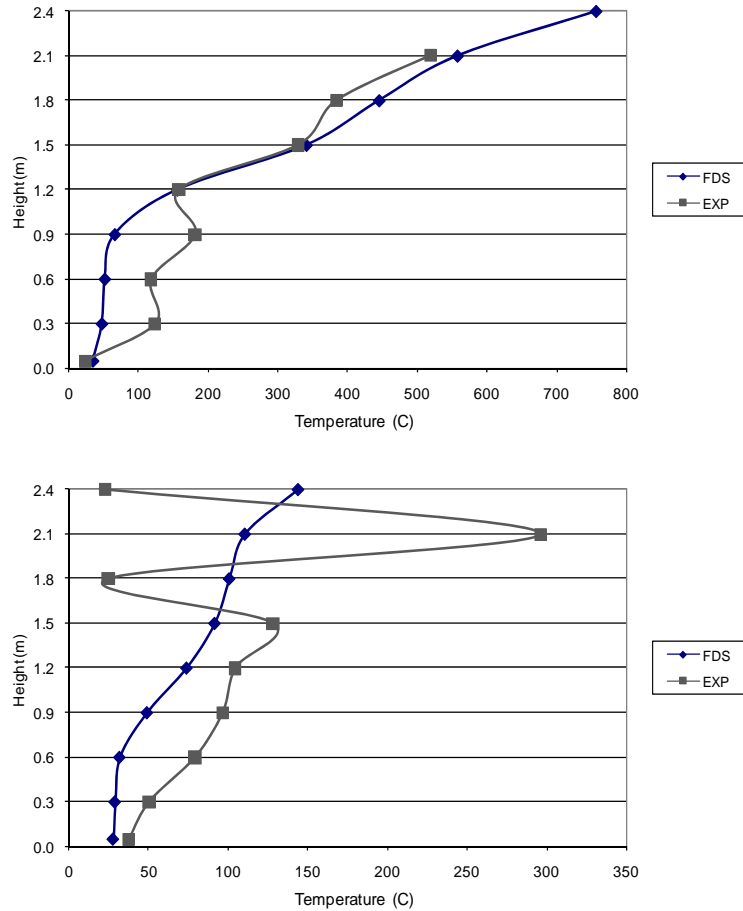
Figure 5-39 Vertical variations of temperature at 1150 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test with door open.

Already at 1150 s the top thermocouple in the kitchen was destroyed by the heat. FDS gives very good predictions in the upper layer in the kitchen and is within 25 % lower down. In the bedroom the top three thermocouples show strange behavior and may not be reliable at this point. Excluding these, FDS is within 13 % of the test measurements.

Temperature measured over the height of the room at 1650 s in the kitchen (top) and bedroom (bottom) are shown in Figure 5-40
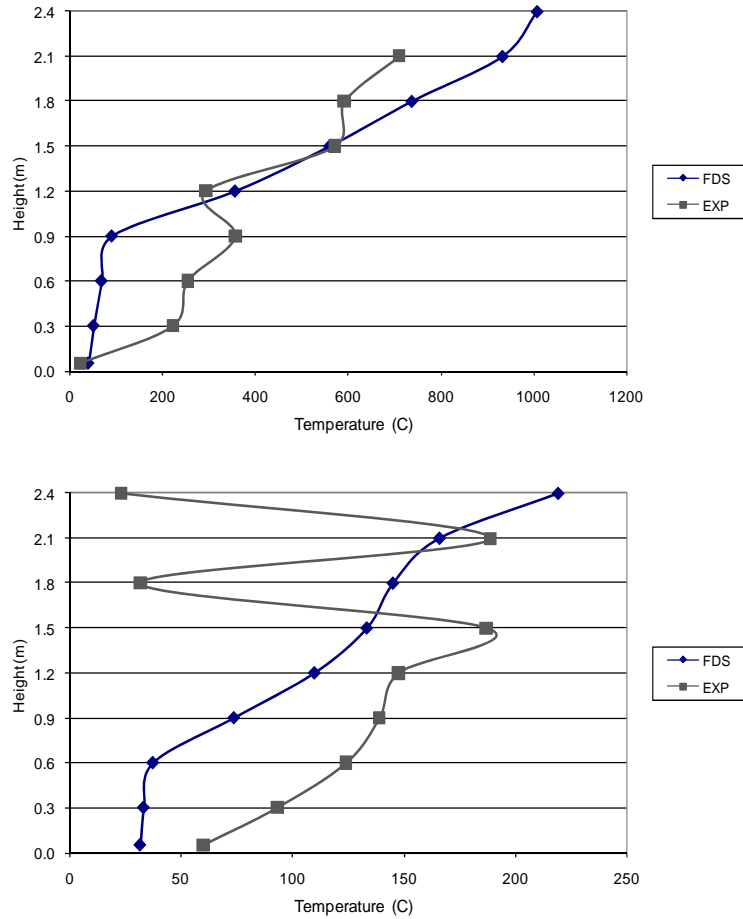
Figure 5-40. Vertical variations of temperature at 1650 s in the kitchen (top) and bedroom (bottom) for
the load cell heat release rate simulation of the cabinet test with door open.

The temperature in the lower layer in FDS continues to be lower than recorded in the test
both in the kitchen and in the bedroom. In the kitchen FDS gives higher temperatures in the
upper layer. Because two or three of the thermocouples in the bedroom may be giving invalid
data it is difficult to assess the accuracy of the FDS predictions.

Temperature measured over the height of the room at 1900 s in the kitchen (top) and
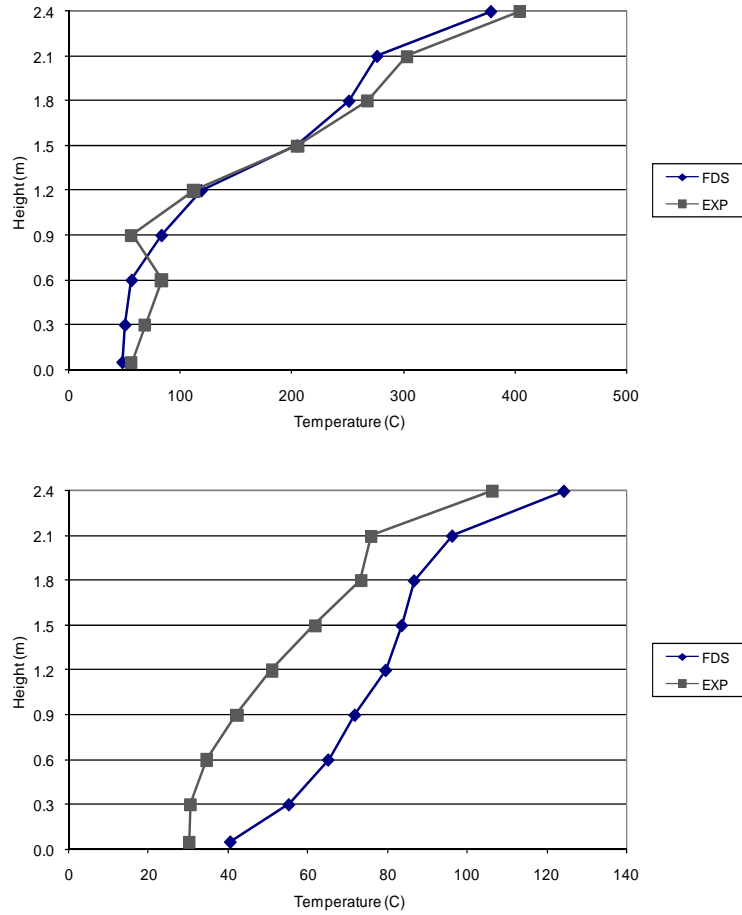bedroom (bottom) are shown in Figure 5-41.
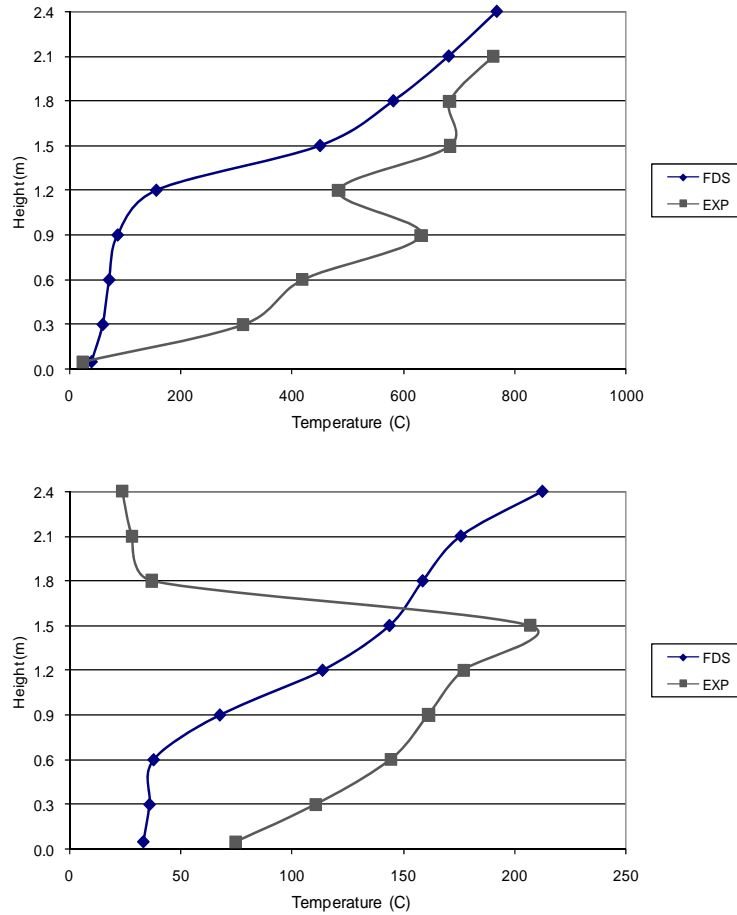
Figure 5-41. Vertical variations of temperature at 1900 s in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test with door open.

