ABSTRACT

Title of Document: SIMULATING THE FUEL MASS LOSS RATE IN FIRE DYNAMICS SIMULATOR (FDS) USING A NEW FURNITURE CALORIMETER DATABASE

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Fire Dynamics Simulator (FDS) is widely used in the fire community to simulate and understand in detail enclosure fire dynamics. Fire models require accurate descriptions of the fuel sources to simulate the fire behavior. One approach in FDS is to describe the fuel mass loss rate from furniture calorimeter tests. Unfortunately furniture calorimeter tests do not account for enclosure effects on the fuel sources (*i.e.* the thermal feedback of the smoke layer and the air vitiation). This work explores a simple pyrolysis model that uses furniture calorimeter data and applies a correction to the data to represent enclosure effects. The study includes: (1) the development of a database which compiles furniture calorimeter data, (2) the development of a modified version of FDS that incorporates a simple pyrolysis model proposed by Professor Quintiere (1) and (3) a performance evaluation of the model by detailed comparisons between FDS results and experimental data from two studies performed at the University of Canterbury (2), (3).

SIMULATING THE FUEL MASS LOSS RATE IN FIRE DYNAMICS SIMULATOR (FDS) USING A NEW FURNITURE CALORIMETER DATABASE

By

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Introduction

1.1 Background

The complexity of fire makes it difficult to predict accurately how a fuel source will burn within a compartment. Over the past 30 plus years numerous people in the fire community have researched the best way to accurately predict how to quantify the fuel mass loss rate from a given fuel source. Two of the most influential tools used nowadays to predict pyrolysis behavior of an object and/or enclosure is by conducting full scale furniture calorimeter experiments and by simulating the fire using Fire Dynamics Simulator (FDS).

1.1.1 Furniture Calorimeter Tests

An important step in fire protection engineering occurred in the 1970s when Parker and Huggett published their calculation methods for the principle of oxygen consumption(4). In the 1980s another important milestone in fire protection occurred when research was conducted to better understand a way to accurately quantify the fire power also known as the heat release rate (HRR) (5). These milestones led the way for Babrauskas and colleagues to develop the cone calorimeter and for this research the all important furniture calorimeter. To this day, these calorimetry tests are used to better understand fuel sources.

Numerous studies have been conducted to determine how the data from calorimetry tests can be used to predict the fuel mass loss rate and heat release rate in an enclosure. Babrauskas has proposed numerous ways to use bench scale (*i.e.* cone calorimeter) results to predict furniture and room calorimeter results. One published method suggested by Babrauskas(6) involves taking into account various characteristics of chairs. These characteristics involve style, mass, frame and fabric of the chair. Although this method was acceptable for the chairs Babrauskas study cannot be used universally for all types of household items (*i.e.* appliances, wardrobe, closets, bookcases, etc.).

Recently Quintiere(1) developed a model which can indirectly calculate the enclosure fuel mass loss rate (MLR) by using furniture calorimeter data, the oxygen concentration and radiative heat flux in the enclosure at a given time and the heat of gasification of the fuel source. Quintiere's model takes into account the enclosure effects (*i.e.* the positive effects of the thermal feedback and negative effects of the air vitiation) when calculating the fuel MLR from the furniture calorimeter data. The following research further discusses implementing Quintiere's model with furniture calorimeter data to determine the fire dynamics of an object burning in an enclosure.

1.1.2 Fire Dynamics Simulator

Although furniture and cone calorimeter experiments are useful to determine the fire behavior of a fuel source another method was needed to minimize cost and time of testing numerous setups. Simulating the fire behavior in a computational fluid dynamics (CFD) program would permit the user to both visually and quantitatively obtain results.

The National Institute of Standards and Technology (NIST) developed an important engineering tool used today in the fire protection field called Fire Dynamics Simulator (FDS)(7). FDS is an engineering tool which minimizes cost and simplifies predicting how an object will burn within a given environment by obtaining fire behavior data through simulations. These simulations can vary in enclosure size, fuel sources, and numerous other variances which occur in a room of origin.

Although simulations can reduce cost and make it easier to "test" rooms of complex geometry, FDS is still a complex program if the user is not experienced in programming and fire dynamics. Users should be familiar with programming in order to create the input file necessary to run a simulation. Fire dynamics knowledge is essential when analyzing the results and when supplying thermal properties for materials.

FDS simulations are very sensitive when it comes to material and thermal properties of the enclosure and fuel source. A slight variation in these properties can alter the results tremendously. Defining these properties accurately though can be cumbersome because material and thermal properties are not known for every possible fuel source. For instance, defining the material of an upholstered sofa precisely may be difficult because the fabric can be a polyacrylic / cotton blended material. Cone calorimeter tests need to be conducted in order to obtain accurate material/thermal properties. Adding data from calorimeter tests help in the accuracy of the simulation results.

A study conducted at the University of Edinburgh shows how important it is to define the input parameters accurately. In this study, numerous teams were required to simulate one of the experiments of the Dalmarnock Fire Tests (8). (The Dalmarnock Fire Tests were a series of large scale fire tests in a high rise building.) Each participating team had to try to simulate accurately the experiment using a detailed description of the compartment geometry, fuel packages, ignition source, and ventilation conditions. This study found a huge discrepancy between each simulation and to the experiment. It was determined that the discrepancies were a result of the numerous uncertainties in the input parameters used to describe the fuel sources.

Besides requiring the user to be knowledgeable in programming and fire behavior, FDS is also incapable of accurately determining the fire behavior in an enclosure using strictly furniture and cone calorimeter results. A study done at the University of Canterbury by Elizabeth Young(9) showed how FDS failed at determining the fire behavior strictly using furniture calorimeter data. In Young's FDS simulation she described the fuel source in an enclosure using furniture calorimeter data, but the HRR results given by FDS were lower than the measured HRR during a room calorimeter test. Young's research proved that FDS needed to be modified in order to accurately calculate the room effects on the fuel mass loss rate using furniture calorimeter data.

The following research discusses modifications to FDS in order to incorporate a model which calculates the enclosure fuel mass loss rate using the furniture calorimeter fuel mass loss rate.

1.2 Objective

As discussed earlier, calorimetry tests and FDS have been developed to quantitatively describe the fire behavior of a fuel source either in a free or enclosed environment. Also methods have been proposed by Babrauskas and Quintiere to predict the full-scale enclosure mass loss rate of a fuel source using cone and/or furniture calorimeter. This research was conducted to continue progress in the fire protection community by combining these three developments into one.

In addition the main objective of this research was to develop a database which would centrally compile readily available furniture calorimeter data of everyday household and office items. The development of this database was funded by NCFS and will benefit both the forensic science and the fire protection communities.

1.3 Approach

The following research describes in detail how the enclosure fuel mass loss rate was simulated in FDS using data from a newly developed furniture calorimeter database. For simplicity this project was broken into two main parts: (1) development of a furniture calorimeter database and (2) simulating the burning characteristics of various fuel sources in FDS.

The first portion of this research required an extensive literature review to determine and collect all readily available furniture calorimeter tests done on everyday household and office furniture. This data was categorized and examined before being included into a new database.

The second portion of this research required several sub-tasks which will be discuss further in a later section. This portion of the research required data from experiments where both furniture and room calorimeter tests were conducted. First, simulations using the room calorimeter data were performed in order to determine if FDS could reproduce the data. Next, FDS was modified to incorporate Quintiere's fuel mass loss rate model. Lastly the modified version of FDS was validated by comparing simulation results where furniture calorimeter data was used to the actual experimental room calorimeter results.

Both the database and FDS simulations portions of the research project are discussed in Chapter 2 and Chapter 3, respectively.

2 Database

2.1 Background / Objective

The National Institute of Justice (NIJ) of the Department of Justice (DOJ) awarded the Department of Fire Protection Engineering (FPE) of the University of Maryland (UMD) and the National Center of Forensic Science (NCFS) of the University of Central Florida (UCF) a grant to develop a centralized database. This database (aka Burning Item Database or BID) was created to benefit the forensic science and fire protection communities. By gathering furniture calorimeter data of common objects in a unique document people would be able to easily find the information to use in diagnostics. In addition to data from furniture calorimeter tests, the BID contains data for thermal properties of common materials. The thermal properties which were deemed important were density (ρ), heat of conductivity (k), specific heat (C_p), the heat of gasification (L_g) and ignition temperature (T_{ig}).

In order to populate the Burning Item Database an extensive literature review was performed. Any source which provided furniture calorimeter results of common household and office items were set aside in order to be compiled into the database. All pertinent information (*i.e.* material composition, first item ignited, heat release rate and mass loss rate history, and reference, etc.) was documented from the sources and categorized as necessary. This information was then published into a centrally located database online (http://FireBID.umd.edu). Compiling the information at a unique location allows people from all areas of interest (*i.e.* forensic science, fire protection, etc.) to easily locate information of household / office items which have already been tested.

2.2 Literature Review

Creating a database filled with the most valuable thermal property data required an extensive literature review. The main steps of the review were to determine what information was already available publicly, how many other databases were available with thermal property data, and how thermal property data could be determined if needed.

2.2.1 Available Sources

Step one of the literature review required an extensive online search for publicly available sources providing information on calorimeter tests and thermal properties of materials or common everyday objects. Numerous data were found with regards to cone, furniture and room calorimeter tests.

2.2.1.1 Types of Calorimeter Tests

Calorimeter tests help to determine the most important factor, heat release rate (HRR) which describes the intensity of the fire. The HRR is the rate of the combustion reactions that produce heat. In these calorimetry tests the burning rate of the object can also be found simply by measuring the mass loss rate (MLR) of the object throughout the test.

The MLR is related to the HRR by the heat of combustion, Δh_c, using the following equation:

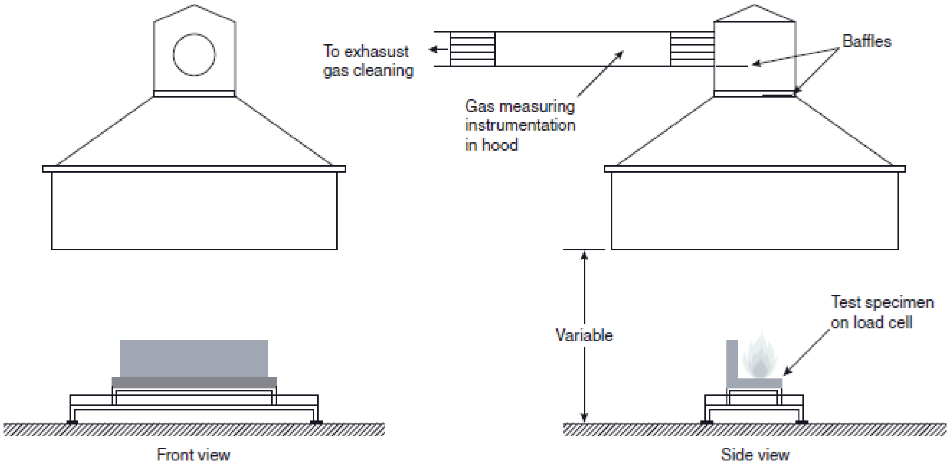
$$HRR = \Delta h_c \times MLR \tag{2-1}$$

Although this equation relates the HRR and MLR with the heat of combustion, this heat of combustion value should not be considered constant throughout the burning of the commodity. The heat of combustion varies throughout the test as well.

The HRR and MLR are both measured in the calorimetry tests. Calorimetry tests are separated into two types: full-scale and bench-scale.

2.2.1.1.1 Full-Scale Testing

Full-Scale testing allows for the HRR of the object to be measured. There are two types of full-scale testing: furniture and room. The furniture calorimeter test (Figure 2-1) is the easier of the two tests to conduct.



(The SFPE Handbook of Fire Protection Engineering)

Figure 2-1 - Setup of a Furniture Calorimeter Test (NORDTEST)

Furniture calorimeters, aka open-burning HRR calorimeters, were developed in the 1980s by Babrauskas and colleagues at NIST and by Heskestad at Factory Mutual Research Corporation (5). Basically, the object in question is placed on a scale underneath a properly rated hood. The object is ignited and allowed to burn for the time required by experimentation. The smoke is exhausted through the hood and passes instrumentation which measures the oxygen content in the smoke.

The oxygen consumption relationship is used to determine the heat release of the object over time (HRR).

$$HRR = E\left(\dot{m}_a Y_{O2}^{a} - \dot{m}_e Y_{O2}^{e}\right) \qquad (2\text{-}2)$$

where E – Heat release per mass unit of oxygen consumed [~13.1 kJ/g]

$Y_{O_2}^{a}$ – Mass fraction of oxygen in the combustion air [0.233 g/g in dry air]

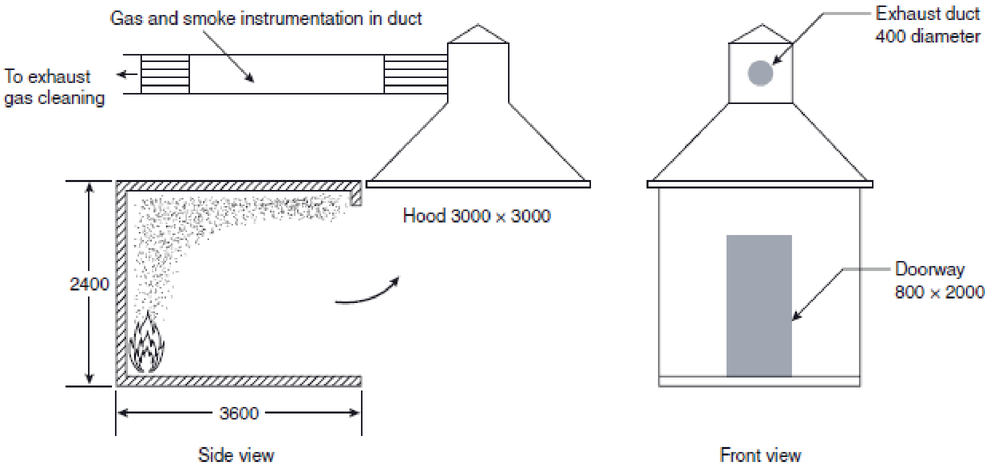
$Y_{O_2}^{e}$ – Mass fraction of oxygen in the combustion products [g/g]

$\dot{m}_a$ – Mass flow rate of air entering control volume [g/s]

$\dot{m}_e$ – Total mass flow rate of combustion products exiting [g/s]

As mentioned above the object is placed on a load cell (or scale) to measure the mass loss throughout the test.

A room calorimeter test uses the same methodology as above but the burning is done in a room mock-up in order to get all effects of the compartment. A room calorimeter test (Figure 2-2) requires construction of a specified room in close proximity to a properly rate hood.



(The SFPE Handbook of Fire Protection Handbook)

Figure 2-2 - Sample of a Room Calorimeter (ISO 9705)

The room calorimeter determines the HRR through the same process (oxygen consumption relationship) as the furniture calorimeter. The HRR measured in room calorimeter tests will be much larger than the HRR measured in furniture calorimeter tests because of the enclosure effects on the development of the fire.

A fire in an enclosure develops depending on the enclosure geometry and ventilation and the fuel type, amount and surface area (10). Development of fires consists of five stages: ignition, growth, flashover, fully developed fire, and decay.

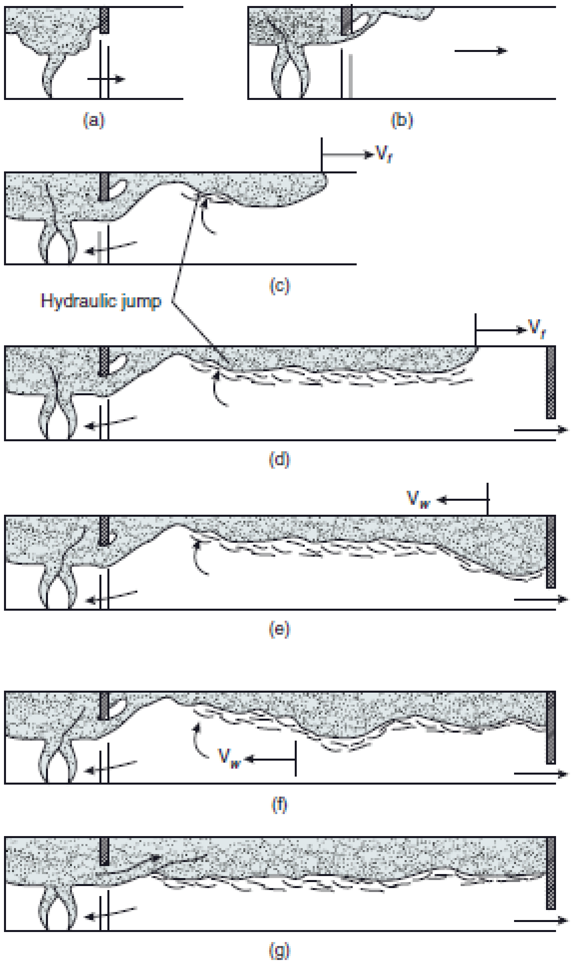


Figure 2-3 – Example of Fire Dynamics in an Enclosure (11)

After ignition the fire spreads and produces an increase amount of energy, toxic and nontoxic gases and solids (soot). An enclosure fire initially develops similar to the development of a fire in an open environment. In this stage the enclosure has no effect on the fire and the fire is considered to be fuel-controlled.

The growth stage begins when a fire plume develops (Figure 2-3a) as the hot gases from the flame rise upward because it is more buoyant than the colder gases in the enclosure. Once the fire plume reaches the ceiling the hot gases will then spread across the ceiling forming ceiling jets (Figure 2-3b). When the ceiling jets reach the walls, the hot gases are forced downward (Figure 2-3e). These hot gases are still buoyant and travel back towards the fire plume creating a hot layer of gases under the ceiling (Figure 2-3f).

Various studies have shown enclosures are divided into two layers: upper (hot) layer and the lower (cold) layer. The upper layer is a mixture of the combustion products and entrained air, while the lower layer is just air. The air from the lower layer is continuously entrained into the fire plume as the fire grows.

The hot layer descends as the fire grows. If vents are present the layer descends to these points and begins to spill outside the enclosure. As the hot layer descends it also increases in temperature. The heat from this layer is transferred by radiation and convection to the ceiling and walls of the enclosure. The heat from this layer is also transferred to the floor, lower layer and fuel through radiation. Heat is radiated to the fuel from the flame, hot layer and hot boundaries. Increasing the amount of heat transferred to the fuel increases the burning rate of the fuel and the heating of other objects in the enclosure.

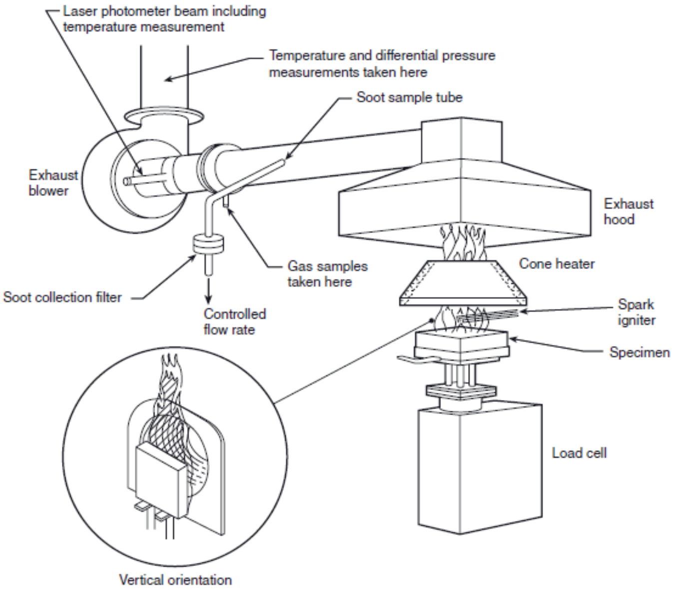
Fires in enclosures continue to grow as long as there is fuel to burn and enough oxygen available in the enclosure to allow for complete combustion. If the upper layer reaches an extremely hot temperature, flashover may occur. Flashover (Third Stage) occurs if the all the combustible materials in the enclosure are ignited causing a rapid increase in energy release rates.

At the fully developed fire stage, all combustibles are involved in the fire and the flames are extending outside the enclosure openings. The fire reaches the decay stage when there is no more fuel left to burn.

If an enclosure does not have any vents or not enough oxygen, the hot layer will descend to the flame region and starve the fire of oxygen. Although the energy release rate decreases, pyrolysis can still continue causing an abundant amount of unburnt gases to collect in the enclosure. If a window or door is open suddenly in a room where a large amount of unburnt gases has collected backdraft is highly likely.

2.2.1.1.2 Bench-Scale Testing

Bench-scale testing estimates the HRR by testing samples of the object in question. The most common bench-scale testing is the cone calorimeter (Figure 2-4) developed by Babrauskas at NIST.



(The SFPE Handbook for Fire Protection Engineering)

Figure 2-4– Example of the Cone Calorimeter

In the cone calorimeter test a 100 mm by 100 mm specimen is placed in the holder underneath the properly rated hood of the system. A known heat flux is applied to the specimen for the duration of the test. Ignition is caused by an intermittent spark located 13 mm above the sample. Once ignited, the smoke is exhausted through the exhaust hood where oxygen consumption instrumentation is present. This process needs to be run several times at different heat fluxes to determine the fire behavior of the material.

The data provided by calorimeter tests is valuable and can be used in various circumstances. Bench-scale tests are more cost effective and easier to reproduce numerous times. These tests are also important to help determine the thermal properties of materials as discussed in Section 2.2.3.

With regards to this research the best calorimeter data to use was from furniture calorimeter tests. As discussed previously in Section 2.2.1.1.1, room calorimeter results produce results that are specific to the room configuration used and cannot be easily extrapolated to other configurations. Furniture calorimeter results can be used for all type of enclosures and is therefore the most beneficial to the database being developed in this study. Therefore this database only compiles furniture calorimeter results for common household and office objects.

2.2.2 Available Databases

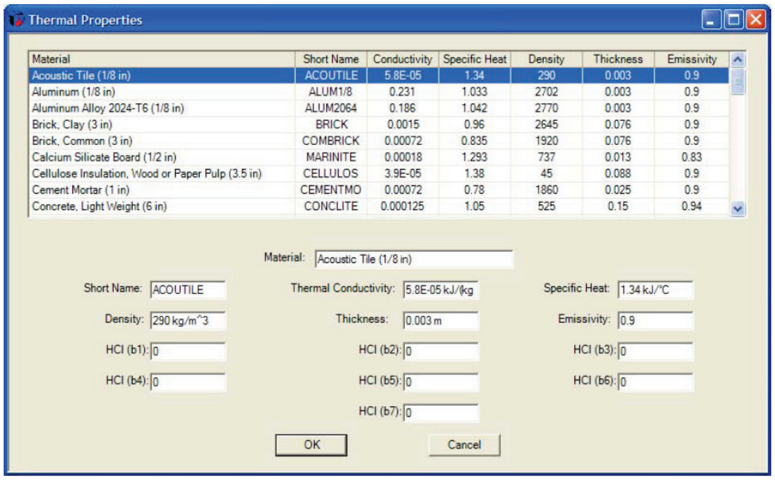
During the literature review a handful of databases which had already compiled fire data were found. Although a handful of databases were found about half of these databases were only discussed in documents and not actually available to the public online. The databases not available online were either still being developed, required registration, required to be bought, or were available only on a computer at the University of Canterbury.

Five open databases were found: 3 with unrestricted access, 1 requiring registration (free), and the last database was available after e-mailing permission. All of these sources provided furniture and/or room calorimeter data or thermal properties (*i.e.* ρ, C_p, k) of a material.

2.2.2.1 FASTData and CFAST

The National Institute of Standards and Technology (NIST) provided two databases: FASTData(12)and CFAST(13). FASTData documents some of the data from cone, furniture and room calorimeter tests conducted at the Building and Fire Research Laboratory. Information given ranged from item tested, location of test, sponsor, date of test, what type of test was conducted, pictures, movies, HRR plots, and smoke extinction plots. For this research the information used from this source was the data from tests run on household/office furniture (*i.e. mattresses, beds, dressers, bookshelves, etc.*). Although this website provided background information on the tests, actual data were not available online. To acquire the actual data the user must purchase a CD which contains the database and all data in a user friendly layout.

CFAST, Consolidated Model of Fire and Smoke Transport, is a computer program used by fire investigators, safety officials, engineers, architects and builders "to simulate the impact of past or potential fires and smoke in a specific building environment" (14). Information taken from this source corresponds to the thermal property database (Figure 2-5) which provides the thermal conductivity (k), specific heat (C_p), density (ρ) for common materials used in construction of rooms.



Material	Short Name	Conductivity	Specific Heat	Density	Thickness	Emissivity
Acoustic Tile (1/8 in)	ACOUTILE	5.8E-05	1.34	290	0.003	0.9
Aluminum (1/8 in)	ALUM1/8	0.231	1.033	2702	0.003	0.9
Aluminum Alloy 2024-T6 (1/8 in)	ALUM2064	0.186	1.042	2770	0.003	0.9
Brick, Clay (3 in)	BRICK	0.0015	0.96	2645	0.076	0.9
Brick, Common (3 in)	COMBRICK	0.00072	0.835	1920	0.076	0.9
Calcium Silicate Board (1/2 in)	MARINITE	0.00018	1.293	737	0.013	0.83
Cellulose Insulation, Wood or Paper Pulp (3.5 in)	CELLULOS	3.9E-05	1.38	45	0.088	0.9
Cement Mortar (1 in)	CEMENTMO	0.00072	0.78	1860	0.025	0.9
Concrete, Light Weight (6 in)	CONCLITE	0.000125	1.05	525	0.15	0.94

Material: Acoustic Tile (1/8 in)

Short Name: ACOUTILE
Thermal Conductivity: 5.8E-05 kJ/(kg
Specific Heat: 1.34 kJ/°C
Density: 290 kg/m^3
Thickness: 0.003 m
Emissivity: 0.9
HCl (b1): 0
HCl (b2): 0
HCl (b3): 0
HCl (b4): 0
HCl (b5): 0
HCl (b6): 0
HCl (b7): 0

Figure 2-5 – Screenshot of Thermal Property Database from CFAST

2.2.2.2 SP Database

The European Commission funded a large research effort called CBUF (Combustion Behaviour of Upholstered Furniture) to study the combustion behavior of upholstered furniture. The purpose of this study(15) was to determine the potential hazards of upholstered furniture using a specified testing and assessment technique. CBUF test included cone calorimeter (ISO 5660), furniture calorimeter (NT FIRE 032) and room calorimeter (ISO 9705) experiments. Some of this information has been compiled into an online database which is publicly available after registration at the website: http://www-v2.sp.se/fire/fdb/frmSearch.aspx(16). This database was created by the SP Swedish National Testing and Research Institute and allows registered users to freely use and publish data in the database as long as proper reference is given in connection to the data. This database is a collection of tests which have been done on cables, upholstered furniture, etc. As discussed earlier the only data used was the furniture calorimeter data.

2.2.2.3 Särdqvist Database

Another publicly available database was created by Stefan Särdqvist who published his findings (17). Särdqvist's report compiled several full scale tests for different items under various conditions (*i.e.* furniture or room calorimeter tests) from various sources. The report documented the description of the item tested, the testing type, the HRR, production of smoke and generation of CO, as well as the source of the information. Also Särdqvist created a digital version of his database which has compiled much of the data from these tests. The items in the database ranged from coffee makers to chairs to vehicles.

2.2.2.4 Young Database

Similar to Särdqvist's database another database(9) which compiled room and furniture calorimeter results was created by Elizabeth Young who was a Master student at the University of Canterbury. This database was obtained from Charlie Fleischmann by e-mail since the database was not included in Young's thesis.

Young's database was a compilation of sources which provided furniture and/or room calorimeter results for chairs. The chairs ranged from stackable chairs to 3-seated sofas. In her database she provided the item tested, the method of testing, material used, mass of the item, description, HRR data and the reference the information is taken from. As with Särdqvist's database only the furniture calorimeter results were used for the database presented in this paper.

Not only was Young's database useful, her research as well as numerous other studies conducted at the University of Canterbury involved studying the fire behavior of upholstered furniture tested for CBUF. These studies will be discussed more in the Chapter 3.

2.2.2.5 Other Databases

Databases which were found during the literature review but were only discussed in papers were FDMS, FIREBASE XML, and EDaFS.

FDMS or the Fire Data Management System was developed by NIST to standardize how fire data could be exchanged between laboratories. NIST and FRS (Fire & Risk Sciences) wanted to have a program which could handle databases and graphics from any fire test. Information on FDMS was last published in 1994 when FDMS 2.0 was being developed. FDMS 2.0 is not readily available on the internet but a technical document suggests it "can be accessed at user locations or downloaded for access in individual FDMS software programs" (18)

FIREBASE XML (19) was developed by MJ Spearpoint to compile the HRR data of experiments in a widely available and easily accessible database. Currently this database is stand-alone and is only available at the University of Canterbury. Spearpoint did create a website where this database could be located in the future (www.civil.canterbury.ac.nz/spearpoint/HRR_Database/).

Another database being developed at Worcester Polytechnic Institute (WPI) is EDaFS, Experiment Database for Fire Science which will be available at http://edafs2.wpi.edu:8050/edafs. This database will be able to store test data, documentation, photographs, video clips and other material in a central location.

Although the databases presented in this section were not available to the public, they still illustrate the importance of compiling fire data in a centralized location.

2.2.3 Determining Thermal Properties

Thermal properties of materials are required inputs to calculate fire behavior of an object. Numerous studies have looked into methods to determine the thermal properties of a material. One of the simplest ways to determine thermal properties is by utilizing cone calorimeter tests. Cone calorimeters tests are much more economical than full scale calorimeter tests because more tests can be run in a shorter time frame, test and human error can be minimized, repeatability tests can be conducted without a large downtime, and the tests are monetarily beneficial. Two methods to determine thermal properties from cone calorimeter data are using simple heat transfer theory such as in the study done by Hopkins and Quintiere (20) and using genetic algorithms.

2.2.3.1 Hopkins and Quintiere Method

Hopkins and Quintiere's study used simple heat transfer theory to determine thermal properties of six thermoplastics (*i.e. nylon 6/6, polyethylene, polypropylene and PMMA)* by utilizing data from cone calorimeter tests.

Using simple heat transfer, Hopkins and Quintiere used a one-dimensional model and assumed surface vaporization occurred at a specified temperature. Conductivity was assumed to remain constant. Therefore the governing equation was:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial y^2} \tag{2-3}$$

Next convection and radiative heat loss were assumed to occur at the surface of the material as illustrated in the following equation:

$$-k\frac{\partial T}{\partial y} = \dot{q}'' \equiv \varepsilon \dot{q}''_{ext} - h_c(T - T_o) - \varepsilon\sigma T^4 \tag{2-4}$$

where k – Thermal conductivity [W/m-K]
$\dot{q}''$ - Net surface heat flux [W/m^2]
ε – Emissivity [1.0]
$\dot{q}''_{ext}$ – External heat flux [W/m^2]
h_c – Convective heat transfer coefficient 10 W/m^2-K]
T – Temperature [K]
T_o – Ambient temperature [293 K]
σ – Stefan Boltzmann constant [5.67 x 10^{-8} W/m^2-K^4]

The depth of the heated layer inside the material is known as the penetration depth, δ. The penetration depth is determined to be approximately:

$$\delta = \sqrt{6\alpha t} \tag{2-5}$$

In theory the ignition time is in the following form:

$$t_{ig} = \frac{2}{3}(k\rho c)\frac{\left(T_{ig}-T_o\right)^2}{\left(\dot{q}''\right)^2} \tag{2-6}$$

where T_{ig} is the ignition temperature. The ignition temperature is related to the critical external heat flux that is required for ignition to occur; the relationship is:

$$\dot{q}''_{cr} \equiv \dot{q}''_{ext} = \frac{1}{\epsilon}\left[h_c\left(T_{ig}-T_o\right) + \epsilon\sigma {T_{ig}}^4\right] \tag{2-7}$$

Also by manipulating Equations 2-4 and 2-6, the following relationship was determined:

$$t_{ig}^{-1/2} = \left[\frac{\epsilon}{\sqrt{\frac{2}{3}k\rho c}\left(T_{ig}-T_o\right)}\right]\dot{q}''_{ext} - \left[\frac{h_c\left(T_{ig}-T_o\right)+\epsilon\sigma T_{ig}^4}{\sqrt{\frac{2}{3}k\rho c}\left(T_{ig}-T_o\right)}\right] \tag{2-8}$$

where,

$$Slope = \left[\frac{\epsilon}{\sqrt{\frac{2}{3}k\rho c}\left(T_{ig}-T_o\right)}\right] \tag{2-9}$$

Next the governing equations (Equations 2-10 to 2-11) when gasification has started are derived.

$$T = T_v \tag{2-10}$$

$$-k\frac{\partial T}{\partial y} = \dot{q}'' - \dot{m}''\Delta H_v \tag{2-11}$$

where the gasification period heat flux is defined as,

$$\dot{q}'' = \epsilon\dot{q}''_{ext} + \dot{q}''_{fl} - \epsilon\sigma T_v^2 \tag{2-12}$$

where,

$\dot{q}''_{fl}$ - Flame heat flux [kW/m^2]

Assuming a quadratic profile for the temperature which satisfies the boundary conditions for the vaporization (Equation 2-11) and substituting the profile into Equation 2-12, the following relationship is produced:

$$\dot{m}''\Delta H_v = \dot{q}'' - \frac{2k}{\delta}(T_v - T_o) \qquad (2\text{-}13)$$

The last term represents the transient conduction heat loss into the solid. Assuming the total flame heat flux constant the differential equation for mass loss rate of thermoplastics was solved to be:

$$t - t_{ig} = \frac{\delta_s^2}{6\alpha}\frac{\Delta H_v}{L}\left[\frac{\delta_{ig}-\delta}{\delta_s} - ln\left(\frac{\delta_s-\delta}{\delta_s-\delta_{ig}}\right)\right] \qquad (2\text{-}14)$$

where the steady penetration depth under burning (δ_s) and the heat of gasification (L) are,

$$\delta_s = \frac{2k}{c}\frac{L}{\dot{q}''} \qquad (2\text{-}15)$$

$$L = \Delta H_v + c(T_v - T_o) \qquad (2\text{-}16)$$

This assumption was determined to be accurate by Quintiere and Rhodes (21) as long as the flame height was above the cone heater and had a diameter greater than 2.

2.2.3.1.1 Utilizing Cone Calorimeter Data with Theory

To determine the thermal properties of a given material, numerous cone calorimeter tests at different heat fluxes ranging from 0 to 90 kW/m^2 need to be conducted. (Note: This heat flux range was used by Hopkins and Quintiere in their study, but is only a recommendation not a requirement. As long as there is data from various heat fluxes, the method developed by Hopkins and Quintiere can be utilized.) Prior to testing, the density and thermal diffusivity for the material are assumed to be known. Density is simply obtained from a weight measurement. During testing the mass loss rate, time to ignition and heat flux was documented. After testing a plot of the radiant heat flux versus the square root of the ignition time was created (Figure 2-1).

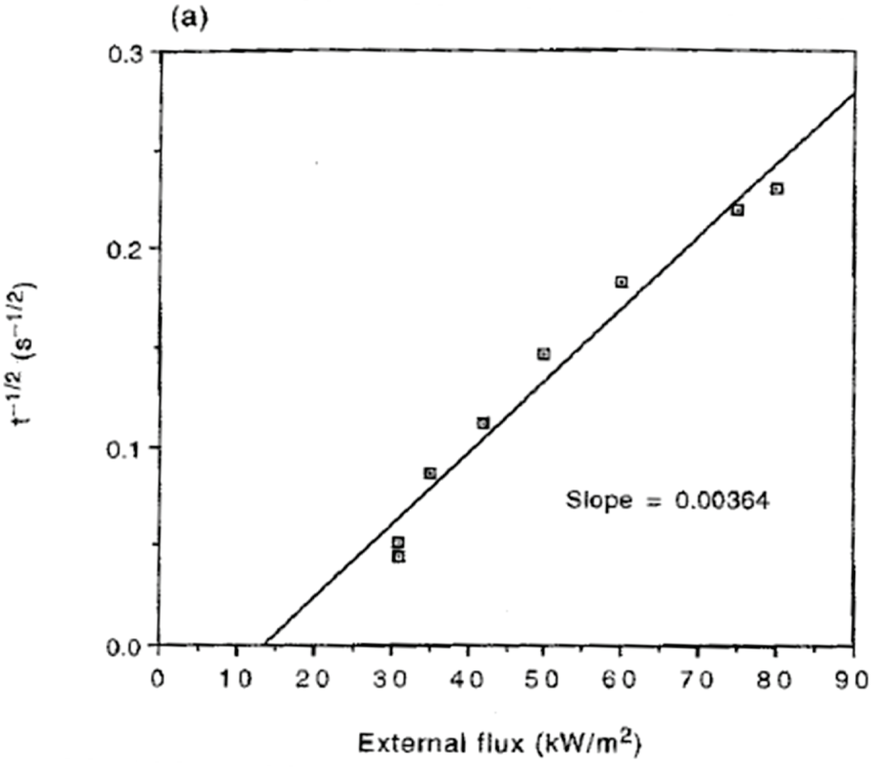


Figure 2-6 – Example of a $t^{-1/2}$ vs. Radiant Heat Flux Plot (20)

The point where the best fit line intercepted the x-axis was determined to be the critical heat flux, q''_{cr}, of the material. With this value for the critical heat flux the ignition temperature, T_{ig}, can be calculated using Equation 2-7. Using the ignition temperature and slope of the linear fit from the plot, the thermal inertia, $k\rho C_p$, can be calculated using Equations 2-8 and 2-9.

Typically the thermal inertia values were seen to be higher than thermal inertia values of the same material found in textbooks. This is due to the fact that $\Delta(k\rho C_p) \sim (\Delta T)^2$ (22). After the thermal inertia has been determined the thermal conductivity (k) and specific heat (C_p) can be calculated using the predetermined values of density and thermal diffusivity.

Finally using the cone calorimeter data the heat of gasification and the flame heat flux can be calculated by creating a plot of the radiant panel heat flux versus the mass loss rate of the material during testing (Figure 2-7).

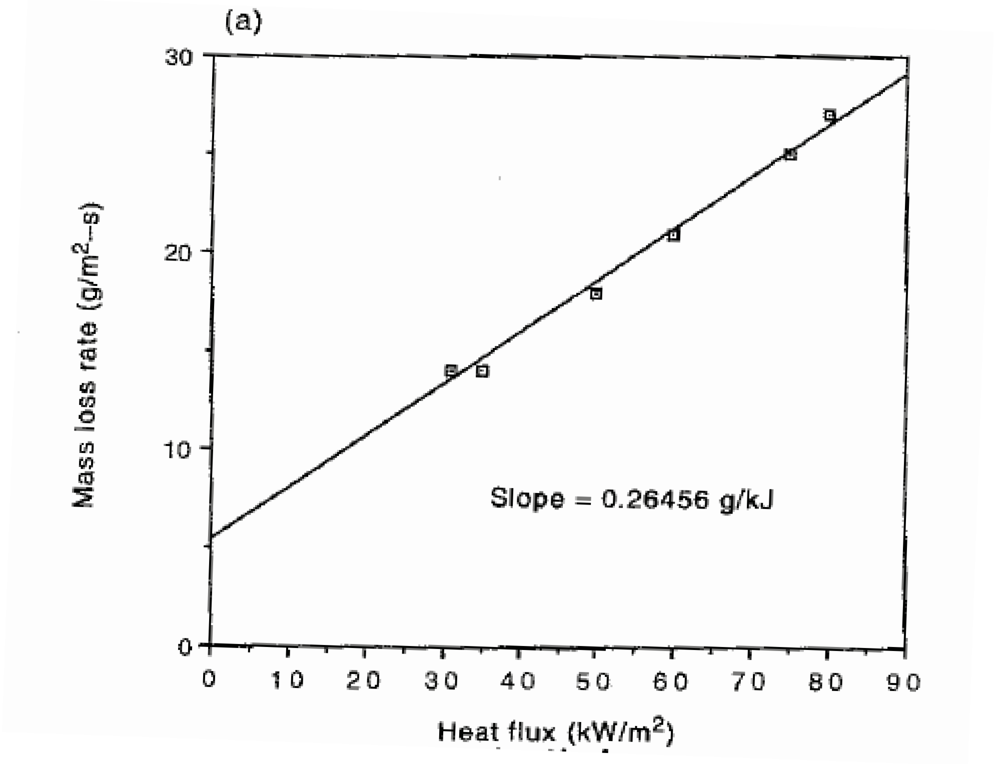


Figure 2-7 – Example of the MLR vs. Radiant Panel Heat Flux Plot (20)

The relationship between the mass loss rate and the heat of gasification and heat flux was determined by substituting the simple relationship $\dot{m}'' = \frac{\dot{q}''}{L}$ into equation 2-13.

$$\dot{m} = \left(\frac{1}{L}\right)\dot{q}_{ext} + \frac{(\dot{q}_{fl} - \epsilon\sigma T_V^4)}{L} \qquad (2\text{-}17)$$

Where,

$$Slope = \frac{1}{L} \qquad (2\text{-}18)$$

Using the Equation 2-18, the heat of gasification was calculated using the slope of the linear fit. With the heat of gasification calculated, the y-intercept of Equation 2-17 determines the flame heat flux, q_{fl}".

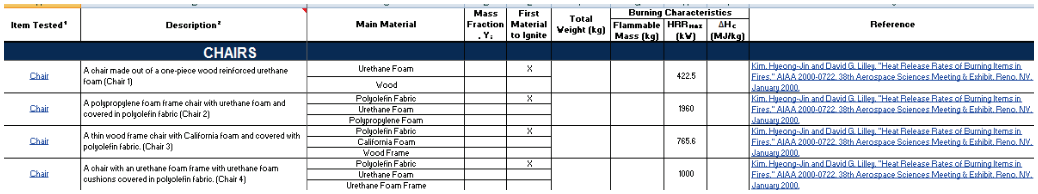
2.2.3.2 Genetic Algorithm

Genetic algorithms are valuable to use for the properties mentioned in Section 2.2.3.1 as well as other properties which are difficult to determine from cone calorimeter tests. Genetic algorithms (GAs) are used as part of an automated optimization technique which estimates material properties from cone calorimeter data. GAs are a search tool that mimics the process of natural selection (23) to determine an optimal solution to a problem with various unknown properties. A methodology developed by Chris Lautenberger, Guillermo Rein and Carlos Fernandez-Pello (24) simulates a cone calorimeter test in FDS and uses a GA to determine a set of material properties that provide the best fit between the model predictions and the experimental data.

2.3 Structure of Database / Website

The database began to take form as data from furniture calorimeter tests were compiled from different sources during the literature review. As discussed previously, only furniture calorimeter data for items typically found in households and offices were collected because this information is the one that is relevant to the objective of our DOJ sponsored study.

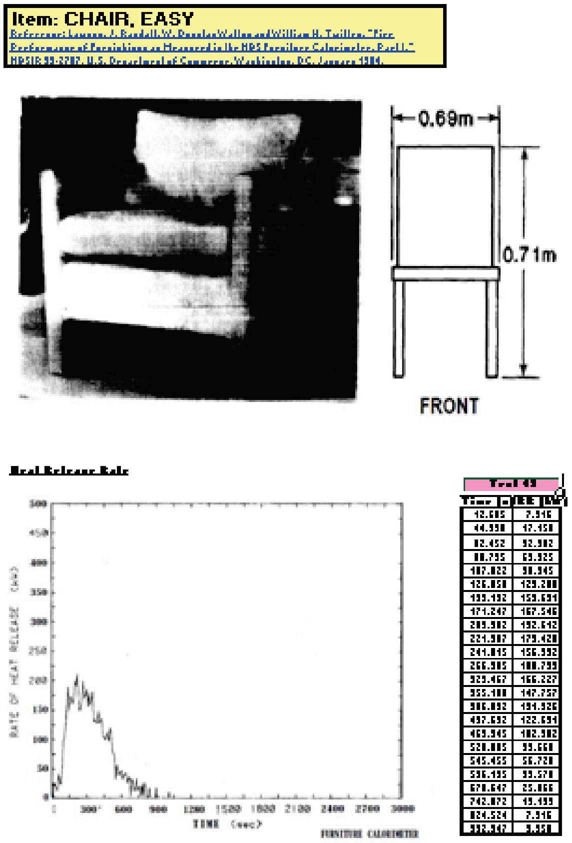
If an item was tested multiple times using a furniture calorimeter, each of these tests was considered a separate entry. Each source was thoroughly examined and all relevant information was documented. All entries included (if available) a description of the item, the main constituent materials, first material to ignite, material mass fraction, total and combustible weight, maximum HRR, heat of combustion and reference of the test. (See Figure 2-8)



						Burning Characteristics			
Item Tested[1]	Description[2]	Main Material	Mass Fraction , Y_i	First Material to Ignite	Total Weight (kg)	Flammable Mass (kg)	HRR_{max} (kW)	ΔH_c (MJ/kg)	Reference
CHAIRS									
Chair	A chair made out of a one-piece wood reinforced urethane foam (Chair 1)	Urethane Foam Wood		X			422.5		Kim, Hyeong-Jin and David G. Lilley, "Heat Release Rates of Burning Items in Fires," AIAA 2000-0722, 38th Aerospace Sciences Meeting & Exhibit, Reno, NV, January 2000.
Chair	A polypropylene foam frame chair with urethane foam and covered in polyolefin fabric (Chair 2)	Polyolefin Fabric Urethane Foam Polypropylene Foam		X			1960		Kim, Hyeong-Jin and David G. Lilley, "Heat Release Rates of Burning Items in Fires," AIAA 2000-0722, 38th Aerospace Sciences Meeting & Exhibit, Reno, NV, January 2000.
Chair	A thin wood frame chair with California foam and covered with polyolefin fabric. (Chair 3)	Polyolefin Fabric California Foam Wood Frame		X			765.6		Kim, Hyeong-Jin and David G. Lilley, "Heat Release Rates of Burning Items in Fires," AIAA 2000-0722, 38th Aerospace Sciences Meeting & Exhibit, Reno, NV, January 2000.
Chair	A chair with an urethane foam frame with urethane foam cushions covered in polyolefin fabric. (Chair 4)	Polyolefin Fabric Urethane Foam Urethane Foam Frame		X			1000		Kim, Hyeong-Jin and David G. Lilley, "Heat Release Rates of Burning Items in Fires," AIAA 2000-0722, 38th Aerospace Sciences Meeting & Exhibit, Reno, NV, January 2000.

Figure 2-8 – Screen Shot of Initial Database

The above figure also illustrates the links each entry has. The links bring the user to either the source or to a spreadsheet (Figure 2-9) specifically designed for the particular entry. This spreadsheet has compiled all data available from the source including (if available) pictures, HRR and MLR figures with data and a link to the original source.



Item: CHAIR, EASY

Figure 2-9 – Example of Single Entry Spreadsheet

The database has been populated with more than 400 hundred entries. The large volume of entries required the database to be split into sub-categories to facilitate user surfing and searches. The sub-categories were determined to be as followed: Beds, Chairs, Curtains/Draperies, Electronics, Multiple Objects, Furniture, Sofas, and Miscellaneous. All sub-categories are self explanatory except for the "Multiple Objects" category. This category catalogs all furniture calorimeter tests done on full room assemblies; be it a bedroom, office workstation or lab.

The intention of this database was for it to be centrally located and readily available to the general public. By centrally locating this database online people of different disciplines and across the world could easily access the data. To do this the database was published publicly online. With this in mind the website http://FireBID.umd.edu was designed to house the database. "FireBID" stands for "**F**ire **B**urning **I**tem **D**atabase".

This website provides visitors with background information about the research (Figure 2-10), valuable links, and most importantly the database.

BACKGROUND

The Department of Fire Protection Engineering at the University of Maryland College Park (UMCP) is working in partnership with the National Center for Forensic Science (NCFS) of the University of Central Florida (UCF) to create a Burning Item Database. This effort is being funded by the National Institute of Justice (NIJ) under contract 2008-DN-BX-K167.

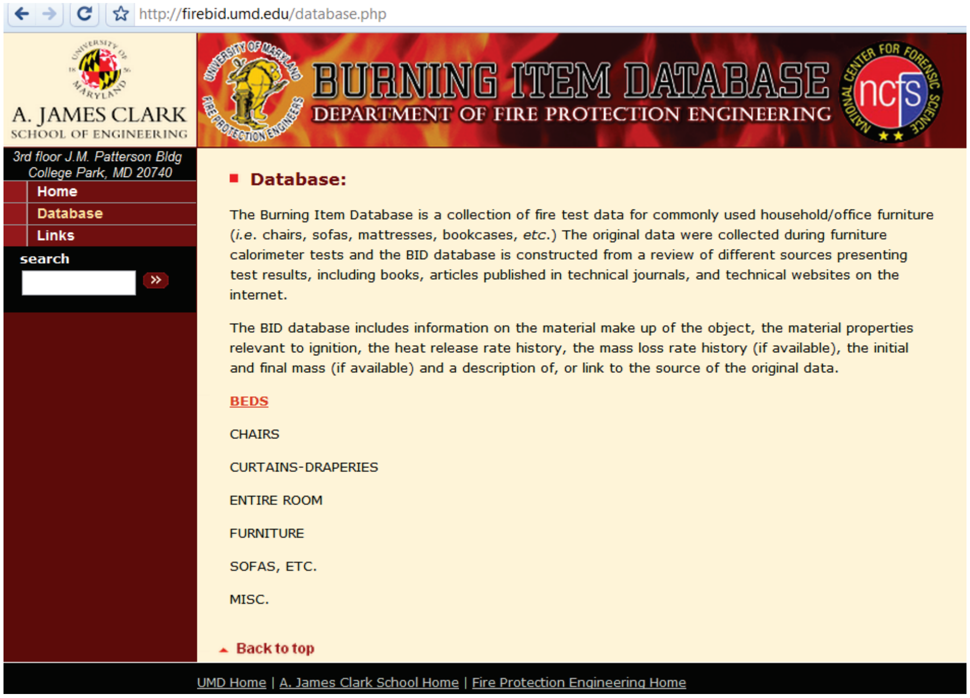
PURPOSE

The purpose of the Burning Item Database (BID) is to provide a central location to describe the burning characteristics of common household/office items. Having this information in a central location will facilitate sharing data and knowledge with the rest of the fire research and engineering

Figure 2-10 – Screenshot of FireBID.umd.edu

The online database was split up into sub-categories as discussed above. Each sub-category link (Figure 2-11) brings the user to the respective sub-database. Once in the sub-database (Figure 2-12) the visitor can easily peruse each entry and determine if any is pertinent to the data he/she needs.

In the future a search and sort function will be added to the database online and hopefully users could be able to add addition information of tests not included in the database. This database will be beneficial to all fire related disciplines because the information is readily available and encompasses a variety of information.



■ **Database:**

The Burning Item Database is a collection of fire test data for commonly used household/office furniture (*i.e.* chairs, sofas, mattresses, bookcases, *etc.*) The original data were collected during furniture calorimeter tests and the BID database is constructed from a review of different sources presenting test results, including books, articles published in technical journals, and technical websites on the internet.

The BID database includes information on the material make up of the object, the material properties relevant to ignition, the heat release rate history, the mass loss rate history (if available), the initial and final mass (if available) and a description of, or link to the source of the original data.

BEDS

CHAIRS

CURTAINS-DRAPERIES

ENTIRE ROOM

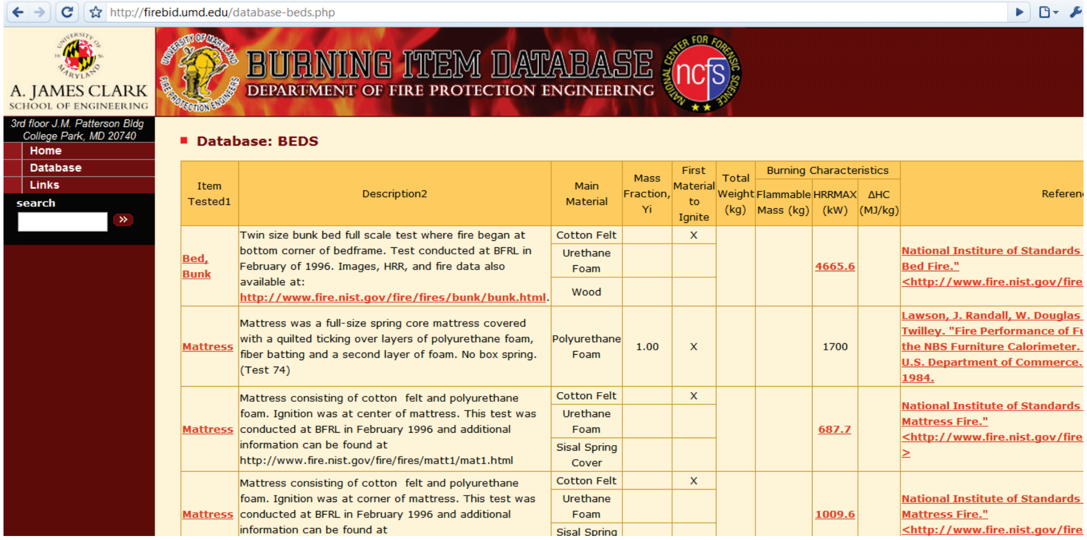
FURNITURE

SOFAS, ETC.

MISC.

Back to top

Figure 2-11 – Screenshot of Sub-Categories of Database on FireBID.umd.edu



■ Database: BEDS

Item Tested1	Description2	Main Material	Mass Fraction, Yi	First Material to Ignite	Total Weight (kg)	Burning Characteristics			Referen
						Flammable Mass (kg)	HRRMAX (kW)	ΔHC (MJ/kg)	
Bed, Bunk	Twin size bunk bed full scale test where fire began at bottom corner of bedframe. Test conducted at BFRL in February of 1996. Images, HRR, and fire data also available at: http://www.fire.nist.gov/fire/fires/bunk/bunk.html.	Cotton Felt		X			4665.6		National Institute of Standards Bed Fire." <http://www.fire.nist.gov/fire
		Urethane Foam							
		Wood							
Mattress	Mattress was a full-size spring core mattress covered with a quilted ticking over layers of polyurethane foam, fiber batting and a second layer of foam. No box spring. (Test 74)	Polyurethane Foam	1.00	X			1700		Lawson, J. Randall, W. Douglas Twilley. "Fire Performance of Fu the NBS Furniture Calorimeter. U.S. Department of Commerce. 1984.
Mattress	Mattress consisting of cotton felt and polyurethane foam. Ignition was at center of mattress. This test was conducted at BFRL in February 1996 and additional information can be found at http://www.fire.nist.gov/fire/fires/matt1/mat1.html	Cotton Felt		X			687.7		National Institute of Standards Mattress Fire." <http://www.fire.nist.gov/fire >
		Urethane Foam							
		Sisal Spring Cover							
Mattress	Mattress consisting of cotton felt and polyurethane foam. Ignition was at corner of mattress. This test was conducted at BFRL in February 1996 and additional information can be found at	Cotton Felt		X			1009.6		National Institute of Standards Mattress Fire." <http://www.fire.nist.gov/fire
		Urethane Foam							
		Sisal Spring							

Figure 2-12 – Screenshot of "Beds" Sub-Category on FireBID.umd.edu

3 FDS Simulations

Fire simulations have become more prevalent in the fire community because they are cost effective, easy to setup and run, and most importantly accurate within a certain domain of application. The fire model Fire Dynamics Simulator (FDS) created by the National Institute of Standards and Technology (NIST) in 2000 is one of the most popular simulations used by the fire community since it is free and readily available online (7).

FDS is a computational fluid dynamics (CFD) model of fire-driven fluid flow. FDS focuses on the smoke and heat transport from fires by numerically solving a form of the Navier-Stokes equations used for low-speed, thermally driven flows (7). FDS is a Fortran based program and reads input parameters from a text file, computes a numerical solution from the governing equation and writes user specified output data to files (25). Thus, FDS requires the user to be knowledgeable in basic fire dynamics and to have an idea of what to expect for results.

In addition, FDS is packaged with a visualization program, Smokeview (SMV) which displays the simulation output. Smokeview allows users as well as people unfamiliar with fire behavior to visualize the fire flows which are expected from a fire source in a specified environment. Both FDS and SMV require refinement to accurately predict complex arrangements and are continuously updated as the field progresses.

3.1 Objective

Refining of FDS is ongoing and is necessary for it to become more accurate for complex simulations, be it complex enclosure geometry, complex fuel source or a complex material. Defining the fuel source thermal properties (*i.e.* k, ρ, C_p, and MLR) accurately is important to obtain accurate simulation results. Some studies (9) have focused on how to incorporate furniture calorimeter data which accurately define the fire behavior of the material into FDS in order for accurate simulation results to be calculated.

Young's study illustrated one such downfall when using furniture calorimeter data in FDS to predict the fire behavior of an object in an enclosure.

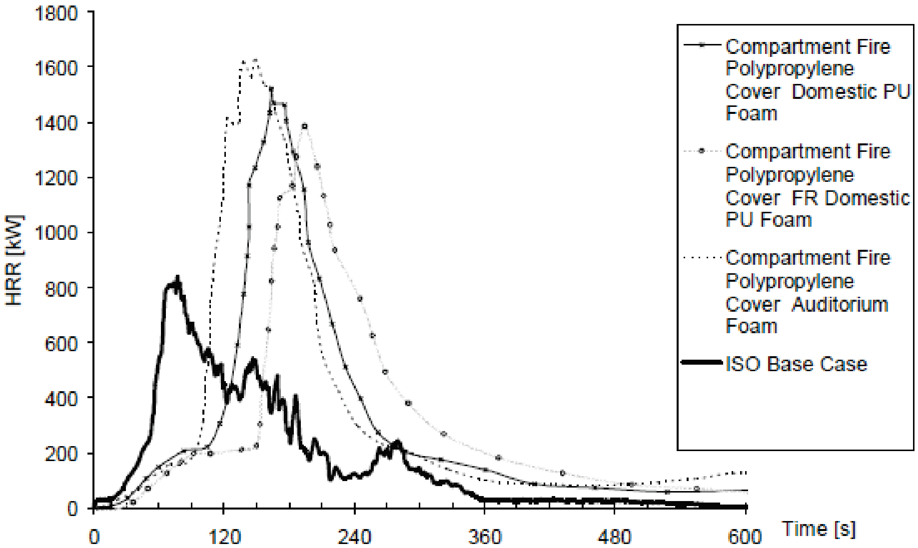


Figure 3-1 – HRR Comparison of Enclosure Simulation vs. Experiment (Young)

Figure 3-1 illustrates the resulting discrepancy between the FDS HRR curve and the experimental enclosure HRR curve. The ISO Base Case is the simulated HRR results, while the other three curves are from Girgis experimental data. The MLR calculated from Denize's furniture calorimeter data was prescribed in the ISO Base Case. Young was trying to determine how well FDS calculated enclosure effects if furniture calorimeter data was prescribed. The simulation results show a maximum HRR which is about 2 times less than the experimental results. Thus FDS is currently incapable of properly calculating the enclosure re-radiation effects when furniture calorimeter data is specified in the input file. A proposed solution investigated by this research is to modify FDS to include a simple pyrolysis model which corrects the furniture calorimeter data to take into account the effects of the enclosure.

To explore this solution a literature review was conducted to determine what information is available. It was foreseen this research would require both furniture and room calorimeter data of the same object. In addition, a method (*aka simple pyrolysis model*) needed to be identified to determine how the source code of FDS was to be modified. Three types of information were collected from the literature review: furniture calorimeter data, room calorimeter data and information pertaining to a simple pyrolysis model.

The literature review provided a significant amount of information with regards to furniture calorimeter data and room calorimeter data. Three studies done at the University of Canterbury by Parkes, Girgis and Denize were designated as the most important cases to use for this research. In addition, a simple pyrolysis model developed by J. Quintiere was identified as the best method to incorporate into FDS's source code.

In Chapters 4 and 5 the preliminary FDS simulations and the modified FDS simulations will be discussed further. The following section will delve into further detail of the literature review and the most useful sources pertaining to this research.

3.2 Literature Review

Sources describing furniture calorimeter test data, room calorimeter data or a simple pyrolysis model were most valuable to this research. A large amount of furniture calorimeter data needed to be found to populate the database discussed in Chapter 2. The Database chapter also goes into further detail into which sources were most valuable with regards to furniture calorimeter data and will not be discussed in this section.

Although furniture calorimeter data were valuable, finding sources which had both furniture and room calorimeter data for the same object was necessary. Having both furniture and room calorimeter data would form the basis of the validation tests described in Chapter 5. The University of Canterbury was found to have had conducted various studies where the furniture and room calorimeter data of an object were available. These studies investigated either the effects of the location of the fuel source and size of the ventilation opening on the burning rate (26) of the fuel or how the burning rate of an upholstered chair is affected by different types of fabric and/or foam (3), (2).

Numerous sources provided furniture and room calorimeter data, but finding sources detailing the development of a simple pyrolysis model were scarce. Although many sources found usually stated estimation of the fire behavior of an object in an enclosure from furniture calorimeter was rather complex and had not yet been developed. A simple pyrolysis model developed by Quintiere (1) was found and deemed acceptable to use for this research. Quintiere's pyrolysis model predicts an object's enclosure mass loss rate (MLR) by using the MLR from furniture calorimeter data and taking into account the enclosure effects on the fuel source (*i.e.* the positive effect of the thermal feedback of the smoke layer and the negative effect of the air vitiation).

3.2.1 Parkes' Research

Parkes (26) conducted research at the University of Canterbury investigating the effects of varying the fuel location within an enclosure with varying vent size on the burning behavior of the fuel. Parkes constructed an enclosure (2.4m wide by 3.6m long by 1.2m high) with varying vent sizes (*open, soffit, and* door). A heptane pool fire (0.2m wide by 0.2m long by 0.05m high) was located at three varying locations (*front, center* *and back*). A total of 10 experiments were conducted as illustrated in Table 3-1. Note Test Number 10 was the furniture calorimeter test conducted on a pool of heptane (0.2m wide by 0.2m long by 0.05m high).

Table 3-1 – Experiments Conducted by Parkes

Test Number	Fire Location	Vent Size
1	Front	Open
2	Front	Soffit
3	Front	Door
4	Center	Open
5	Center	Soffit
6	Center	Door
7	Rear	Open
8	Rear	Soffit
9	Rear	Door
10	FREE BURN	

Figure 3-2 illustrates the room used for Parkes' experiments and also provides the locations of the pan and vents for all experiments.

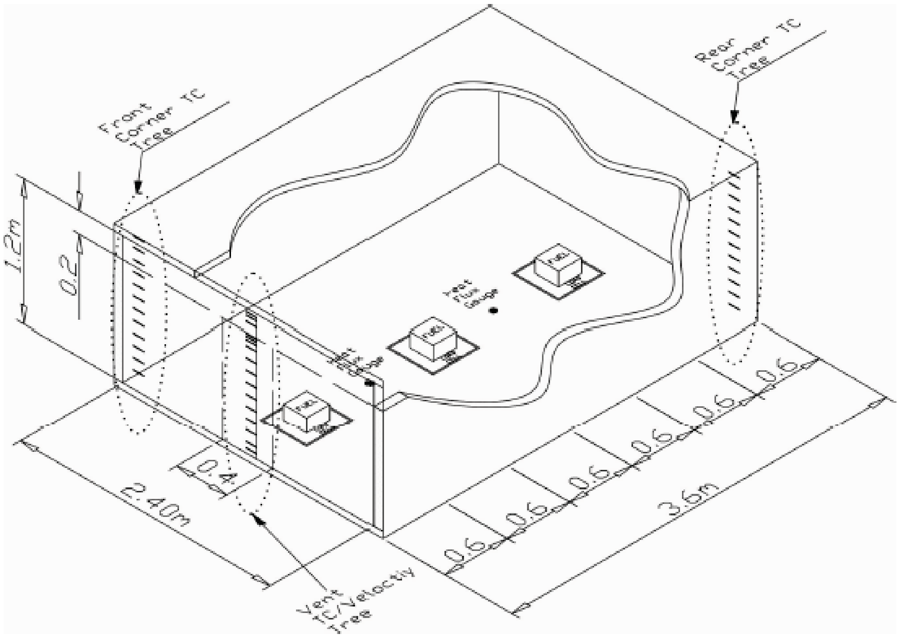


Figure 3-2 – Setup of Room Calorimeter Experiments (Parkes)

Parkes' research was valuable because it includes both furniture and room calorimeter data for a simple fuel. These data were easily manipulated to use in two types of FDS simulations: preliminary simulations using room calorimeter data (Section 4.1) and simulations using furniture calorimeter data with Quintiere's pyrolysis model (Section 5.2.1).

3.2.2 Denize's Research

The second valuable research from the University of Canterbury was done by Denize. Denize studied the fire behavior of chairs with varying types of polyurethane foam and fabrics (*i.e.* 100% polypropylene or 100% wool) in a furniture calorimeter.

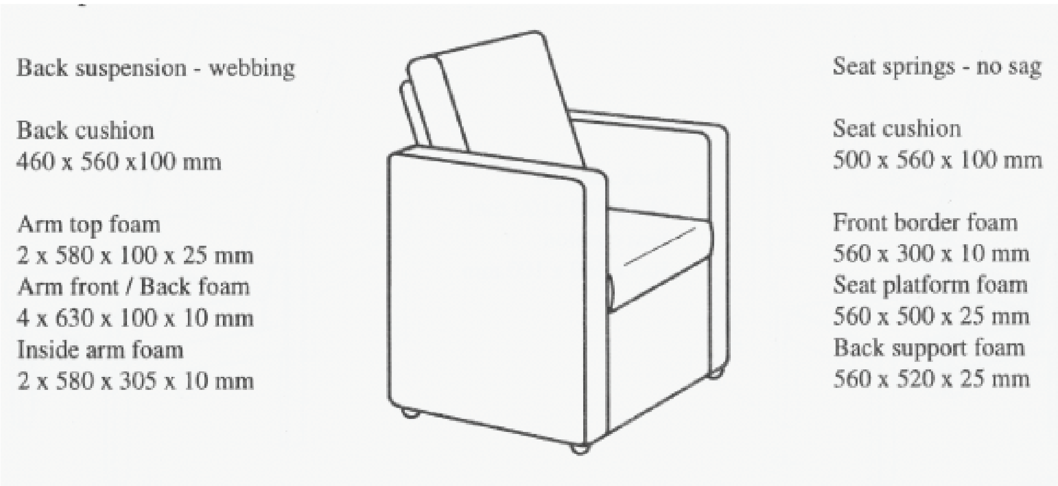


Figure 3-3 – Example of Chair Used for Girgis & Denize Experiments

These chairs (Figure 3-3) were similar to one of the chairs studied in the CBUF research (15) and were specially constructed for Denize's research. Denize tested ten types of chairs as illustrated in Table 3-2. The letter in the chair code refers to the type of foam, where the number refers to the type of fabric used.

Table 3-2 – Chairs Tested in Denize's Research

Experiment Number	Chair Code
1	G-21
2	H-21
3	I-21
4	J-21
5	L-21
6	G-22
7	H-22
8	I-22
9	J-22
10	L-22

Denize also conducted cone calorimeter tests on the different types of foam, fabric and foam/fabric combinations that were used in the furniture calorimeter tests. The cone calorimeter measurements were done at a heat flux of 35 kW/m^2.

The most valuable information from Denize's research was the furniture calorimeter results for the chairs which were tested in an enclosure in the work down by Girgis (Section 3.2.3). These furniture calorimeter data were used in simulations where Quintiere's pyrolysis model was incorporated into FDS's source code. Section 5.2.2 goes into further detail on how this data was incorporated into the simulations.

3.2.3 Girgis' Research

The third study from the University of Canterbury was conducted by Girgis (2). Girgis researched how varying the foam affected the burning behavior of a specially made upholstered chair being tested in an ISO 9705 enclosure (27). The chairs constructed (Figure 3-3) for this research were similar to one of the chairs used in the CBUF (15) research and to 5 of the chairs studied in Denize's research (Section 3.2.2). Each chair was constructed from a wooden frame, a type of polyurethane foam covered with a 100% polypropylene fabric. The chairs only varied by the type of foam each was constructed from. The following table details the chairs tested in Girgis' research. It should be noted that the only chair which was not also tested by Denize is chair K-21.

Table 3-3 – Chairs Tested in Girgis' Research

Experiment Number	Chair Code
1	G-21
2	H-21
3	I-21
4	J-21
5	*K-21*
6	L-21

Girgis also constructed an enclosure to the ISO 9705 specifications. Thermocouples and heat flux gauges were placed at specific locations in the enclosure. For each test the chair was located in the corner of the enclosure as illustrated in Figure 3-4. The 'Gas burner' in the figure corresponds to the placement of the chair during Girgis' experiments. Oxygen consumption analysis took place as the smoke exited the room and entered the exhaust hood allowing the HRR of the object to be calculated.

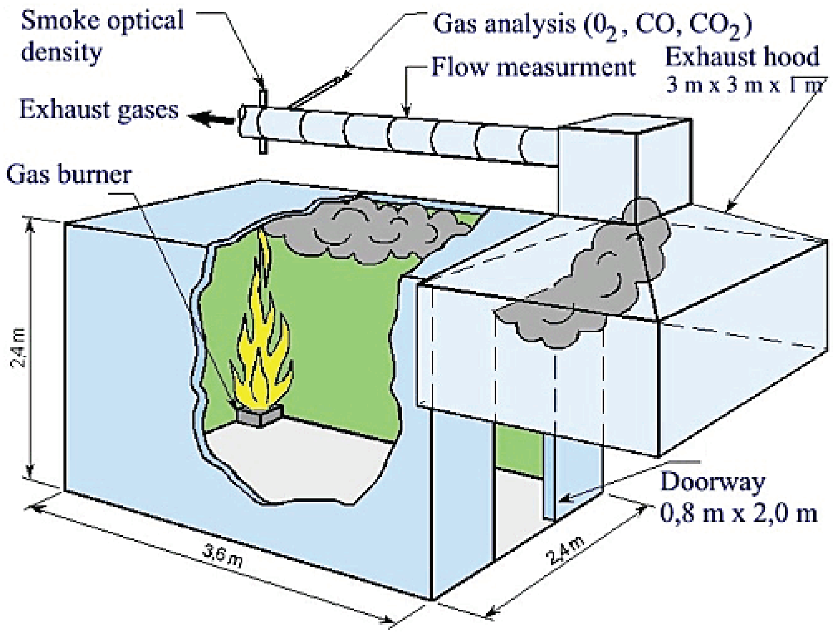


Figure 3-4 – Setup of the ISO 9705 Test

Girgis used his results to compare how the fire dynamics was affected by the varying foam types. Girgis also briefly compared the results he obtained to Denize's results. He found his resulting heat release rates were much higher than the results found by Denize (3). Girgis' as well as Denize's experimental data was used in this research and will be discussed further in Chapters 4 and 5.

3.2.4 Quintiere's Pyrolysis Model

It is simple to measure the HRR of an object in a room calorimeter test through the oxygen consumption method. Unfortunately these results are configuration-specific. These data cannot be used to estimate the burning characteristics of the same object in a completely different enclosure size and geometry because of the enclosure effects on the fire dynamics.

Furniture calorimeter tests provide the burning characteristics of an object for a free-burn like configuration and do not take into account the enclosure effects. An object burning in an enclosure is affected by both the oxygen concentration and emissive power of the smoke layer and walls. Typically in an enclosure with restricted ventilation the oxygen concentration decreases as the fire progresses. Oxygen depletion has a negative impact on the fuel mass loss rate. Another effect associated with the accumulation of hot gases in the fire room. This build up of hot gases at the ceiling causes an upper layer to develop and descend in the room. The ceiling and wall temperatures increase as the upper layer grows and descends towards the floor. Both the upper layer and the walls provide additional heat feedback to the fuel source. Heat feedback from the smoke layer has a positive impact on the fuel mass loss rate

Figure 3-5 illustrates the heat transfer occurring at the fuel source when it is being burning in an enclosure. The fuel source receives a heat flux, $\dot{q}''_{fl}$, from the flame (due to bothradiative and convective heat transfer). In addition, the fuel source receives a heat flux $\dot{q}''_{UL}$ from the smoke layer (due to radiative heat transfer).

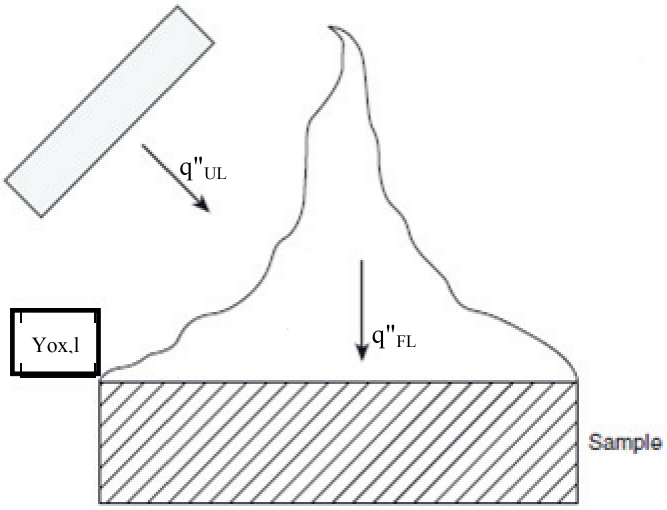


Figure 3-5 – Diagram of Heat Transfer in Enclosure Fire (11)

As discussed earlier, furniture calorimeter data can be used to simulate a fire in various enclosure configurations if the data are manipulated to include enclosure effects. A pyrolysis model, such as the model developed by J. Quintiere (1), provide methodology to correct furniture calorimeter data to include enclosure effects.

Quintiere's model (Equation 3-1) takes furniture calorimeter MLR data, $\dot{m}''_{\infty}$, and manipulates it to account for the enclosure effects.

$$\dot{m}''_F = \dot{m}''_{\infty}\left(\frac{Y_{ox,l}}{Y_{ox,o}}\right) + \frac{\dot{q}''_{UL}}{L_g} \qquad (3\text{-}1)$$

$$\dot{q}''_{UL} = \dot{q}''_{rad,in} - \dot{q}''_{fl} \qquad (3\text{-}2)$$

where,

$Y_{ox,o} = 0.23$
$Y_{ox,l}$ – Oxygen concentration in the vicinity of the fuel source
L_g – Heat of gasification of fuel
$\dot{q}''_{UL}$ – Irradiation from smoke layer and walls [kW]
$\dot{q}''_{rad,in}$ – Total irradiation [kW]
$\dot{q}''_{fl}$ – Flame heat flux [kW] – varies depending on fuel
$\dot{m}''_{\infty}$ - Mass loss rate per unit area from furniture calorimeter test [kg/m^2/s]
$\dot{m}_F$ - Mass loss rate per unit area in enclosure configuration [kg/ s]

These effects include the positive effect of the thermal feedback of the smoke layer,$\dot{q}''_{UL}$, and the negative effect of the reduced oxygen levels when the enclosure is under-ventilated, $\left(\frac{Y_{ox,l}}{Y_{ox,o}}\right)$. The $Y_{ox,l}$ value is determined close to the fuel surface as shown in Figure 3-5. The upper layer effect onto the fuel source is shown in Equation 3-2. The irradiation from the smoke layer is approximated as the total incoming ration heat flux, $\dot{q}''_{rad,in}$, minus the flame heat flux, $\dot{q}''_{fl}$. This expression can be refined but is considered here as a suitable expression for a first step. Note that the flame heat flux is removed from the total heat flux, $\dot{q}''_{rad,in}$, because it is already taken into account in the furniture calorimeter data, $\dot{m}''_{\infty}$.

Although room calorimeter data give the best burning characteristics of an object in an enclosure, it is not practical to conduct room calorimeter tests for multiple enclosures. By incorporating Quintiere's pyrolysis model into the source code of FDS, the burning characteristics of an object in any given enclosure could be described using furniture calorimeter MLR data.

Incorporating this simple pyrolysis model into the source code of FDS allows for furniture calorimeter data to be used in the FDS input files and results in simulation results which compare well to room calorimeter results. This pyrolysis model was incorporated into FDS. Exactly how this model is implemented is discussed in further detail in Section 5.1.1.

3.2.5 Conclusion

As discussed in previous sections, three studies conducted at the University of Canterbury were valuable to this research. Parkes' experiments provided both furniture and room calorimeter data for ten experiments done with heptane. Each of these experiments was simulated using the current version of FDS (5.3.1) and a modified version of FDS which incorporates Quintiere's pyrolysis model.

Similarly, the work done by Denize and Girgis provided furniture and room calorimeter results, respectively, for 5 similar upholstered chairs. Each of these experiments was also simulated using the current version of FDS and a modified version of FDS.

Parkes' data is valuable because he used a simple fuel which can easily be defined in FDS, whereas defining the upholstered chair used in Denize's and Girgis' experiments is much more difficult to define in FDS. Thus the simulation results from Parkes' cases will be more valuable since the fuel is well-defined.

4 Preliminary FDS Simulations

Prior to modifying FDS to include the Quintiere's pyrolysis model, preliminary simulations were done to validate the FDS input file created for each experiment. These simulations use the current version of FDS which at the time of this research was 5.3.1 and the data from the room calorimeter tests.

Each simulation simulated the exact setup used in the experiments done by Parkes or Girgis (See Appendix A or Appendix B for input files, respectively). These simulations were run on the University of Maryland's Linux Cluster called *Deepthought. Deepthought* is a high performance computing cluster corresponding to a 1,104 processors computing system built with 220 Dell PowerEdge servers, each equipped with dual-processor, dual-core or quad-core, 2.33 Gigahertz or higher, Intel Xeon technology. The cluster is also supported by a 5 Terabyte storage system.

A descriptive comparison was done between the room calorimeter results and the simulation results to validate the setup of the environment in the input file. Further discussion of this process is found in Sections 4.1 and 4.2.

4.1 Parkes' Enclosure Experiments

As discussed earlier, Parkes conducted a total of 10 experiments to determine how the burning rate of a pool of heptane was affected by the location of the fuel and the size of the ventilation of the room. Nine of these experiments were room calorimeter tests while the last experiment was a furniture calorimeter test.

In his paper Parkes published the data for 7 of these 9 room calorimeter tests. Thus only seven simulations were run during this phase. Table 4-1 shows which tests were simulated using the room calorimeter data.

Table 4-1 – Experiment Results Published by Parkes

Test Number	Fire Location	Vent Size
3	Front	Door
4	Center	Open
5	Center	Soffit
6	Center	Door
7	Rear	Open
8	Rear	Soffit
9	Rear	Door

Prior to running these simulations the FDS input files (Appendix A) needed to be created. The enclosure used during experimentation as well as a small open area outside the room was defined as the simulation area (Figure 4-1).

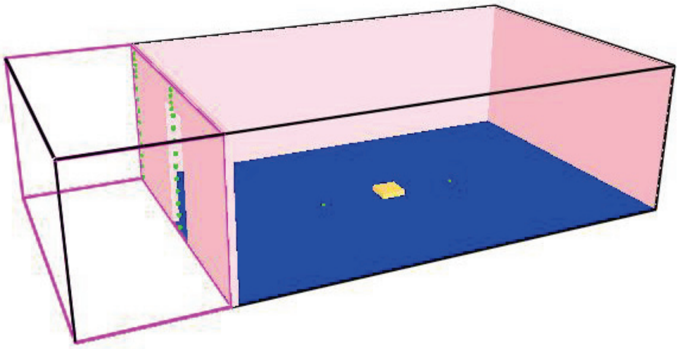


Figure 4-1 – FDS Set-up of Enclosure Used by Parkes (Center – Door)

The walls, ceiling, floor and fuel were each defined by their thermal and mechanical properties. Each simulation had a unique heat release rate per unit area (HRRPUA) which was determined by digitizing Parkes' plots in "Plot Digitizer" (28). The simulations were then run on the University of Maryland's cluster *Deepthought.*

The simulation results were compiled and compared to the data Parkes had published in his paper. Parkes published results for the total heat release rate, temperature profile, temperature history, heat flux, and velocity profile for these simulations. Although there were some discrepancies between experimental and simulation results overall the agreement was good.

4.1.1 Simulation Results

The seven simulations (Table 4-1) were run for the same duration (60 minutes) as Parkes' experiments. The following sections compare the simulation results to the published experimental data.

4.1.1.1 Heat Release Rate

The following three figures illustrate the simulation results versus the experimental results. The distinction between the experimental and the simulation results is the marker (*i.e.* triangle, square or diamond). The heat release was only compared for the cases where the fire was located in the center of the room because this was the only HRR data published by Parkes.