At the end of the fire the test data gives temperatures in the kitchen up to 60 % higher than FDS, especially in the lower layer FDS does not exceed 100 °C, compared to over 300 °C in the test. In the bedroom temperatures in FDS are also lower at all heights, except for the top three thermocouples which have uncertain accuracy at this point.

5.7.4   Carbon Monoxide Concentration

The concentration of CO in volume percent at the ceiling is shown in Figure 5-42 for the kitchen (top) and bedroom (bottom).

135
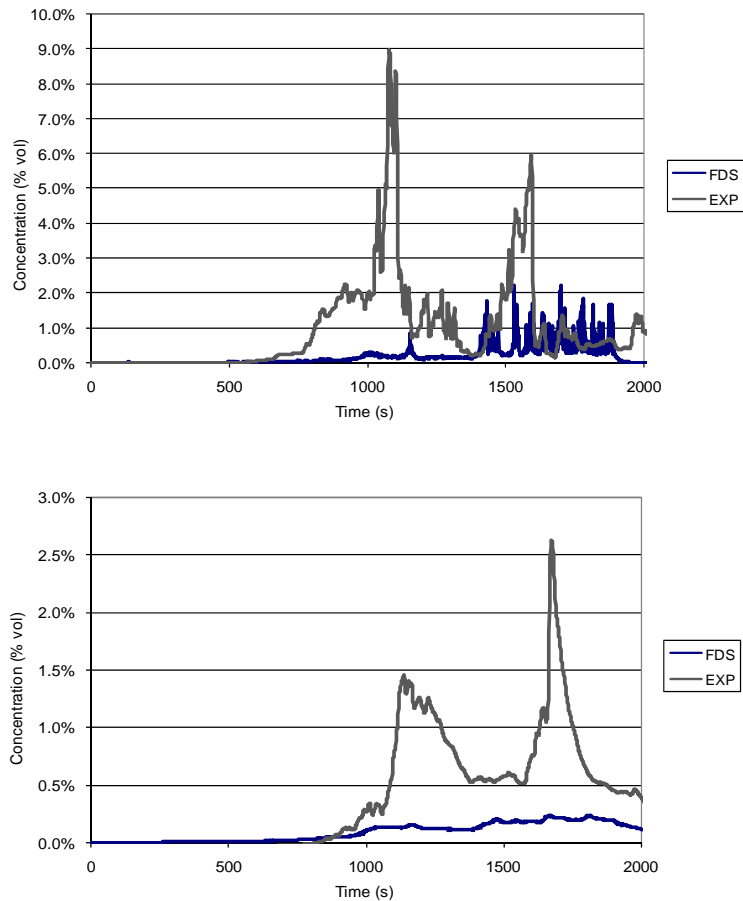
Figure 5-42 Concentration in volume percent of carbon monoxide at the ceiling in the kitchen (top) and bedroom (bottom) for the load cell heat release rate simulation of the low cabinet test with door open.

The CO concentrations in FDS does reach 2 % by volume with this configuration later in the test, after 1500 s. But the test data reaches 9 % already around 1100 s, and is higher than the FDS results at all times. In the bedroom the CO concentrations in FDS do not exceed 0.3 %, much lower than recorded in the test at all times.

5.8   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 but the simulation was run for 1700 s.

5.8.1   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 5-43.

136
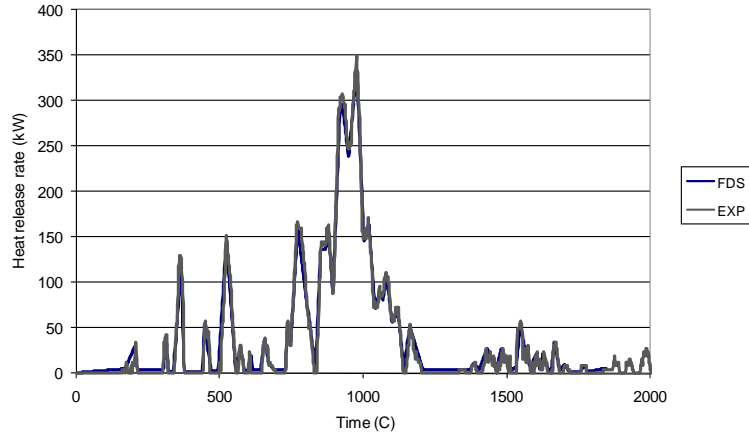
Figure 5-43. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Sofa in the closed compartment.

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

5.8.2   Oxygen Concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 5-44.
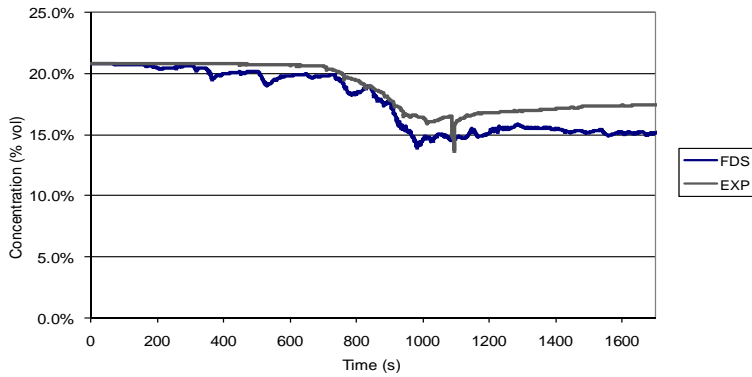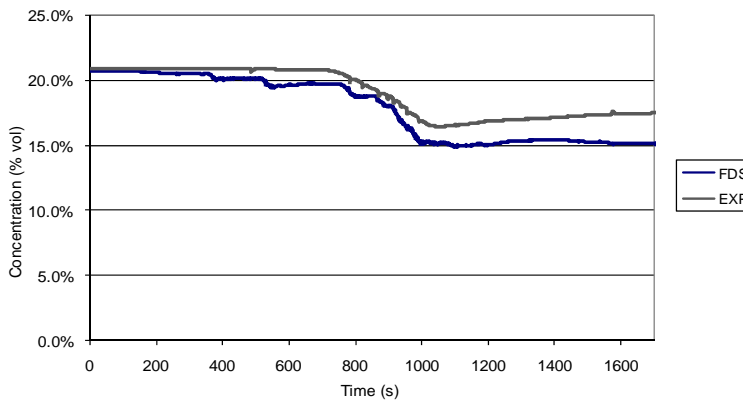
Figure 5-44. Oxygen concentrations at 2.4 m (8 ft) in the living room (top) and bedroom (bottom) for the
sofa test in the closed compartment.

The oxygen concentration curves follow similar shapes in both FDS and the test, but FDS
gives constantly lower values in both the living room and the bedroom, up to a difference of 2 %
by volume.

5.8.3   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 5-45.

138
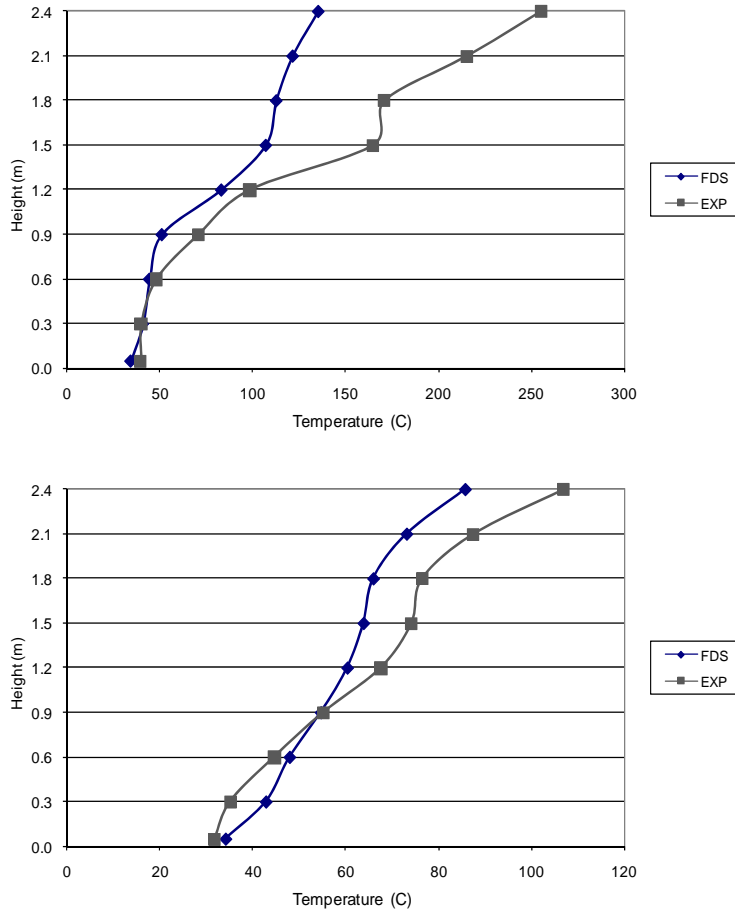
Figure 5-45. Vertical variations of temperature at 900 s in the living room (top) and the bedroom (bottom) for the sofa test in the closed compartment.

In the living room the FDS predictions are lower than the test results and the difference increases with height, up to a 23 % difference at the top. In the bedroom FDS is within 6 % of the experimental results at all heights with an underprediction of temperatures higher up.