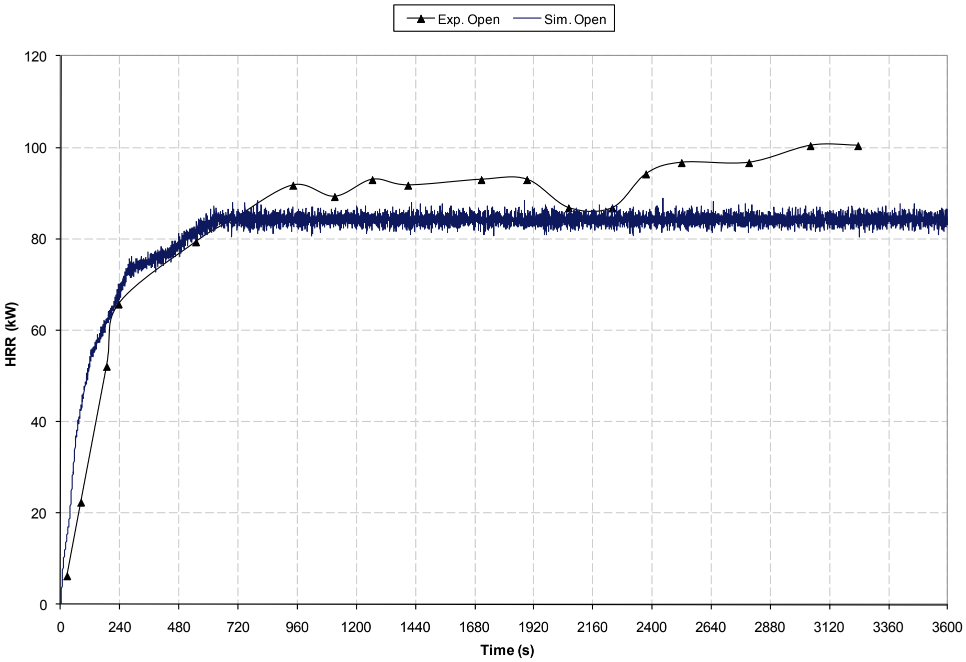


Figure 4-2- Heat Release Rate Comparison (Rear – Open)

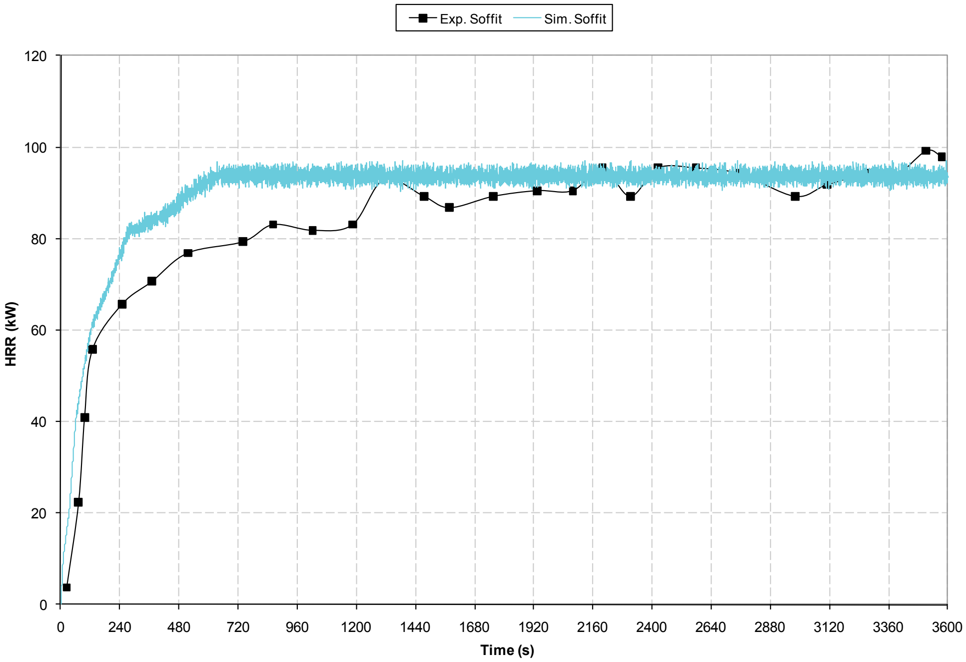


Figure 4-3 – Heat Release Rate Comparison (Rear – Soffit)

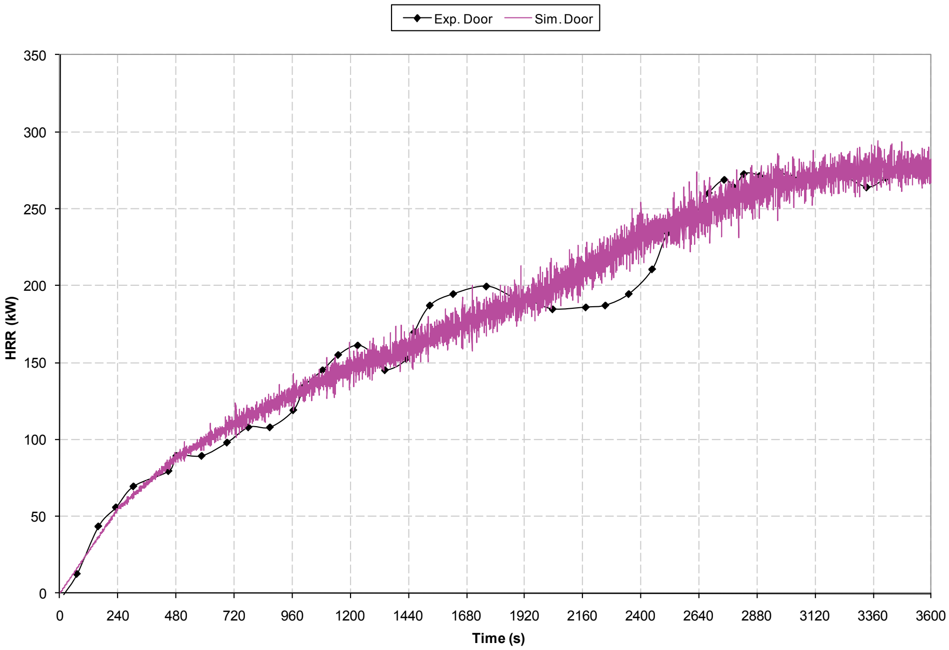


Figure 4-4 - Heat Release Rate Comparison (Rear – Door)

Figure 4-2 to Figure 4-4 show that the simulated heat release rate (HRR) fits the experimental results well. Figure 4-2 and Figure 4-3 could be adjusted slightly for a better fit, but overall the fit is good. The Center – Door simulation fits the experimental results very well and no adjustment is necessary.

4.1.1.2 Heat Flux

Parkes' experiments used two heat flux gauges located at floor level 1.2 meters and 1.8 meters from the front opening. Figure 3-2 shows the location of the heat flux gauges if needed. Parkes did not clarify if the three point average of heat flux gauge 1, heat flux gauge 2 or the average heat flux of the two gauges was used. Early simulations (not published in this report) determined Parkes measured the heat flux at Gauge 1. The simulation and experimental data from this single heat flux gauge are compared in the following figures. Again, the experimental data is designated by the line with the marker.

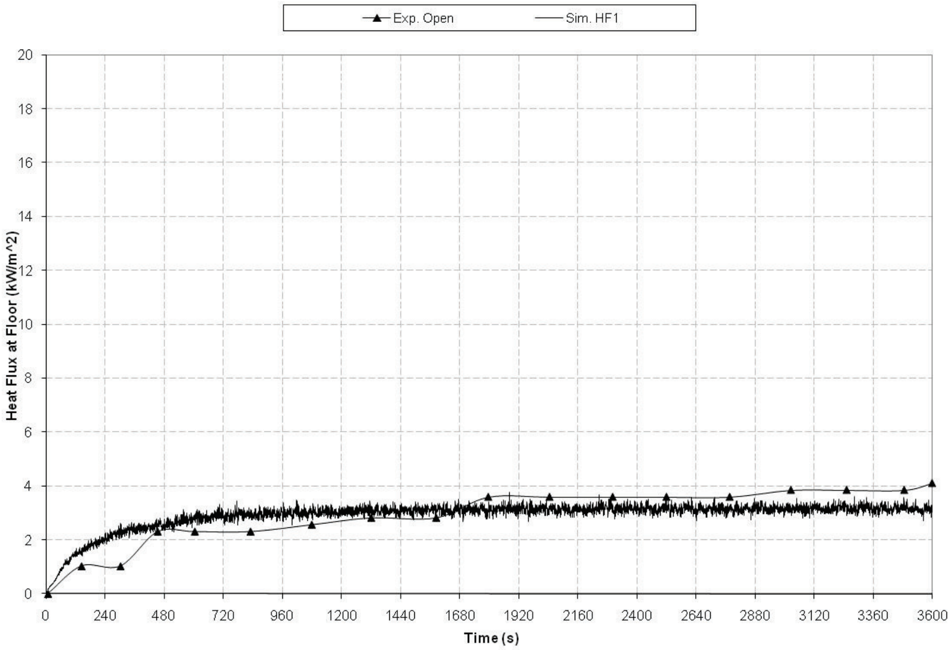


Figure 4-5 – Heat Flux Comparison (Rear – Open)

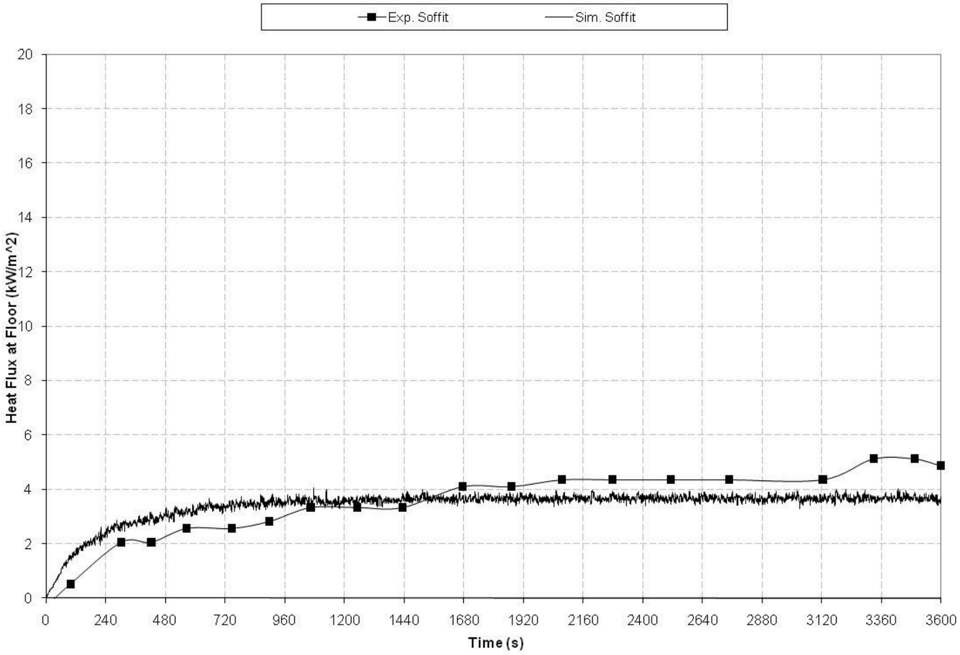


Figure 4-6 – Heat Flux Comparison (Rear – Soffit)

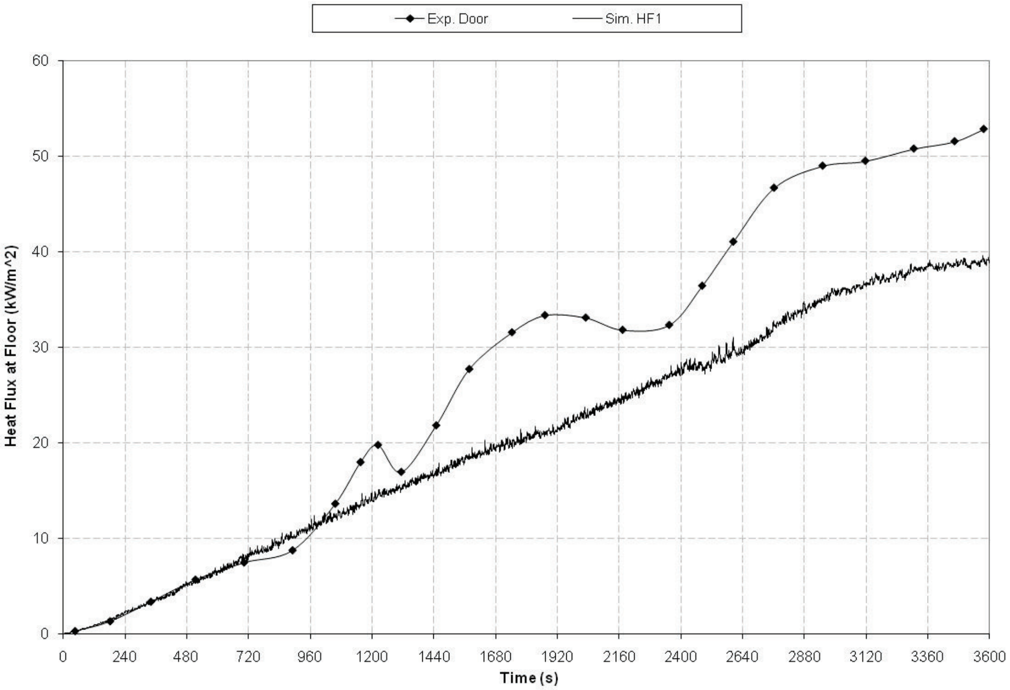


Figure 4-7 – Heat Flux Comparison (Rear – Door)

Similar to the HRR data, all heat flux data were taken from the cases where the fire was located in the center of the room. As illustrated in Figure 4-5 to Figure 4-7, Gauge 1 data from the simulation fits well with the experimental data. In all three cases, the simulated heat flux is slightly lower than the measured values. This could be due to errors in the experimental heat flux gauge or discrepancies in the HRR defined in the simulation.

4.1.1.3 Temperature History

The enclosure used in Parkes' experiments had three thermocouple trees located in two corners and at the center of the vent opening. Figure 3-2 illustrates the exact locations of the thermocouple trees. The thermocouple trees consisted of 14 thermocouples spaced 0.1 meter from one another. The thermocouple at the top of the thermocouple tree (closest to the ceiling) located in the front corner of the room was used to make comparisons.

Figure 4-8 to Figure 4-10 illustrate how well the simulation results fit with the experimental results where the fire is located in the center of the room. The simulation results tend to underestimate the temperature of the enclosure. It should be noted that the simulated temperature does behave similarly to the experimental results.

Discrepancies between the simulation and experimental results could be due to errors when digitizing the HRR plot. Not defining the heat release rate of the fuel perfectly could have resulted in the discrepancies.

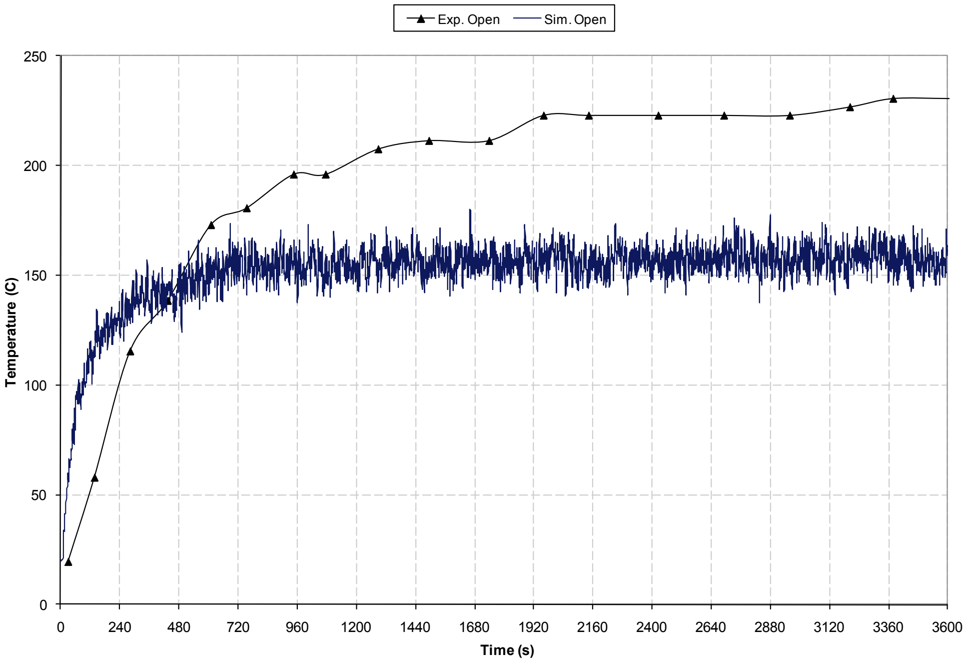


Figure 4-8 – Temperature Comparison (Rear– Open)

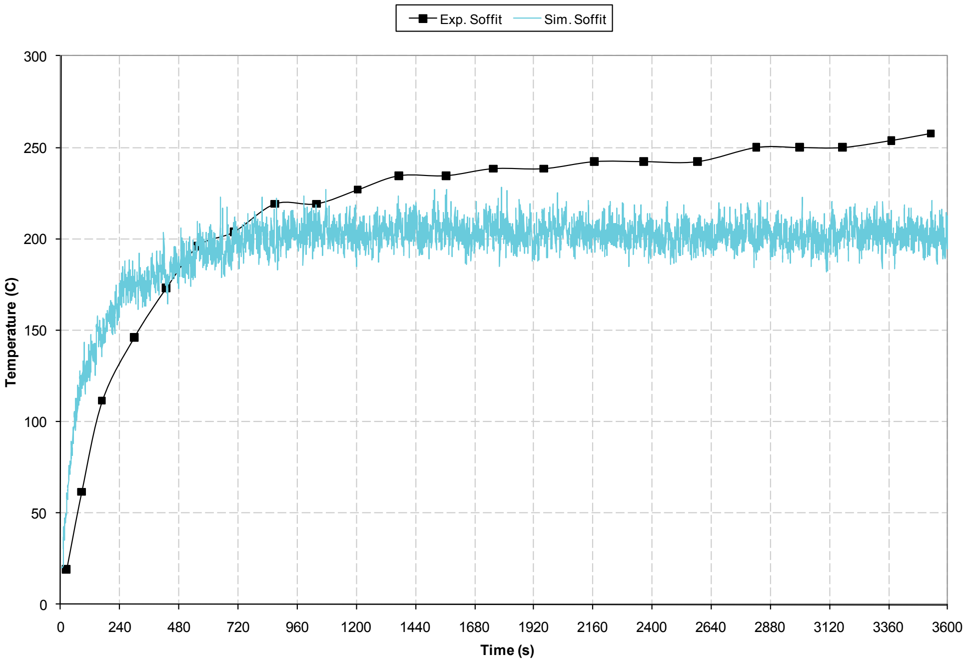


Figure 4-9 – Temperature Comparison (Rear– Soffit)

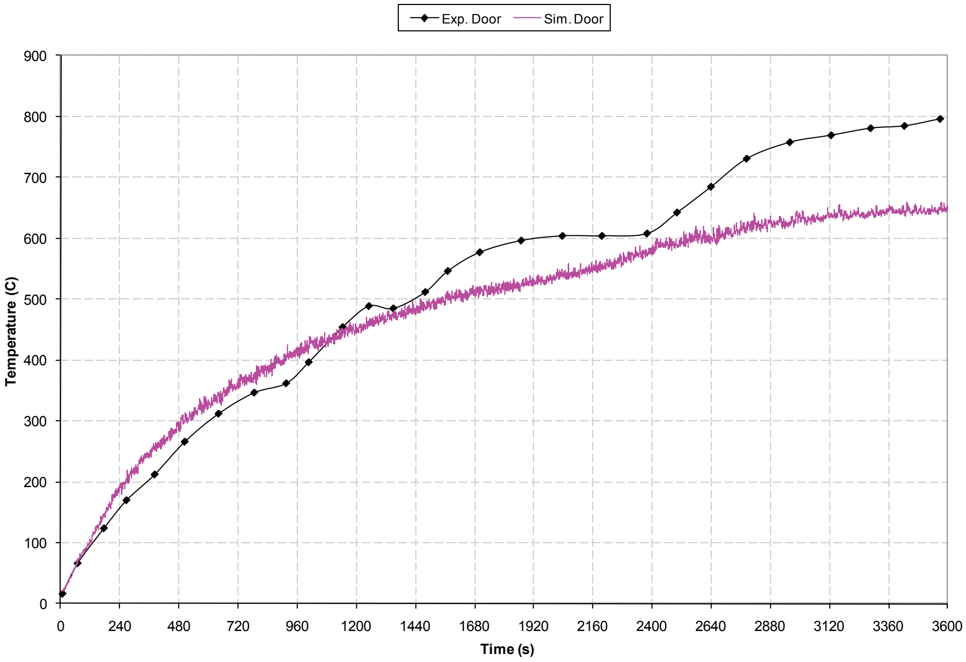


Figure 4-10 – Temperature Comparison (Rear – Door)

4.1.1.4 Temperature Profile

Unlike the previous comparisons, the temperature and velocity profiles were determined for the enclosures where the fire was located at the front or rear of the room. The vent was still varied in size (*i.e.* door, soffit or open).

The temperature profile of the enclosure at the end of the experiment (1 hour) was determined using the same thermocouple tree used in the previous section (located at the front corner of the fire room). Data from all 14 thermocouples were used to obtain the temperature profile data. The data collected from the simulation was collected every 0.5 seconds and was averaged over the last 5 data points taken to minimize any anomalies in the data. Figure 4-11 and Figure 4-12 illustrate how well the simulations predicted the temperature profile in the enclosure. Experimental data corresponds to the line with marker.

Figure 4-11 shows that the simulation fits very well with the experimental data for an enclosure where the fire is located in the rear of the room. The vent is varied from an open wall to a soffit.

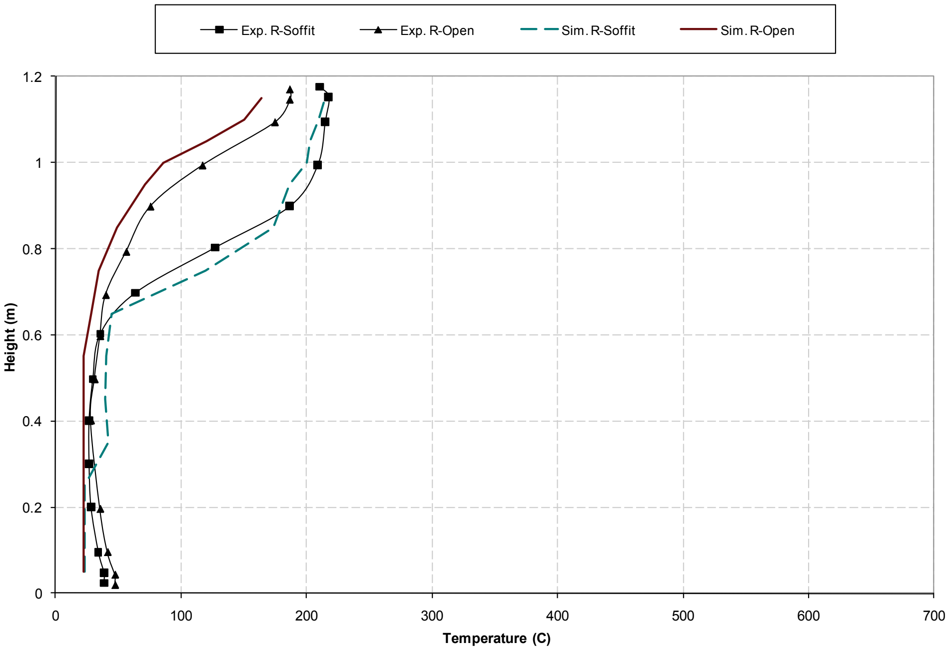


Figure 4-11 – Temperature Profile Comparison (Rear – Open/Soffit)

Figure 4-12 shows the temperature profiles for an enclosure with a door and the fire varying in location (front, center, rear*)*. The simulation results have a good fit with the experimental results. The simulation results for the Front – Door exhibits the same behavior as the experimental data, but the simulation temperature is approximately 50 ºC warmer. The simulation results for the Rear-Door and Center-Door do not fit the experimental data as well, but the simulated temperature is around the same magnitude as the experimental data.

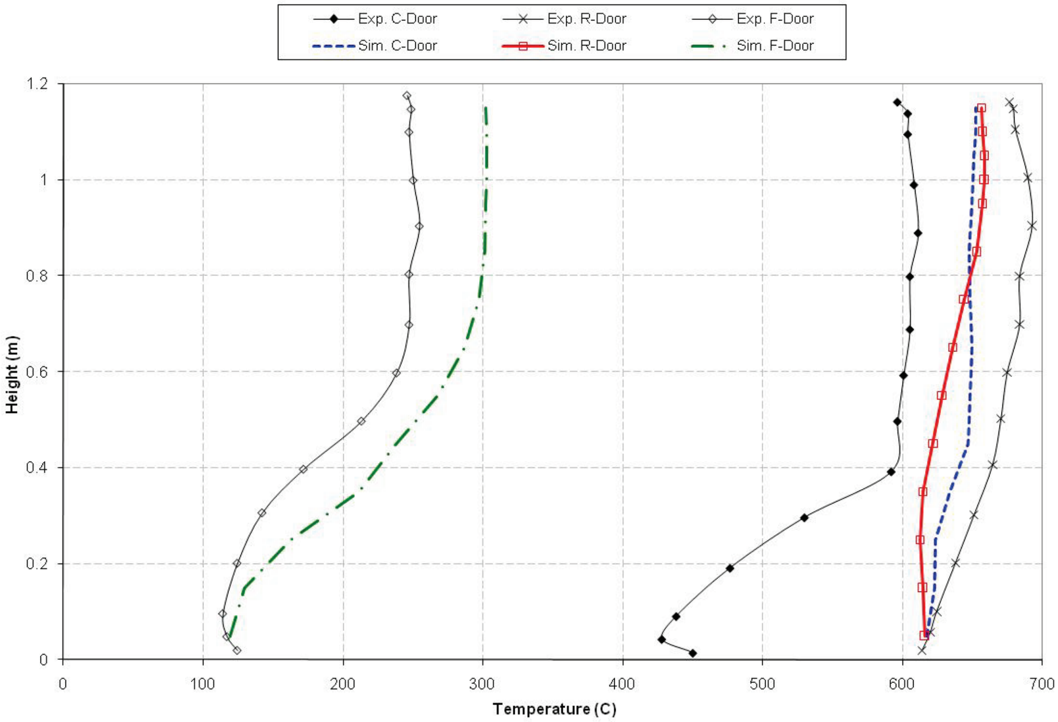


Figure 4-12 – Temperature Profile Comparison (Door)

4.1.1.5 Velocity Profile

Similar to the temperature profile data, the velocity profiles were taken after 1 hour. The measurements were taken at the center of the ventilation opening. The simulation data were collected every 0.5 seconds and were averaged over that last 30 data points collected to minimize any anomalies in the data. Figure 4-13 to Figure 4-15 present the comparison between the experimental and simulation velocity profile data. Only the u-velocity is presented below. (NOTE: Closer detail needs to be taken when examining Figure 4-15 because both experimental and simulated results use markers.)

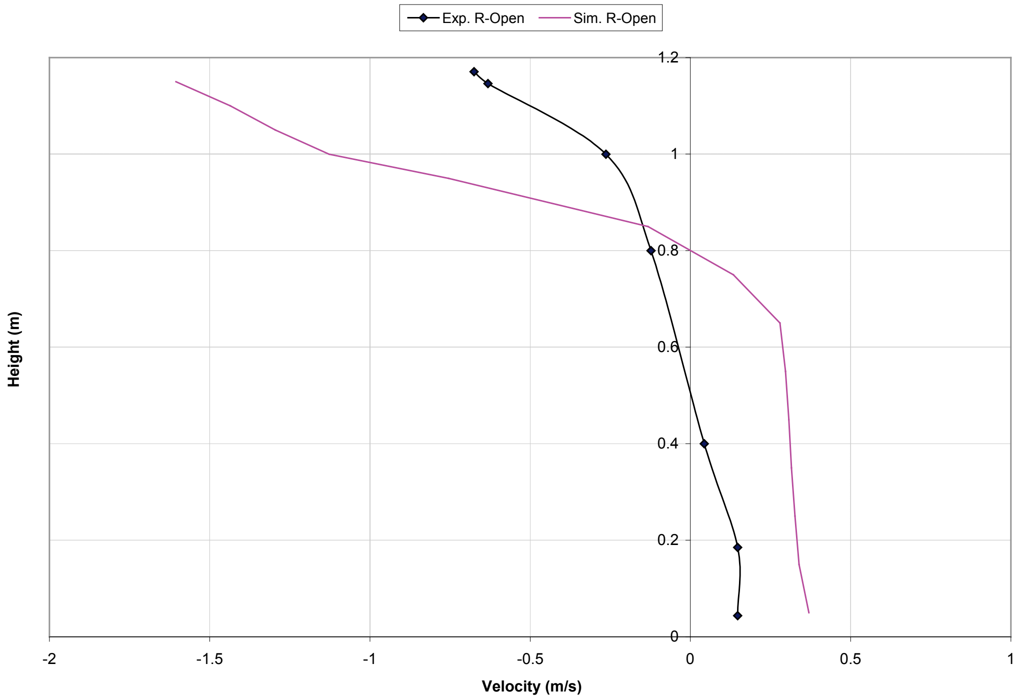


Figure 4-13 – Velocity Profile Comparison (Rear – Open)

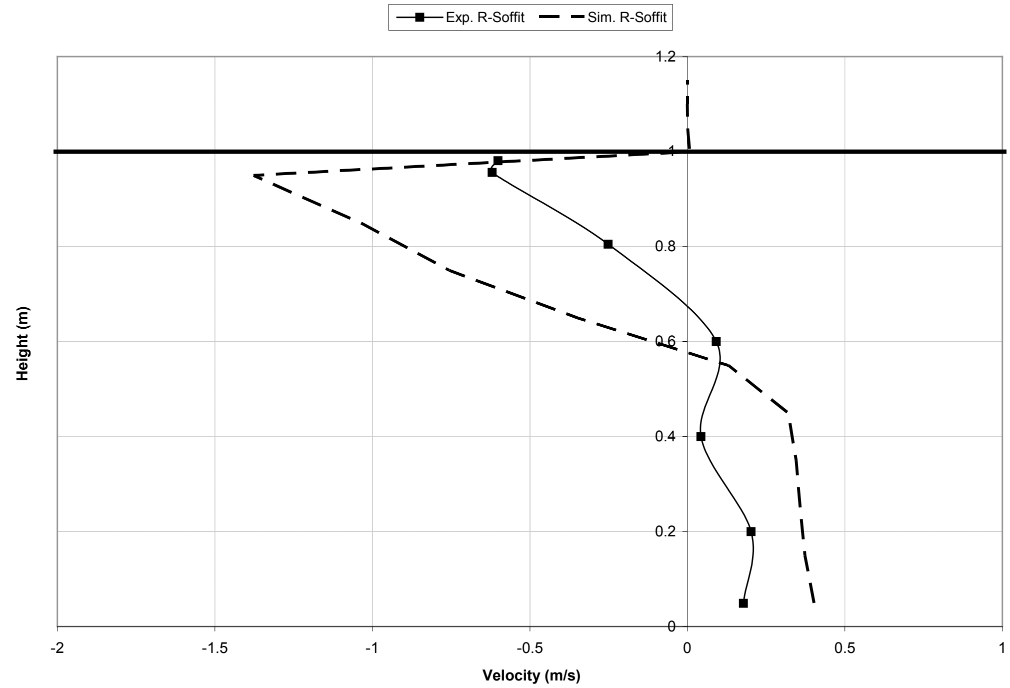


Figure 4-14 – Velocity Profile Comparison (Rear – Soffit)

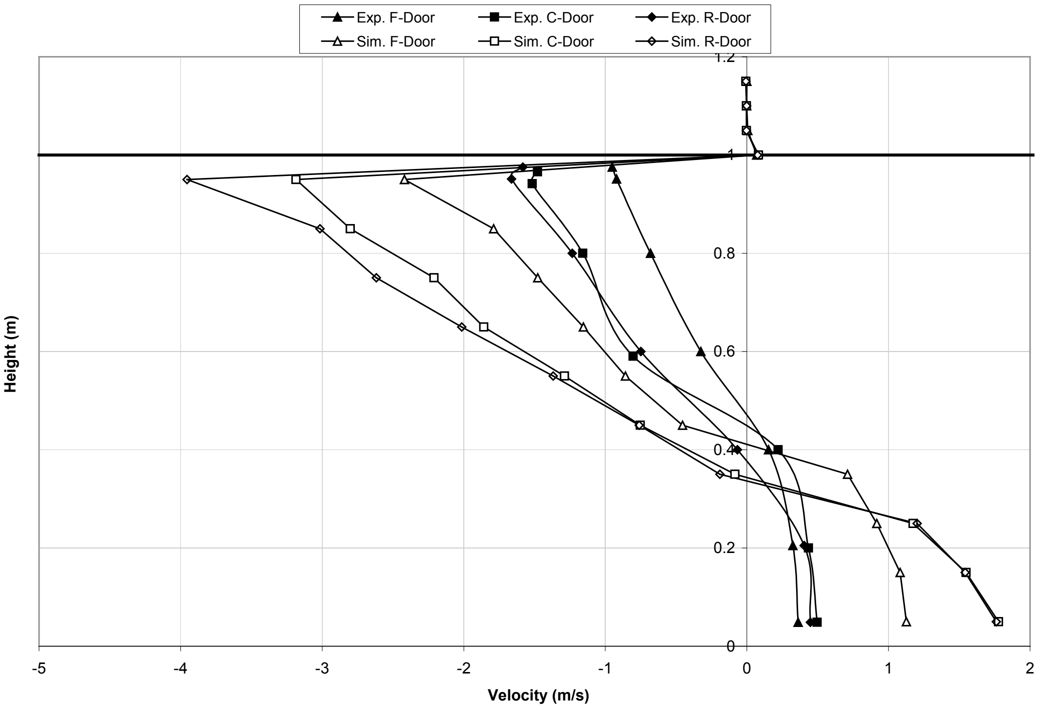


Figure 4-15 – Velocity Profile Comparison for (Door)

Figure 4-13 to Figure 4-15 show that the comparison between the simulation results and experimental data is fair. In all cases, the simulated velocity profiles overshoot the experimental velocity profiles. Although the simulations overestimate the experimental data, the profiles still behave similarly data. Discrepancies could have been caused by not defining the fire properly in the simulation, inproper measurements during experimentation, or due to not defining a large enough open area outside the simulated room.

4.1.2 Conclusion

The preliminary simulations of Parkes' experiments compare well with the experimental data. These simulations validated that the FDS input files were properly set-up. The next step was to modify the source code of FDS to include Quintiere's pyrolysis model and to use the furniture calorimeter MLR data in the input file which is discussed further in Chapter 5.

4.2 Denize / Girgis Experiments

Specially made upholstered chairs similar to ones tested in the CBUF research were constructed for the studies conducted by both Denize and Girgis. Denize and Girgis studied five chairs similar to one another. These chairs where built to the specifications in Figure 3-3 and consisted of a wood frame with polyurethane foam covered with a 100% polypropylene fabric. The polyurethane foam varied for each chair. Denize and Girgis studied these chairs in a furniture and room calorimeter, respectively.

Girgis' research was used for these preliminary FDS simulations. To simulate Girgis' five experiments the FDS input files (Appendix B) were developed. Each input file reconstructed the ISO 9705 room and used the heat release rate data found by digitizing the plots provided by Girgis. An open area outside the simulated room (Figure 4-16) was also defined because fire dynamics changed if an outside room was not present.

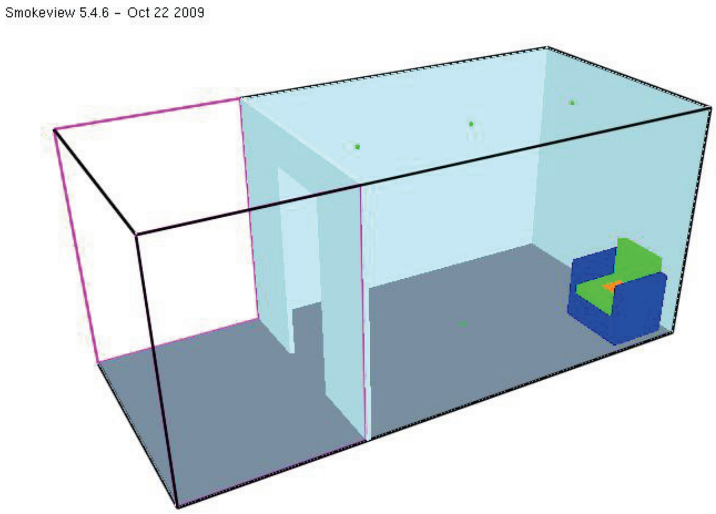


Figure 4-16 – Simulated ISO 9705 Room Used by Girgis

The walls, floor, ceiling and upholstered chair were defined by the thermal and mechanical properties which were found in available sources.

One difficulty with these experiments was how to define the materials of the chairs. The thermal properties for polypropylene and polyurethane foam can vary from one source to the next. These values could only be estimated and could not be found using the method developed by Hopkins and Quintiere. Hopkins and Quintiere's method could not be used because (1) there was no available cone calorimeter data from various heat fluxes and (2) the University of Canterbury conducted these tests thus the material was not available to the University of Maryland for cone calorimeter tests to be conducted.

4.2.1 Thermal Properties of Polypropylene Fabric

The polypropylene fabric was constant throughout all five simulations because the same fabric was used for all five chairs.

Another research project done at the University of Canterbury by Chen (29) tested the fabric in cone calorimeter tests. Although she did not test the 100% polypropylene fabric used in the experiments conducted by Girgis and Denize, it was assumed that the polyester fabric would have similar thermal properties to the polypropylene fabric since both are thermosets.

Chen concluded the polyester fabric had a the following properties (Table 4-2):

Table 4-2 – Chen Fabric Properties

Property	
ρL_o	0.23 kg/m^2
$\rho L_o C_p$	1.09 kJ/m^2-K

where ρ – density [kg/m3]

L_o – thickness of material [0.0125 m]

C_p – specific heat [kJ/kg-K

Using the information from Chen's work, the density and specific heat of the fabric can be calculated as followed:

$$\rho = \frac{(\rho L_o)}{L_o} = \frac{0.23}{0.0125} \rightarrow \rho = 184\ \frac{kg}{m^3} \tag{4-1}$$

$$c_p = \frac{(\rho L_o c_p)}{(\rho L_o)} = \frac{1.09}{0.23} \rightarrow c_p = 4.74 \frac{kJ}{kg-K} \tag{4-2}$$

Next, the thermal properties were found assuming the thermal diffusivity (α) of polypropylene to be 6.7 x 10^{-8} m^2/s. Using Equation 4-3 the thermal conductivity was calculated.

$$\alpha = \frac{k}{(\rho)(C_p)} \quad \Rightarrow \quad \left(6.7x10^{-8}\ \frac{m^2}{s}\right)\left(184\ \frac{kg}{m^3}\right)\left(4.74\ \frac{kJ}{kg-K}\right)$$
$$\Rightarrow \quad k = 0.058\frac{W}{m-K} \tag{4-3}$$

4.2.2 Thermal Properties of Polyurethane Foam

Although the foam varied five times, determining the thermal properties of the polyurethane foam was much simpler than finding the thermal properties for the polypropylene fabric. The thermal properties which varied from the type of foam were the specific heat (C_p) and density (ρ).

The work done by Denize provided the density of the polyurethane foam used in these experiments by Girgis. The densities of the foams were as followed:

Table 4-3 – Densities of the Polyurethane Foam

Polyurethane Type	Density, ρ [kg/m^3]
G	28
H	37
I	35
J	36
L	36

While conducting a literature review the thermal diffusivity and heat of conductivity of polyurethane were found. A study by Aleksander Prociak *et al.* (30) investigated the thermal diffusivity of polyurethane foams. Within this study the thermal properties of the foam in question in this paper were provided. These values were assumed to be similar to the values of the polyurethane foam used in Girgis' experiments because the densities were similar. Therefore the thermal conductivity was equal to 0.0214 W/m-K and the thermal diffusivity was equal to 0.4065 x 10^{-6} m^2/s.

Using these values stated above and in Table 4-3 the heat of capacity of the polyurethane foam can be calculated using equation 4-3.

Table 4-4 breaks down the thermal properties for each of the five foams.

Table 4-4 – Thermal Properties for Polyurethane Foams

Polyurethane Type	Density, ρ [kg/m^3]	Thermal Diffusivity, α [m^2/s]	Thermal Conductivity, k [W/m-K]	Specific Heat, C_p [kJ/kg-K]
G	28	0.4065×10^{-6}	0.0214	1.88
H	37	0.4065×10^{-6}	0.0214	1.423
I	35	0.4065×10^{-6}	0.0214	1.504
J	36	0.4065×10^{-6}	0.0214	1.462
L	36	0.4065×10^{-6}	0.0214	1.462

4.2.3 Heat Release Rate per Unit Area for Chair G-21

The next step after determining the thermal properties for the fabric and foams was to determine the heat release rate per unit area (HRRPUA) for each of the chairs. The procedure below was followed for all chairs (G-21, H-21, I-21, J-21, and L-21). We explain below the method for one of the chairs (G-21. The HRRPUA information for the other four chairs can be found in the input files in Appendix B.

The HRRPUA used in the simulation was determined by digitizing the Girgis' heat release rate (*HRR*) plots. The area of the fuel source was determined to be the area (0.0625 m^2) of the burner which supplied a constant heat flux during testing. To find the HRRPUA at a given time the following equation was used.

$$HRRPUA_i = \frac{HRR_i}{A_{burner}} \tag{4-4}$$

Table 4-5 provides both the HRRPUA value used at a given time and the actual code used in the FDS simulation.

Table 4-5 – HRRPUA and FDS Script for G-21 Chair

Time [s]	$HRRPUA_{Exp}$ [kW/m^2]	F_i	FDS Script
25.623	295.84	0.01	&RAMP ID='HRRPUA_RAMP', T=26,F=0.01/
40.996	986.24	0.04	&RAMP ID='HRRPUA_RAMP', T=41,F=0.04/
61.495	2465.76	0.11	&RAMP ID='HRRPUA_RAMP', T=61,F=0.11/
92.242	3254.72	0.14	&RAMP ID='HRRPUA_RAMP', T=92,F=0.14/
114.448	4536.96	0.20	&RAMP ID='HRRPUA_RAMP', T=114,F=0.2/
126.406	6410.88	0.28	&RAMP ID='HRRPUA_RAMP', T=126,F=0.28/
148.612	19331.52	0.83	&RAMP ID='HRRPUA_RAMP', T=149,F=0.83/
158.861	22783.52	0.98	&RAMP ID='HRRPUA_RAMP', T=159,F=0.98/
170.819	**23178.08**	1.00	&RAMP ID='HRRPUA_RAMP', T=171,F=1/
184.484	21501.44	0.93	&RAMP ID='HRRPUA_RAMP', T=184,F=0.93/
227.189	9073.92	0.39	&RAMP ID='HRRPUA_RAMP', T=227,F=0.39/
247.687	5720.48	0.25	&RAMP ID='HRRPUA_RAMP', T=248,F=0.25/
280.142	3353.44	0.14	&RAMP ID='HRRPUA_RAMP', T=280,F=0.14/
329.680	2663.04	0.11	&RAMP ID='HRRPUA_RAMP', T=330,F=0.11/
387.758	1676.64	0.07	&RAMP ID='HRRPUA_RAMP', T=388,F=0.07/
440.712	1183.52	0.05	&RAMP ID='HRRPUA_RAMP', T=441,F=0.05/
471.459	1183.52	0.05	&RAMP ID='HRRPUA_RAMP', T=471,F=0.05/

In the FDS input script, T refers to the time rounded to the nearest whole number and F refers to the specified fraction of the maximum HRRPUA at the given time (Equation 4-7).

$$F_i = \frac{HRRPUA_{i,Exp}}{HRRPUA_{\max}}, \quad where \quad i = T \tag{4-5}$$

The following illustrates how Equation 4-7 was used to determine F at T = 92 seconds.

$$\begin{gathered} F_i = \frac{HRRPUA_{i,Exp}}{HRRPUA_{\max}}, \quad where \quad i = T = 92 \quad and \quad HRRPUA_{\max} = 23178 \quad kW/m^2 \\ F_{92} = \frac{3255 \quad kW/m^2}{23178 \quad kW/m^2} \quad \Rightarrow \quad F_{92} = 0.14 \end{gathered} \tag{4-6}$$

4.2.4 Simulation Results

The following results are for the G-21 chair. Results for all other chairs (H-21, I-21, J-21, and L-21) can be found in Appendix C.. All available experimental data were compared to the simulation data.

Table 4-6 – Comparison of Results from Girgis and Simulations

		Experimental	Simulation
HRR	**Peak HRR (MW)**	1.45	1.54
	Time to Peak (s)	184.3	169
	Time to 500 kW (s)	130	130
Temperature	**Max Temp 1.0m above floor (°C)**	572	500
	Max Temp 1.8m above floor (°C)	640	521
Temperature History	**Time to reach 120 °C @ 1.6 m (s)**	59	58
	Time to reach 500 °C	145.5	153
Heat Flux	**Max Heat Flux at Floor Level**	36.74	**8.17**
	Time (s)	169	190
	Time to 20kW/m	144	**N/A**
Mass Loss Rate	**Mass Loss Rate (kg/s)**	0.0636	0.0662

Table 4-6 lists the properties that Girgis documented during his enclosure tests. These properties were the HRR, temperature at specific heights, temperature history, heat flux, and the maximum mass loss rate.

From the table it can be seen that the simulations represents the experiment data fairly well. For instance simulation values found for the HRR, temperature history and mass loss rate compare well to the experimental values. On the other hand the temperature profile of the simulation is not as high as the measurements from the experiment and the heat flux of the simulations are off by an order of magnitude from the experimental data.

4.2.4.1 Heat Release Rate

Figure 4-21 illustrates how well the simulated HRR curves fit the experimental HRR curve. Thus the simulation properly simulates the experiment.

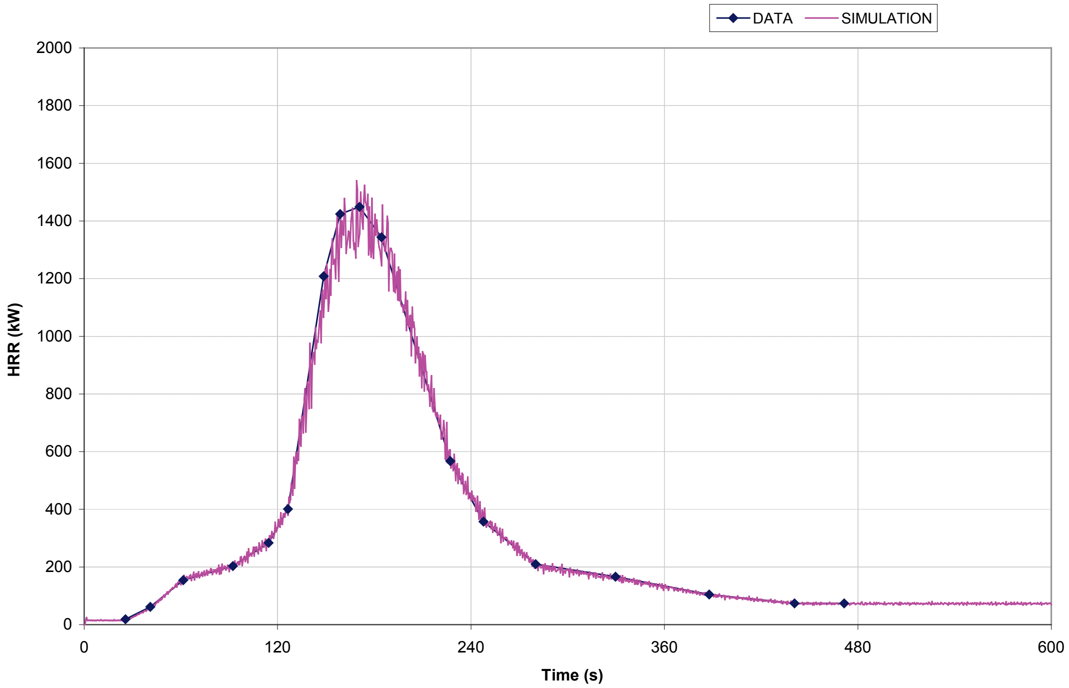


Figure 4-17 –Heat Release Rate of G-21 Chair

4.2.4.2 Mass Loss History

The mass loss history for the simulation has a very good fit with the experimental results. In Figure 4-18, the agreement between simulation results and experimental data is very good from 0 to 420 seconds. From 420 to 600 seconds the simulated mass loss trend of the simulations begins to deviate from the experimental data. Deviations could be caused by melting of the upholstered chair in the experiment which does not occur in the simulation.

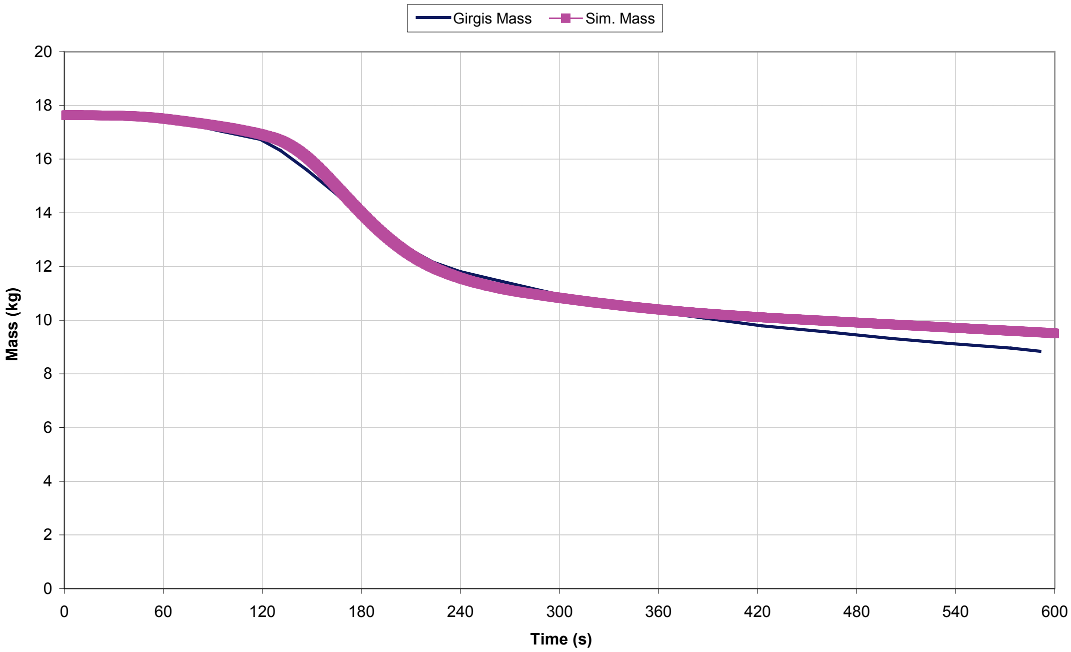


Figure 4-18 – Mass Loss of G-21 in Adjusted Simulation

4.2.4.2.1 Temperature Profiles

Figure 4-19 and Figure 4-20 present the experimental and simulation temperature profiles, respectively. It can be seen there is a slight discrepancy between the experimental results and the simulation results. The experimental results has a temperature profile which varies from 125°C to 625°C, whereas the simulated temperature profiles vary from 125°C to 525°C.

Differences in the temperature profiles could be due to the definition of the material in FDS. A generic polyurethane foam was defined which may not have the exact same properties as the polyurethane used in experimentation. In addition the experiments used a GIB board for the material on the wall and did not provide the exact type of GIB board used. Varying the thermal properties of the GIB board could drastically affect the temperature of the enclosure.

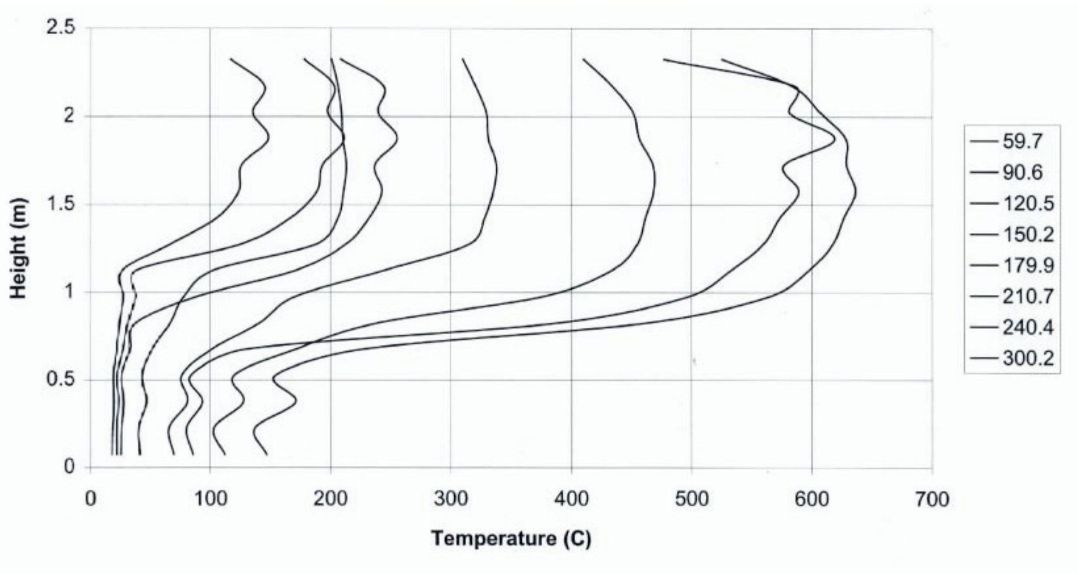


Figure 4-19 – Experimental Temperature Profile of G-21 Chair (Girgis)

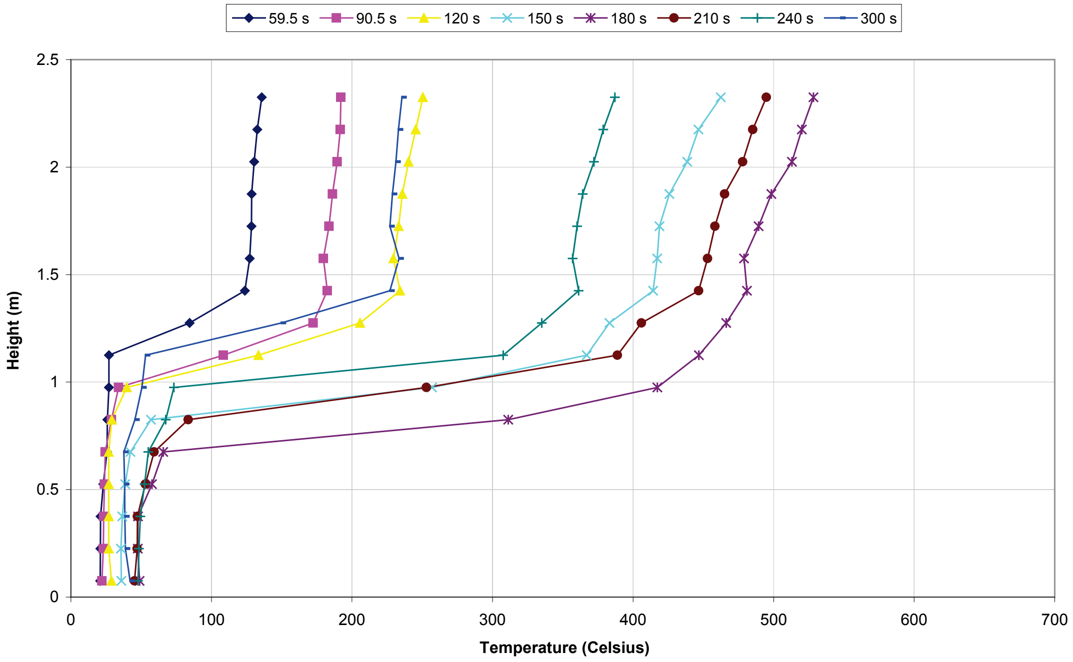


Figure 4-20 –Simulation Temperature Profile of G-21 Chair

4.2.4.3 Temperature History

Figure 4-21 and Figure 4-22 graphical show the experimental and simulation temperature history, respectively. The simulations were only run for 600 seconds since the behavior is steady thereafter. The simulation temperature curves behave similarly to the experimental curve, but the temperature does not get as high as it does in the experiment. The experiment shows a peak temperature of 650°C while the simulations have a maximum temperature of 525°C. Again, discrepancies in the material properties (*i.e.* upholstered chair and/or wall) may be the reason as to why the simulations are exhibiting lower temperatures.

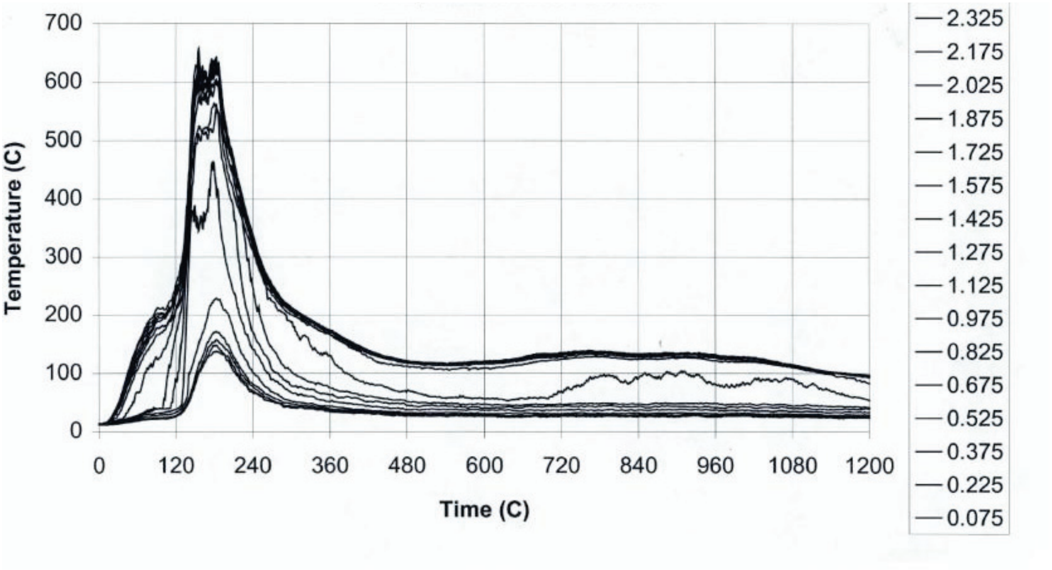


Figure 4-21 – Experimental Temperature History of G-21 Chair (Girgis)

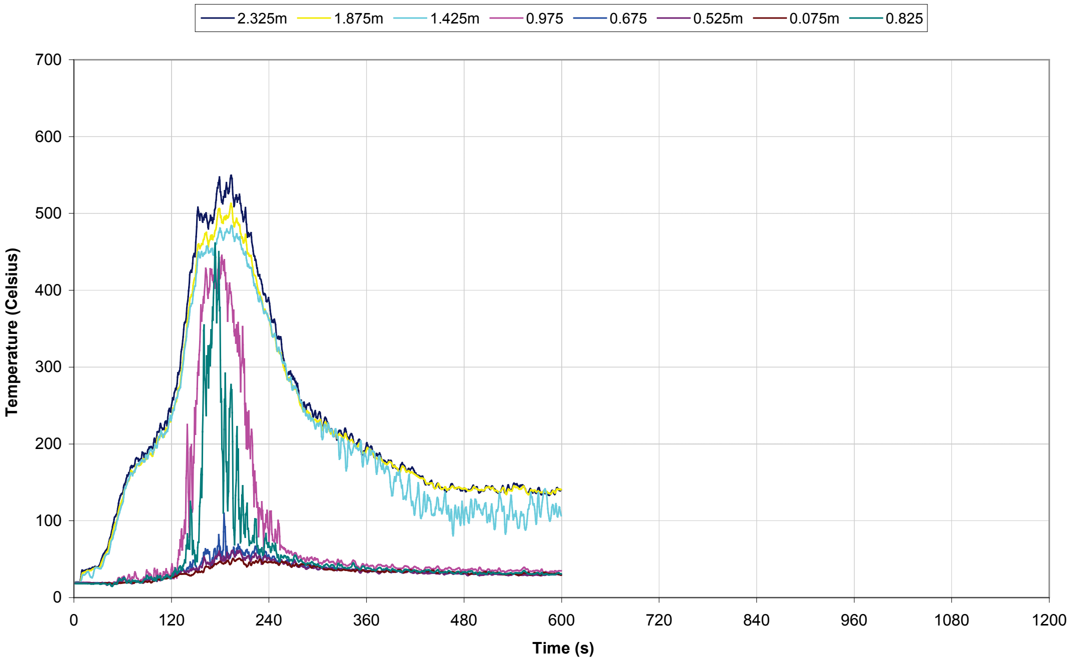


Figure 4-22 –Simulation Temperature History of G-21 Chair

4.2.5 Conclusion

In conclusion the simulations accurately predict the experimental results although there are some minor discrepancies. These discrepancies could be the results of defining inaccurately the properties for polyurethane foam and the GIB board. Defining the material accurately could not be done because neither Girgis nor Denize identified the exact properties and/or the manufacturer of the materials. At this time only generic material properties could be define.

4.3 Implementing Furniture Calorimeter Data

These preliminary FDS simulations helped validate the input files and definitions of the materials. The results from the simulations of Parkes' experiments showed a much better fit to the experimental results. This is most likely due to the easily defined fuel (heptane). On the other hand, the simulations of Girgis' experiments had discrepancies from the experimental data because the exact thermal properties of the fabric, foam and GIB board could not be determined neither Girgis nor Denize identified the exact type of material used. Slight variations in the material properties can cause discrepancies in simulations.

The next step was to use these same FDS input files but instead of changing the HRRPUA code for each test, only the furniture calorimeter data would be used. In addition the source code of FDS would be modified to include Quintiere's pyrolysis model to take into account enclosure effects. This will be discussed in further detail in Chapter 5.

5 Modified FDS Simulations

5.1 *Introduction*

Fire simulations are being used widely in the fire protection / forensics community. Simulating accurate fire behavior of materials/objects in an enclosure is very difficult without the correct properties and MLR data.

Utilizing furniture calorimeter MLR data would be the easiest and most economical method to simulate fire dynamics in various enclosures. As discussed earlier, furniture calorimeter results do not take into account the enclosure effects. Young (9) presented how using furniture calorimeter data in FDS results in underestimated HRR values.

This research proposes implementing Quintiere's pyrolysis model into FDS. This would allow for furniture calorimeter data to be used and for the enclosure effects to be taken into account. The following section discusses how FDS was modified to include Quintiere's pyrolysis model and presents a comparison between modified FDS results and room calorimeter data.

5.1.1 FDS Input File (.fds)

Before modifying the FDS source code, the input files which were used for previous simulations were modified to include furniture calorimeter MLR data. Parkes and Denize each conducted furniture calorimeter tests on a pool of heptane and a variety of upholstered chairs (G, H, I, J, and L), respectively. This data was digitized using *Plot Digitizer* and was implemented into the FDS input script as found in Appendix C.

These FDS input files were then run using the modified FDS version, from here on referred to as ModFDS. ModFDS was a modified version of the current version of FDS (5.3.1). The source code of FDS was modified to include Quintiere's pyrolysis model so that furniture calorimeter data could be manipulated to include enclosure effects. The biggest question was *where* to include the pyrolysis model in the source code and *how* to implement it.

5.1.1.1 FDS Source Code (wall.f90)

The file "wall.f90" of the source code for FDS was deemed the portion of the code which would be the best location to implement Quintiere's model. The "wall.f90" code includes all the subroutines FDS goes through to determine all solid surfaces boundary conditions. The pyrolysis model was located in the following section of the "wall.f90" script:

- wall.f90
  - SUBROUTINE SPECIES_BC
    - WALL_CELL_LOOP
      - CASE (SPECIFIED_MASS_FLUX) METHOD_OF_MASS_TRANSFER
        - Quintiere's Pyrolysis Model

The "SUBROUTINE SPECIES_BC" determines the boundary conditions of species in FDS. FDS defines each cell in the simulation environment with a unique 'IW' value. The "WALL_CELL_LOOP" loops through each cell in the simulation area (*IW)*. While in this loop the program looks in the FDS input file to determine if the user specified the burning rate of the fuel (*i.e.* MLRPUA or HRRPUA*).* If the user did specify the burning rate, then the program goes into the "(SPECIFIED_MASS_FLUX) METHOD_OF_MASS_TRANSFER" case. It was determined that the pyrolysis model should be located in this case since the burning rate of the fuel would be defined by the user using furniture calorimeter data. Thus, the pyrolysis model is applied to each mesh cell, IW.

The next step was to determine how to implement Quintiere's pyrolysis model. Initially, the exact pyrolysis model developed by Quintiere (Equations 3-1 and 3-3) were implemented into the source code, but the simulation results (*Not shown in this report*) were extremely overestimated and the model became very unstable. Quintiere's model was then modified to include a correction factor which was a ratio of the enclosure MLRPUA to the free burn MLRPUA of the fuel (Equation 5-1).

$$\dot{q}''_{ext} = \dot{q}''_{rad,in} - \dot{q}''_{fl}\left(\frac{\dot{m}''_F}{\dot{m}''_\infty}\right) \tag{5-1}$$

The pyrolysis model (Equation 3-1) was simplified to the following relationship:

$$\dot{m}''_F = \frac{\dot{m}''_\infty\left(\frac{Y_{ox,l}}{Y_{ox,o}}\right)+\frac{\dot{q}''_{rad,in}}{L_g}}{1+\frac{\dot{q}''_{fl}}{(\dot{m}''_\infty)(L_g)}} \tag{5-2}$$

Where,

$Y_{ox,o} = 0.23$
$Y_{ox,l}$ – oxygen concentration in enclosure
L_g – heat of gasification of fuel
$\dot{q}''_{rad,in}$ – radiant heat flux from upper layer [kW/m^2]
$\dot{q}''_{fl}$ – flame heat flux [kW/m^2] – varies depending on fuel
$\dot{m}''_\infty$ - furniture calorimeter mass loss rate per unit area [kg/m^2/s]
$\dot{m}''_F$ - enclosure mass loss rate per unit area [kg/m^2/s]

The above equation was implemented into FDS using the following code:

```
Line 1    if(N == I_FUEL) then
Line 2         II   = “X-LOCATION OF FRONT RIGHT CELL OF FUEL SOURCE”
Line 3         JJ   = “Y-LOCATION OF FRONT RIGHT CELL OF FUEL SOURCE”
Line 4         KK   = “Z-LOCATION OF FRONT RIGHT CELL OF FUEL SOURCE”
Line 5         IIG = II
Line 6         JJG = JJ
Line 7         KKG = KK+1
Line 8
Line 9         Y_IN(:) = YY(IIG-1,JJG-1,KKG,:)
Line 10        CALL GET_MASS_FRACTION(Y_IN,O2_INDEX,Y_O2)
Line 11
Line 12        MASSFLUX0      = MASSFLUX(IW,N)
Line 13        QRADIN0        = “FLAME HEAT FLUX”
Line 14
Line 15        IF( (QRADIN(IW)-QRADIN0*Y_O2/0.230_EB) < 0.0_EB ) THEN
Line 16           MASSFLUX(IW,N) = MASSFLUX0*(Y_O2/0.230_EB)
Line 17        ELSE
Line 18           MASSFLUX(IW,N) = ( MASSFLUX0*(Y_O2/0.230_EB) + abs(QRADIN(IW)/&
Line 19           “HEAT OF GASIFICATION OF MATERIAL”))&
Line 20           /( 1._EB + (QRADIN0/MASSFLUX0/“HEAT OF GASIFICATION OF
MATERIAL”))
Line 21        ENDIF
Line 22
Line 23        if(IW == “UNIQUE CELL NUMBER OF FRONT RIGHT CELL OF FUEL SOURCE”)
then
Line 24           write(111,*) T,MASSFLUX0,MASSFLUX(IW,N)
Line 25        endif
Line 26
Line 27     endif
```

This script runs every time step for each cell in the simulation area. The portions of the code which are in quotes and italicized (Lines 2-4, 13, 19, 20 and 23) are the values which were changed for each FDS simulation. The heat of gasification and flame heat flux are dependent on the material being burned. As shown in Section 5.2, the flame heat flux term is used to fine tune the results of the simulation.

Lines 2 to 7 determine the location of the front right corner of the fuel source in the x-, y-, and z-directions (*i.e.* II, JJ, KK*)*. Determining the location of the front right corner of the fuel source (marked with a star in Figure 5-1) helps to define where the oxygen concentration of the enclosure is to be measured.

Lines 9 and 10 define a cell location where the oxygen mass fraction (*Y_O2*) should be measured. The location is close to the fuel source (one cell away from the fuel source.) Figure 5-1 illustrates which cell's oxygen concentration was used in the pyrolysis model. The red blocks are the fuel source and the green block is the cell where the oxygen concentration was measured.

In line 12, the user-defined MLRPUA (*i.e.* furniture calorimeter MLRPUA*)* is defined as MASSFLUX0. The flame heat flux is next defined as QRADIN0 in line 13.

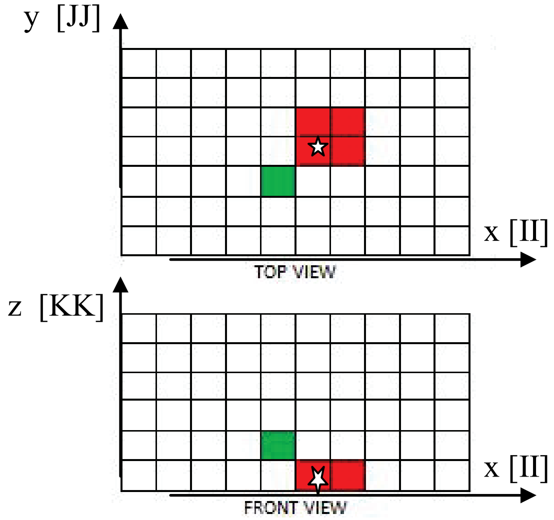


Figure 5-1 – Example of Location where Y_O2 was Measured

Lines 15 thru 21 are the modified Quintiere pyrolysis model. This 'IF' loop first determines if the radiant heat flux from the enclosure is dominant over the flame heat flux. If it is not then the MLRPUA in the enclosure is only affected by the oxygen concentration, but if it is dominant then the enclosure MLRPUA is affected by both the oxygen concentration and thermal feedback of the upper layer. Finally, lines 23 through 25 write the time, free burn MLR and enclosure MLR of the simulation to a file.

As discussed previously, the II, JJ, KK and IW were dependent on which simulation was being run. These values varied depending on the simulation area size, the location of the fuel source and the size of the mesh size. The II, JJ, and KK values represented the number of cells in the x-, y-, and z-direction, respectively. The II, JJ and KK location had to be determined for the fuel source in each simulation. In addition, each cell in the simulation area is given a unique ‘IW’ number, thus the IW value represented the unique value of the front right cell of the fuel source. These values were determined before any simulations were started.

Table 5-1 – II, JJ, KK and IW for Parkes’ & Girgis/Denize Experiments

	DOOR	**MESH**	**IW**	**II**	**JJ**	**KK**
PARKES	FRONT	0.05	17601	34	23	1
		0.1	4393	28	12	1
	CENTER	0.05	17601	55	23	1
		0.1	4393	28	12	1
	REAR	0.05	17601	79	23	1
		0.1	4393	28	12	1
	SOFFIT					
	CENTER	0.05	16001	55	23	1
		0.1	3993	28	12	1
	REAR	0.05	16001	79	23	1
		0.1	3993	28	12	1
	OPEN					
	CENTER	0.05	15569	55	23	1
		0.1	3897	28	12	1
	REAR	0.05	15569	79	23	1
		0.1	3897	28	12	1
GIRGIS/ DENIZE	**CHAIR**					
	G, H, I, J, L	0.05	25913	79	8	8
		0.1	6479	40	5	4

Table 5-1 lists the II, JJ, KK and IW values which were used when running simulations using data from Parkes and Girgis/Denize. For instance, in the simulation where the enclosure had a door and the fuel source was located in the rear with a mesh size of 0.05, the II, JJ, KK and IW values would be equal to 79, 23, 1, and 17601, respectively.

Finally after modifying the source code to include the pyrolysis model and correct II, JJ, KK and IW values, ModFDS needed to be compiled before the program was able to run any simulations. After compiling the program, ModFDS was used on the University of Maryland's cluster, *Deepthought*, to simulate the 13 cases simulated in previous sections. These simulations were then compared to room calorimeter data.

5.2 Simulation Results

A total of 13 simulations were run using ModFDS. Each of these simulations was run on the University of Maryland's cluster, *Deepthought,* after ModFDS was compiled properly to include the modified wall.f90 file. Sections 5.2.1 and 5.2.2 discuss the simulation results with the respective room calorimeter data.

5.2.1 Parkes' Experiments

Using the ModFDS input file (Appendix D) with furniture calorimeter HRR data, the accuracy of Quintiere's pyrolysis model was validated by comparing the simulation results to the room calorimeter measurements taken by Parkes (26).

Prior to running the simulation ModFDS program had to be compiled to properly set up the environment for the fuel in the position which was unique to the simulation. Hence II, JJ, KK, IW and heat of gasification had to be hard coded into wall.f90 for each simulation run. The values used for II, JJ, KK and IW are in Table 5-1 and the heat of gasification for heptane was found to be approximately 365000 J/kg (11). The flame heat flux also had to be hard coded into the wall.f90 file for each simulation. This value was used to fine tune the simulation results to obtain results fairly similar to the experimental results. In the following results the flame heat flux was set to 20000 W/m^2 and the mesh was 0.05 meters.

Similar to Section 4.1.1, ModFDS simulation results were compared to the measurements taken by Parkes for the heat release rate, heat flux history, temperature history, temperature profile and velocity profile

5.2.1.1 Heat Release Rate

The heat release rate was compared for three of the cases where the fire was located in the rear of the enclosure for all three vent sizes. Figure 5-2 to Figure 5-4 illustrate how well the pyrolysis model predicts the heat release rate of the fuel source. These figures show that the pyrolysis model does a fairly good job at predicting the HRR of the fuel source for all three cases. Figure 5-4 shows the simulation results has a much better fit to the experimental results than the other two figures. ModFDS simulation tends to overestimate the HRR for all three cases.

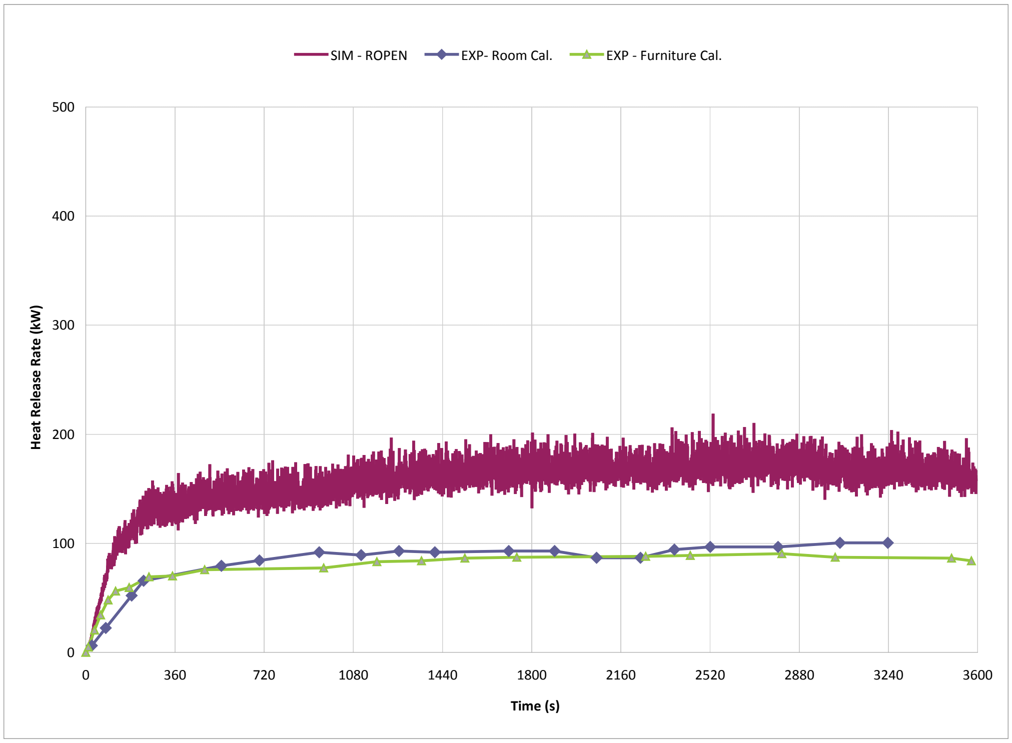


Figure 5-2 – ModFDS HRR Comparison (Rear – Open)

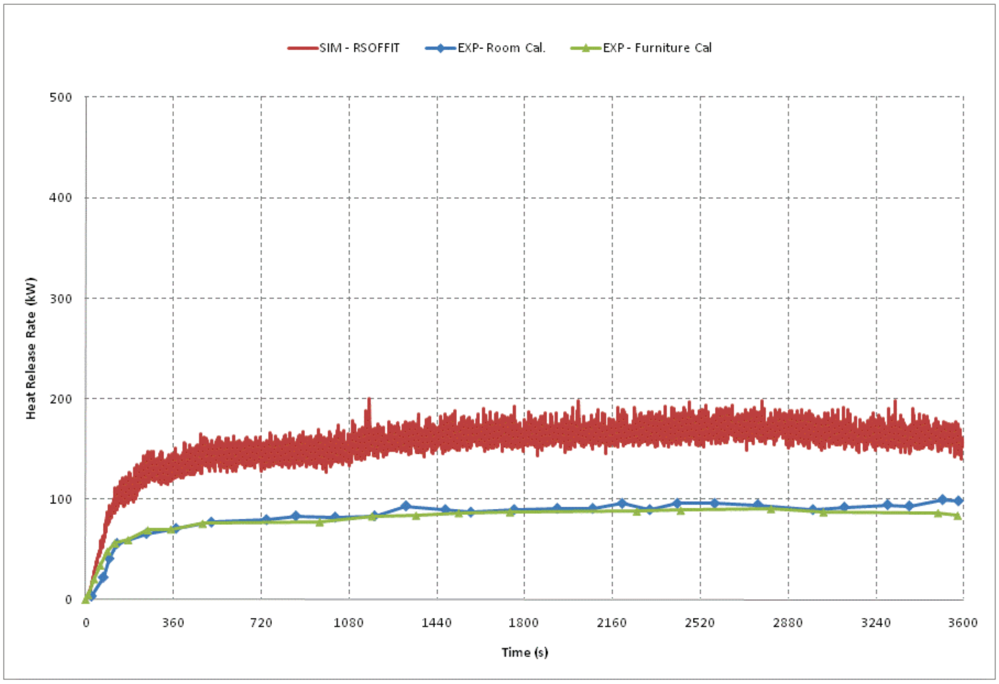


Figure 5-3 – ModFDS HRR Comparison (Rear – Soffit)

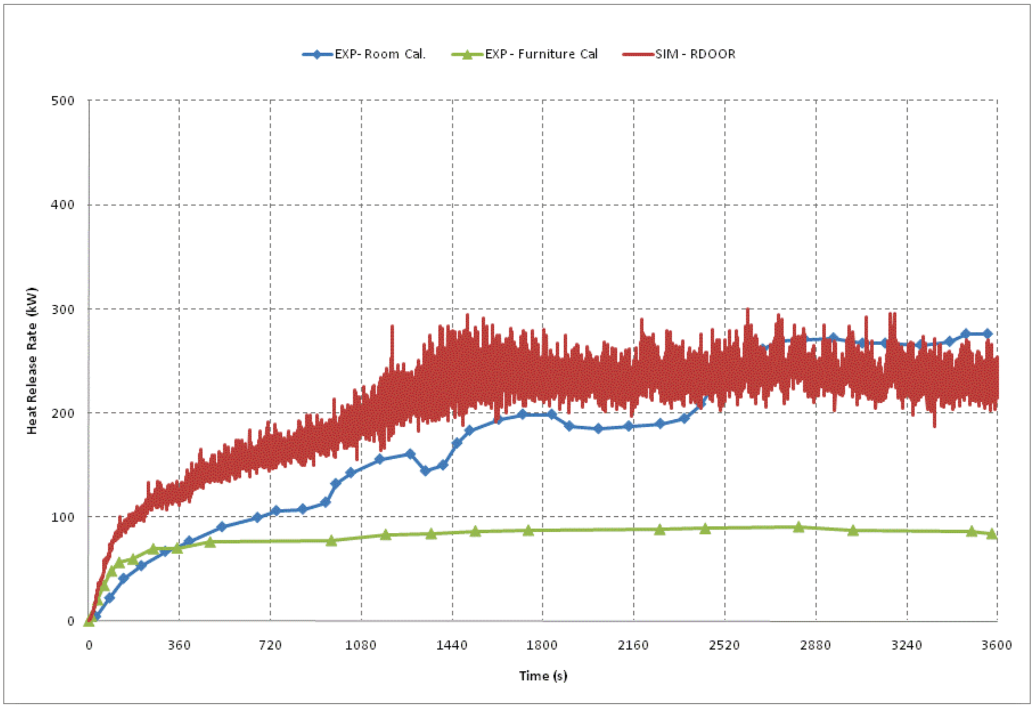


Figure 5-4 – ModFDS HRR Comparison (Rear –Door)

The discrepancies of the HRR comparison could be due to how the pyrolysis model was implemented into FDS. Implementing the pyrolysis model differently into FDS will need to be looked at to see if better simulation results can be obtained.