Temperature measured over the height of the room at 1000 s in the living room (top) and bedroom (bottom) are shown in Figure 5-46.
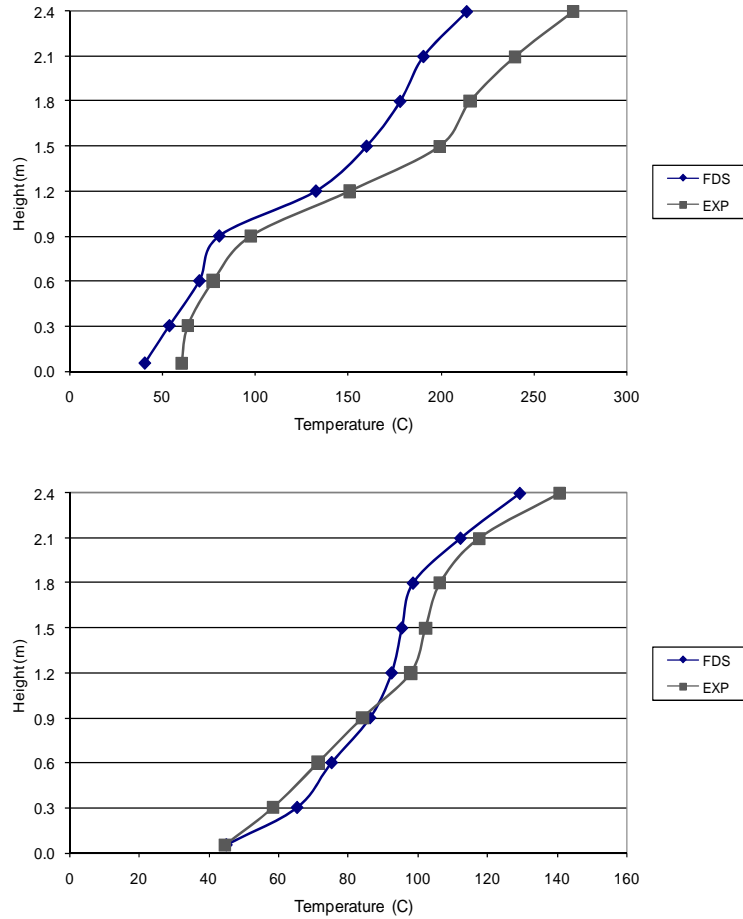
Figure 5-46. Vertical variations of temperature at 1000 s. in the living room (top) and the bedroom (bottom) for the sofa test in the closed compartment.

At 1000 s FDS gives the same shape as the curve for the experimental results but with lower temperatures in both locations. In the living room the difference increases up to 10 % while in the bedroom it is no more than 3 % at all heights.

Temperature measured over the height of the room at 1700 s in the living room (top) and bedroom (bottom) are shown in Figure 5-47.
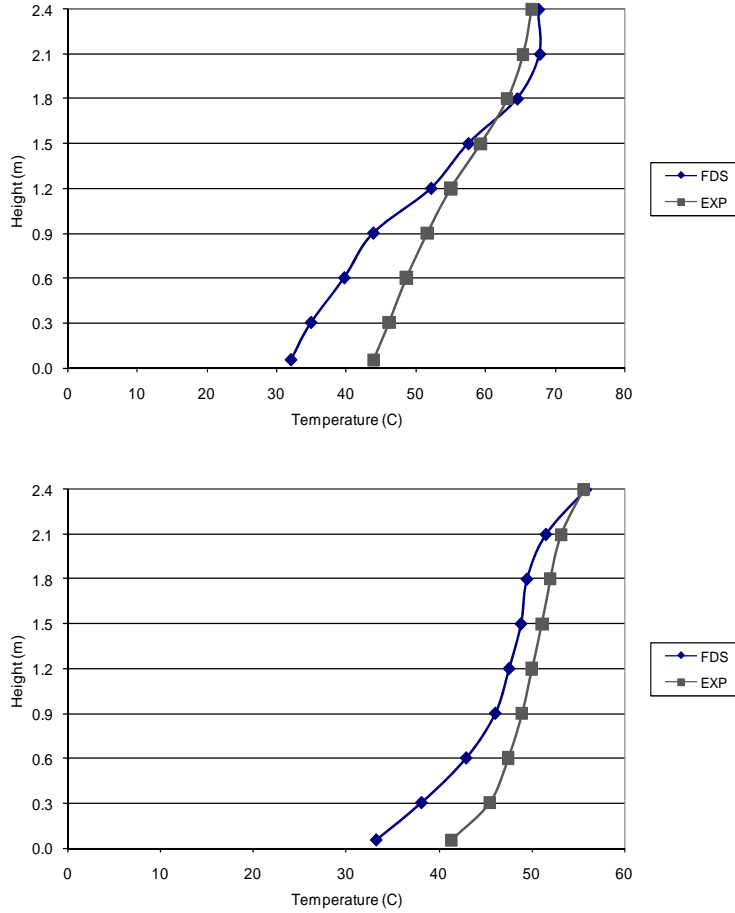
Figure 5-47. Vertical variations of temperature at 1700 s in the living room (top) and the bedroom (bottom) for the sofa test in the closed compartment.

At the end of the simulation the FDS predictions can still be said to be very good. The temperatures are within 4 % of the test results in both the bedroom and living room and the shape of the curve and placement of the layer interfaces is similar.

5.8.4   Carbon Monoxide Concentration

The concentration of CO in volume percent at the ceiling is shown in Figure 5-48 for the living room (top) and bedroom (bottom).

141
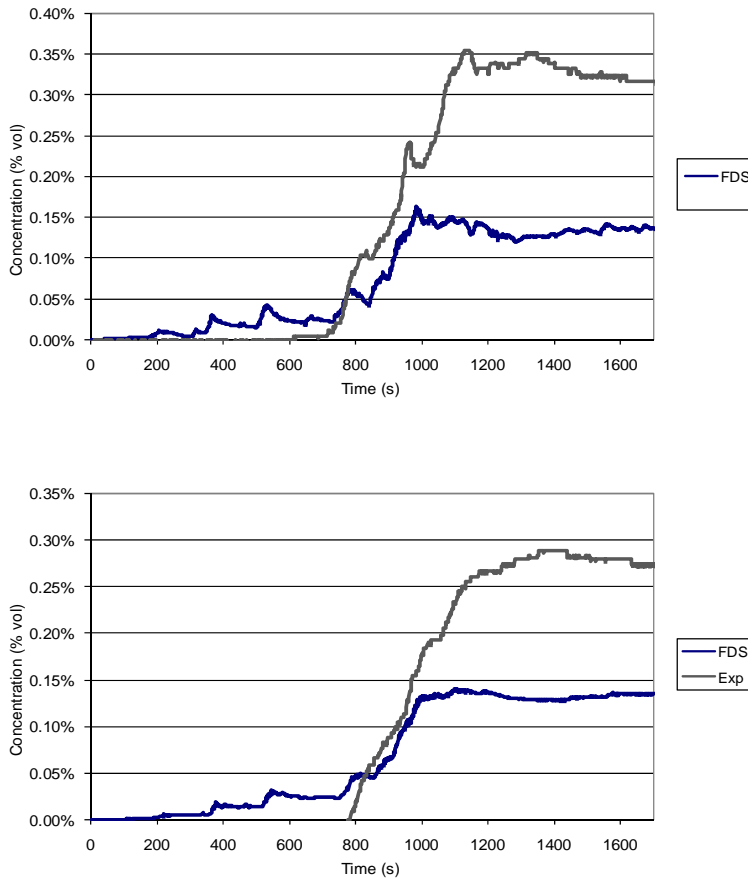
Figure 5-48 Concentration in volume percent of carbon monoxide at the ceiling in the living room (top) and bedroom (bottom) for the load cell heat release rate simulation of the sofa test in closed compartment.

Despite perfect replication of the heat release curve and good agreement between FDS and the test data both for temperatures and oxygen concentration the predicted peak CO concentrations are lower in FDS in both rooms. However the shape of the curve and the timing of the increases agrees well with the test data.

5.9   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.

5.9.1   Heat Release Rate

The resulting heat release rates from FDS and the experiment are shown in Figure 5-49.

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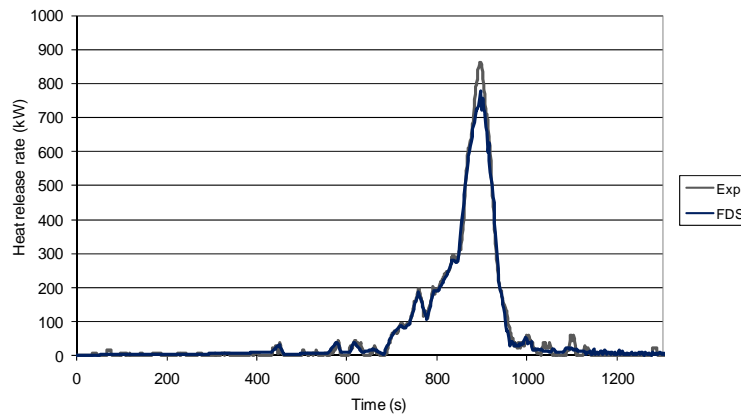
Figure 5-49. Heat release rate in the FDS load cell heat release rate simulation compared to the one calculated from the test mass loss data. Sofa with window half open

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

5.9.2 Oxygen concentration

The oxygen concentrations measured at the ceiling, 2.4 m (8 ft), in the center of the room in the living room (top) and in the bedroom (bottom) are shown in Figure 5-50.

143
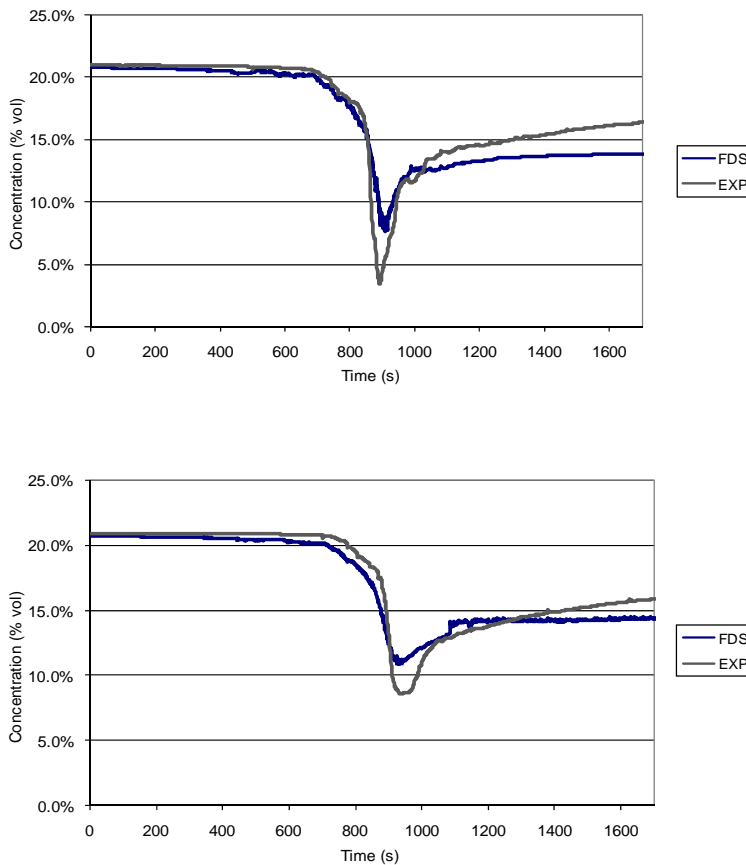
Figure 5-50. Oxygen concentrations at 2.4 m (8 ft) in the living room (top) and bedroom (bottom) for sofa test with bedroom window half open

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 but the test data reaches a lower minimum value. The test does show a more rapid increase in oxygen after the fire self-extinguished, indicating larger inflow of fresh air.