5.2.1.2 Heat Flux History

Similar to the HRR comparison the heat flux history was compared for the three cases where the fuel source was located in the rear of the room for all three vent sizes. It can be seen in Figure 5-5 to Figure 5-7 the heat flux predicted by ModFDS simulations has a good fit for all three cases. The predicted heat flux for the enclosure with a door and fire in the rear of the room has an underestimated heat flux, but has the same trend as the experimental measurements

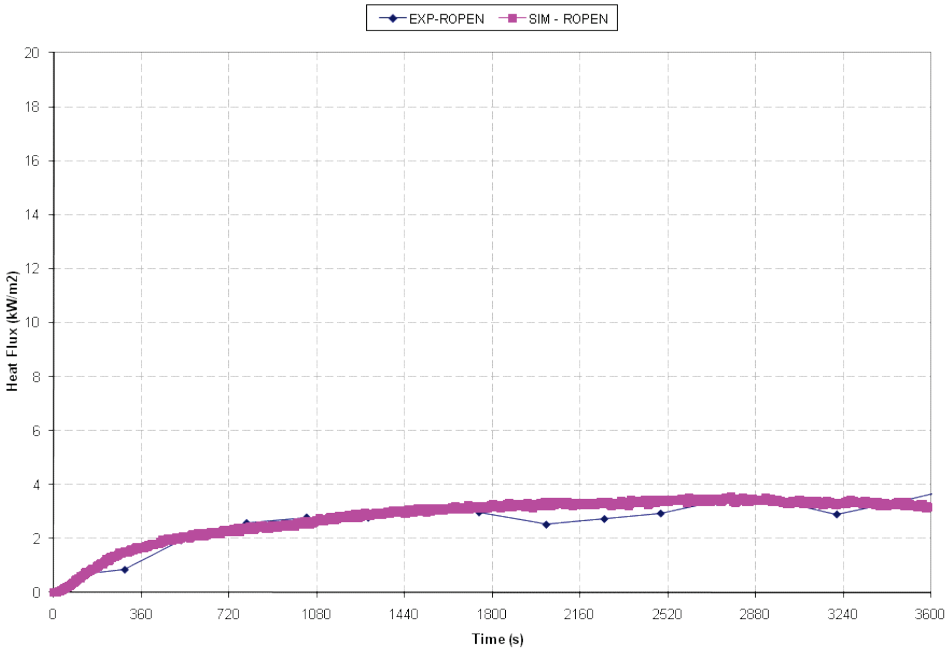


Figure 5-5 – ModFDS Heat Flux Comparison (Rear – Open)

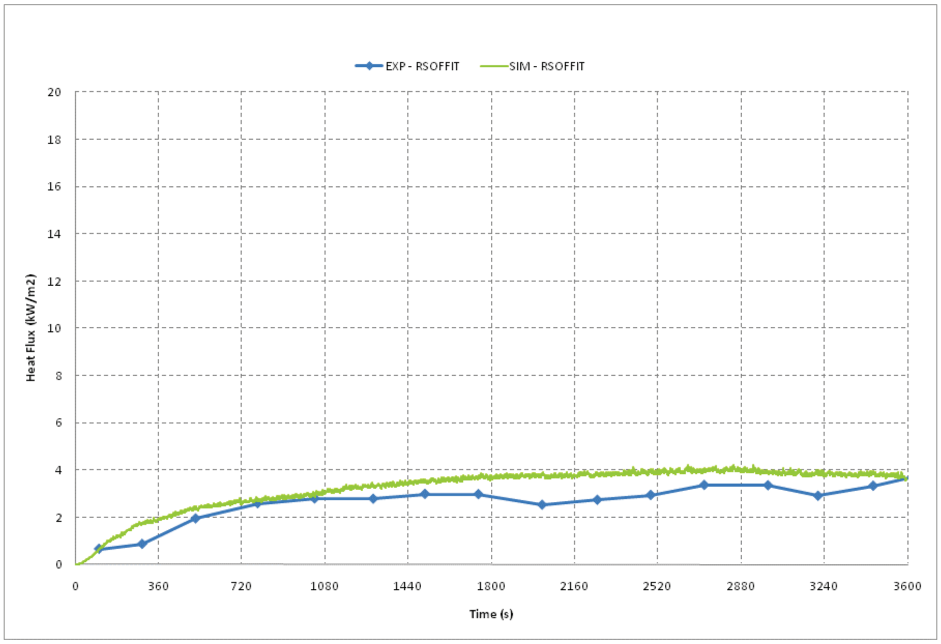


Figure 5-6 – ModFDS Heat Flux Comparison (Rear –Soffit)

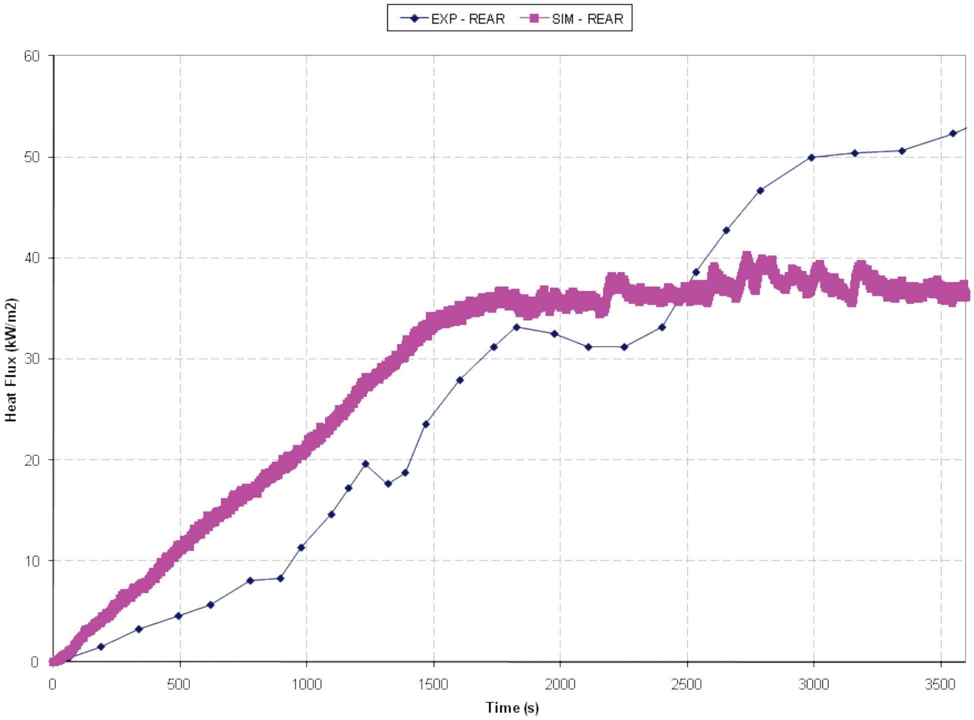


Figure 5-7 – ModFDS Heat Flux Comparison (Rear – Door)

The heat flux comparison is very similar to the heat flux comparison shown earlier in Section 4.1.1.2. This shows discrepancies could be due to the way FDS calculates the heat flux values.

5.2.1.3 Temperature History

Again the cases where the fuel source was located in the rear of the compartment with all three vent sizes were used to compare the temperature history to the experimental measurements. As discussed in Section 4.1.1.3 the temperature was measured by Parkes at the thermocouple closest to the ceiling. Figure 5-8 to Figure 5-10 show a good fit between the simulated temperature and the experimental temperature measurements.

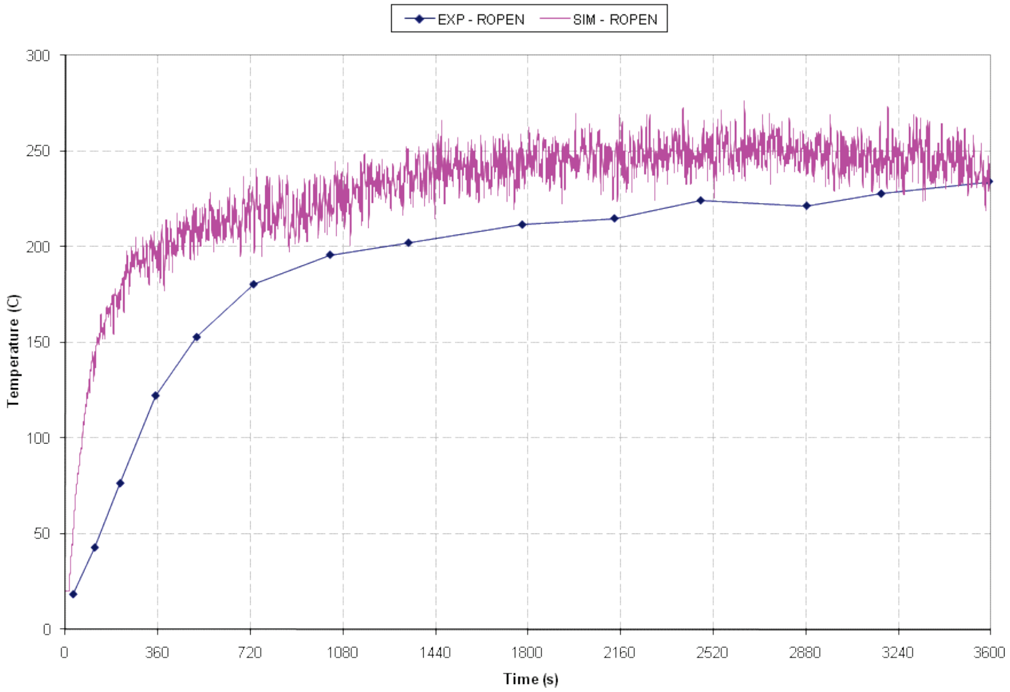


Figure 5-8 – ModFDS Temperature Comparison (Rear – Open)

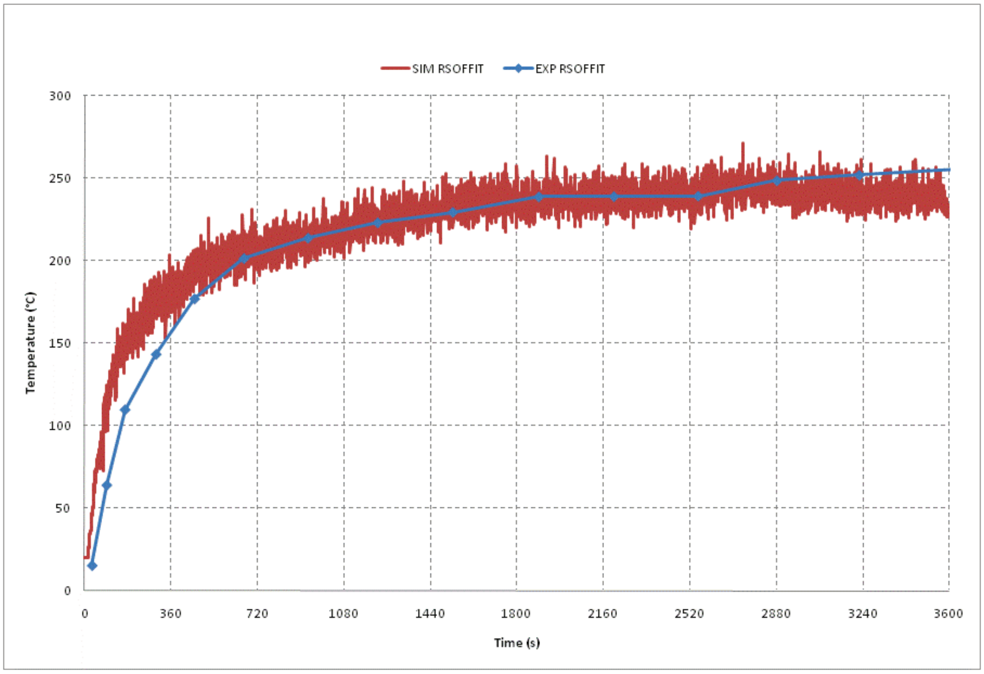


Figure 5-9 – ModFDS Temperature Comparison (Rear – Soffit)

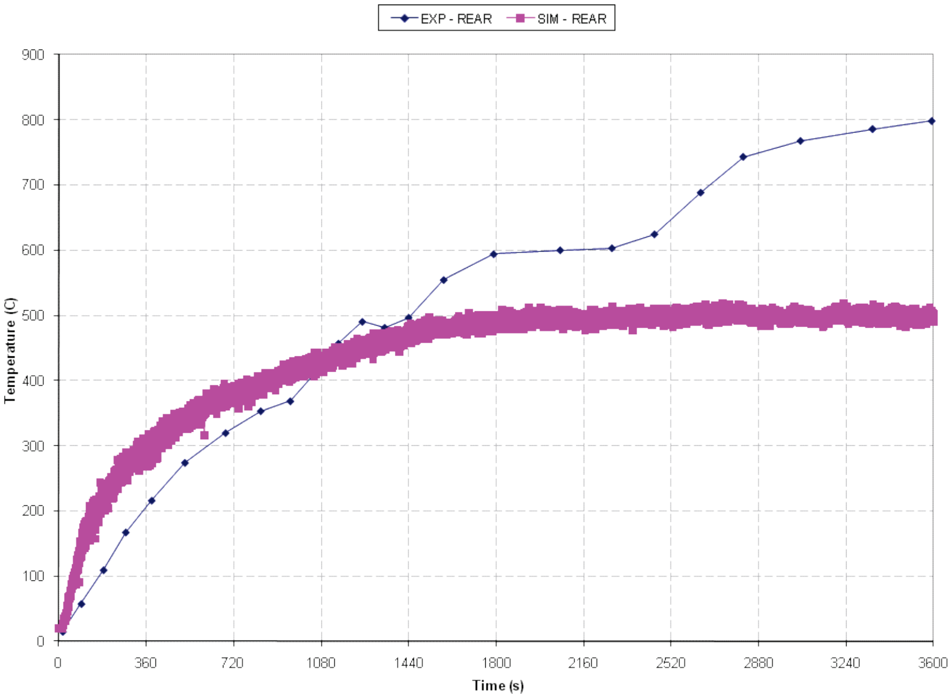


Figure 5-10 – ModFDS Temperature Comparison (Rear – Door)

The simulation of the enclosure with the door underestimates the temperature after about 24 minutes. This time corresponds to around the time the HRR is underestimated by the simulation (Figure 5-4). This discrepancy could be due to the actual pyrolysis model and/or how it was implemented into the source code of FDS. In addition the simulations in Section 4.1.1.3 exhibit a behavior which fits the experimental data much worse than the simulation results show above.

5.2.1.4 Temperature Profile

Discussed in Section 4.1.1.4 a thermocouple tree was located at the front corner of the enclosure. Using the same location as in the experiment, the simulation temperature profile was recorded for cases where the fuel source varied in location (front, center, and rear) and the vent size varied (open, soffit, and door). Figure 5-11 and Figure 5-12 (closed markers are experimental measurements and open markers are simulation data) show a good agreement between the simulated temperature profile versus the experimental temperature profile. But the comparison for the three cases in the enclosure with the door is not good.

Although the fit is not good the temperature profile trends are similar and the profiles do increase in temperature as the fuel source moves further back in the room, but the simulated temperature profiles are either 150ºC warmer or cooler than the experimental measurements.

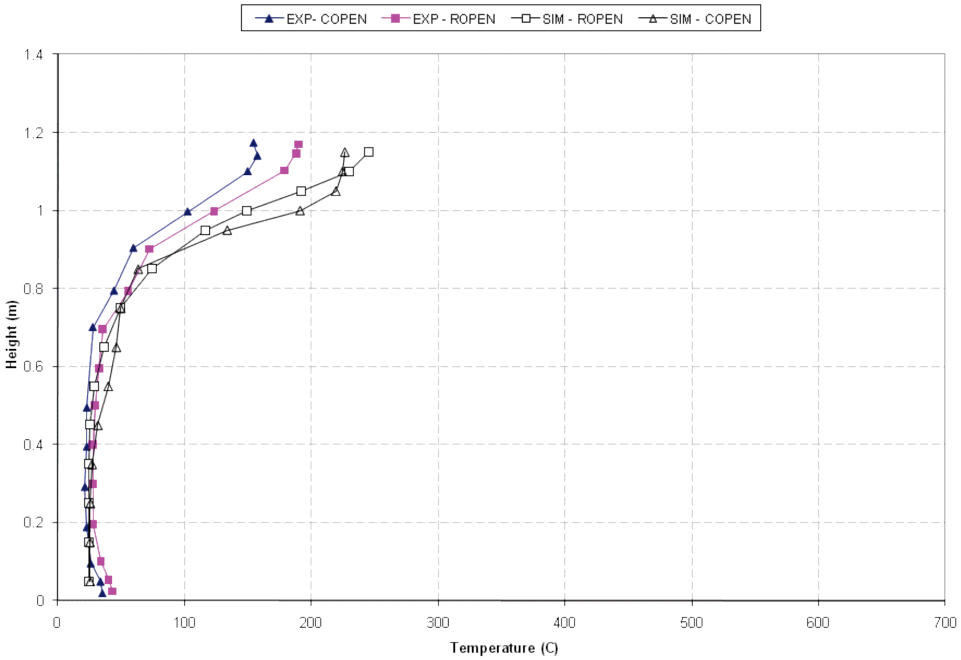


Figure 5-11 – ModFDS Temperature Profile Comparison (OPEN)

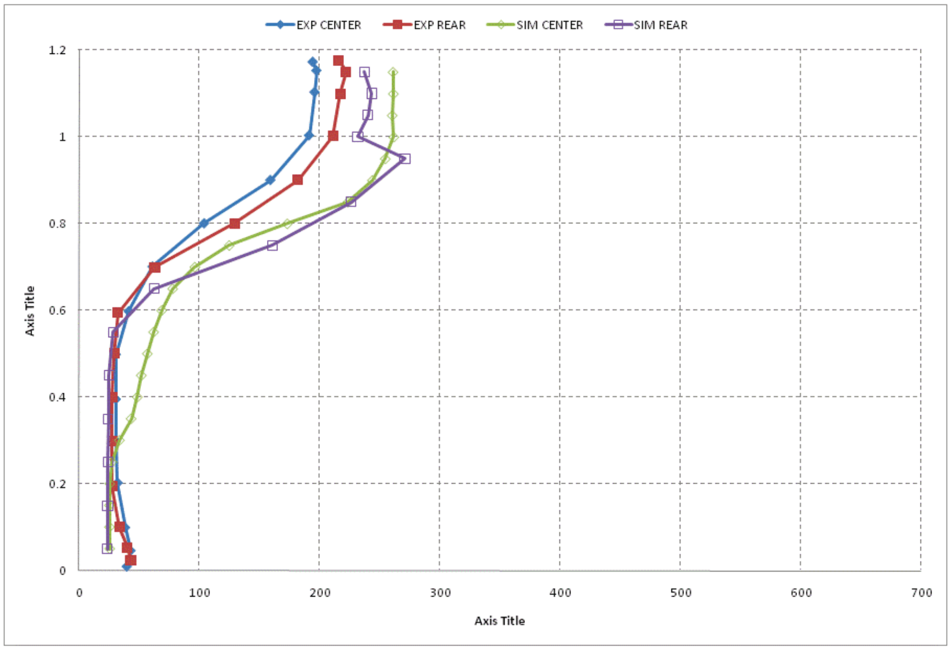


Figure 5-12 – ModFDS Temperature Profile Comparison (SOFFIT)

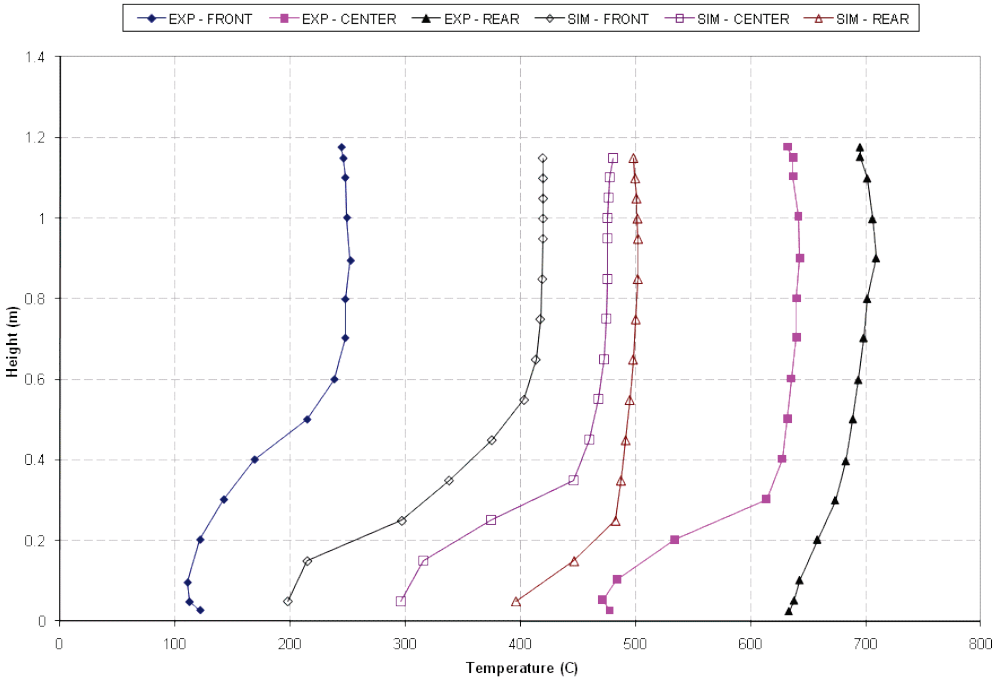


Figure 5-13 – ModFDS Temperature Profile Comparison (DOOR)

Figure 5-13 shows ModFDS temperature profile comparison when a mesh of 0.05 meters is used. It is unknown why the temperature profiles for the OPEN and SOFFIT cases have a good fit and why the cases with the DOOR have a poor fit. A previous job using ModFDS with a mesh of 0.1 meters exhibits a slightly better fit for the thermal property (Figure 5-14), but again there is a big difference between the simulated profile and experimental profile. Discrepancies could be caused by the way FDS calculates the temperature.

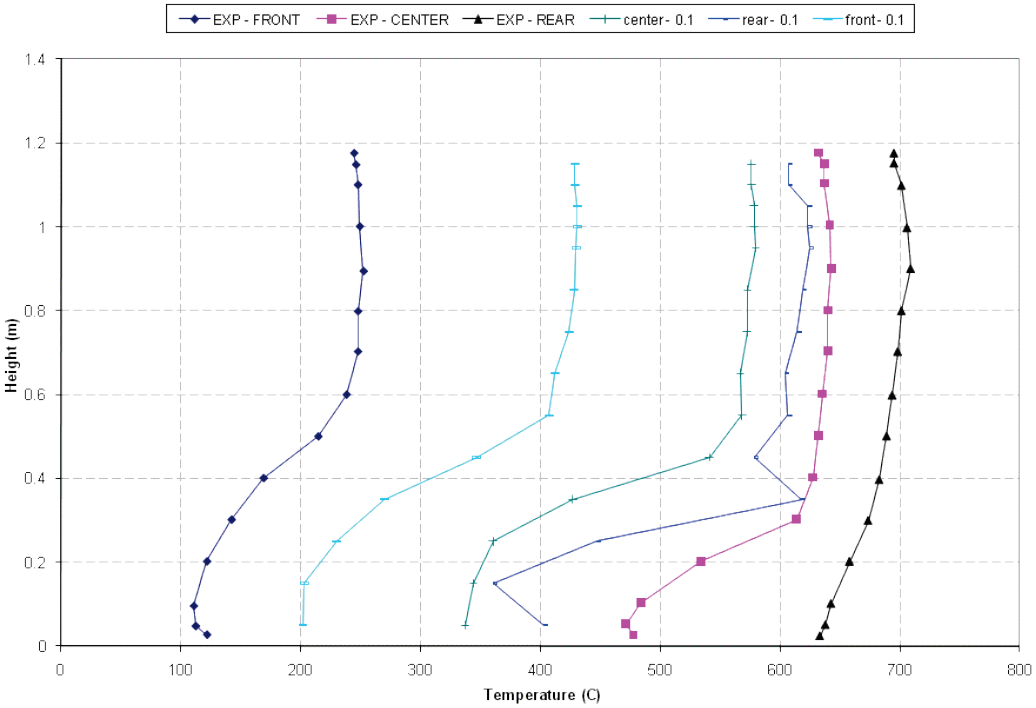


Figure 5-14 – ModFDS Temperature Profile Comparison (DOOR – Mesh 0.1m)

5.2.1.5 Velocity Profile

The velocity profile was measured in the simulation at the same location (center of the vent of the room) as in the experiments done by Parkes. The results of the velocity profile from ModFDS simulations behaved very similar to the results discussed in Section 4.1.1.5.

Like the previous results, the velocity profiles shown in Figure 5-15 to Figure 5-17 (open markers are simulation data and filled markers are experimental data) overestimate the experimental measurements. Although the simulated velocities are overestimated, the height where the velocity goes to zero is fairly well predicted.

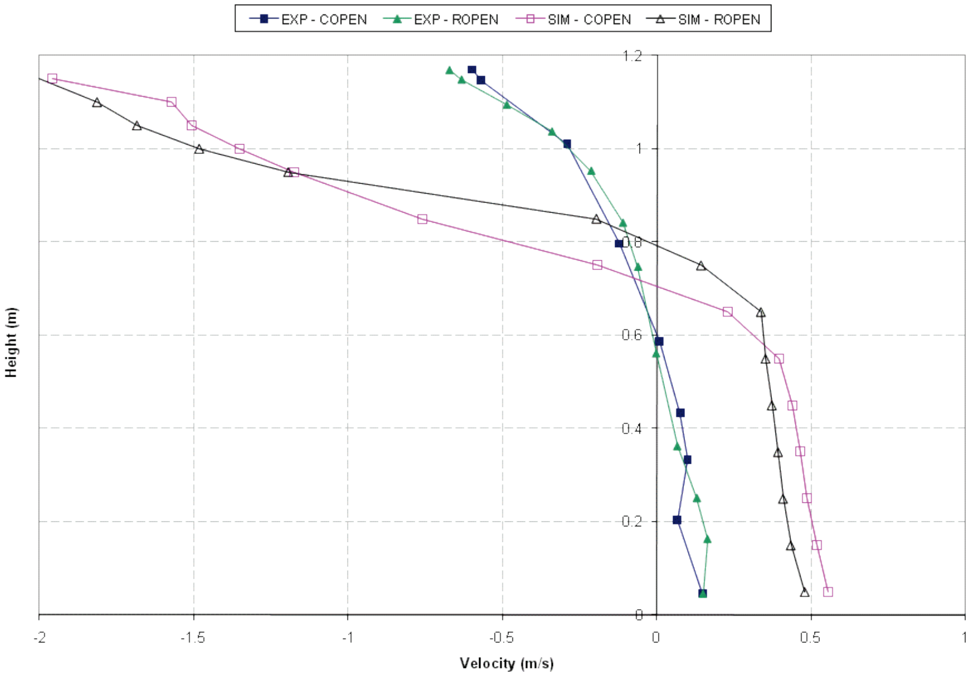


Figure 5-15 – ModFDS Velocity Profile Comparison (OPEN)

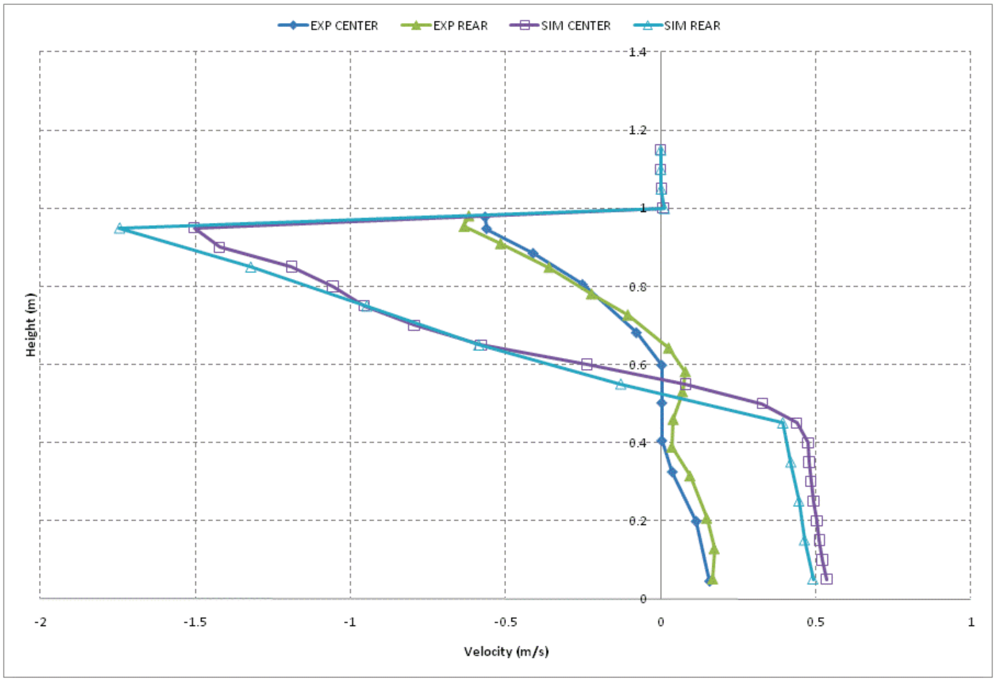


Figure 5-16 – ModFDS Velocity Profile Comparison (SOFFIT)

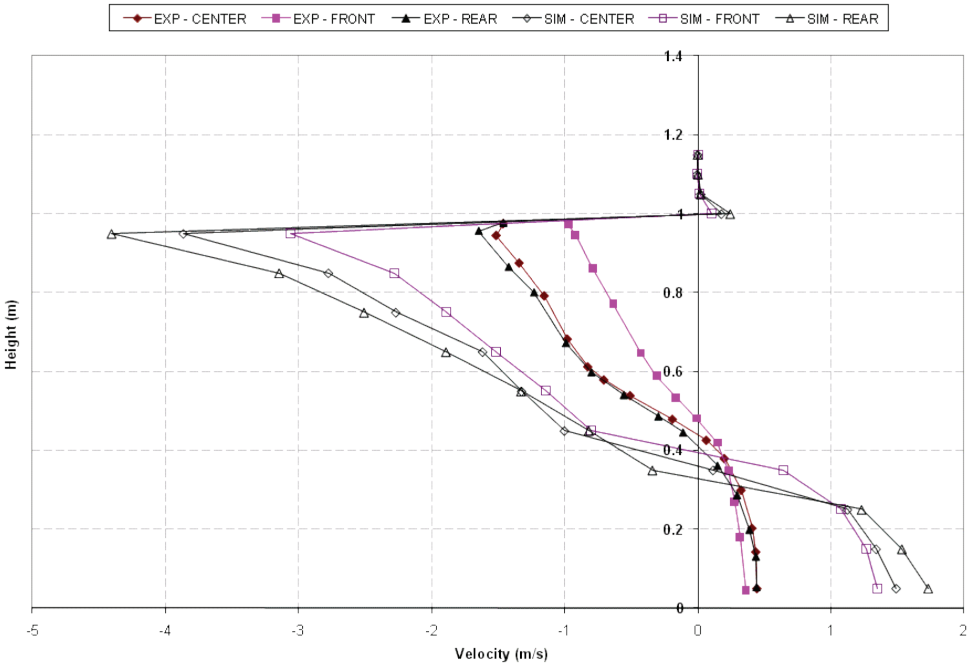


Figure 5-17 – ModFDS Velocity Profile Comparison (DOOR)

The velocity profiles for ModFDS simulation behave very similar to the simulation results in Section 4.1.1.5. The discrepancies could be due to how FDS calculates the velocity and to how the simulated area was defined. The experiments were done in a large lab environment whereas the simulation just included a small open area outside the enclosure (Figure 4-1).

5.2.2 Girgis' and Denize's Experiments

Next the experiments conducted by Girgis and Denize were used to simulate the burning of 5 upholstered chairs (*i.e.* G-21, H-21, I-21, J-21 and L-21) using ModFDS with furniture calorimeter HRR data. The furniture calorimeter data were obtained from the experiments done by Denize (3) and were implemented into ModFDS input file as shown in Appendix E.

Prior to running the simulations the proper ModFDS environment had to be compiled using the II, JJ, KK, IW, heat of gasification and flame heat flux which corresponded to the simulation being run. Unlike ModFDS simulations of Parkes' experiments, the II, JJ, KK and IW values did not vary from simulation to simulation since each chair was burned at the same location. The values hard coded into the source code are found in Table 5-1. The heat of gasification for both the polypropylene fabric and polyurethane foam where found to be approximately $1.4 \text{x} 10^6$ J/kg (31) and $2.0 \text{x} 10^6$ J/kg (31) respectively.

Chen (29) provided the mass fraction of the two materials in the cone calorimeter samples she tested. Using the mass fractions from Chen and the heat of gasification from above, the upholstered chair heat of gasification was determined using the following equation.

$$L_{g,Total} = \left[(Y)(L_g)\right]_{fabric} + \left[(Y)(L_g)\right]_{foam} \tag{5-3}$$

where $L_{g,Total}$ – heat of gasification of upholstered chair [J/kg]

Y_{fabric} – mass fraction of fabric in upholstered chair [g/g]

$L_{g,fabric}$ – heat of gasification of fabric [$2.0 \text{x} 10^6$ J/kg]

Y_{foam} – mass fraction of foam in upholstered chair [g/g]

$L_{g,foam}$ – heat of gasification of foam [$1.4 \text{x} 10^6$ J/kg]

The heat of gasification which was hard coded into the source code for each simulation are shown in Table 5-2. The flame heat flux had to be hard coded in addition and was set to 15000 W/m^2 for the following results.

Table 5-2 – Heat of Gasification of Upholstered Chairs

Chair	Heat of Gasification [J/kg]
G-21	$1.485 \text{x} 10^6$
H-21	$1.466 \text{x} 10^6$
I-21	$1.47 \text{x} 10^6$
J-21	$1.468 \text{x} 10^6$
K-21	$1.468 \text{x} 10^6$

Each simulation was run for 600 seconds because the most important part of the fire (growth and decay) occurred in the first 400 seconds. Minimizing the length of time allowed the results to be obtained sooner. The mesh was coarse due to time constraints and was set to 0.05 meters.

The results from ModFDS simulations were compared to the room calorimeter results measured by Girgis (2). The simulation results for HRR, mass loss, temperature profile and temperature history for the G-21 simulation are in the next sections and the results for the other four chairs can be found in Appendix F.

5.2.2.1 Heat Release Rate

The heat release rate of the simulation did not have a good fit with the room calorimeter measurements as seen in Figure 5-18. The simulated peak HRR value is approximately 600 kW lower than what was measured by Girgis in his experiments. Also, the figure below illustrates how the heat release rate from the simulation is exactly similar to the furniture calorimeter data. Thus, the pyrolysis model did not work as well as it did for the simulations in Section 5.2.1.

Discrepancies could be due to the large value of the heat of gasification and/or the more complex geometry of the upholstered chair compared to the heptane pool fire. The pyrolysis model could also not be suitable for more complex fuels such as the ones found in upholstered furniture.

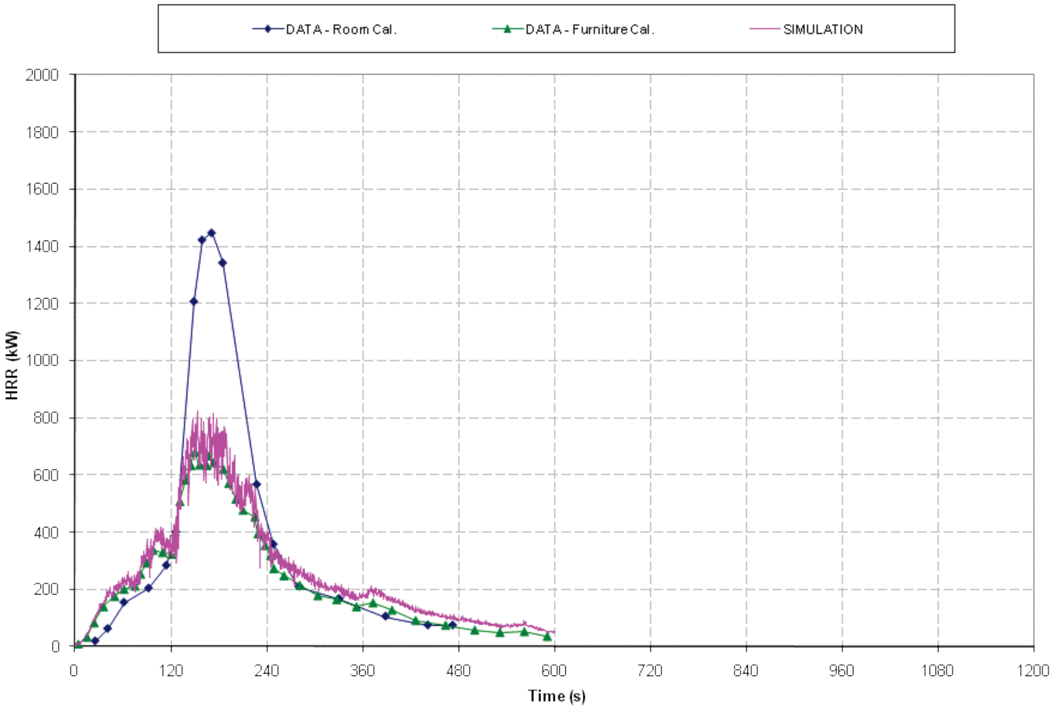


Figure 5-18 – ModFDS HRR Comparison (G-21)

5.2.2.2 Mass Loss History

Figure 5-19 shows the simulation had the same mass loss as the experiment for the first 2 minutes. After two minutes the simulation did not reach a peak HRR as high as observed in the experiment (Figure 5-18) thus causing a slower mass loss in the simulation compared to the experiment.

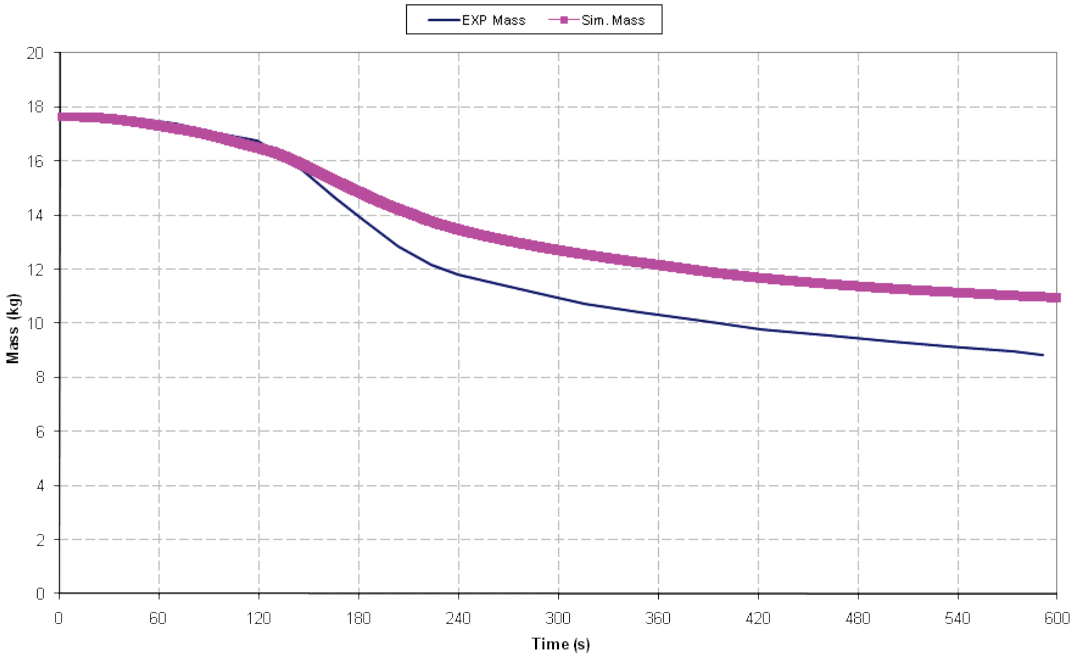


Figure 5-19 – ModFDS Mass Loss History Comparison (G-21)

5.2.2.3 Temperature Profile

The temperature was measured at a thermocouple tree located close to the door and is presented in Figure 5-20. The measurements found in the simulation compare well with the temperature profiles measured by Girgis in his experiments (Figure 4-19). The temperature from Girgis' experiments range from 125ºC to 625ºC, while the temperatures from the simulations range from 350ºC to 525ºC.

Although the HRR of the simulation does not compare well with the experimental results, the temperature profile has a reasonable fit. The simulation results from ModFDS compare well to the experimental results in Figure 4-19.

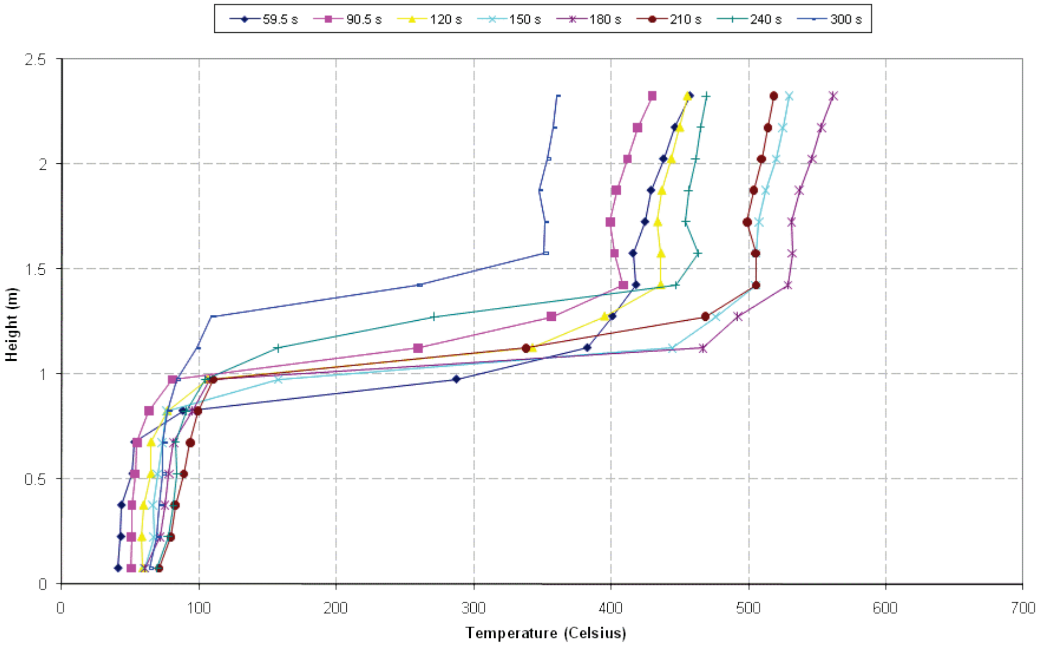


Figure 5-20 – ModFDS Temperature Profile (G-21)

5.2.2.4 Temperature History

The temperature history of the simulation (Figure 5-21) has a fair fit with the experimental data. The simulation data does not behave quite like the experimental data (Figure 4-21). The experimental data peaks in temperature from around 120 to 260 seconds, whereas the simulation data shows the temperature peaks from 40 to 260 seconds.

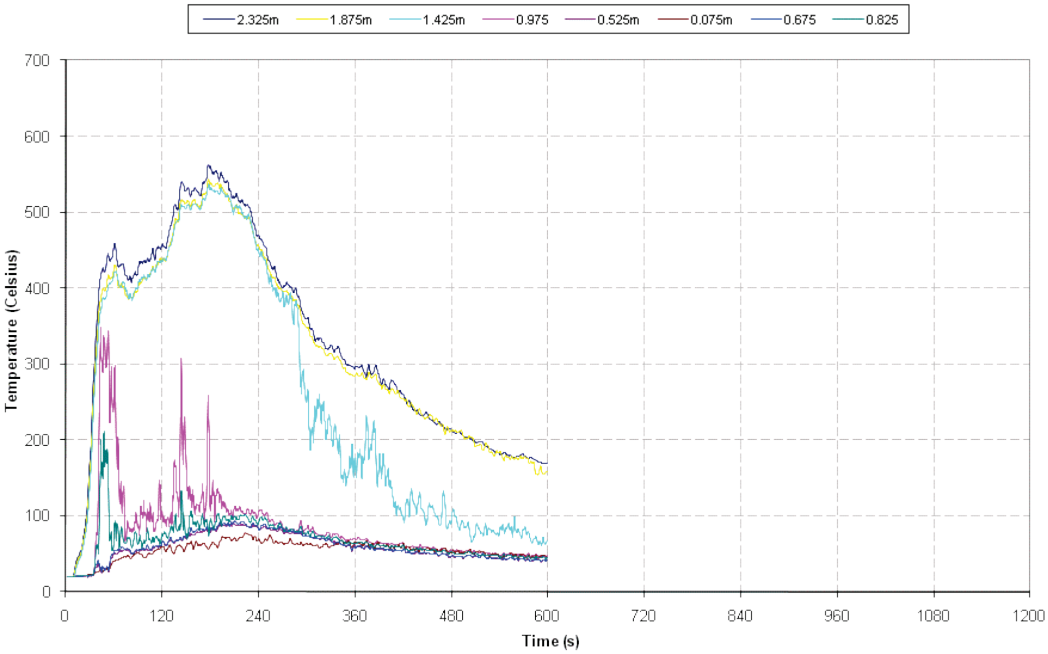


Figure 5-21 – ModFDS Temperature History (G-21)

Figure 5-18 to Figure 5-21 illustrate how ModFDS simulations did not give as good results for the upholstered chairs as it did for the heptane pool fires. It is believed that the pyrolysis model is too simple for more complex fuels and needs to be modified to properly simulate fires of more complex fuels.

5.2.2.5 Effects of Decreased Heat of Gasification

Unlike the simulations from Section 5.2.1, varying the flame heat flux did not change the simulation HRR curve. Thus the only other value which could be altered before running the simulation was the heat of gasification of the fuel. The discrepancies in Figure 5-18 to Figure 5-21 were believed to be the result of the large heat of gasification value of the upholstered chair.

A version of ModFDS was compiled for the G-21 chair which had a heat of gasification value six times smaller than what was given in Table 5-2. The hope was the decreased heat of gasification would increase the HRR in the portion of the curve (120 to 240 seconds) where it did not fit well with the experimental HRR curve.

As seen in Figure 5-22 the HRR does increase, but it increases at every point along the curve. Although a lower heat of gasification affects the HRR curve, simply lowering this value is not the proper way to fix the problem with the pyrolysis model. Instead further work needs to be done to determine how to implement the heat of gasification into the pyrolysis model. Figure 5-22 shows that the heat of gasification plays a dominant role in how the fire grows.

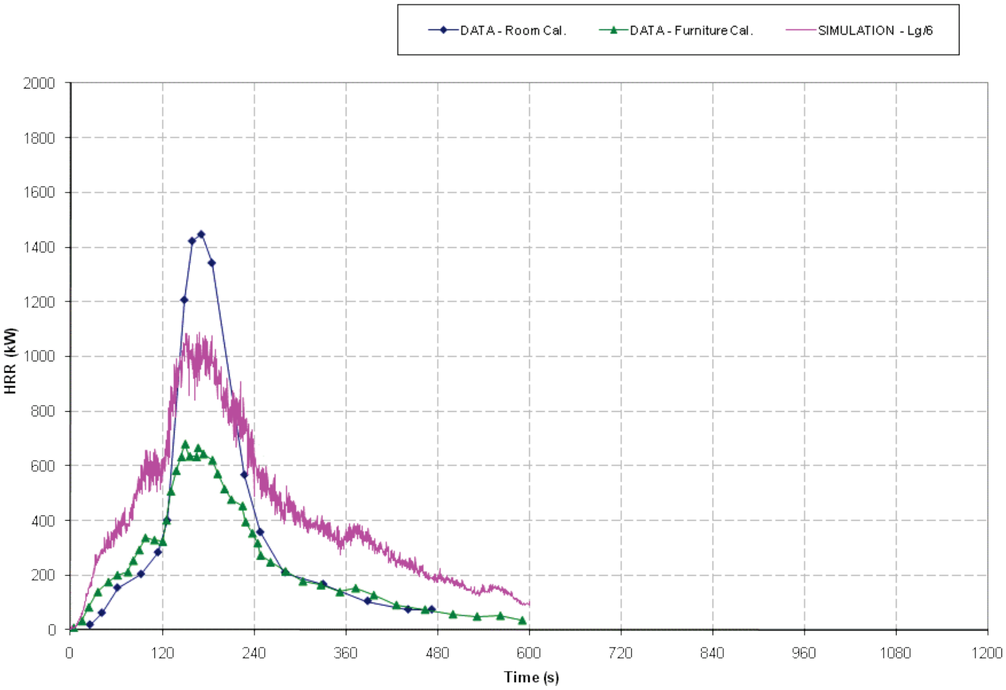


Figure 5-22 – ModFDS HRR Comparison – $L_g/6$ (G-21)

5.3 Conclusion

From the results presented above it can be concluded that Quintiere's simple pyrolysis model works best for simple fuels as illustrated in the simulations of Parkes' heptane experiments. On the other hand more complex fuels (*i.e.* upholstered furniture) do not work well with Quintiere's model when estimating the HRR of the fire.

In both simulations (heptane and upholstered chair), the pyrolysis model did not estimate the HRR curve exactly. Discrepancies could be due to how the pyrolysis model was implemented into ModFDS. Slightly changing the location where the oxygen concentration is measured or how the heat of gasification is manipulated in the model could result in much better simulation results.

6 Conclusion & Future Work

FDS is an engineering tool with many benefits. Unfortunately the current version of FDS is incapable of calculating enclosure effects on the fuel source (*i.e.* the thermal feedback of the smoke layer and the air vitiation) when furniture calorimeter data are used to describe the fuel mass loss rate. This study considers semi-empirical modeling strategies of the fuel mass loss rate based on furniture calorimeter data and theoretical corrections proposed to account for enclosure effects.

This study was broken down into three parts: (1) the development of a database which compiles furniture calorimeter data, (2) the development of a modified version of FDS (ModFDS) that incorporates Quintiere's semi-empirical pyrolysis model and (3) a detailed comparison between FDS results and experimental data.

The database was developed to centrally locate furniture calorimeter data for common household/office furniture. Centrally locating this database on the internet (http://www.FireBID.umd.edu) allows public easy access. The FireBID database provides valuable information for both the fire protection engineering and fire forensic communities. Data from this database were also used to define a fuel source when running ModFDS.

This research considers a simple pyrolysis model that uses furniture calorimeter data and applies a correction to the data to represent enclosure effects. The model is implemented into a modified version of FDS called ModFDS. ModFDS in theory should be able to take fuel sources defined by furniture calorimeter data and produce results similar to room calorimeter results. ModFDS was test in enclosure simulations with two different fuels: a simple fuel (heptane) and a complex fuel (upholstered chair). The ModFDS results were than compared to the room calorimeter measurements. Results obtained with heptane are encouraging whereas results obtained with upholstered chairs are less satisfactory. Note that the pyrolysis model features adjustable factors (the flame heat flux and the heat of gasification) and results can be improved by careful calibration of these factors.

7 Appendix A

The following are the FDS input files for the 7 simulations of Parkes' experiments using room calorimeter HRR data.

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<u>Fire Location</u>: CENTER

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%DEFINES WALLS, CEILING AND FLOOR
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&SURF  ID='CEILING', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='GREEN'/
&SURF  ID='FLOOR', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='BLUE'/

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&RAMP  ID='COND_RAMP', T=426.7, F=0.081/
&RAMP  ID='COND_RAMP', T=648.9, F=0.147/
&RAMP  ID='COND_RAMP', T=871.1, F=0.193/
&RAMP  ID='COND_RAMP', T=1093.3, F=0.288/

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&VENT  MB=XMAX, SURF_ID='WALL'/
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       ID='Tw_2'/

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&DEVC  XYZ=0.15,2.3,0.15   QUANTITY='THERMOCOUPLE'    ID='TC2'/
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Fire Location: REAR

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%DEFINES FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='PINK'/
&SURF  ID='CEILING', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='GREEN'/
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       PLOT3D_QUANTITY(2)='W-VELOCITY'
       PLOT3D_QUANTITY(3)='HRRPUV'
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//WALL TEMPERATURE//
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       ID='Tw_2'/

//THERMOCOUPLE TEMPERATURE AT 2 POINTS//
&DEVC  XYZ=0.15,2.3,0.05    QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15    QUANTITY='THERMOCOUPLE'    ID='TC2'/
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&DEVC  XYZ=0.15,2.3,0.55    QUANTITY='THERMOCOUPLE'    ID='TC6'/
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Vent: SOFFIT
Fire Location: CENTER

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&MESH  IJK=184,96,48, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0 / MESH #1

%DEFINES FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='PINK'/
&SURF  ID='CEILING', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='GREEN'/
&SURF  ID='FLOOR', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='BLUE'/

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       SPECIFIC_HEAT=1.13,  EMISSIVITY=0.9/

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&RAMP  ID='COND_RAMP', T=871.1, F=0.193/
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&SURF  ID='BURNER'   MLRPUA=0.051  RAMP_Q='MLRPUA_RAMP'/
&RAMP  ID='MLRPUA_RAMP'     T=0.0         F=0.0/
&RAMP  ID='MLRPUA_RAMP'     T=10.         F=0.11/
&RAMP  ID='MLRPUA_RAMP'     T=35.         F=0.22/
&RAMP  ID='MLRPUA_RAMP'     T=60.         F=0.43/
&RAMP  ID='MLRPUA_RAMP'     T=90.         F=0.54/
&RAMP  ID='MLRPUA_RAMP'     T=125.        F=0.65/
&RAMP  ID='MLRPUA_RAMP'     T=205.        F=0.76/
&RAMP  ID='MLRPUA_RAMP'     T=275.        F=0.87/
&RAMP  ID='MLRPUA_RAMP'     T=435.        F=0.91/
&RAMP  ID='MLRPUA_RAMP'     T=525.        F=0.96/
&RAMP  ID='MLRPUA_RAMP'     T=635.        F=1.0/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
       DT_HRR=0.5
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='W-VELOCITY'
       PLOT3D_QUANTITY(3)='HRRPUV'
       PLOT3D_QUANTITY(4)='TEMPERATURE'/
```

```
//TWO HEAT FLUX GAUGES//
&DEVC  XYZ=1.2,1.2,0       QUANTITY='GAUGE HEAT FLUX'        IOR=+3
       ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0       QUANTITY='GAUGE HEAT FLUX'        IOR=+3
       ID='HF_2'/

//WALL TEMPERATURE//
&DEVC  XYZ=1.2,1.2,0.02    QUANTITY='WALL TEMPERATURE'       IOR=+3
       ID='Tw_1'/
&DEVC  XYZ=2.4,1.2,0.02    QUANTITY='WALL TEMPERATURE'       IOR=+3
       ID='Tw_2'/

//THERMOCOUPLE TEMPERATURE AT 2 POINTS//
&DEVC  XYZ=0.15,2.3,0.05   QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15   QUANTITY='THERMOCOUPLE'    ID='TC2'/
&DEVC  XYZ=0.15,2.3,0.25   QUANTITY='THERMOCOUPLE'    ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.35   QUANTITY='THERMOCOUPLE'    ID='TC4'/
&DEVC  XYZ=0.15,2.3,0.45   QUANTITY='THERMOCOUPLE'    ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.55   QUANTITY='THERMOCOUPLE'    ID='TC6'/
&DEVC  XYZ=0.15,2.3,0.65   QUANTITY='THERMOCOUPLE'    ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.75   QUANTITY='THERMOCOUPLE'    ID='TC8'/
&DEVC  XYZ=0.15,2.3,0.85   QUANTITY='THERMOCOUPLE'    ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.95   QUANTITY='THERMOCOUPLE'    ID='TC10'/
&DEVC  XYZ=0.15,2.3,1      QUANTITY='THERMOCOUPLE'    ID='TC11'/
&DEVC  XYZ=0.15,2.3,1.05   QUANTITY='THERMOCOUPLE'    ID='TC12'/
&DEVC  XYZ=0.15,2.3,1.1    QUANTITY='THERMOCOUPLE'    ID='TC13'/
&DEVC  XYZ=0.15,2.3,1.15   QUANTITY='THERMOCOUPLE'    ID='TC14'/

//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05    QUANTITY='U-VELOCITY'      ID='U1'/
&DEVC  XYZ=0,1.2,0.15      QUANTITY='U-VELOCITY'      ID='U2'/
&DEVC  XYZ=0,1.2,0.25      QUANTITY='U-VELOCITY'      ID='U3'/
&DEVC  XYZ=0,1.2,0.35      QUANTITY='U-VELOCITY'      ID='U4'/
&DEVC  XYZ=0.0,1.2,0.45    QUANTITY='U-VELOCITY'      ID='U5'/
&DEVC  XYZ=0.0,1.2,0.55    QUANTITY='U-VELOCITY'      ID='U6'/
&DEVC  XYZ=0.0,1.2,0.65    QUANTITY='U-VELOCITY'      ID='U7'/
&DEVC  XYZ=0.0,1.2,0.75    QUANTITY='U-VELOCITY'      ID='U8'/
&DEVC  XYZ=0.0,1.2,0.85    QUANTITY='U-VELOCITY'      ID='U9'/
&DEVC  XYZ=0.0,1.2,0.95    QUANTITY='U-VELOCITY'      ID='U10'/
&DEVC  XYZ=0.0,1.2,1.0     QUANTITY='U-VELOCITY'      ID='U11'/
&DEVC  XYZ=0.0,1.2,1.05    QUANTITY='U-VELOCITY'      ID='U12'/
&DEVC  XYZ=0.0,1.2,1.1     QUANTITY='U-VELOCITY'      ID='U13'/
&DEVC  XYZ=0.0,1.2,1.15    QUANTITY='U-VELOCITY'      ID='U14'/
```

&TAIL/

Vent: SOFFIT

Fire Location: REAR

```
&HEAD  CHID= 'R-SOFFIT-05'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - REAR - SOFFIT'/

&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=184,96,48, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0 / MESH #1

%DEFINES FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='PINK'/
&SURF  ID='CEILING', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='GREEN'/
&SURF  ID='FLOOR', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='BLUE'/

&MATL  ID='FIBERBOARD',        CONDUCTIVITY_RAMP='COND_RAMP',        DENSITY=288.,
       SPECIFIC_HEAT=1.13,  EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP', T=20., F=0.043/
&RAMP  ID='COND_RAMP', T=204.4, F=0.052/
&RAMP  ID='COND_RAMP', T=426.7, F=0.081/
&RAMP  ID='COND_RAMP', T=648.9, F=0.147/
&RAMP  ID='COND_RAMP', T=871.1, F=0.193/
&RAMP  ID='COND_RAMP', T=1093.3, F=0.288/

&VENT  MB=XMIN, SURF_ID='OPEN'/
&VENT  MB=XMAX, SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2, SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2, SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2, SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2, SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0, SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0, SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,1.2,1.2, SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2, SURF_ID='OPEN'/
&OBST  XB=0.0,0.02,0.0,2.4,1.0,1.2, SURF_ID='WALL'/
&OBST  XB=2.9,3.1,1.1,1.3,0.0,0.05, SURF_IDS='BURNER','INERT','INERT'/

&SURF  ID='BURNER'   MLRPUA=0.065  RAMP_Q='MLRPUA_RAMP'/
&RAMP  ID='MLRPUA_RAMP'     T=0.0         F=0.0/
&RAMP  ID='MLRPUA_RAMP'     T=10.         F=0.11/
&RAMP  ID='MLRPUA_RAMP'     T=35.         F=0.22/
&RAMP  ID='MLRPUA_RAMP'     T=60.         F=0.43/
&RAMP  ID='MLRPUA_RAMP'     T=90.         F=0.54/
&RAMP  ID='MLRPUA_RAMP'     T=125.        F=0.65/
&RAMP  ID='MLRPUA_RAMP'     T=205.        F=0.76/
&RAMP  ID='MLRPUA_RAMP'     T=275.        F=0.87/
&RAMP  ID='MLRPUA_RAMP'     T=435.        F=0.91/
&RAMP  ID='MLRPUA_RAMP'     T=525.        F=0.96/
&RAMP  ID='MLRPUA_RAMP'     T=635.        F=1.0/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
       DT_HRR=0.5
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='W-VELOCITY'
       PLOT3D_QUANTITY(3)='HRRPUV'
       PLOT3D_QUANTITY(4)='TEMPERATURE'/
```

```
//TWO HEAT FLUX GAUGES//
&DEVC  XYZ=1.2,1.2,0        QUANTITY='GAUGE HEAT FLUX'        IOR=+3
       ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0        QUANTITY='GAUGE HEAT FLUX'        IOR=+3
       ID='HF_2'/

//WALL TEMPERATURE//
&DEVC  XYZ=1.2,1.2,0.02     QUANTITY='WALL TEMPERATURE'       IOR=+3
       ID='Tw_1'/
&DEVC  XYZ=2.4,1.2,0.02     QUANTITY='WALL TEMPERATURE'       IOR=+3
       ID='Tw_2'/

//THERMOCOUPLE TEMPERATURE AT 2 POINTS//
&DEVC  XYZ=0.15,2.3,0.05    QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15    QUANTITY='THERMOCOUPLE'    ID='TC2'/
&DEVC  XYZ=0.15,2.3,0.25    QUANTITY='THERMOCOUPLE'    ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.35    QUANTITY='THERMOCOUPLE'    ID='TC4'/
&DEVC  XYZ=0.15,2.3,0.45    QUANTITY='THERMOCOUPLE'    ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.55    QUANTITY='THERMOCOUPLE'    ID='TC6'/
&DEVC  XYZ=0.15,2.3,0.65    QUANTITY='THERMOCOUPLE'    ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.75    QUANTITY='THERMOCOUPLE'    ID='TC8'/
&DEVC  XYZ=0.15,2.3,0.85    QUANTITY='THERMOCOUPLE'    ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.95    QUANTITY='THERMOCOUPLE'    ID='TC10'/
&DEVC  XYZ=0.15,2.3,1       QUANTITY='THERMOCOUPLE'    ID='TC11'/
&DEVC  XYZ=0.15,2.3,1.05    QUANTITY='THERMOCOUPLE'    ID='TC12'/
&DEVC  XYZ=0.15,2.3,1.1     QUANTITY='THERMOCOUPLE'    ID='TC13'/
&DEVC  XYZ=0.15,2.3,1.15    QUANTITY='THERMOCOUPLE'    ID='TC14'/

//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05     QUANTITY='U-VELOCITY'      ID='U1'/
&DEVC  XYZ=0,1.2,0.15       QUANTITY='U-VELOCITY'      ID='U2'/
&DEVC  XYZ=0,1.2,0.25       QUANTITY='U-VELOCITY'      ID='U3'/
&DEVC  XYZ=0,1.2,0.35       QUANTITY='U-VELOCITY'      ID='U4'/
&DEVC  XYZ=0.0,1.2,0.45     QUANTITY='U-VELOCITY'      ID='U5'/
&DEVC  XYZ=0.0,1.2,0.55     QUANTITY='U-VELOCITY'      ID='U6'/
&DEVC  XYZ=0.0,1.2,0.65     QUANTITY='U-VELOCITY'      ID='U7'/
&DEVC  XYZ=0.0,1.2,0.75     QUANTITY='U-VELOCITY'      ID='U8'/
&DEVC  XYZ=0.0,1.2,0.85     QUANTITY='U-VELOCITY'      ID='U9'/
&DEVC  XYZ=0.0,1.2,0.95     QUANTITY='U-VELOCITY'      ID='U10'/
&DEVC  XYZ=0.0,1.2,1.0      QUANTITY='U-VELOCITY'      ID='U11'/
&DEVC  XYZ=0.0,1.2,1.05     QUANTITY='U-VELOCITY'      ID='U12'/
&DEVC  XYZ=0.0,1.2,1.1      QUANTITY='U-VELOCITY'      ID='U13'/
&DEVC  XYZ=0.0,1.2,1.15     QUANTITY='U-VELOCITY'      ID='U14'/
```

&TAIL/

Vent: DOOR

Fire Location: CENTER

```
&HEAD  CHID= 'C-DOOR-05'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - CENTER - DOORWAY'/

&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=184,96,48, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0 / MESH #1

%DEFINES FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='PINK'/
&SURF  ID='CEILING', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='GREEN'/
&SURF  ID='FLOOR', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='BLUE'/

&MATL  ID='FIBERBOARD',       CONDUCTIVITY_RAMP='COND_RAMP',       DENSITY=288.,
       SPECIFIC_HEAT=1.13,  EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP', T=20., F=0.043/
&RAMP  ID='COND_RAMP', T=204.4, F=0.052/
&RAMP  ID='COND_RAMP', T=426.7, F=0.081/
&RAMP  ID='COND_RAMP', T=648.9, F=0.147/
&RAMP  ID='COND_RAMP', T=871.1, F=0.193/
&RAMP  ID='COND_RAMP', T=1093.3, F=0.288/

&VENT  MB=XMIN, SURF_ID='OPEN'/
&VENT  MB=XMAX, SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2, SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2, SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2, SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2, SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0, SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0, SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,1.2,1.2, SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2, SURF_ID='OPEN'/
&OBST  XB=0.0,0.02,0.0,2.4,1.0,1.2, SURF_ID='WALL'/
&OBST  XB=0.0,0.02,0.0,1.0,0.0,1.0, SURF_ID='WALL'/
&OBST  XB=0.0,0.02,1.4,2.4,0.0,1.0, SURF_ID='WALL'/
&OBST  XB=1.7,1.9,1.1,1.3,0.0,0.05, SURF_IDS='BURNER','INERT','INERT'/

&SURF  ID='BURNER',  HRRPUA=6875,  RAMP_Q='HRRPUA_RAMP'/
&RAMP  ID='HRRPUA_RAMP'     T=0.0         F=0.0/
&RAMP  ID='HRRPUA_RAMP'     T=240.        F=0.2/
&RAMP  ID='HRRPUA_RAMP'     T=480.        F=0.32/
&RAMP  ID='HRRPUA_RAMP'     T=720.        F=0.4/
&RAMP  ID='HRRPUA_RAMP'     T=960.        F=0.47/
&RAMP  ID='HRRPUA_RAMP'     T=1200.       F=0.53/
&RAMP  ID='HRRPUA_RAMP'     T=1440.       F=0.58/
&RAMP  ID='HRRPUA_RAMP'     T=1680.       F=0.64/
&RAMP  ID='HRRPUA_RAMP'     T=1920.       F=0.69/
&RAMP  ID='HRRPUA_RAMP'     T=2160.       F=0.76/
&RAMP  ID='HRRPUA_RAMP'     T=2400.       F=0.84/
&RAMP  ID='HRRPUA_RAMP'     T=2640.       F=0.89/
&RAMP  ID='HRRPUA_RAMP'     T=2880.       F=0.95/
&RAMP  ID='HRRPUA_RAMP'     T=3120.       F=0.98/
&RAMP  ID='HRRPUA_RAMP'     T=3360.       F=1.0/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
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```
       DT_HRR=0.5
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='W-VELOCITY'
       PLOT3D_QUANTITY(3)='HRRPUV'
       PLOT3D_QUANTITY(4)='TEMPERATURE'/

//TWO HEAT FLUX GAUGES//
&DEVC  XYZ=1.2,1.2,0        QUANTITY='GAUGE HEAT FLUX'         IOR=+3
       ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0        QUANTITY='GAUGE HEAT FLUX'         IOR=+3
       ID='HF_2'/

//WALL TEMPERATURE//
&DEVC  XYZ=1.2,1.2,0.02     QUANTITY='WALL TEMPERATURE'        IOR=+3
       ID='Tw_1'/
&DEVC  XYZ=2.4,1.2,0.02     QUANTITY='WALL TEMPERATURE'        IOR=+3
       ID='Tw_2'/

//THERMOCOUPLE TEMPERATURE AT 2 POINTS//
&DEVC  XYZ=0.15,2.3,0.05    QUANTITY='THERMOCOUPLE'     ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15    QUANTITY='THERMOCOUPLE'     ID='TC2'/
&DEVC  XYZ=0.15,2.3,0.25    QUANTITY='THERMOCOUPLE'     ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.35    QUANTITY='THERMOCOUPLE'     ID='TC4'/
&DEVC  XYZ=0.15,2.3,0.45    QUANTITY='THERMOCOUPLE'     ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.55    QUANTITY='THERMOCOUPLE'     ID='TC6'/
&DEVC  XYZ=0.15,2.3,0.65    QUANTITY='THERMOCOUPLE'     ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.75    QUANTITY='THERMOCOUPLE'     ID='TC8'/
&DEVC  XYZ=0.15,2.3,0.85    QUANTITY='THERMOCOUPLE'     ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.95    QUANTITY='THERMOCOUPLE'     ID='TC10'/
&DEVC  XYZ=0.15,2.3,1       QUANTITY='THERMOCOUPLE'     ID='TC11'/
&DEVC  XYZ=0.15,2.3,1.05    QUANTITY='THERMOCOUPLE'     ID='TC12'/
&DEVC  XYZ=0.15,2.3,1.1     QUANTITY='THERMOCOUPLE'     ID='TC13'/
&DEVC  XYZ=0.15,2.3,1.15    QUANTITY='THERMOCOUPLE'     ID='TC14'/

//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05     QUANTITY='U-VELOCITY'       ID='U1'/
&DEVC  XYZ=0,1.2,0.15       QUANTITY='U-VELOCITY'       ID='U2'/
&DEVC  XYZ=0,1.2,0.25       QUANTITY='U-VELOCITY'       ID='U3'/
&DEVC  XYZ=0,1.2,0.35       QUANTITY='U-VELOCITY'       ID='U4'/
&DEVC  XYZ=0.0,1.2,0.45     QUANTITY='U-VELOCITY'       ID='U5'/
&DEVC  XYZ=0.0,1.2,0.55     QUANTITY='U-VELOCITY'       ID='U6'/
&DEVC  XYZ=0.0,1.2,0.65     QUANTITY='U-VELOCITY'       ID='U7'/
&DEVC  XYZ=0.0,1.2,0.75     QUANTITY='U-VELOCITY'       ID='U8'/
&DEVC  XYZ=0.0,1.2,0.85     QUANTITY='U-VELOCITY'       ID='U9'/
&DEVC  XYZ=0.0,1.2,0.95     QUANTITY='U-VELOCITY'       ID='U10'/
&DEVC  XYZ=0.0,1.2,1.0      QUANTITY='U-VELOCITY'       ID='U11'/
&DEVC  XYZ=0.0,1.2,1.05     QUANTITY='U-VELOCITY'       ID='U12'/
&DEVC  XYZ=0.0,1.2,1.1      QUANTITY='U-VELOCITY'       ID='U13'/
&DEVC  XYZ=0.0,1.2,1.15     QUANTITY='U-VELOCITY'       ID='U14'/

&TAIL/
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Vent: DOOR

Fire Location: FRONT

```
&HEAD  CHID= 'F-DOOR-05'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - FRONT - DOORWAY'/

&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=184,96,48, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0 / MESH #1

%DEFINES FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='PINK'/
&SURF  ID='CEILING', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='GREEN'/
&SURF  ID='FLOOR', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='BLUE'/

&MATL  ID='FIBERBOARD',       CONDUCTIVITY_RAMP='COND_RAMP',       DENSITY=288.,
       SPECIFIC_HEAT=1.13,  EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP', T=20., F=0.043/
&RAMP  ID='COND_RAMP', T=204.4, F=0.052/
&RAMP  ID='COND_RAMP', T=426.7, F=0.081/
&RAMP  ID='COND_RAMP', T=648.9, F=0.147/
&RAMP  ID='COND_RAMP', T=871.1, F=0.193/
&RAMP  ID='COND_RAMP', T=1093.3, F=0.288/

&VENT  MB=XMIN, SURF_ID='OPEN'/
&VENT  MB=XMAX, SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2, SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2, SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2, SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2, SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0, SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0, SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,1.2,1.2, SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2, SURF_ID='OPEN'/
&OBST  XB=0.0,0.02,0.0,2.4,1.0,1.2, SURF_ID='WALL'/
&OBST  XB=0.0,0.02,0.0,1.0,0.0,1.0, SURF_ID='WALL'/
&OBST  XB=0.0,0.02,1.4,2.4,0.0,1.0, SURF_ID='WALL'/
&OBST  XB=0.5,0.7,1.1,1.3,0.0,0.05, SURF_IDS='BURNER','INERT','INERT'/

&SURF  ID='BURNER',  HRRPUA=1875,  RAMP_Q='HRRPUA_RAMP'/
&RAMP  ID='HRRPUA_RAMP'     T=0.0         F=0.0/
&RAMP  ID='HRRPUA_RAMP'     T=240.        F=0.2/
&RAMP  ID='HRRPUA_RAMP'     T=480.        F=0.32/
&RAMP  ID='HRRPUA_RAMP'     T=720.        F=0.4/
&RAMP  ID='HRRPUA_RAMP'     T=960.        F=0.47/
&RAMP  ID='HRRPUA_RAMP'     T=1200.       F=0.53/
&RAMP  ID='HRRPUA_RAMP'     T=1440.       F=0.58/
&RAMP  ID='HRRPUA_RAMP'     T=1680.       F=0.64/
&RAMP  ID='HRRPUA_RAMP'     T=1920.       F=0.69/
&RAMP  ID='HRRPUA_RAMP'     T=2160.       F=0.76/
&RAMP  ID='HRRPUA_RAMP'     T=2400.       F=0.84/
&RAMP  ID='HRRPUA_RAMP'     T=2640.       F=0.89/
&RAMP  ID='HRRPUA_RAMP'     T=2880.       F=0.95/
&RAMP  ID='HRRPUA_RAMP'     T=3120.       F=0.98/
&RAMP  ID='HRRPUA_RAMP'     T=3360.       F=1.0/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
```

```
       DT_HRR=0.5
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='W-VELOCITY'
       PLOT3D_QUANTITY(3)='HRRPUV'
       PLOT3D_QUANTITY(4)='TEMPERATURE'/

//TWO HEAT FLUX GAUGES//
&DEVC  XYZ=1.2,1.2,0        QUANTITY='GAUGE HEAT FLUX'         IOR=+3
       ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0        QUANTITY='GAUGE HEAT FLUX'         IOR=+3
       ID='HF_2'/

//WALL TEMPERATURE//
&DEVC  XYZ=1.2,1.2,0.02     QUANTITY='WALL TEMPERATURE'        IOR=+3
       ID='Tw_1'/
&DEVC  XYZ=2.4,1.2,0.02     QUANTITY='WALL TEMPERATURE'        IOR=+3
       ID='Tw_2'/

//THERMOCOUPLE TEMPERATURE AT 2 POINTS//
&DEVC  XYZ=0.15,2.3,0.05    QUANTITY='THERMOCOUPLE'     ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15    QUANTITY='THERMOCOUPLE'     ID='TC2'/
&DEVC  XYZ=0.15,2.3,0.25    QUANTITY='THERMOCOUPLE'     ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.35    QUANTITY='THERMOCOUPLE'     ID='TC4'/
&DEVC  XYZ=0.15,2.3,0.45    QUANTITY='THERMOCOUPLE'     ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.55    QUANTITY='THERMOCOUPLE'     ID='TC6'/
&DEVC  XYZ=0.15,2.3,0.65    QUANTITY='THERMOCOUPLE'     ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.75    QUANTITY='THERMOCOUPLE'     ID='TC8'/
&DEVC  XYZ=0.15,2.3,0.85    QUANTITY='THERMOCOUPLE'     ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.95    QUANTITY='THERMOCOUPLE'     ID='TC10'/
&DEVC  XYZ=0.15,2.3,1       QUANTITY='THERMOCOUPLE'     ID='TC11'/
&DEVC  XYZ=0.15,2.3,1.05    QUANTITY='THERMOCOUPLE'     ID='TC12'/
&DEVC  XYZ=0.15,2.3,1.1     QUANTITY='THERMOCOUPLE'     ID='TC13'/
&DEVC  XYZ=0.15,2.3,1.15    QUANTITY='THERMOCOUPLE'     ID='TC14'/

//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05     QUANTITY='U-VELOCITY'       ID='U1'/
&DEVC  XYZ=0,1.2,0.15       QUANTITY='U-VELOCITY'       ID='U2'/
&DEVC  XYZ=0,1.2,0.25       QUANTITY='U-VELOCITY'       ID='U3'/
&DEVC  XYZ=0,1.2,0.35       QUANTITY='U-VELOCITY'       ID='U4'/
&DEVC  XYZ=0.0,1.2,0.45     QUANTITY='U-VELOCITY'       ID='U5'/
&DEVC  XYZ=0.0,1.2,0.55     QUANTITY='U-VELOCITY'       ID='U6'/
&DEVC  XYZ=0.0,1.2,0.65     QUANTITY='U-VELOCITY'       ID='U7'/
&DEVC  XYZ=0.0,1.2,0.75     QUANTITY='U-VELOCITY'       ID='U8'/
&DEVC  XYZ=0.0,1.2,0.85     QUANTITY='U-VELOCITY'       ID='U9'/
&DEVC  XYZ=0.0,1.2,0.95     QUANTITY='U-VELOCITY'       ID='U10'/
&DEVC  XYZ=0.0,1.2,1.0      QUANTITY='U-VELOCITY'       ID='U11'/
&DEVC  XYZ=0.0,1.2,1.05     QUANTITY='U-VELOCITY'       ID='U12'/
&DEVC  XYZ=0.0,1.2,1.1      QUANTITY='U-VELOCITY'       ID='U13'/
&DEVC  XYZ=0.0,1.2,1.15     QUANTITY='U-VELOCITY'       ID='U14'/

&TAIL/
```

Vent: DOOR
Fire Location: REAR

```
&HEAD  CHID= 'R-DOOR-05'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - REAR - DOORWAY'/

&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=184,96,48, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0 / MESH #1

%DEFINES FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='PINK'/
&SURF  ID='CEILING', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='GREEN'/
&SURF  ID='FLOOR', MATL_ID='FIBERBOARD', THICKNESS=0.02, COLOR='BLUE'/

&MATL  ID='FIBERBOARD',       CONDUCTIVITY_RAMP='COND_RAMP',       DENSITY=288.,
       SPECIFIC_HEAT=1.13,  EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP', T=20., F=0.043/
&RAMP  ID='COND_RAMP', T=204.4, F=0.052/
&RAMP  ID='COND_RAMP', T=426.7, F=0.081/
&RAMP  ID='COND_RAMP', T=648.9, F=0.147/
&RAMP  ID='COND_RAMP', T=871.1, F=0.193/
&RAMP  ID='COND_RAMP', T=1093.3, F=0.288/

&VENT  MB=XMIN, SURF_ID='OPEN'/
&VENT  MB=XMAX, SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2, SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2, SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2, SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2, SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0, SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0, SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,1.2,1.2, SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2, SURF_ID='OPEN'/
&OBST  XB=0.0,0.02,0.0,2.4,1.0,1.2, SURF_ID='WALL'/
&OBST  XB=0.0,0.02,0.0,1.0,0.0,1.0, SURF_ID='WALL'/
&OBST  XB=0.0,0.02,1.4,2.4,0.0,1.0, SURF_ID='WALL'/
&OBST  XB=2.9,3.1,1.1,1.3,0.0,0.05, SURF_IDS='BURNER','INERT','INERT'/

&SURF  ID='BURNER',  HRRPUA=8250,  RAMP_Q='HRRPUA_RAMP'/
&RAMP  ID='HRRPUA_RAMP'     T=0.0         F=0.0/
&RAMP  ID='HRRPUA_RAMP'     T=240.        F=0.2/
&RAMP  ID='HRRPUA_RAMP'     T=480.        F=0.32/
&RAMP  ID='HRRPUA_RAMP'     T=720.        F=0.4/
&RAMP  ID='HRRPUA_RAMP'     T=960.        F=0.47/
&RAMP  ID='HRRPUA_RAMP'     T=1200.       F=0.53/
&RAMP  ID='HRRPUA_RAMP'     T=1440.       F=0.58/
&RAMP  ID='HRRPUA_RAMP'     T=1680.       F=0.64/
&RAMP  ID='HRRPUA_RAMP'     T=1920.       F=0.69/
&RAMP  ID='HRRPUA_RAMP'     T=2160.       F=0.76/
&RAMP  ID='HRRPUA_RAMP'     T=2400.       F=0.84/
&RAMP  ID='HRRPUA_RAMP'     T=2640.       F=0.89/
&RAMP  ID='HRRPUA_RAMP'     T=2880.       F=0.95/
&RAMP  ID='HRRPUA_RAMP'     T=3120.       F=0.98/
&RAMP  ID='HRRPUA_RAMP'     T=3360.       F=1.0/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
```

```
       DT_HRR=0.5
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='W-VELOCITY'
       PLOT3D_QUANTITY(3)='HRRPUV'
       PLOT3D_QUANTITY(4)='TEMPERATURE'/

//TWO HEAT FLUX GAUGES//
&DEVC  XYZ=1.2,1.2,0       QUANTITY='GAUGE HEAT FLUX'        IOR=+3
       ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0       QUANTITY='GAUGE HEAT FLUX'        IOR=+3
       ID='HF_2'/

//WALL TEMPERATURE//
&DEVC  XYZ=1.2,1.2,0.02    QUANTITY='WALL TEMPERATURE'       IOR=+3
       ID='Tw_1'/
&DEVC  XYZ=2.4,1.2,0.02    QUANTITY='WALL TEMPERATURE'       IOR=+3
       ID='Tw_2'/

//THERMOCOUPLE TEMPERATURE AT 2 POINTS//
&DEVC  XYZ=0.15,2.3,0.05   QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15   QUANTITY='THERMOCOUPLE'    ID='TC2'/
&DEVC  XYZ=0.15,2.3,0.25   QUANTITY='THERMOCOUPLE'    ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.35   QUANTITY='THERMOCOUPLE'    ID='TC4'/
&DEVC  XYZ=0.15,2.3,0.45   QUANTITY='THERMOCOUPLE'    ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.55   QUANTITY='THERMOCOUPLE'    ID='TC6'/
&DEVC  XYZ=0.15,2.3,0.65   QUANTITY='THERMOCOUPLE'    ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.75   QUANTITY='THERMOCOUPLE'    ID='TC8'/
&DEVC  XYZ=0.15,2.3,0.85   QUANTITY='THERMOCOUPLE'    ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.95   QUANTITY='THERMOCOUPLE'    ID='TC10'/
&DEVC  XYZ=0.15,2.3,1      QUANTITY='THERMOCOUPLE'    ID='TC11'/
&DEVC  XYZ=0.15,2.3,1.05   QUANTITY='THERMOCOUPLE'    ID='TC12'/
&DEVC  XYZ=0.15,2.3,1.1    QUANTITY='THERMOCOUPLE'    ID='TC13'/
&DEVC  XYZ=0.15,2.3,1.15   QUANTITY='THERMOCOUPLE'    ID='TC14'/

//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05    QUANTITY='U-VELOCITY'      ID='U1'/
&DEVC  XYZ=0,1.2,0.15      QUANTITY='U-VELOCITY'      ID='U2'/
&DEVC  XYZ=0,1.2,0.25      QUANTITY='U-VELOCITY'      ID='U3'/
&DEVC  XYZ=0,1.2,0.35      QUANTITY='U-VELOCITY'      ID='U4'/
&DEVC  XYZ=0.0,1.2,0.45    QUANTITY='U-VELOCITY'      ID='U5'/
&DEVC  XYZ=0.0,1.2,0.55    QUANTITY='U-VELOCITY'      ID='U6'/
&DEVC  XYZ=0.0,1.2,0.65    QUANTITY='U-VELOCITY'      ID='U7'/
&DEVC  XYZ=0.0,1.2,0.75    QUANTITY='U-VELOCITY'      ID='U8'/
&DEVC  XYZ=0.0,1.2,0.85    QUANTITY='U-VELOCITY'      ID='U9'/
&DEVC  XYZ=0.0,1.2,0.95    QUANTITY='U-VELOCITY'      ID='U10'/
&DEVC  XYZ=0.0,1.2,1.0     QUANTITY='U-VELOCITY'      ID='U11'/
&DEVC  XYZ=0.0,1.2,1.05    QUANTITY='U-VELOCITY'      ID='U12'/
&DEVC  XYZ=0.0,1.2,1.1     QUANTITY='U-VELOCITY'      ID='U13'/
&DEVC  XYZ=0.0,1.2,1.15    QUANTITY='U-VELOCITY'      ID='U14'/

&TAIL/
```

8 Appendix B

The following are the FDS input files for the 5 simulations of Denize/Girgis experiments using room calorimeter HRR data.