5.9.3   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 5-51.

144
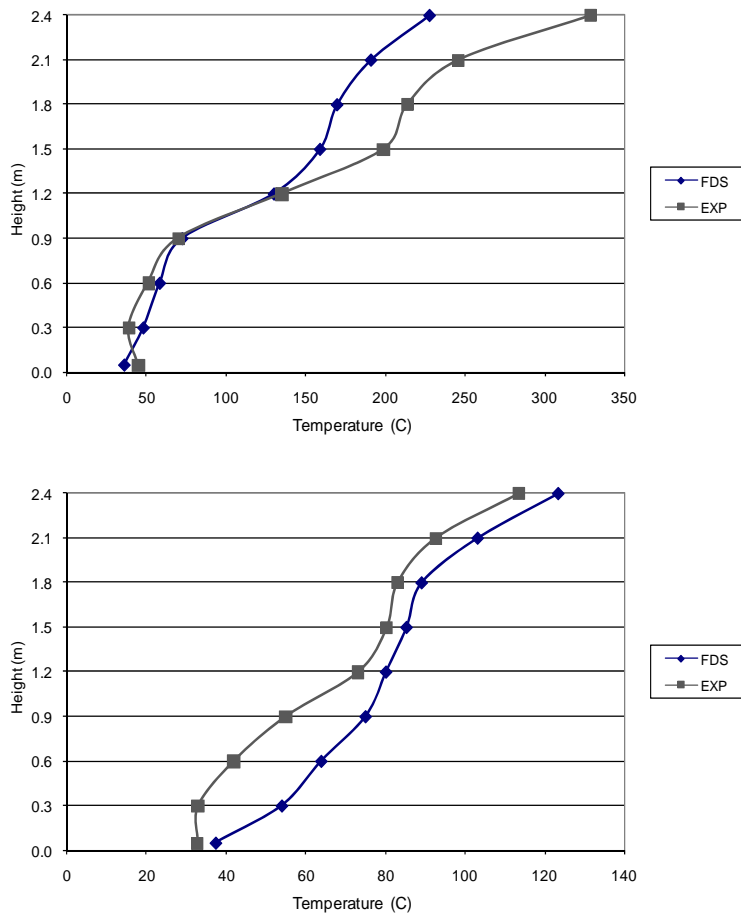
Figure 5-51. Vertical variations of temperature at 850 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open

The shape of the two graphs is similar in both rooms but FDS shows a lower temperature in the upper layer in the living room and a higher temperature across all heights in the bedroom. In the living room the difference is up to 17 %, while FDS is within 4 % of the test data in the bedroom.

Temperature measured over the height of the room at 900 s in the living room (top) and bedroom (bottom) are shown in Figure 5-52.
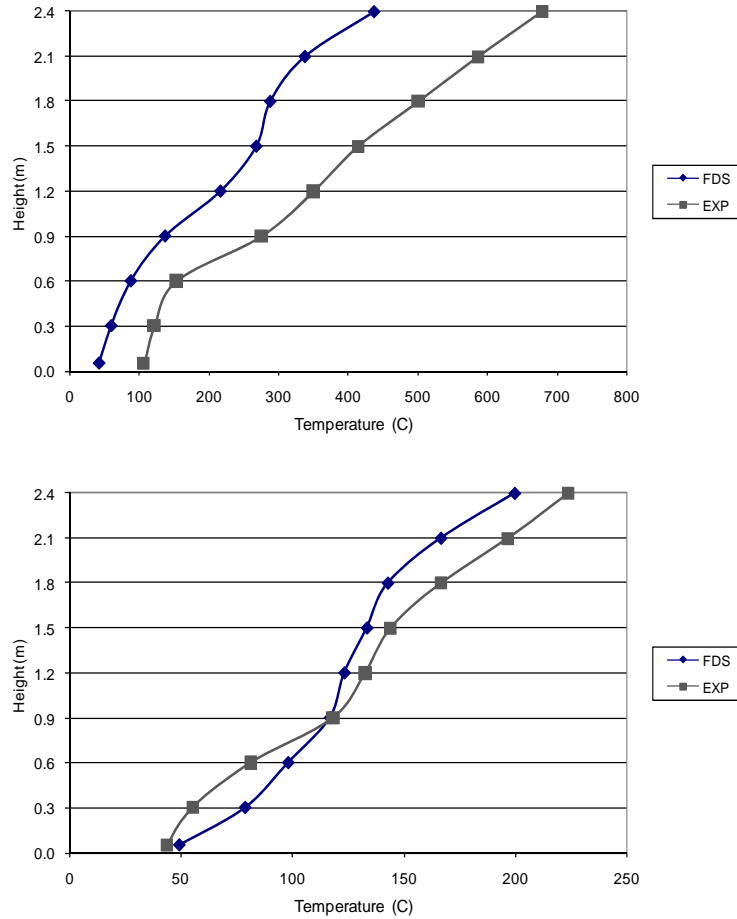
Figure 5-52 Vertical variations of temperature at 900 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open

Only 50 s later the temperature in FDS is lower than in the test at all locations in the living room, from 15 – 25 % lower. In the bedroom FDS also gives up to 6 % lower temperatures in the upper layer.

Temperature measured over the height of the room at 1700 s in the living room (top) and bedroom (bottom) are shown in Figure 5-53.

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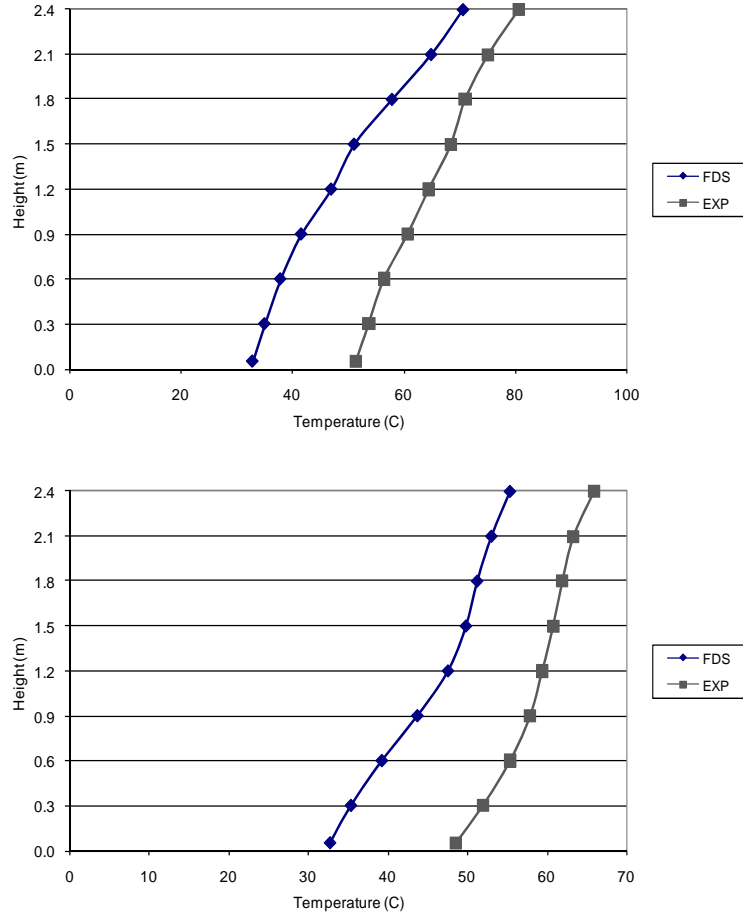
Figure 5-53. Vertical variations of temperature at 1300 s in the living room (top) and the bedroom (bottom) for the sofa test with bedroom window half open

At the end of the fire a similar picture is seen in both locations. As was indicated in the closed sofa test, the temperatures in FDS has decreased more rapidly than in the test. However FDS is still within 6 % of the test results in both the living room and the bedroom.