G-21 Chair

```
&HEAD CHID='G21_1'
      TITLE='GIRGIS - FDS - G21'/

% MESH OF 0.05
&MESH IJK=88,48,48,     XB=-0.8,3.6,0,2.4,0,2.4/

&TIME T_END=600/

%DEFINES FUEL
&REAC ID='POLYURETHANE'
      C=1   H=1.8 O=0.3 N=0.05      SOOT_YIELD=0.17   CO_YIELD=0.04/

%DEFINES WALLS,CEILING AND FLOOR
&SURF ID='WALL'   MATL_ID='GIB'     THICKNESS=0.025   COLOR='POWDER
BLUE'/
&SURF ID='CEILING'      MATL_ID='GIB'     THICKNESS=0.025
      COLOR='PINK'/

&SURF ID='FLOOR'
      MATL_ID='PLYWOOD','GIB'
      COLOR='SLATE GRAY'
      THICKNESS=0.0125,0.0125/

&MATL ID='GIB'
      CONDUCTIVITY=0.12
      DENSITY=680
      SPECIFIC_HEAT_RAMP='SH_RAMP'
      EMISSIVITY=0.9/

&RAMP ID='SH_RAMP', T=0,F=.900/
&RAMP ID='SH_RAMP', T=105,F=38.000/
&RAMP ID='SH_RAMP', T=140,F=2.000/
&RAMP ID='SH_RAMP', T=200,F=1.000/
&RAMP ID='SH_RAMP', T=205,F=9.000/
&RAMP ID='SH_RAMP', T=220,F=1.000/
&RAMP ID='SH_RAMP', T=400,F=.900/
&RAMP ID='SH_RAMP', T=700,F=.800/

&MATL ID='PLYWOOD'
      CONDUCTIVITY=0.12
      DENSITY=545
      SPECIFIC_HEAT=1.215
      EMISSIVITY=0.9/

% DEFINING ROOM
&VENT MB=XMAX                       SURF_ID='WALL'/
&VENT XB=0,3.6,2.4,2.4,0,2.4        SURF_ID='WALL'/
&VENT XB=-0.8,0,2.4,2.4,0,2.4       SURF_ID='OPEN'/
&VENT XB=0,3.6,0,0,0,2.4            SURF_ID='WALL'/
&VENT XB=-0.8,0,0,0,0,2.4           SURF_ID='OPEN'/
```

```
&OBST XB=0,0.025,0,0.8,0,2          SURF_ID='WALL'/
&OBST XB=0,0.025,1.6,2.4,0,2        SURF_ID='WALL'/
&OBST XB=0,0.025,0,2.4,2,2.4        SURF_ID='WALL'/
&VENT MB=ZMIN                       SURF_ID='FLOOR'/
&VENT XB=-0.8,0,0,2.4,2.4,2.4       SURF_ID='OPEN'/
&VENT XB=0,3.6,0,2.4,2.4,2.4        SURF_ID='CEILING'/

&MATL ID='FABRIC'
      FYI='100% POLYPROPYLENE'
      SPECIFIC_HEAT = 4.74
      CONDUCTIVITY = 0.058
      DENSITY = 184.0/

&MATL ID='FOAM'
      FYI='VARIES FOR CHAIRS - POLYURETHANE AUDITORIUM FOAM'
      SPECIFIC_HEAT = 1.88
      CONDUCTIVITY = 0.0214
      DENSITY = 28.0/

&SURF ID='UPHOLSTERY'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='BLUE'
      THICKNESS(1:2)=0.002,0.01
      HEAT_OF_VAPORIZATION=1500/

&SURF ID='CUSHION'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='GREEN'
      THICKNESS(1:2)=0.002,0.1
      HEAT_OF_VAPORIZATION=1500/


% DEFINING FUEL
&OBST XB=2.9,3.5,0.2,0.75,0.0,0.3, SURF_ID='UPHOLSTERY'/ % BASE
&OBST XB=2.9,3.5,0.1,0.2,0.0,0.65, SURF_ID='UPHOLSTERY'/ % LT ARMREST
&OBST XB=2.9,3.5,0.75,0.85,0.0,0.65, SURF_ID='UPHOLSTERY'/ % RT ARMREST
&OBST XB=3.4,3.5,0.2,0.75,0.3,0.8, SURF_ID='CUSHION'/ % BACK CUSHION

&OBST XB=2.9,3.4,0.2,0.75,0.3,0.39,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=2.9,3.1,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.2,0.35,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.6,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.35,3.4,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION

&OBST XB= 3.1, 3.35, 0.35, 0.6, 0.39, 0.4, SURF_ID='BURNER',
COLOR='ORANGE'/

&SURF ID='BURNER', HRRPUA=23178, RAMP_Q='HRRPUA_RAMP'/ %HRR CURVE FROM
DENIZE THESIS
&RAMP ID='HRRPUA_RAMP', T=26,F=0.01/
&RAMP ID='HRRPUA_RAMP', T=41,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=61,F=0.11/
&RAMP ID='HRRPUA_RAMP', T=92,F=0.14/
&RAMP ID='HRRPUA_RAMP', T=114,F=0.2/
&RAMP ID='HRRPUA_RAMP', T=126,F=0.28/
&RAMP ID='HRRPUA_RAMP', T=149,F=0.83/
&RAMP ID='HRRPUA_RAMP', T=159,F=0.98/
```

```
&RAMP ID='HRRPUA_RAMP', T=171,F=1/
&RAMP ID='HRRPUA_RAMP', T=184,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=227,F=0.39/
&RAMP ID='HRRPUA_RAMP', T=248,F=0.25/
&RAMP ID='HRRPUA_RAMP', T=280,F=0.14/
&RAMP ID='HRRPUA_RAMP', T=330,F=0.11/
&RAMP ID='HRRPUA_RAMP', T=388,F=0.07/
&RAMP ID='HRRPUA_RAMP', T=441,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=471,F=0.05/

&DUMP DT_PL3D=20,
      DT_DEVC=0.5,
      DT_HRR=0.5,
      DT_RESTART=20,
      DT_SLCF=20,
      WRITE_XYZ=.TRUE./

% THERMOCOUPLES
&DEVC XYZ=0.05,1.75,0.075, QUANTITY='THERMOCOUPLE', ID=T1/
&DEVC XYZ=0.05,1.75,0.225, QUANTITY='THERMOCOUPLE', ID=T2/
&DEVC XYZ=0.05,1.75,0.375, QUANTITY='THERMOCOUPLE', ID=T3/
&DEVC XYZ=0.05,1.75,0.525, QUANTITY='THERMOCOUPLE', ID=T4/
&DEVC XYZ=0.05,1.75,0.675, QUANTITY='THERMOCOUPLE', ID=T5/
&DEVC XYZ=0.05,1.75,0.825, QUANTITY='THERMOCOUPLE', ID=T6/
&DEVC XYZ=0.05,1.75,0.975, QUANTITY='THERMOCOUPLE', ID=T7/
&DEVC XYZ=0.05,1.75,1.125, QUANTITY='THERMOCOUPLE', ID=T8/
&DEVC XYZ=0.05,1.75,1.275, QUANTITY='THERMOCOUPLE', ID=T9/
&DEVC XYZ=0.05,1.75,1.425, QUANTITY='THERMOCOUPLE', ID=T10/
&DEVC XYZ=0.05,1.75,1.575, QUANTITY='THERMOCOUPLE', ID=T11/
&DEVC XYZ=0.05,1.75,1.725, QUANTITY='THERMOCOUPLE', ID=T12/
&DEVC XYZ=0.05,1.75,1.875, QUANTITY='THERMOCOUPLE', ID=T13/
&DEVC XYZ=0.05,1.75,2.025, QUANTITY='THERMOCOUPLE', ID=T14/
&DEVC XYZ=0.05,1.75,2.175, QUANTITY='THERMOCOUPLE', ID=T15/
&DEVC XYZ=0.05,1.75,2.325, QUANTITY='THERMOCOUPLE', ID=T16/

% ANIMATION OF TEMPERATURE PROFILE
&SLCF XB=0,3.6,1.75,1.75,0,2.4, QUANTITY='TEMPERATURE', VECTOR=.TRUE./

% HEAT FLUX GAUGES
&DEVC XYZ=1.8,1.2,0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='HF1'/
&DEVC XYZ=1.8,1.2,0, QUANTITY='NET HEAT FLUX', IOR=+3, ID='HF2'/

% MOL FRACTION (CO2, CO, O2)
&DEVC XYZ=0.6,1.2,2.2, QUANTITY='carbon dioxide', ID=CO2_1/
&DEVC XYZ=1.8,1.2,2.2, QUANTITY='carbon dioxide', ID=CO2_2/
&DEVC XYZ=3.0,1.2,2.2, QUANTITY='carbon dioxide', ID=CO2_3/

&TAIL/
```

H-21 Chair

```
&HEAD CHID='H21_1'
      TITLE='GIRGIS - FDS - H21'/

% MESH OF 0.05
&MESH IJK=88,48,48,     XB=-0.8,3.6,0,2.4,0,2.4/

&TIME T_END=600/

%DEFINES FUEL
&REAC ID='POLYURETHANE' C=1   H=1.8 O=0.3 N=0.05/

%DEFINES WALLS,CEILING AND FLOOR
&SURF ID='WALL'   MATL_ID='GIB'     THICKNESS=0.025   COLOR='POWDER
BLUE'/

&SURF ID='CEILING'      MATL_ID='GIB'     THICKNESS=0.025
      COLOR='PINK'/

&SURF ID='FLOOR'
      MATL_ID='PLYWOOD','GIB'
      COLOR='SLATE GRAY'
      THICKNESS=0.0125,0.0125/

&MATL ID='GIB'
      CONDUCTIVITY=0.12
      DENSITY=680
      SPECIFIC_HEAT_RAMP='SH_RAMP'
      EMISSIVITY=0.9/

&RAMP ID='SH_RAMP', T=0,F=.900/
&RAMP ID='SH_RAMP', T=105,F=38.000/
&RAMP ID='SH_RAMP', T=140,F=2.000/
&RAMP ID='SH_RAMP', T=200,F=1.000/
&RAMP ID='SH_RAMP', T=205,F=9.000/
&RAMP ID='SH_RAMP', T=220,F=1.000/
&RAMP ID='SH_RAMP', T=400,F=.900/
&RAMP ID='SH_RAMP', T=700,F=.800/

&MATL ID='PLYWOOD'
      CONDUCTIVITY=0.12
      DENSITY=545
      SPECIFIC_HEAT=1.215
      EMISSIVITY=0.9/

% DEFINING ROOM
&VENT MB=XMAX                       SURF_ID='WALL'/
&VENT XB=0,3.6,2.4,2.4,0,2.4        SURF_ID='WALL'/
&VENT XB=-0.8,0,2.4,2.4,0,2.4       SURF_ID='OPEN'/
&VENT XB=0,3.6,0,0,0,2.4            SURF_ID='WALL'/
&VENT XB=-0.8,0,0,0,0,2.4           SURF_ID='OPEN'/
&OBST XB=0,0.025,0,0.8,0,2          SURF_ID='WALL'/
&OBST XB=0,0.025,1.6,2.4,0,2        SURF_ID='WALL'/
&OBST XB=0,0.025,0,2.4,2,2.4        SURF_ID='WALL'/
&VENT MB=ZMIN                       SURF_ID='FLOOR'/
&VENT XB=-0.8,0,0,2.4,2.4,2.4       SURF_ID='OPEN'/
```

```
&VENT XB=0,3.6,0,2.4,2.4,2.4        SURF_ID='CEILING'/

&MATL ID='FABRIC'
      FYI='100% POLYPROPYLENE'
      SPECIFIC_HEAT = 4.74
      CONDUCTIVITY = 0.058
      DENSITY = 184.0/

&MATL ID='FOAM'
      FYI='VARIES FOR CHAIRS - POLYURETHANE AUDITORIUM FOAM'
      SPECIFIC_HEAT = 1.423
      CONDUCTIVITY = 0.0214
      DENSITY = 37.0/

&SURF ID='UPHOLSTERY'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='BLUE'
      THICKNESS(1:2)=0.002,0.01/

&SURF ID='CUSHION'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='GREEN'
      THICKNESS(1:2)=0.002,0.1/


% DEFINING FUEL
&OBST XB=2.9,3.5,0.2,0.75,0.0,0.3, SURF_ID='UPHOLSTERY'/ % BASE
&OBST XB=2.9,3.5,0.1,0.2,0.0,0.65, SURF_ID='UPHOLSTERY'/ % LT ARMREST
&OBST XB=2.9,3.5,0.75,0.85,0.0,0.65, SURF_ID='UPHOLSTERY'/ % RT ARMREST
&OBST XB=3.4,3.5,0.2,0.75,0.3,0.8, SURF_ID='CUSHION'/ % BACK CUSHION

&OBST XB=2.9,3.4,0.2,0.75,0.3,0.39,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=2.9,3.1,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.2,0.35,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.6,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.35,3.4,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION

&OBST  XB=  3.1,  3.35,  0.35,  0.6,  0.39,  0.4,  SURF_ID='BURNER',
COLOR='ORANGE'/

&SURF ID='BURNER', HRRPUA=21399, RAMP_Q='HRRPUA_RAMP'/ %HRR CURVE FROM
DENIZE THESIS
&RAMP ID='HRRPUA_RAMP', T=20,F=0.01/
&RAMP ID='HRRPUA_RAMP', T=42,F=0.03/
&RAMP ID='HRRPUA_RAMP', T=66,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=88,F=0.13/
&RAMP ID='HRRPUA_RAMP', T=144,F=0.16/
&RAMP ID='HRRPUA_RAMP', T=171,F=0.76/
&RAMP ID='HRRPUA_RAMP', T=189,F=1/
&RAMP ID='HRRPUA_RAMP', T=208,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=220,F=0.74/
&RAMP ID='HRRPUA_RAMP', T=247,F=0.56/
&RAMP ID='HRRPUA_RAMP', T=277,F=0.33/
&RAMP ID='HRRPUA_RAMP', T=316,F=0.21/
&RAMP ID='HRRPUA_RAMP', T=392,F=0.12/
&RAMP ID='HRRPUA_RAMP', T=441,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=473,F=0.07/
```

```
&DUMP DT_PL3D=20,
      DT_DEVC=0.5,
      DT_HRR=0.5,
      DT_RESTART=20,
      DT_SLCF=20,
      WRITE_XYZ=.TRUE./

% THERMOCOUPLES
&DEVC XYZ=0.05,1.75,0.075, QUANTITY='THERMOCOUPLE', ID=T1/
&DEVC XYZ=0.05,1.75,0.225, QUANTITY='THERMOCOUPLE', ID=T2/
&DEVC XYZ=0.05,1.75,0.375, QUANTITY='THERMOCOUPLE', ID=T3/
&DEVC XYZ=0.05,1.75,0.525, QUANTITY='THERMOCOUPLE', ID=T4/
&DEVC XYZ=0.05,1.75,0.675, QUANTITY='THERMOCOUPLE', ID=T5/
&DEVC XYZ=0.05,1.75,0.825, QUANTITY='THERMOCOUPLE', ID=T6/
&DEVC XYZ=0.05,1.75,0.975, QUANTITY='THERMOCOUPLE', ID=T7/
&DEVC XYZ=0.05,1.75,1.125, QUANTITY='THERMOCOUPLE', ID=T8/
&DEVC XYZ=0.05,1.75,1.275, QUANTITY='THERMOCOUPLE', ID=T9/
&DEVC XYZ=0.05,1.75,1.425, QUANTITY='THERMOCOUPLE', ID=T10/
&DEVC XYZ=0.05,1.75,1.575, QUANTITY='THERMOCOUPLE', ID=T11/
&DEVC XYZ=0.05,1.75,1.725, QUANTITY='THERMOCOUPLE', ID=T12/
&DEVC XYZ=0.05,1.75,1.875, QUANTITY='THERMOCOUPLE', ID=T13/
&DEVC XYZ=0.05,1.75,2.025, QUANTITY='THERMOCOUPLE', ID=T14/
&DEVC XYZ=0.05,1.75,2.175, QUANTITY='THERMOCOUPLE', ID=T15/
&DEVC XYZ=0.05,1.75,2.325, QUANTITY='THERMOCOUPLE', ID=T16/

% ANIMATION OF TEMPERATURE PROFILE
&SLCF XB=0,3.6,1.75,1.75,0,2.4, QUANTITY='TEMPERATURE', VECTOR=.TRUE./


% HEAT FLUX GAUGES
&DEVC XYZ=1.8,1.2,0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='HF1'/
&DEVC XYZ=1.8,1.2,0, QUANTITY='NET HEAT FLUX', IOR=+3, ID='HF2'/

&TAIL/
```

I-21 Chair

```
&HEAD CHID='I21_1'
TITLE='GIRGIS - FDS - I21'/

% MESH OF 0.05
&MESH IJK=88,48,48,
      XB=-0.8,3.6,0,2.4,0,2.4/

&TIME T_END=600/

%DEFINES FUEL
&REAC ID='POLYURETHANE' C=1   H=1.8 O=0.3 N=0.05/

%DEFINES WALLS,CEILING AND FLOOR
&SURF ID='WALL'   MATL_ID='GIB'     THICKNESS=0.025   COLOR='POWDER
BLUE'/

&SURF ID='CEILING'      MATL_ID='GIB'     THICKNESS=0.025
      COLOR='PINK'/

&SURF ID='FLOOR'
      MATL_ID='PLYWOOD','GIB'
      COLOR='SLATE GRAY'
      THICKNESS=0.0125,0.0125/

&MATL ID='GIB'
      CONDUCTIVITY=0.12
      DENSITY=680
      SPECIFIC_HEAT_RAMP='SH_RAMP'
      EMISSIVITY=0.9/

&RAMP ID='SH_RAMP', T=0,F=.900/
&RAMP ID='SH_RAMP', T=105,F=38.000/
&RAMP ID='SH_RAMP', T=140,F=2.000/
&RAMP ID='SH_RAMP', T=200,F=1.000/
&RAMP ID='SH_RAMP', T=205,F=9.000/
&RAMP ID='SH_RAMP', T=220,F=1.000/
&RAMP ID='SH_RAMP', T=400,F=.900/
&RAMP ID='SH_RAMP', T=700,F=.800/

&MATL ID='PLYWOOD'
      CONDUCTIVITY=0.12
      DENSITY=545
      SPECIFIC_HEAT=1.215
      EMISSIVITY=0.9/

% DEFINING ROOM
&VENT MB=XMAX                       SURF_ID='WALL'/
&VENT XB=0,3.6,2.4,2.4,0,2.4        SURF_ID='WALL'/
&VENT XB=-0.8,0,2.4,2.4,0,2.4       SURF_ID='OPEN'/
&VENT XB=0,3.6,0,0,0,2.4            SURF_ID='WALL'/
&VENT XB=-0.8,0,0,0,0,2.4           SURF_ID='OPEN'/
&OBST XB=0,0.025,0,0.8,0,2          SURF_ID='WALL'/
&OBST XB=0,0.025,1.6,2.4,0,2        SURF_ID='WALL'/
&OBST XB=0,0.025,0,2.4,2,2.4        SURF_ID='WALL'/
&VENT MB=ZMIN                       SURF_ID='FLOOR'/
```

```
&VENT XB=-0.8,0,0,2.4,2.4,2.4       SURF_ID='OPEN'/
&VENT XB=0,3.6,0,2.4,2.4,2.4        SURF_ID='CEILING'/

&MATL ID='FABRIC'
      FYI='100% POLYPROPYLENE'
      SPECIFIC_HEAT = 4.74
      CONDUCTIVITY = 0.058
      DENSITY = 184.0/

&MATL ID='FOAM'
      FYI='VARIES FOR CHAIRS - POLYURETHANE AUDITORIUM FOAM'
      SPECIFIC_HEAT = 1.504
      CONDUCTIVITY = 0.0214
      DENSITY = 35.0/

&SURF ID='UPHOLSTERY'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='BLUE'
      THICKNESS(1:2)=0.002,0.01/

&SURF ID='CUSHION'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='GREEN'
      THICKNESS(1:2)=0.002,0.1/


% DEFINING FUEL
&OBST XB=2.9,3.5,0.2,0.75,0.0,0.3, SURF_ID='UPHOLSTERY'/ % BASE
&OBST XB=2.9,3.5,0.1,0.2,0.0,0.65, SURF_ID='UPHOLSTERY'/ % LT ARMREST
&OBST XB=2.9,3.5,0.75,0.85,0.0,0.65, SURF_ID='UPHOLSTERY'/ % RT ARMREST
&OBST XB=3.4,3.5,0.2,0.75,0.3,0.8, SURF_ID='CUSHION'/ % BACK CUSHION

&OBST XB=2.9,3.4,0.2,0.75,0.3,0.39,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=2.9,3.1,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.2,0.35,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.6,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.35,3.4,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION

&OBST XB= 3.1, 3.35, 0.35, 0.6, 0.39, 0.4, SURF_ID='BURNER',
COLOR='ORANGE'/

&SURF ID='BURNER', HRRPUA=25086, RAMP_Q='HRRPUA_RAMP'/ %HRR CURVE FROM
DENIZE THESIS
&RAMP ID='HRRPUA_RAMP', T=19,F=0.01/
&RAMP ID='HRRPUA_RAMP', T=79,F=0.1/
&RAMP ID='HRRPUA_RAMP', T=94,F=0.13/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.81/
&RAMP ID='HRRPUA_RAMP', T=145,F=1/
&RAMP ID='HRRPUA_RAMP', T=164,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=203,F=0.46/
&RAMP ID='HRRPUA_RAMP', T=234,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=280,F=0.13/
&RAMP ID='HRRPUA_RAMP', T=337,F=0.08/
&RAMP ID='HRRPUA_RAMP', T=389,F=0.06/
&RAMP ID='HRRPUA_RAMP', T=449,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=471,F=0.06/
```

```
&DUMP DT_PL3D=20,
      DT_DEVC=0.5,
      DT_HRR=0.5,
      DT_RESTART=20,
      DT_SLCF=20,
      WRITE_XYZ=.TRUE./

% THERMOCOUPLES
&DEVC XYZ=0.05,1.75,0.075, QUANTITY='THERMOCOUPLE', ID=T1/
&DEVC XYZ=0.05,1.75,0.225, QUANTITY='THERMOCOUPLE', ID=T2/
&DEVC XYZ=0.05,1.75,0.375, QUANTITY='THERMOCOUPLE', ID=T3/
&DEVC XYZ=0.05,1.75,0.525, QUANTITY='THERMOCOUPLE', ID=T4/
&DEVC XYZ=0.05,1.75,0.675, QUANTITY='THERMOCOUPLE', ID=T5/
&DEVC XYZ=0.05,1.75,0.825, QUANTITY='THERMOCOUPLE', ID=T6/
&DEVC XYZ=0.05,1.75,0.975, QUANTITY='THERMOCOUPLE', ID=T7/
&DEVC XYZ=0.05,1.75,1.125, QUANTITY='THERMOCOUPLE', ID=T8/
&DEVC XYZ=0.05,1.75,1.275, QUANTITY='THERMOCOUPLE', ID=T9/
&DEVC XYZ=0.05,1.75,1.425, QUANTITY='THERMOCOUPLE', ID=T10/
&DEVC XYZ=0.05,1.75,1.575, QUANTITY='THERMOCOUPLE', ID=T11/
&DEVC XYZ=0.05,1.75,1.725, QUANTITY='THERMOCOUPLE', ID=T12/
&DEVC XYZ=0.05,1.75,1.875, QUANTITY='THERMOCOUPLE', ID=T13/
&DEVC XYZ=0.05,1.75,2.025, QUANTITY='THERMOCOUPLE', ID=T14/
&DEVC XYZ=0.05,1.75,2.175, QUANTITY='THERMOCOUPLE', ID=T15/
&DEVC XYZ=0.05,1.75,2.325, QUANTITY='THERMOCOUPLE', ID=T16/

% ANIMATION OF TEMPERATURE PROFILE
&SLCF XB=0,3.6,1.75,1.75,0,2.4, QUANTITY='TEMPERATURE', VECTOR=.TRUE./

&TAIL/
```

J-21 Chair

```
&HEAD CHID='J21_1'
      TITLE='GIRGIS - FDS - J21_1'/

% MESH OF 0.05
&MESH IJK=88,48,48,
      XB=-0.8,3.6,0,2.4,0,2.4/

&TIME T_END=600/

%DEFINES FUEL
&REAC ID='POLYURETHANE' C=1   H=1.8 O=0.3 N=0.05/

%DEFINES WALLS,CEILING AND FLOOR
&SURF ID='WALL'   MATL_ID='GIB'     THICKNESS=0.025   COLOR='POWDER
BLUE'/

&SURF ID='CEILING'      MATL_ID='GIB'     THICKNESS=0.025
      COLOR='PINK'/

&SURF ID='FLOOR'
      MATL_ID='PLYWOOD','GIB'
      COLOR='SLATE GRAY'
      THICKNESS=0.0125,0.0125/

&MATL ID='GIB'
      CONDUCTIVITY=0.12
      DENSITY=680
      SPECIFIC_HEAT_RAMP='SH_RAMP'
      EMISSIVITY=0.9/

&RAMP ID='SH_RAMP', T=0,F=.900/
&RAMP ID='SH_RAMP', T=105,F=38.000/
&RAMP ID='SH_RAMP', T=140,F=2.000/
&RAMP ID='SH_RAMP', T=200,F=1.000/
&RAMP ID='SH_RAMP', T=205,F=9.000/
&RAMP ID='SH_RAMP', T=220,F=1.000/
&RAMP ID='SH_RAMP', T=400,F=.900/
&RAMP ID='SH_RAMP', T=700,F=.800/


&MATL ID='PLYWOOD'
      CONDUCTIVITY=0.12
      DENSITY=545
      SPECIFIC_HEAT=1.215
      EMISSIVITY=0.9/

% DEFINING ROOM
&VENT MB=XMAX                       SURF_ID='WALL'/
&VENT XB=0,3.6,2.4,2.4,0,2.4        SURF_ID='WALL'/
&VENT XB=-0.8,0,2.4,2.4,0,2.4       SURF_ID='OPEN'/
&VENT XB=0,3.6,0,0,0,2.4            SURF_ID='WALL'/
&VENT XB=-0.8,0,0,0,0,2.4           SURF_ID='OPEN'/
&OBST XB=0,0.025,0,0.8,0,2          SURF_ID='WALL'/
&OBST XB=0,0.025,1.6,2.4,0,2        SURF_ID='WALL'/
&OBST XB=0,0.025,0,2.4,2,2.4        SURF_ID='WALL'/
```

```
&VENT MB=ZMIN                        SURF_ID='FLOOR'/
&VENT XB=-0.8,0,0,2.4,2.4,2.4        SURF_ID='OPEN'/
&VENT XB=0,3.6,0,2.4,2.4,2.4         SURF_ID='CEILING'/

&MATL ID='FABRIC'
      FYI='100% POLYPROPYLENE'
      SPECIFIC_HEAT = 4.74
      CONDUCTIVITY = 0.058
      DENSITY = 184.0/

&MATL ID='FOAM'
      FYI='VARIES FOR CHAIRS - POLYURETHANE AUDITORIUM FOAM'
      SPECIFIC_HEAT = 1.462
      CONDUCTIVITY = 0.0214
      DENSITY = 36.0/

&SURF ID='UPHOLSTERY'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='BLUE'
      THICKNESS(1:2)=0.002,0.01/

&SURF ID='CUSHION'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='GREEN'
      THICKNESS(1:2)=0.002,0.1/


% DEFINING FUEL
&OBST XB=2.9,3.5,0.2,0.75,0.0,0.3, SURF_ID='UPHOLSTERY'/ % BASE
&OBST XB=2.9,3.5,0.1,0.2,0.0,0.65, SURF_ID='UPHOLSTERY'/ % LT ARMREST
&OBST XB=2.9,3.5,0.75,0.85,0.0,0.65, SURF_ID='UPHOLSTERY'/ % RT ARMREST
&OBST XB=3.4,3.5,0.2,0.75,0.3,0.8, SURF_ID='CUSHION'/ % BACK CUSHION

&OBST XB=2.9,3.4,0.2,0.75,0.3,0.39,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=2.9,3.1,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.2,0.35,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.6,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.35,3.4,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION

&OBST  XB=  3.1,  3.35,  0.35,  0.6,  0.39,  0.4,  SURF_ID='BURNER',
COLOR='ORANGE'/

&SURF ID='BURNER', HRRPUA=27920, RAMP_Q='HRRPUA_RAMP'/ %HRR CURVE FROM
DENIZE THESIS
&RAMP ID='HRRPUA_RAMP', T=19,F=0.01/
&RAMP ID='HRRPUA_RAMP', T=121,F=0.12/
&RAMP ID='HRRPUA_RAMP', T=133,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=150,F=0.13/
&RAMP ID='HRRPUA_RAMP', T=178,F=0.82/
&RAMP ID='HRRPUA_RAMP', T=211,F=1/
&RAMP ID='HRRPUA_RAMP', T=225,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=248,F=0.69/
&RAMP ID='HRRPUA_RAMP', T=285,F=0.39/
&RAMP ID='HRRPUA_RAMP', T=336,F=0.18/
&RAMP ID='HRRPUA_RAMP', T=381,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=456,F=0.05/
```

```
&DUMP DT_PL3D=20,
      DT_DEVC=0.5,
      DT_HRR=0.5,
      DT_RESTART=20,
      DT_SLCF=20,
      WRITE_XYZ=.TRUE./

% THERMOCOUPLES
&DEVC XYZ=0.05,1.75,0.075, QUANTITY='THERMOCOUPLE', ID=T1/
&DEVC XYZ=0.05,1.75,0.225, QUANTITY='THERMOCOUPLE', ID=T2/
&DEVC XYZ=0.05,1.75,0.375, QUANTITY='THERMOCOUPLE', ID=T3/
&DEVC XYZ=0.05,1.75,0.525, QUANTITY='THERMOCOUPLE', ID=T4/
&DEVC XYZ=0.05,1.75,0.675, QUANTITY='THERMOCOUPLE', ID=T5/
&DEVC XYZ=0.05,1.75,0.825, QUANTITY='THERMOCOUPLE', ID=T6/
&DEVC XYZ=0.05,1.75,0.975, QUANTITY='THERMOCOUPLE', ID=T7/
&DEVC XYZ=0.05,1.75,1.125, QUANTITY='THERMOCOUPLE', ID=T8/
&DEVC XYZ=0.05,1.75,1.275, QUANTITY='THERMOCOUPLE', ID=T9/
&DEVC XYZ=0.05,1.75,1.425, QUANTITY='THERMOCOUPLE', ID=T10/
&DEVC XYZ=0.05,1.75,1.575, QUANTITY='THERMOCOUPLE', ID=T11/
&DEVC XYZ=0.05,1.75,1.725, QUANTITY='THERMOCOUPLE', ID=T12/
&DEVC XYZ=0.05,1.75,1.875, QUANTITY='THERMOCOUPLE', ID=T13/
&DEVC XYZ=0.05,1.75,2.025, QUANTITY='THERMOCOUPLE', ID=T14/
&DEVC XYZ=0.05,1.75,2.175, QUANTITY='THERMOCOUPLE', ID=T15/
&DEVC XYZ=0.05,1.75,2.325, QUANTITY='THERMOCOUPLE', ID=T16/

% ANIMATION OF TEMPERATURE PROFILE
&SLCF XB=0,3.6,1.75,1.75,0,2.4, QUANTITY='TEMPERATURE', VECTOR=.TRUE./

&TAIL/
```

L-21 Chair

```
&HEAD CHID=L21_1'
      TITLE='GIRGIS - FDS - L21_1'/

% MESH OF 0.05
&MESH IJK=88,48,48,
      XB=-0.8,3.6,0,2.4,0,2.4/

&TIME T_END=600/

%DEFINES FUEL
&REAC ID='POLYURETHANE' C=1   H=1.8 O=0.3 N=0.05/

%DEFINES WALLS,CEILING AND FLOOR
&SURF ID='WALL'   MATL_ID='GIB'     THICKNESS=0.025   COLOR='POWDER
BLUE'/
&SURF ID='CEILING'      MATL_ID='GIB'     THICKNESS=0.025
      COLOR='PINK'/

&SURF ID='FLOOR'
      MATL_ID='PLYWOOD','GIB'
      COLOR='SLATE GRAY'
      THICKNESS=0.0125,0.0125/

&MATL ID='GIB'
      CONDUCTIVITY=0.12
      DENSITY=680
      SPECIFIC_HEAT_RAMP='SH_RAMP'
      EMISSIVITY=0.9/

&RAMP ID='SH_RAMP', T=0,F=.900/
&RAMP ID='SH_RAMP', T=105,F=38.000/
&RAMP ID='SH_RAMP', T=140,F=2.000/
&RAMP ID='SH_RAMP', T=200,F=1.000/
&RAMP ID='SH_RAMP', T=205,F=9.000/
&RAMP ID='SH_RAMP', T=220,F=1.000/
&RAMP ID='SH_RAMP', T=400,F=.900/
&RAMP ID='SH_RAMP', T=700,F=.800/

&MATL ID='PLYWOOD'
      CONDUCTIVITY=0.12
      DENSITY=545
      SPECIFIC_HEAT=1.215
      EMISSIVITY=0.9/

% DEFINING ROOM
&VENT MB=XMAX                       SURF_ID='WALL'/
&VENT XB=0,3.6,2.4,2.4,0,2.4        SURF_ID='WALL'/
&VENT XB=-0.8,0,2.4,2.4,0,2.4       SURF_ID='OPEN'/
&VENT XB=0,3.6,0,0,0,2.4            SURF_ID='WALL'/
&VENT XB=-0.8,0,0,0,0,2.4           SURF_ID='OPEN'/
&OBST XB=0,0.025,0,0.8,0,2          SURF_ID='WALL'/
&OBST XB=0,0.025,1.6,2.4,0,2        SURF_ID='WALL'/
&OBST XB=0,0.025,0,2.4,2,2.4        SURF_ID='WALL'/
&VENT MB=ZMIN                       SURF_ID='FLOOR'/
&VENT XB=-0.8,0,0,2.4,2.4,2.4       SURF_ID='OPEN'/
```

```
&VENT XB=0,3.6,0,2.4,2.4,2.4        SURF_ID='CEILING'/

&MATL ID='FABRIC'
      FYI='100% POLYPROPYLENE'
      SPECIFIC_HEAT = 4.74
      CONDUCTIVITY = 0.058
      DENSITY = 184.0/

&MATL ID='FOAM'
      FYI='VARIES FOR CHAIRS - POLYURETHANE AUDITORIUM FOAM'
      SPECIFIC_HEAT = 1.462
      CONDUCTIVITY = 0.0214
      DENSITY = 36.0/

&SURF ID='UPHOLSTERY'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='BLUE'
      THICKNESS(1:2)=0.002,0.01/

&SURF ID='CUSHION'
      MATL_ID(1:2,1)='FABRIC','FOAM'
      COLOR='GREEN'
      THICKNESS(1:2)=0.002,0.1/


% DEFINING FUEL
&OBST XB=2.9,3.5,0.2,0.75,0.0,0.3, SURF_ID='UPHOLSTERY'/ % BASE
&OBST XB=2.9,3.5,0.1,0.2,0.0,0.65, SURF_ID='UPHOLSTERY'/ % LT ARMREST
&OBST XB=2.9,3.5,0.75,0.85,0.0,0.65, SURF_ID='UPHOLSTERY'/ % RT ARMREST
&OBST XB=3.4,3.5,0.2,0.75,0.3,0.8, SURF_ID='CUSHION'/ % BACK CUSHION

&OBST XB=2.9,3.4,0.2,0.75,0.3,0.39,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=2.9,3.1,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.2,0.35,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.6,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.35,3.4,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION

&OBST  XB=  3.1,  3.35,  0.35,  0.6,  0.39,  0.4,  SURF_ID='BURNER',
COLOR='ORANGE'/

&SURF ID='BURNER', HRRPUA=34434, RAMP_Q='HRRPUA_RAMP'/ %HRR CURVE FROM
DENIZE THESIS
&RAMP ID='HRRPUA_RAMP', T=20,F=0.01/
&RAMP ID='HRRPUA_RAMP', T=90,F=0.15/
&RAMP ID='HRRPUA_RAMP', T=129,F=0.91/
&RAMP ID='HRRPUA_RAMP', T=141,F=1/
&RAMP ID='HRRPUA_RAMP', T=155,F=0.91/
&RAMP ID='HRRPUA_RAMP', T=188,F=0.79/
&RAMP ID='HRRPUA_RAMP', T=223,F=0.27/
&RAMP ID='HRRPUA_RAMP', T=243,F=0.16/
&RAMP ID='HRRPUA_RAMP', T=281,F=0.08/
&RAMP ID='HRRPUA_RAMP', T=341,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=420,F=0.03/
&RAMP ID='HRRPUA_RAMP', T=462,F=0.02/

&DUMP DT_PL3D=20,
      DT_DEVC=0.5,
```

```
      DT_HRR=0.5,
      DT_RESTART=20,
      DT_SLCF=20,
      WRITE_XYZ=.TRUE./

% THERMOCOUPLES
&DEVC XYZ=0.05,1.75,0.075, QUANTITY='THERMOCOUPLE', ID=T1/
&DEVC XYZ=0.05,1.75,0.225, QUANTITY='THERMOCOUPLE', ID=T2/
&DEVC XYZ=0.05,1.75,0.375, QUANTITY='THERMOCOUPLE', ID=T3/
&DEVC XYZ=0.05,1.75,0.525, QUANTITY='THERMOCOUPLE', ID=T4/
&DEVC XYZ=0.05,1.75,0.675, QUANTITY='THERMOCOUPLE', ID=T5/
&DEVC XYZ=0.05,1.75,0.825, QUANTITY='THERMOCOUPLE', ID=T6/
&DEVC XYZ=0.05,1.75,0.975, QUANTITY='THERMOCOUPLE', ID=T7/
&DEVC XYZ=0.05,1.75,1.125, QUANTITY='THERMOCOUPLE', ID=T8/
&DEVC XYZ=0.05,1.75,1.275, QUANTITY='THERMOCOUPLE', ID=T9/
&DEVC XYZ=0.05,1.75,1.425, QUANTITY='THERMOCOUPLE', ID=T10/
&DEVC XYZ=0.05,1.75,1.575, QUANTITY='THERMOCOUPLE', ID=T11/
&DEVC XYZ=0.05,1.75,1.725, QUANTITY='THERMOCOUPLE', ID=T12/
&DEVC XYZ=0.05,1.75,1.875, QUANTITY='THERMOCOUPLE', ID=T13/
&DEVC XYZ=0.05,1.75,2.025, QUANTITY='THERMOCOUPLE', ID=T14/
&DEVC XYZ=0.05,1.75,2.175, QUANTITY='THERMOCOUPLE', ID=T15/
&DEVC XYZ=0.05,1.75,2.325, QUANTITY='THERMOCOUPLE', ID=T16/

% ANIMATION OF TEMPERATURE PROFILE
&SLCF XB=0,3.6,1.75,1.75,0,2.4, QUANTITY='TEMPERATURE', VECTOR=.TRUE./

&TAIL/
```

9 Appendix C

Results for the 4 other types of chairs (H-21, I-21, J-21, and L-21) simulated in FDS using room calorimeter data from Girgis' experiments (2).