5.9.4   Carbon Monoxide Concentration

The concentration of CO in volume percent at the ceiling is shown in Figure 5-54 for the living room (top) and bedroom (bottom).
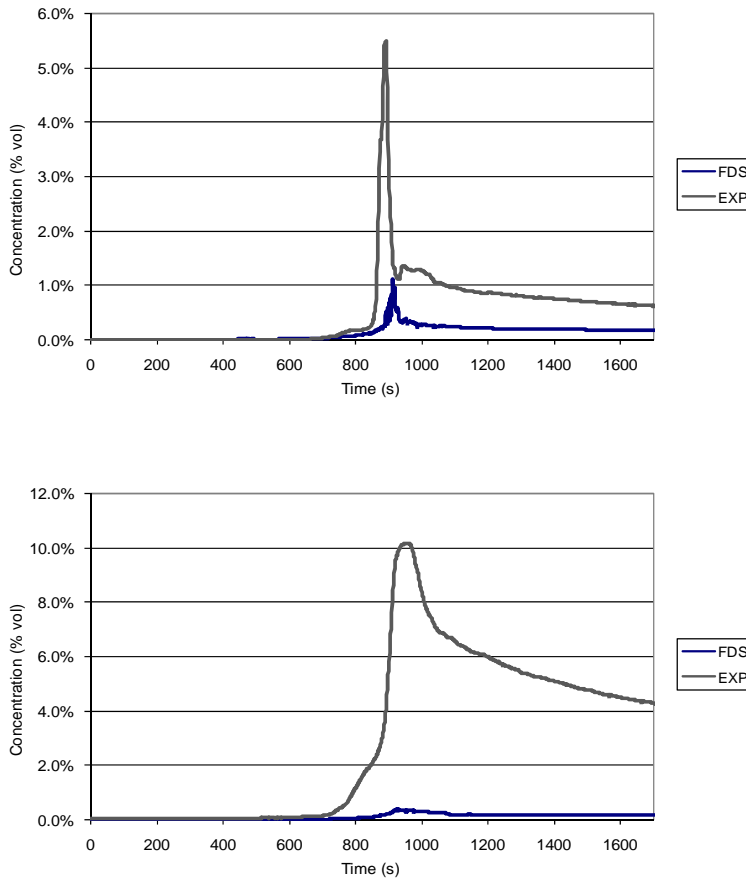
Figure 5-54 Concentration in volume percent of carbon monoxide at the ceiling in the living room (top) and bedroom (bottom) for the load cell heat release rate simulation of the sofa test with bedroom window half open

The FDS data shows an increase in CO concentrations between 900 – 1000 s in both rooms, which is similar to the behavior in the test. However as in all the other simulations FDS does not show CO concentrations higher than 1 % whereas the test results show 5 % and 10 % in the living room and bedroom, respectively.

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6   DISCUSSION

6.1   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.

6.2   Effects of Different Heat Release Rate Inputs to FDS

6.2.1   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 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 at the base of the fire 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 6-1, 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
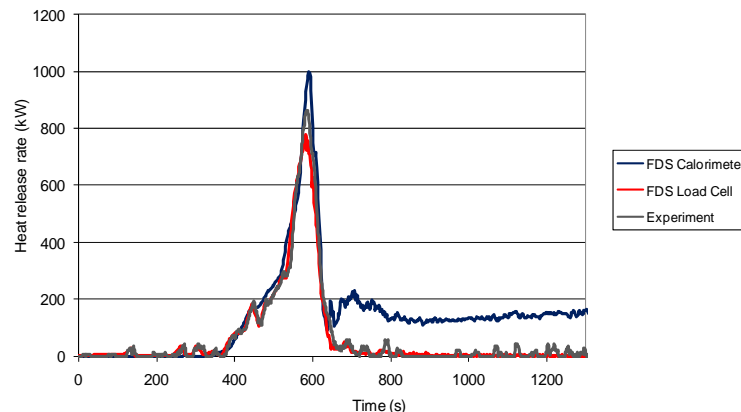
Figure 6-1. Comaprison of heat release rate in the sofa test with half open bedroom window for the
calorimeter heat release rate simualtions, load cell heat release rate simualtions and experimental data.

Up until 650 s the three graphs follow the same shape closely. The peak heat release rate
in the FDS calorimeter data simulation was about 150 kW higher than the test data, which again
was 80 kW higher than the FDS 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.

Overall the two heat release rate inputs to FDS gave reasonable temperature predictions,
both within 25 – 30 % in the living room at the times analyzed. The largest deviations occurred
at peak heat release rate. In the bedroom FDS gave temperatures within 10 % in all but one case

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for all times. The temperature predictions followed expected behavior based on the heat release rate. The simulations using calorimeter data had a higher peak heat release rate and also overpredicted temperatures in the living room after the peak, whereas the load cell simulations tended to show underpredictions at this time.

The oxygen concentrations in the FDS load cell heat release rate simulations of the two sofa tests showed good agreement with the test for both the configuration with closed and open window. Overall it was clear that the simulations using the load cell data gave more accurate predictions than the simulations based on the calorimeter heat release rate. Also considering the shape of the curve and timing of minimum value both inputs to FDS gave good agreement with the test data but the load cell data resulted in slightly less deviation from the test data.

6.2.2 Cabinet Tests

The kitchen cabinet tests varied with respect to the ventilation conditions and the two cabinet placements. 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):

$$\dot{m}_{air} = \frac{1}{2} A \sqrt{H} \qquad\qquad \text{Equation 6-1}$$

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, $\Delta H_c / r_s$

$$\dot{Q} = \dot{m}_{air} Y_{O_2 air} \frac{\Delta H_c}{r_s} \qquad\qquad \text{Equation 6-2}$$

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.

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Table 6-1. 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, Boehmer, Alvear 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, Vandsburger and Floyd 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):

$$\Phi = \frac{r_s \dot{m}_{fuel}}{\dot{m}_{air} y_{O_2 air}}$$ Equation 6-3

Where:

$$r_s = \frac{y_{O_2} MW_{O_2}}{MW_{fuel}}$$ Equation 6-4

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

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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, Simo Hostikka, Jason Floyd et al. 2008b). 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:

$$\dot{m}_{fuel} = Z\rho_{mix}V \qquad\qquad \text{Equation 6-5}$$

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

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:

$$F/O = \frac{Z\rho_{\infty}V}{(1-Z)\rho_{\infty}VY_{O2air}} = \frac{Z}{(1-Z)Y_{O2,air}} \qquad\qquad \text{Equation 6-7}$$

Dividing by the stoichiometric ratio gives:

$$\Phi = \frac{\frac{Z}{(1-Z)Y_{O2,air}}}{\frac{Z_{stoic}}{(1-Z_{stoic})Y_{O2,air}}} = \frac{\frac{Z}{(1-Z)}}{\frac{Z_{stoic}}{(1-Z_{stoic})}} \qquad\qquad \text{Equation 6-8}$$

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 ratios in the four simulations of the elevated kitchen cabinet tests using the load cell heat release rate are shown in Figure 6-2. The equivalence ratios for the three low cabinet simulations are shown in Figure 6-3.
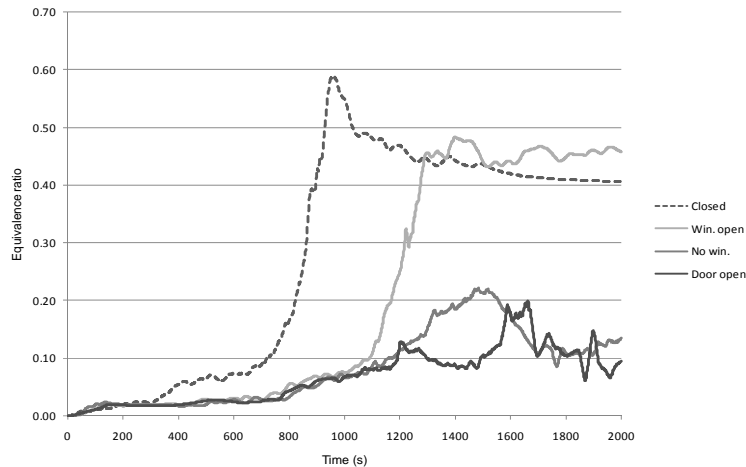
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Figure 6-2. The equivalence ratio in the kitchen for the simulations of the four different cabinet tests with closed compartment, window half open, window removed and door open.
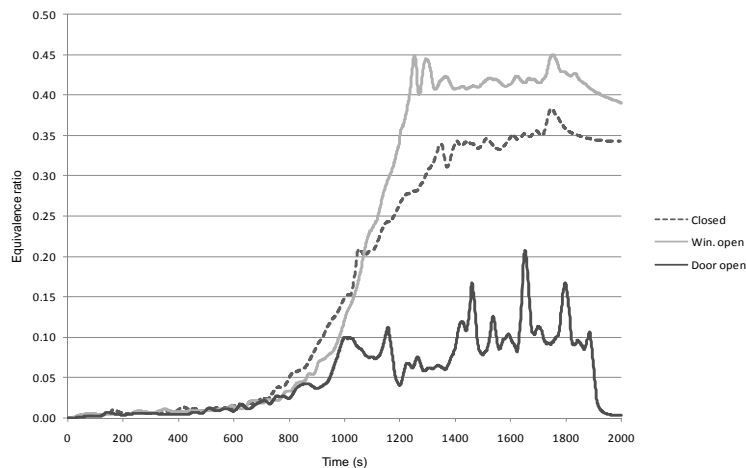
Figure 6-3 The equivalence ratio in the kitchen for the simulations of the four different cabinet tests with closed compartment, window half open, window removed and door open.

None of the four ventilation conditions or the two cabinet configurations resulted in a $\Phi > 1$ that would signify 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 elevated cabinets were placed almost at the ceiling inside the smoke layer and the even with the low cabinets the smoke layer quickly descended below the fire source. 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

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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 tests reached a steady value for the closed test and the window open test. But in the test with the window removed and the door open the CO concentrations reached a peak value 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, while 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 this correlation lacking (Wieczorek, Vandsburger and Floyd 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, using this heat release rate as input to FDS produced a severely underestimated fire size when compared to the test in the compartment. The closed compartment cabinet tests, which gave the lowest heat release rates, 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 (Harmathy 1975) explained, 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 kitchen was also a small space so even with the low cabinet configuration the smoke layer built up quickly. The sofa test, which was placed lower in the bigger living room showed better correlation between calorimeter and test data.

The temperature measurements from the FDS simulations tended to show a more pronounced separation into a cold lower layer and a hot upper layer in the fire room with all configurations. In the two tests with larger 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 elevated kitchen cabinet in the closed compartment are shown in Figure 6-4.

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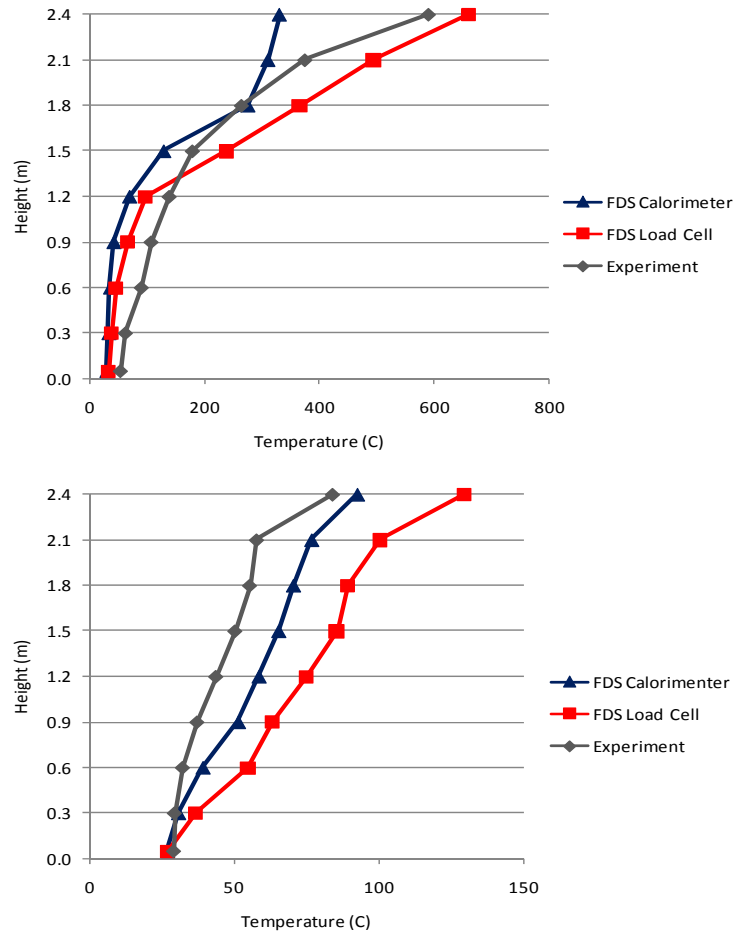
Figure 6-4. Temperature in the kitchen (top) and bedroom (bottom) at peak heat release rate in the calorimeter and load cell simulations and in the experiment for the kitchen cabinet test in the closed compartment.

The graphs in Figure 6-4 are representative of the results seen in the simulations in the closed compartment using and with the window half open with both elevated and low cabinets. In the kitchen the FDS simulations 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 was typical for the two cabinet tests with only minimal ventilation, using both high and low configurations.

Looking at the simulations using the load cell data for heat release rate input, FDS gives predictions mostly within 25 % of the test data in the living room, with some exceptions as high as 40 – 50 %. For the elevated cabinet, window open test FDS gives the largest deviations. The temperature predictions in the bedroom are better for these four simulations, mostly within 15 %. Again the simulation of the elevated cabinet with window open has the largest discrepancies between FDS and the test data.

In the scenarios with the window removed and the door open, the difference between temperatures recorded in the test and in FDS is increases for both the elevated and low cabinets.

No tests were conducted with the low cabinet and the window removed. For these simulations the difference between FDS and the test data is as high as 30 – 40 % in the kitchen for all cases. In the bedroom the FDS predictions are somewhat better, staying below 15 % for most of the points analyzed.

For all configurations 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. 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 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 minimal 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 simulations using the load cell data show better agreement with the test data. The heat feedback effects increased the fire size inside the compartment but the limited ventilation worked 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 also have inaccuracies, 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 from a life safety standpoint.

One of the possible causes of the inaccuracies in the FDS predictions may have been the placement of the cabinets. The top edge of the elevated cabinets was positioned 10 cm (4 in) from the ceiling and the top edge of the low cabinets was 1.3 m (4.3 ft) 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 occurred 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.
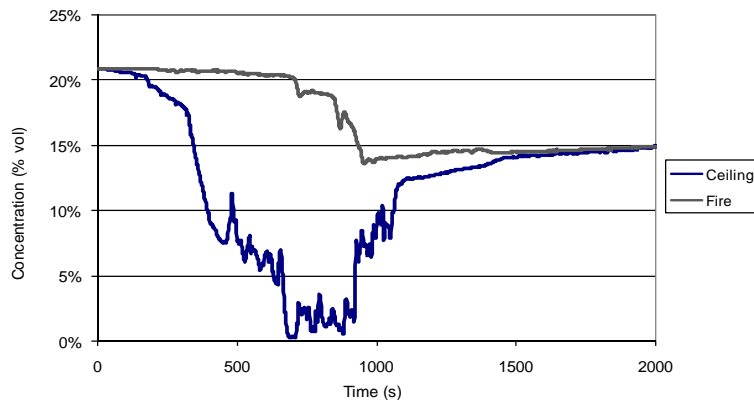
Figure 6-5. Oxygen concentrations at the ceiling and at the base of the fire, 1.5 m (5 ft), in the kitchen in the elevated cabinet test in the closed compartment.

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. For some of the measurements the simulations of the low cabinet tests showed better agreement between FDS and the test data, indicating that the placement of the cabinets higher up made FDS predictions less accurate. However, at certain positions the low cabinet simulations gave less accurate results than seen in the elevated cabinet simulations so this is difficult to determine. Additionally the sofa tests were presumably even less affected by the smoke layer than the low cabinets but showed underestimation of the temperatures in the living room of up to 30 % in the test with open window. It is likely that some combination of complex burning inside the smoke layer and underventilated combustion in general caused an increased inaccuracy in FDS beyond what is generally reported elsewhere for well-ventilated cases.

6.3   Carbon Monoxide Concentration Results

In all the simulation performed the concentrations of CO was much lower in FDS than was recorded in the tests. The cause of this is most likely the treatment of CO in FDS, as discussed in Section 1.3.2. The yield of CO is based on free-burning value given as input to the model. If underventilated combustion occurs, the CO production model in FDSv5 will use information about the chemical composition of the fuel, also given as input, to estimate an increased yield of CO. It is therefore clear that the CO yield in an underventilated fire is very sensitive to changes in input from the user. In this case two distinct fuels which differed in chemical composition were used and both showed the same behavior with regards to CO concentration in the compartment. Additionally, the free-burn CO yield was taken from calorimeter test of similar furniture items. This indicates that the CO production model in FDS underestimates the CO yield, but further study is needed where other fuels are used, preferably more homogenous materials with a known composition.

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6.4   Effects of Changes to the Parameters in the Combustion Model on Results

Four early versions of two elevated cabinet simulations and two sofa simulations were run with the extinction model in FDS off and compared to similar simulations with the extinction algorithm active. This gave predictable results for heat release rate. 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 simulations. The simulation of the sofa in the closed compartment gave two 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. 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 6-6. The left picture is the simulation with extinction on and the right is with extinction off.
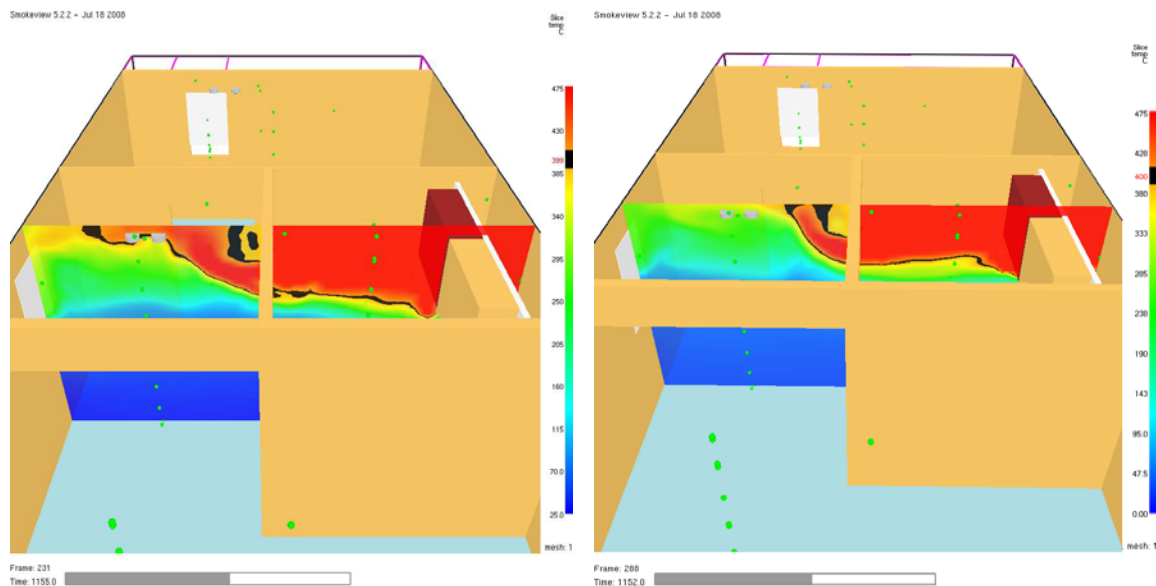
Figure 6-6. Temperature slice at x = 4.5 showing how hot gases are moving out of the kitchen at 1150 s in the simulation with extinction on to the left and extinction off to the right.

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.
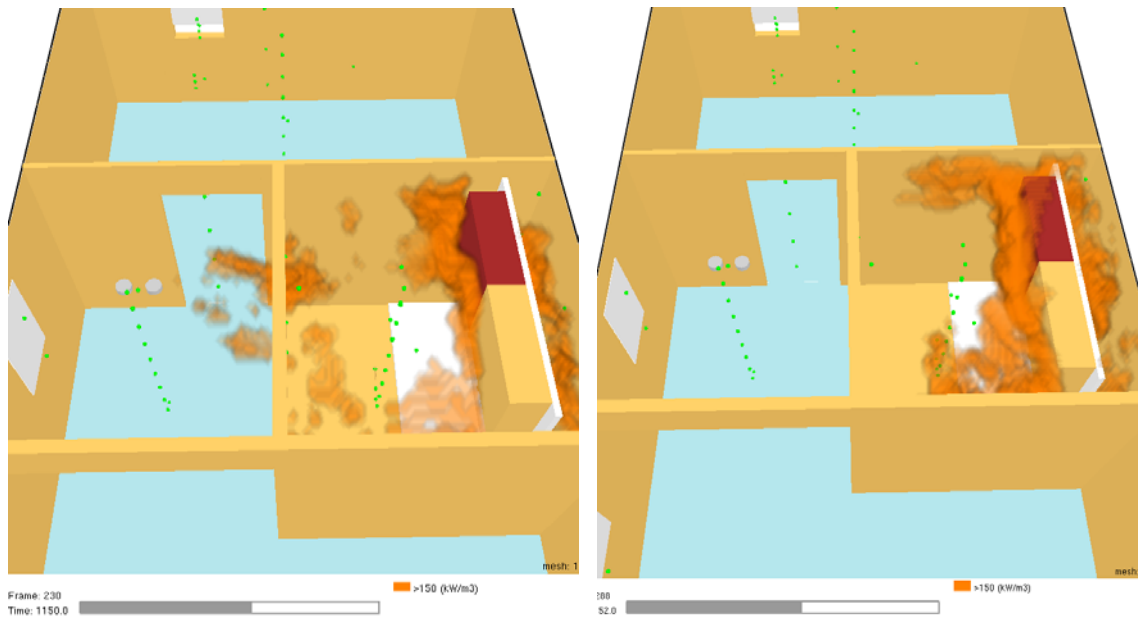
Figure 6-7. Plot 3D rendering of the heat release rate per unit volume where it exceeds 150 kW/m3 in the kitchen cabinet simulations at 1150 s. Left with extinction model active and right without extinction.

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. It was concluded that using the extinction model in FDS gave a more realistic simulation of the fire and additionally represents the way in which FDS will most likely be used to model actual fire scenarios. Therefore the extinction model was used for all of the later simulations used in this report.

7   CONCLUSIONS

Several full-scale compartment fire tests were simulated using Fire Dynamics Simulator version 5.2.5 with different heat release rate inputs. The tests were performed using two realistic fuel items, a sofa and a kitchen cabinet array, in two locations, the living room and the kitchen of a small four room apartment structure. The kitchen cabinet array was placed in both an elevated and a low configuration. Two small natural gas burner tests were also performed in the compartment. The tests had five different ventilation conditions ranging from a completely closed compartment to an open entrance door.

Pre-test simulations in the compartment were performed using heat release rate data from free burn oxygen-consumption calorimeter tests of identical fuel items. For post-test simulations, 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. In all cases using the load cell data as input to FDS gave a heat release rate closer to that seen in the tests, and with some exceptions, more accurate temperature and oxygen predictions. This was caused by FDS not accounting for the heat feedback effects caused by the enclosure and the smoke layer which were not present in the calorimeter tests.

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 an accuracy around ± 30 % in the living room, which is a larger discrepancy than reported in previous validation studies which usually have more favorable ventilation conditions.

The simulations using cabinets placed both near the ceiling and close to the floor gave oxygen concentration measurements that overall showed good agreement with the test data. In some scenarios the oxygen concentration went to zero in the tests while in FDS it did not go below 5 % by volume, possibly a restriction resulting from the limiting oxygen algorithm in FDS. The temperature in the bedroom also showed good agreement between FDS and the test data, within 10 % for most times analyzed. For the temperatures in the kitchen however, the accuracy of FDS was less clear. For all cases, there were FDS measurements with a discrepancy of up to 30 – 40 % from the test data in some locations, but also more accurate measurements elsewhere. There was some indication that the cabinets in the low configuration gave more accurate results than the elevated cabinets. This may be due to less combustion occurring within the oxygen-poor upper layer.

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, and (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

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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.

Considering the concentrations of CO, FDS showed poor agreement with the test measurements. In the cases were there was reasonable agreement for the oxygen concentrations FDS could predict where spikes in CO concentrations occurred, but the value was always lower in FDS than in the test by a significant amount. This is a result of the way FDS calculated CO yield during underventilated combustion, which in this case does not give an adequate increase in CO yield over the free burn value. Additional sources of uncertainty are the free-burn CO yield input and the description of the fuel chemistry as well as CO production during pyrolysis which is currently not included in FDS. This study indicates that the added CO produced by FDS in underventilated fire conditions is lower than measured in tests, but further study is required to determine the effect the fuel description input to FDS has on the results.

Four of the simulations were compared for three different settings of the combustion model in FDS, and it was found that the difference between simulations with and without the extinction model was significant. When local flame extinction was modeled, the limited ventilation led to reduced heat release rate and caused the combustion zone to move out of the fire room towards the ventilation opening. Flames outside the fire room were not observed in the test, but overall the extinction model resulted in a fire behavior that better represented that seen in the tests. The extinction model may lead to increased computational costs, but the effects are significant and it is recommended that it is used for compartment fire simulations.

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

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APPENDIX A

SELECTED FDS INPUT FILES

A.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','VELOCIT
Y','HRRPUV'/      <set




&REAC
C=1.06084,H=4.076451,N=0.015529,O=0.014848,HEAT_OF_COMBUSTION=48249,IDEAL=.TR
UE.,SOOT_YIELD=0.015,CO_YIELD=0.0/



&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
```

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&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' /
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&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'/
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&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/
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       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
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&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
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```
&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, 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, 1.54,1.54, 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, 0.61,0.61, 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, 1.54,1.54, 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'/
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&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/
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A.2 Cabinet Test, Window Half Open Using Calorimeter Heat Release Rate

```
&HEAD CHID='cabV_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, 0.8,1.6, 1.0,1.4 / 2.5cm - window vent
30 720
&MESH IJK=15,8,24,  XB=-0.7,0.8, 0.0,0.8, 0.0,2.4 / 10cm - LEFT OF window
2520
&MESH IJK=15,30,24, XB=-0.7,0.8, 1.6,4.6, 0.0,2.4 / 10cm - RIGHT OF window
10 800
&MESH IJK=15,8,10,  XB=-0.7,0.8, 0.8,1.6, 0.0,1.0 / 10cm - UNDER window
1200
&MESH IJK=15,8,10,  XB=-0.7,0.8, 0.8,1.6, 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=12300 / 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,
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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 /
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&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 /
&RAMP ID='RAMP_Q_TISSUE',      T=   266.53    ,F=   0.454 /
&RAMP ID='RAMP_Q_TISSUE',      T=   277.29    ,F=   0.485 /
&RAMP ID='RAMP_Q_TISSUE',      T=   313.87    ,F=   0.406 /
&RAMP ID='RAMP_Q_TISSUE',      T=   324.63    ,F=   0.488 /
&RAMP ID='RAMP_Q_TISSUE',      T=   335.39    ,F=   0.570 /
&RAMP ID='RAMP_Q_TISSUE',      T=   356.91    ,F=   0.594 /
&RAMP ID='RAMP_Q_TISSUE',      T=   384.89    ,F=   0.529 /
&RAMP ID='RAMP_Q_TISSUE',      T=   393.50    ,F=   0.488 /
&RAMP ID='RAMP_Q_TISSUE',      T=   423.63    ,F=   0.529 /
&RAMP ID='RAMP_Q_TISSUE',      T=   451.60    ,F=   0.410 /
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&RAMP ID='RAMP_Q_TISSUE',      T=   526.92    ,F=   0.287 /
&RAMP ID='RAMP_Q_TISSUE',      T=   569.96    ,F=   0.290 /
&RAMP ID='RAMP_Q_TISSUE',      T=   602.24    ,F=   0.212 /
&RAMP ID='RAMP_Q_TISSUE',      T=   613.00    ,F=   0.307 /
&RAMP ID='RAMP_Q_TISSUE',      T=   621.61    ,F=   0.334 /
&RAMP ID='RAMP_Q_TISSUE',      T=   625.92    ,F=   0.294 /
&RAMP ID='RAMP_Q_TISSUE',      T=   632.37    ,F=   0.406 /
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&RAMP ID='RAMP_Q_TISSUE',       T=      649.59       ,F=     0.471  /
&RAMP ID='RAMP_Q_TISSUE',       T=      668.96       ,F=     0.413  /
&RAMP ID='RAMP_Q_TISSUE',       T=      673.26       ,F=     0.512  /
&RAMP ID='RAMP_Q_TISSUE',       T=      694.78       ,F=     0.573  /
&RAMP ID='RAMP_Q_TISSUE',       T=      703.39       ,F=     0.683  /
&RAMP ID='RAMP_Q_TISSUE',       T=      712.00       ,F=     0.826  /
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&RAMP ID='RAMP_Q_TISSUE',       T=      733.52       ,F=     1.000  /
&RAMP ID='RAMP_Q_TISSUE',       T=      739.97       ,F=     0.894  /
&RAMP ID='RAMP_Q_TISSUE',       T=      752.89       ,F=     0.782  /
&RAMP ID='RAMP_Q_TISSUE',       T=      763.65       ,F=     0.515  /
&RAMP ID='RAMP_Q_TISSUE',       T=      783.01       ,F=     0.304  /
&RAMP ID='RAMP_Q_TISSUE',       T=      808.84       ,F=     0.259  /
&RAMP ID='RAMP_Q_TISSUE',       T=      838.97       ,F=     0.208  /
&RAMP ID='RAMP_Q_TISSUE',       T=      862.64       ,F=     0.249  /
&RAMP ID='RAMP_Q_TISSUE',       T=      905.68       ,F=     0.184  /
&RAMP ID='RAMP_Q_TISSUE',       T=      920.74       ,F=     0.154  /
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&RAMP ID='RAMP_Q_TISSUE',       T=      970.24       ,F=     0.253  /
&RAMP ID='RAMP_Q_TISSUE',       T=      981.00       ,F=     0.205  /
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&RAMP ID='RAMP_Q_TISSUE',       T=      1155.64      ,F=     0.249  /
&RAMP ID='RAMP_Q_TISSUE',       T=      1198.68      ,F=     0.184  /
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&RAMP ID='RAMP_Q_TISSUE',       T=      1274.00      ,F=     0.205  /
&RAMP ID='RAMP_Q_TISSUE',       T=      1276.00      ,F=     0.0    /


&SURF ID='CABINET'
      COLOR='BROWN'
      HRRPUA= 221.08
      RAMP_Q= 'RAMP_Q_CABINET'/   hrrmax=666.55 kw / 3.015m = 221.08 kw/m2

&RAMP ID='RAMP_Q_CABINET',      T=      0.00   ,F=    0.000  /
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&RAMP ID='RAMP_Q_CABINET',      T=      698.80       ,F=     0.065  /
&RAMP ID='RAMP_Q_CABINET',      T=      728.87       ,F=     0.129  /
&RAMP ID='RAMP_Q_CABINET',      T=      763.23       ,F=     0.183  /
&RAMP ID='RAMP_Q_CABINET',      T=      776.12       ,F=     0.294  /
&RAMP ID='RAMP_Q_CABINET',      T=      784.71       ,F=     0.308  /
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&RAMP ID='RAMP_Q_CABINET',      T=      819.07       ,F=     0.269  /
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&RAMP ID='RAMP_Q_CABINET',      T=      850.00       ,F=     0.358  /
&RAMP ID='RAMP_Q_CABINET',      T=      857.73       ,F=     0.337  /
&RAMP ID='RAMP_Q_CABINET',      T=      870.62       ,F=     0.305  /
&RAMP ID='RAMP_Q_CABINET',      T=      874.91       ,F=     0.294  /
&RAMP ID='RAMP_Q_CABINET',      T=      883.51       ,F=     0.308  /
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&RAMP ID='RAMP_Q_CABINET',      T=      913.57       ,F=     0.258  /
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&RAMP ID='RAMP_Q_CABINET',      T=      939.35        ,F=      0.256 /
&RAMP ID='RAMP_Q_CABINET',      T=      947.94        ,F=      0.29  /
&RAMP ID='RAMP_Q_CABINET',      T=      960.82        ,F=      0.244 /
&RAMP ID='RAMP_Q_CABINET',      T=      978.01        ,F=      0.287 /
&RAMP ID='RAMP_Q_CABINET',      T=      995.19        ,F=      0.366 /
&RAMP ID='RAMP_Q_CABINET',      T=      1003.78       ,F=      0.358 /
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&RAMP ID='RAMP_Q_CABINET',      T=      2008.93       ,F=      0.308 /
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&RAMP ID='RAMP_Q_CABINET',      T=      2210.82       ,F=      0.405 /
&RAMP ID='RAMP_Q_CABINET',      T=      2236.60       ,F=      0.430 /
&RAMP ID='RAMP_Q_CABINET',      T=      2258.08       ,F=      0.384 /
&RAMP ID='RAMP_Q_CABINET',      T=      2283.85       ,F=      0.380 /
&RAMP ID='RAMP_Q_CABINET',      T=      2331.10       ,F=      0.312 /
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&RAMP ID='RAMP_Q_CABINET',     T=      2352.58       ,F=    0.319 /
&RAMP ID='RAMP_Q_CABINET',     T=      2399.83       ,F=    0.280 /
&RAMP ID='RAMP_Q_CABINET',     T=      2438.49       ,F=    0.280 /
&RAMP ID='RAMP_Q_CABINET',     T=      2464.26       ,F=    0.319 /
&RAMP ID='RAMP_Q_CABINET',     T=      2481.44       ,F=    0.287 /
&RAMP ID='RAMP_Q_CABINET',     T=      2567.35       ,F=    0.333 /
&RAMP ID='RAMP_Q_CABINET',     T=      2593.13       ,F=    0.376 /
&RAMP ID='RAMP_Q_CABINET',     T=      2631.79       ,F=    0.297 /
&RAMP ID='RAMP_Q_CABINET',     T=      2683.33       ,F=    0.330 /
&RAMP ID='RAMP_Q_CABINET',     T=      2713.40       ,F=    0.767 /
&RAMP ID='RAMP_Q_CABINET',     T=      2734.88       ,F=    0.699 /
&RAMP ID='RAMP_Q_CABINET',     T=      2756.36       ,F=    0.824 /
&RAMP ID='RAMP_Q_CABINET',     T=      2807.90       ,F=    0.502 /
&RAMP ID='RAMP_Q_CABINET',     T=      2820.79       ,F=    0.509 /
&RAMP ID='RAMP_Q_CABINET',     T=      2855.15       ,F=    0.337 /
&RAMP ID='RAMP_Q_CABINET',     T=      2880.93       ,F=    0.330 /
&RAMP ID='RAMP_Q_CABINET',     T=      2928.18       ,F=    0.265 /
&RAMP ID='RAMP_Q_CABINET',     T=      2971.13       ,F=    0.287 /
&RAMP ID='RAMP_Q_CABINET',     T=      2988.32       ,F=    0.258 /
&RAMP ID='RAMP_Q_CABINET',     T=      3005.50       ,F=    0.280 /
&RAMP ID='RAMP_Q_CABINET',     T=      3061.34       ,F=    0.244 /


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= -0.01,0.101, 1.5,4.5, 0.0,2.4, SURF_ID='GWB'/ BR WALL1
&OBST XB= -0.01,0.101, 0.0,0.9, 0.0,2.4, SURF_ID='GWB'/ BR WALL2
&OBST XB= -0.01,0.101, 0.9,1.5, 0.0,1.1, SURF_ID='GWB'/ BR WALL3
&OBST XB= -0.01,0.101, 0.9,1.5, 1.3,2.4, SURF_ID='GWB'/ BR WALL4
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fix mesh alignment
&OBST XB= 0.0, 0.8, 4.5, 4.6, 0.0, 2.4, SURF_ID='GWB' /


        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, 0.0,4.6, 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, 4.6,4.6, 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= 1.5, QUANTITY='TEMPERATURE' /
&SLCF PBY= 2.3, QUANTITY='TEMPERATURE' /
&SLCF PBX= 4.5, QUANTITY='TEMPERATURE' /
&SLCF PBX= 6.3, QUANTITY='TEMPERATURE' /

&SLCF PBY= 1.5, 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= 1.3, QUANTITY='U-VELOCITY' /
&SLCF PBY= 1.2, QUANTITY='U-VELOCITY' /


                        DEVICES:
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&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
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&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/
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                                                                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=4.4,3.1, 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=1.6,2.2, 2.35, QUANTITY='oxygen', ID='B-O2-ceil'/
tree
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&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=4.61, 3.0, 0.91, QUANTITY='GAUGE_HEAT_FLUX', IOR=+2, ID='K-fireHF',
PROP_ID='hf1' / kitchen
&DEVC XYZ=7.9, 3.31, 0.91, 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
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&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, 0.61,0.61, 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, 1.54,1.54, 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, 0.61,0.61, 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, 1.54,1.54, 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_1.9'/

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

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```
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/
```

A.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, 0.8,1.6, 1.0,1.4 / 2.5cm - window vent
30 720
&MESH IJK=15,8,24,  XB=-0.7,0.8, 0.0,0.8, 0.0,2.4 / 10cm - LEFT OF window
2520
&MESH IJK=15,30,24, XB=-0.7,0.8, 1.6,4.6, 0.0,2.4 / 10cm - RIGHT OF window
10 800
&MESH IJK=15,8,10,  XB=-0.7,0.8, 0.8,1.6, 0.0,1.0 / 10cm - UNDER window
1200
&MESH IJK=15,8,10,  XB=-0.7,0.8, 0.8,1.6, 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=1850 / 1850                <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=14000/  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'
```

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```
        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=  619.92,
        RAMP_Q= 'RAMP_Q_SOFA'/

&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 /
&RAMP ID='RAMP_Q_SOFA', T=  429.91      ,F=   0.010 /
&RAMP ID='RAMP_Q_SOFA', T=  448.60      ,F=   0.038 /
&RAMP ID='RAMP_Q_SOFA', T=  457.94      ,F=   0.003 /
&RAMP ID='RAMP_Q_SOFA', T=  501.56      ,F=   0.006 /
&RAMP ID='RAMP_Q_SOFA', T=  554.52      ,F=   0.006 /
&RAMP ID='RAMP_Q_SOFA', T=  576.32      ,F=   0.048 /
&RAMP ID='RAMP_Q_SOFA', T=  585.67      ,F=   0.010 /
&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 /
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```
&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 /
&RAMP ID='RAMP_Q_SOFA', T=      978.19      ,F=    0.029 /
&RAMP ID='RAMP_Q_SOFA', T=     1000.00      ,F=    0.067 /
&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 /
&RAMP ID='RAMP_Q_SOFA', T=     1121.50      ,F=    0.029 /
&RAMP ID='RAMP_Q_SOFA', T=     1130.84      ,F=    0.016 /
&RAMP ID='RAMP_Q_SOFA', T=     1274.14      ,F=    0.006 /
&RAMP ID='RAMP_Q_SOFA', T=     1283.49      ,F=    0.022 /
&RAMP ID='RAMP_Q_SOFA', T=     1286.60      ,F=    0.010 /
&RAMP ID='RAMP_Q_SOFA', T=     1317.76      ,F=    0.006 /
&RAMP ID='RAMP_Q_SOFA', T=     1327.10      ,F=    0.019 /
&RAMP ID='RAMP_Q_SOFA', T=     1336.45      ,F=    0.006 /
&RAMP ID='RAMP_Q_SOFA', T=     1373.83      ,F=    0.006 /
&RAMP ID='RAMP_Q_SOFA', T=     1375.00      ,F=    0.048 /
&RAMP ID='RAMP_Q_SOFA', T=     1386.29      ,F=    0.006 /
&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 /
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&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)=0.0105     pressure zone -
leak area (as measured in NEW tests (0.021/2))  <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

fix mesh alignment
&OBST XB= 0.0, 0.8, 4.5, 4.6, 0.0, 2.4, SURF_ID='GWB' /


      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, 0.0,4.6, 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, 4.6,4.6, 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= 1.5, QUANTITY='TEMPERATURE' /
&SLCF PBY= 2.3, QUANTITY='TEMPERATURE' /
&SLCF PBX= 4.5, QUANTITY='TEMPERATURE' /
&SLCF PBX= 6.3, QUANTITY='TEMPERATURE' /

&SLCF PBY= 1.5, 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' /
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&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'/
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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
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&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'/
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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
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        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, 0.61,0.61, 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, 1.54,1.54, 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, 0.61,0.61, 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, 1.54,1.54, 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
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        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= 3.4,1.5,1.98, QUANTITY='V-VELOCITY', ID='VEL_1.9'/


&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
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&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/
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