CHAIR H-21

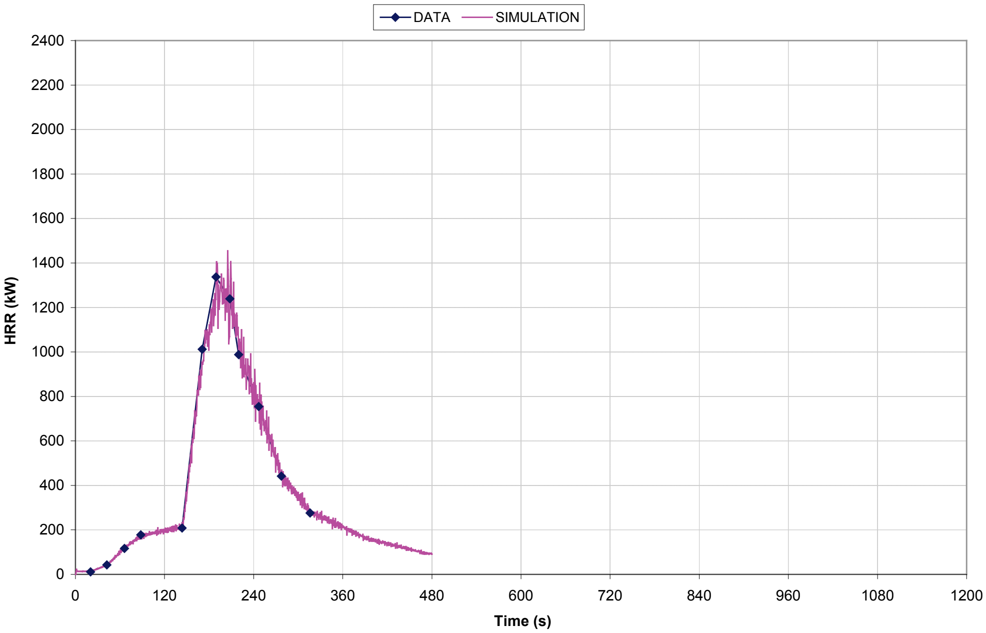

Figure 9-1 – HRR Comparison (H-21)

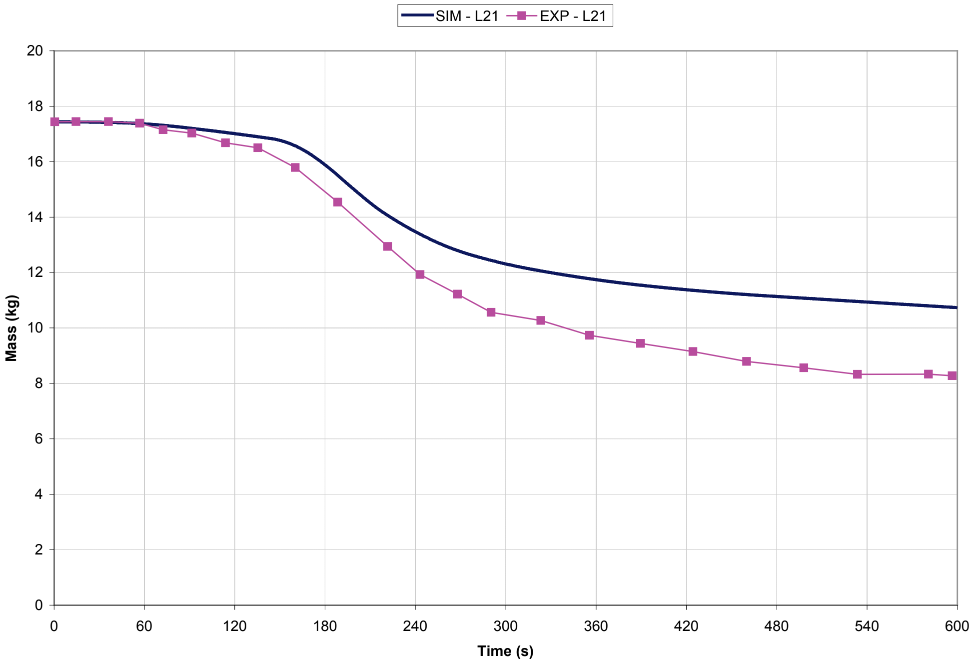

Figure 9-2 – Mass History Comparison (H-21)

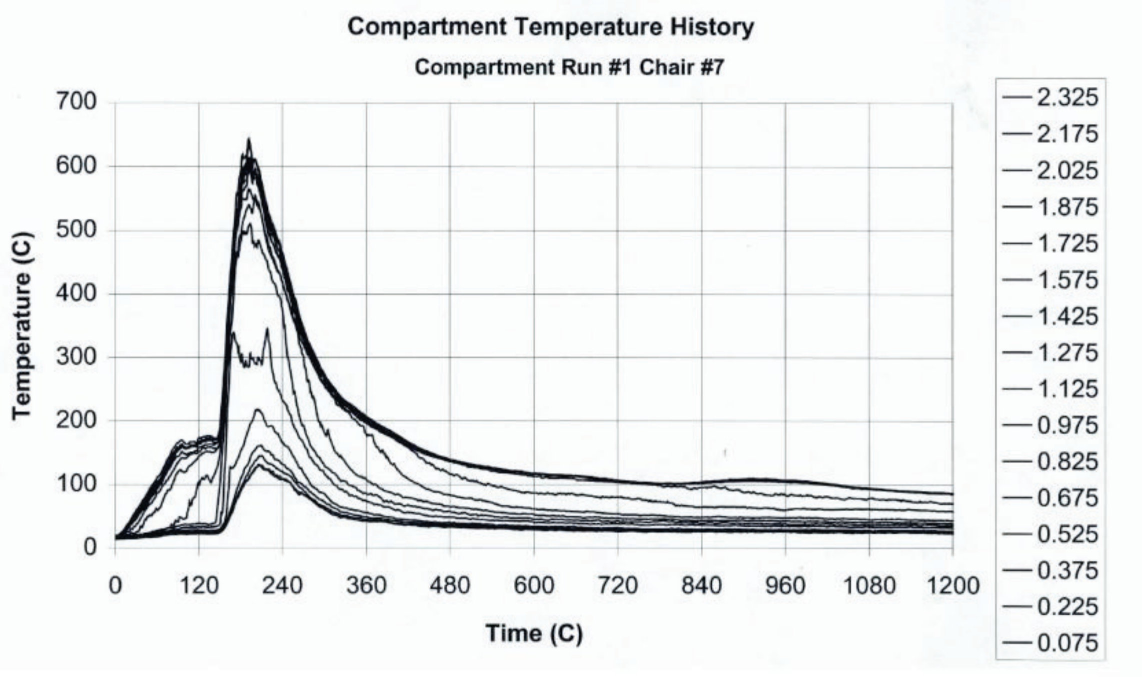

Figure 9-3 – Experiment Temperature History (H-21) (2)

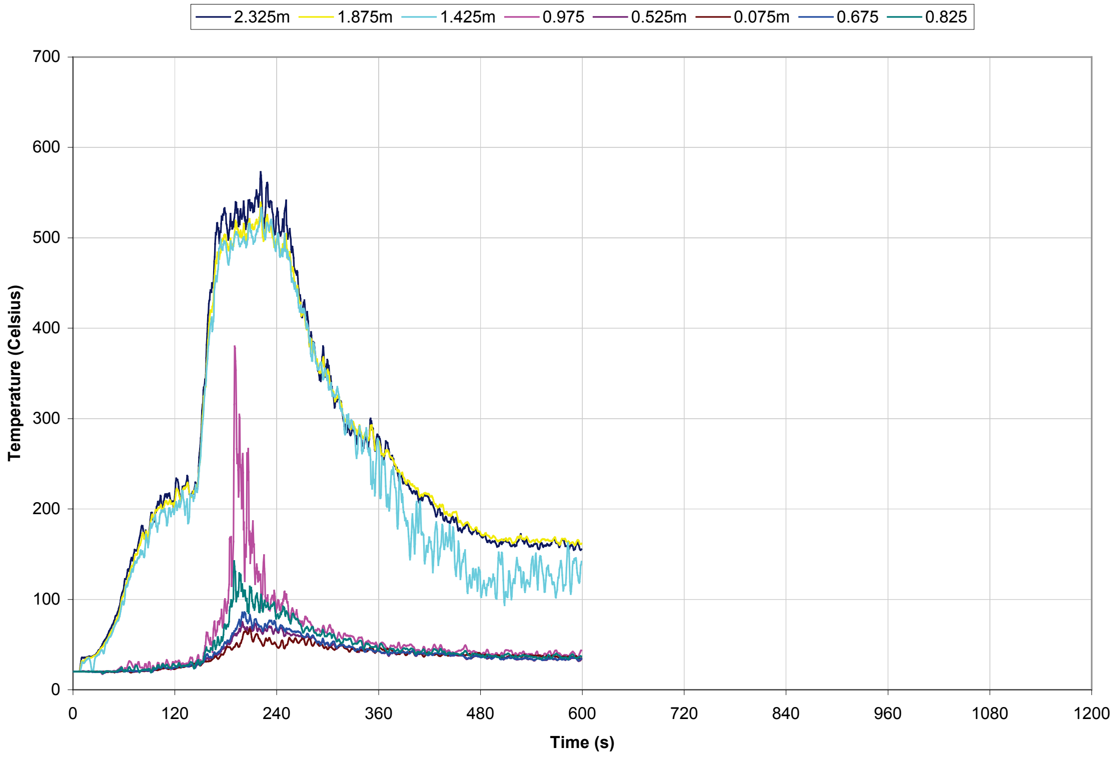

Figure 9-4 – Simulation Temperature History (H-21)

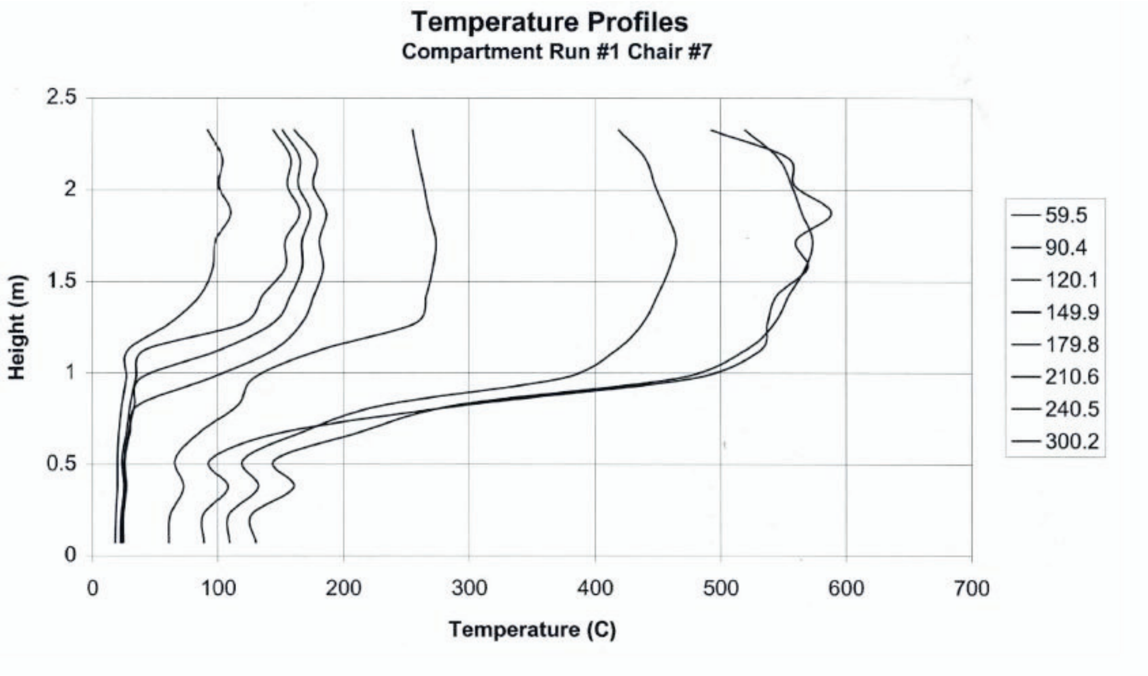

Figure 9-5 – Experiment Temperature Profiles (H-21) (2)

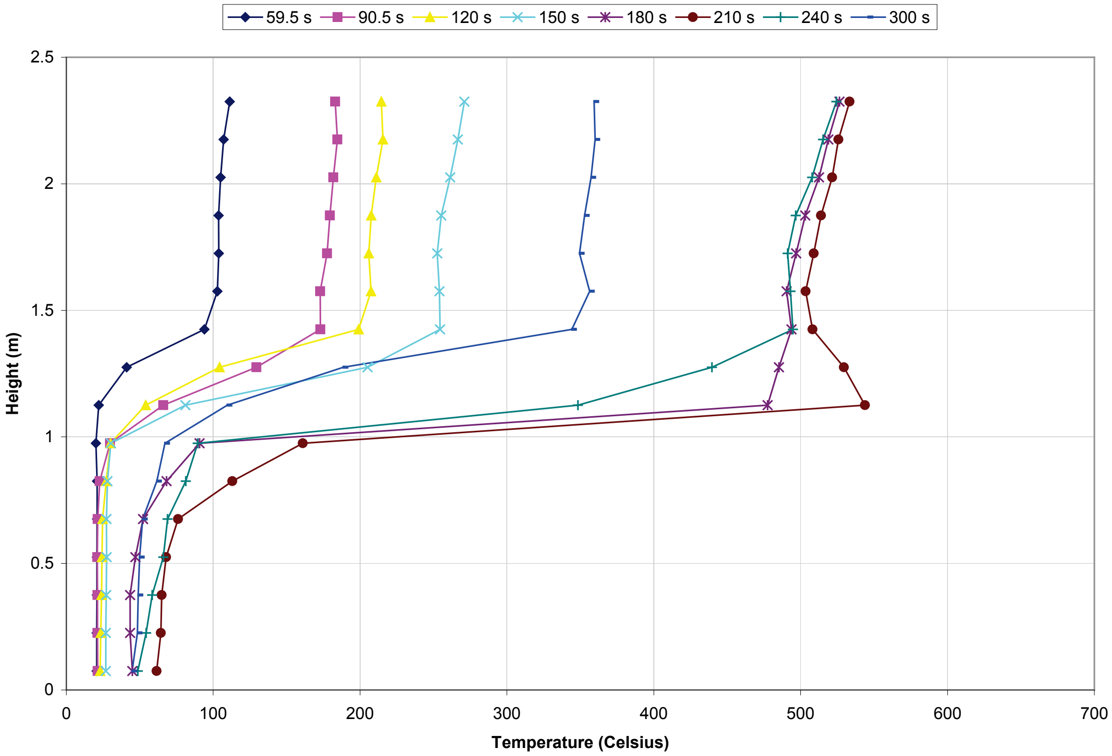

Figure 9-6 – Simulation Temperature Profiles (H-21)

CHAIR I-21

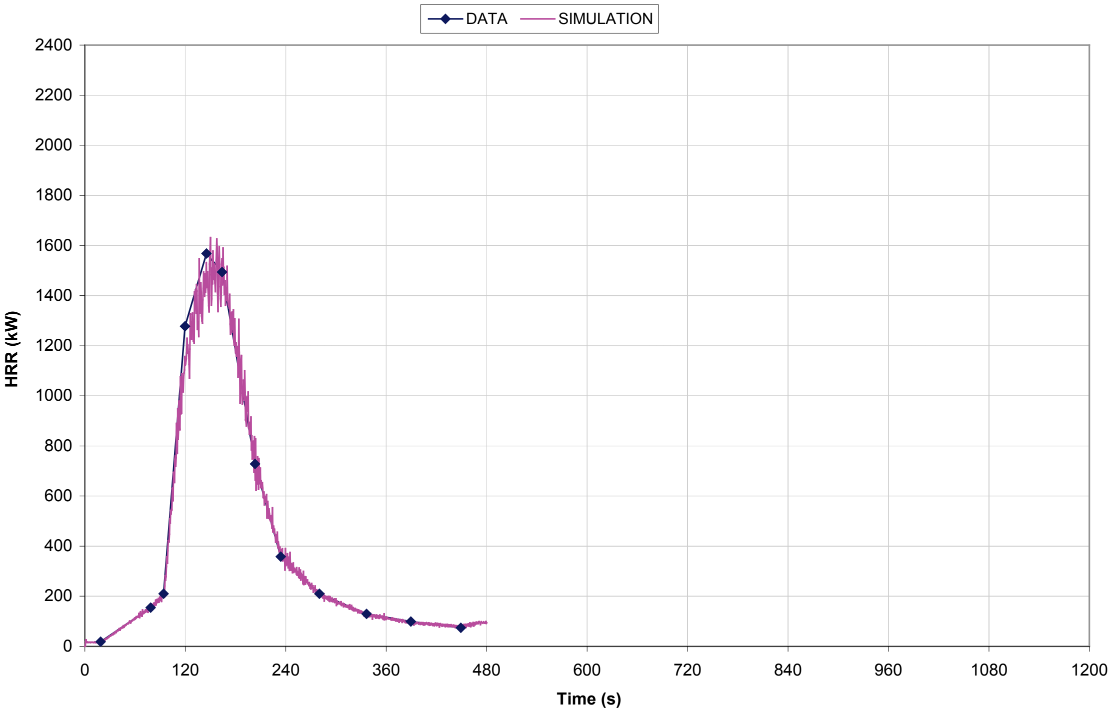

Figure 9-7 – HRR Comparison (I-21)

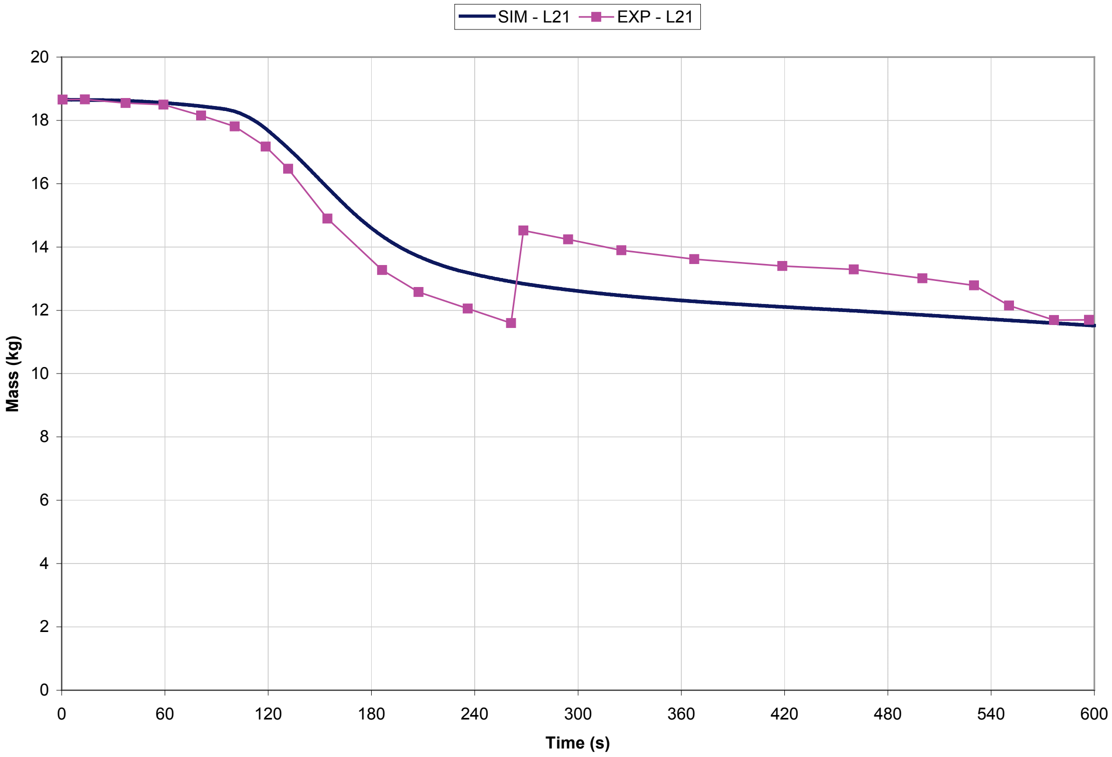

Figure 9-8 – Mass History Comparison (I-21)

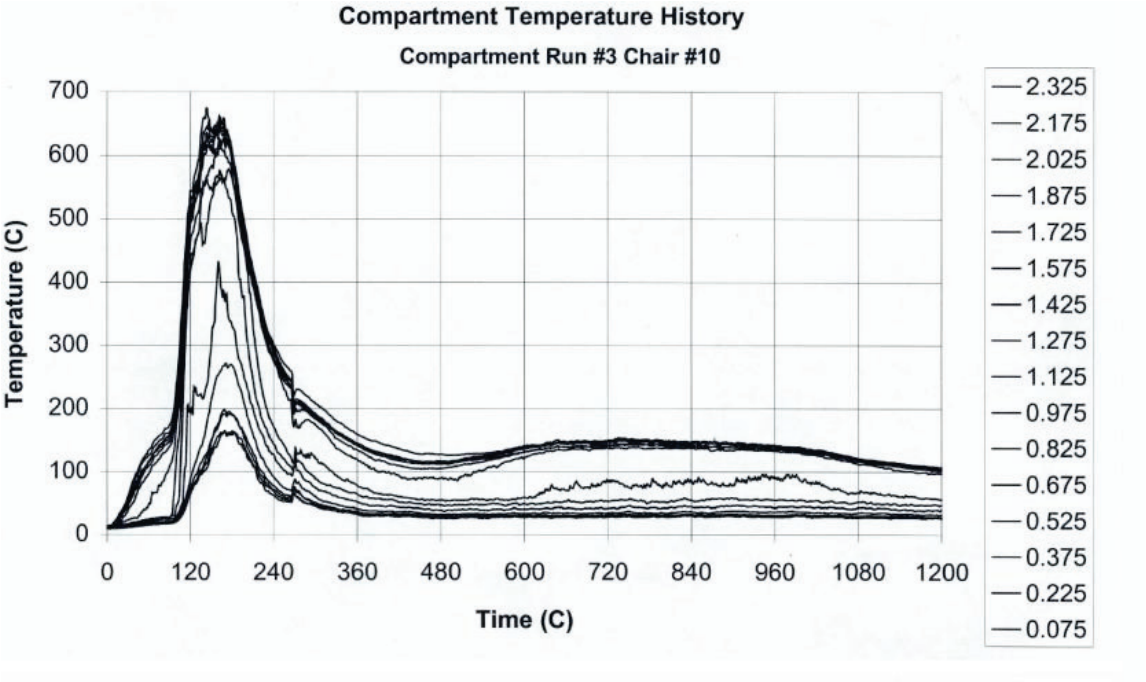

Figure 9-9 - Experiment Temperature History (I-21) (2)

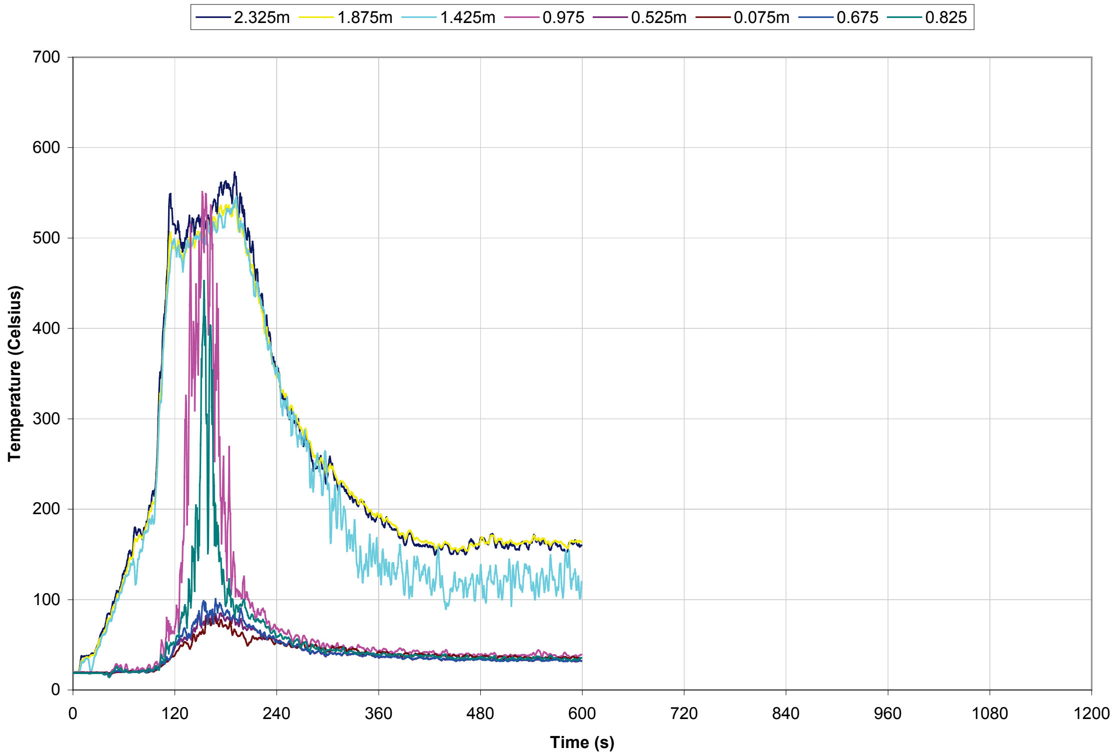

Figure 9-10 – Simulation Temperature History (I-21)

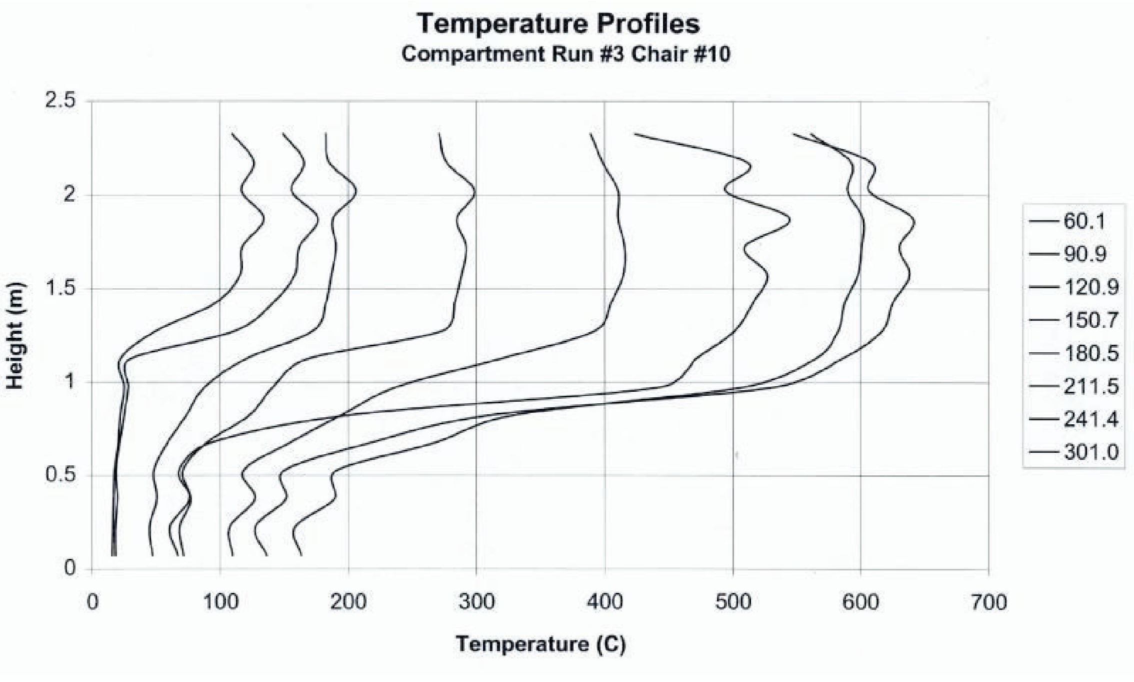

Figure 9-11 – Experiment Temperature Profile (I-21) (2)

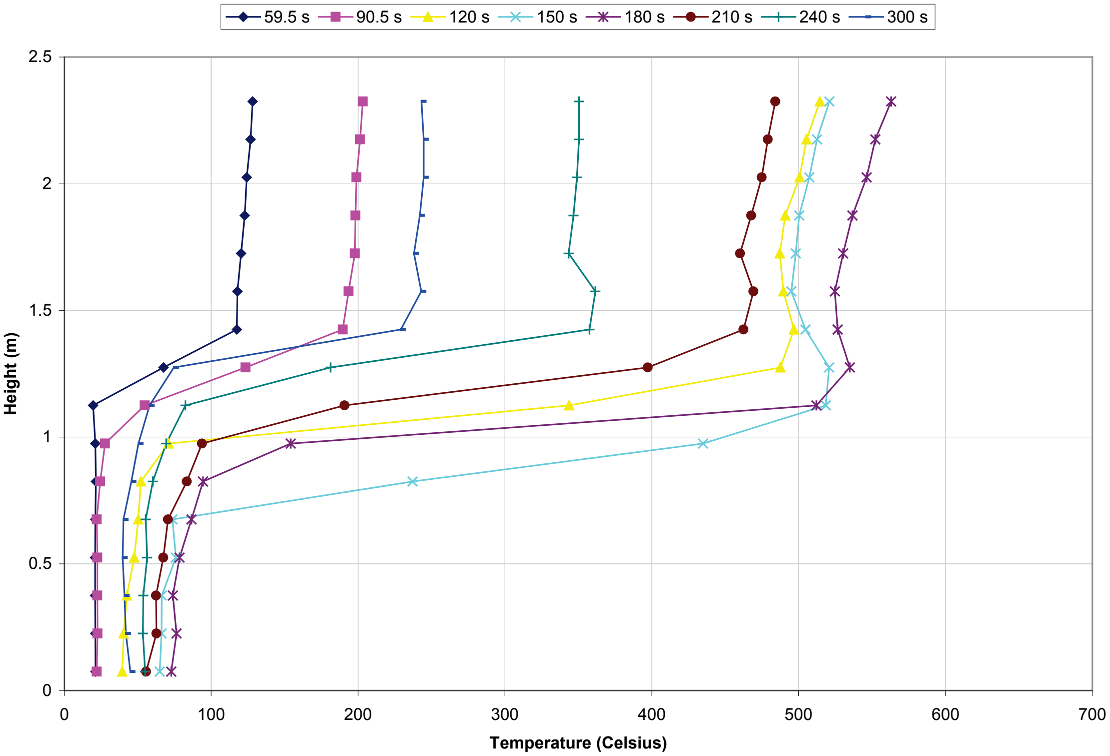

Figure 9-12 – Simulation Temperature Profile (I-21)

CHAIR J-21

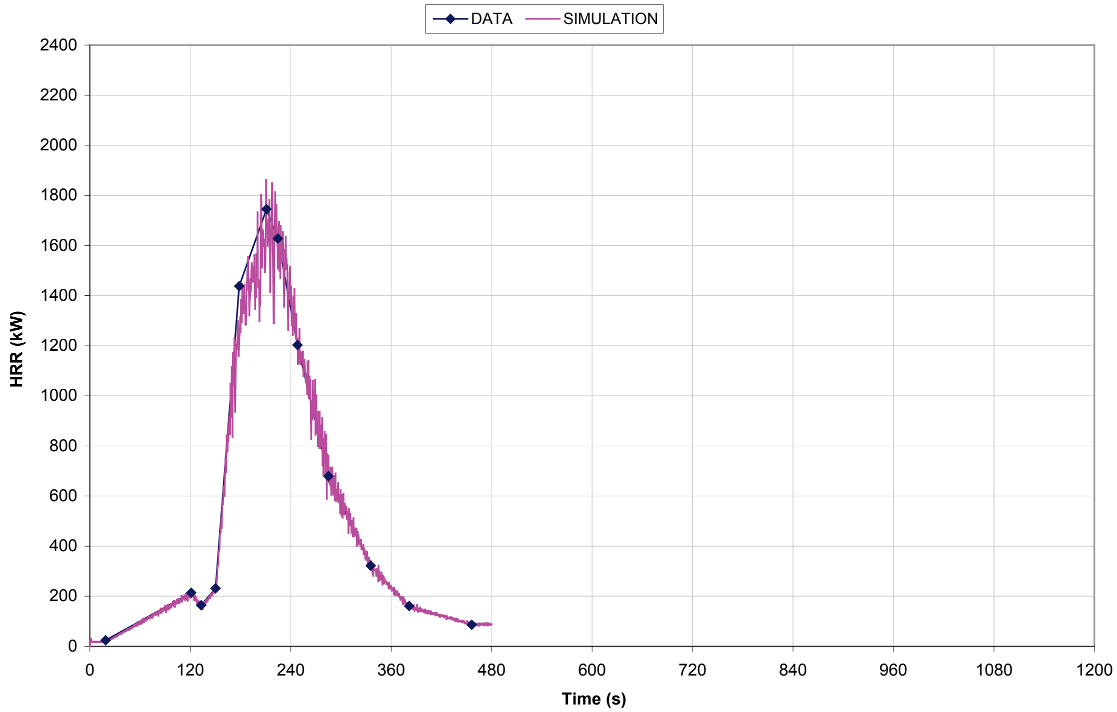

Figure 9-13 – HRR Comparison (J-21)

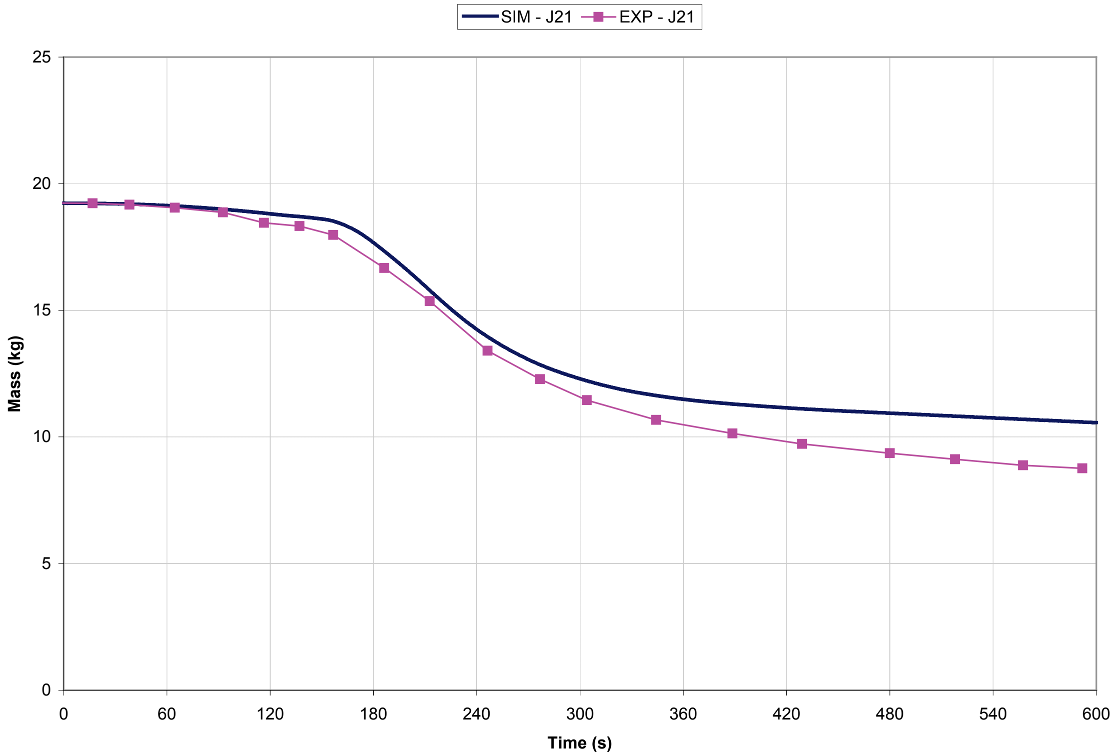

Figure 9-14 – Mass History Comparison (J-21)

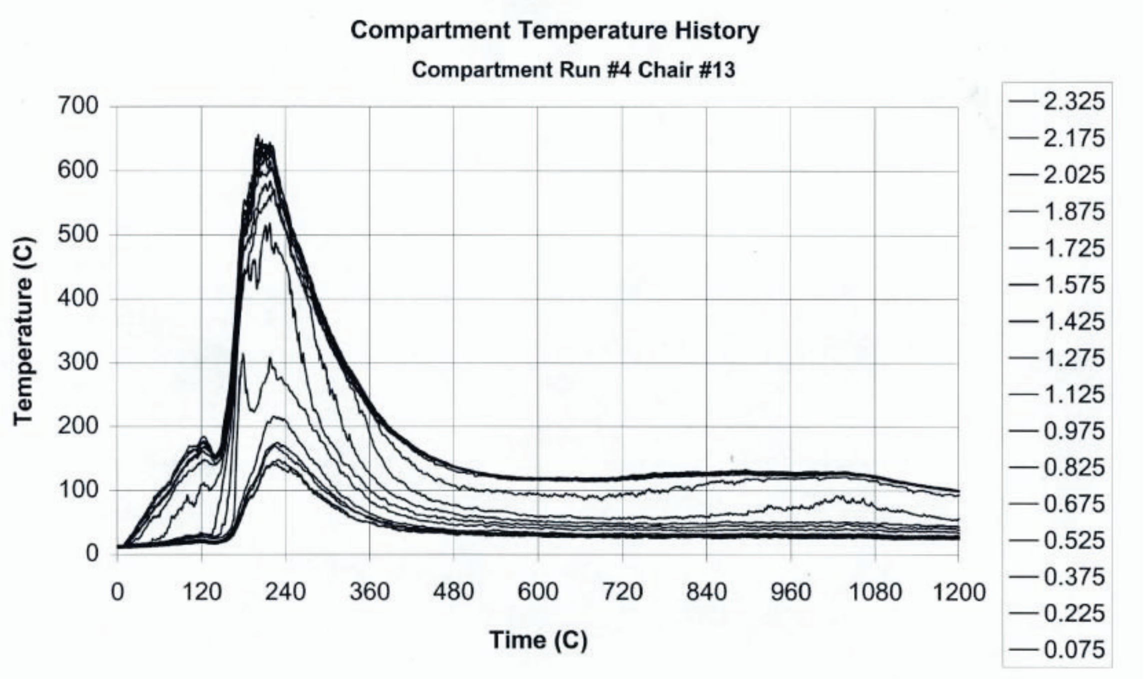

Figure 9-15 - Experiment Temperature History (J-21) (2)

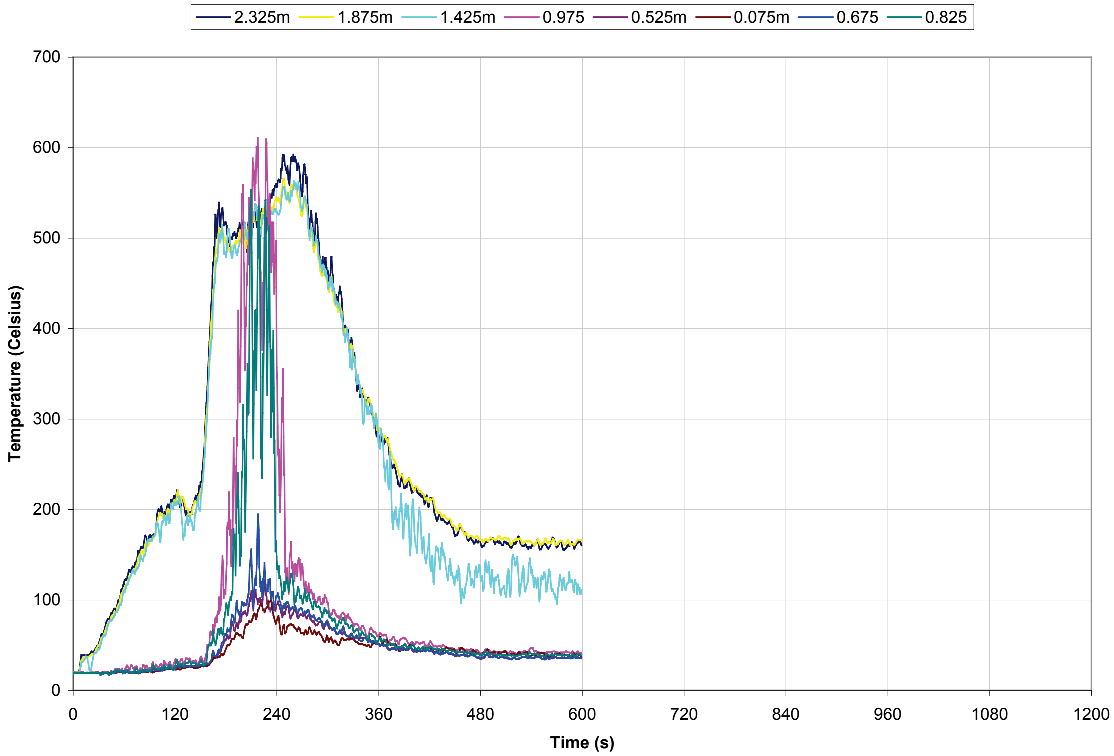

Figure 9-16 – Simulation Temperature History (J-21)

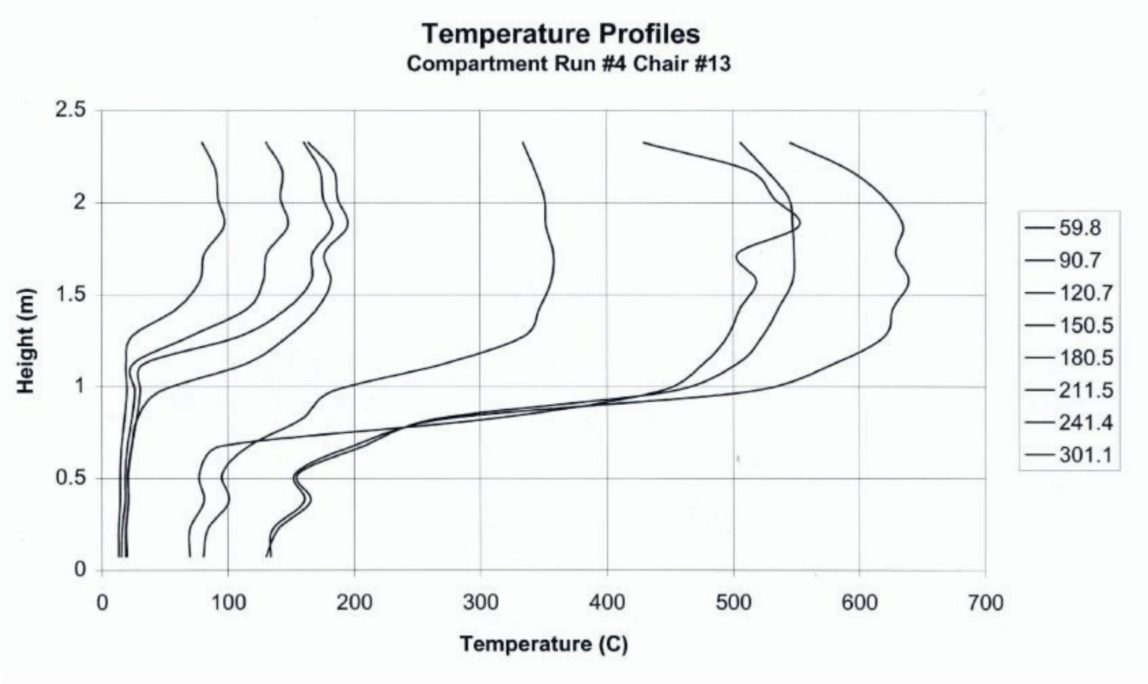

Figure 9-17 - Experiment Temperature Profile (J-21) (2)

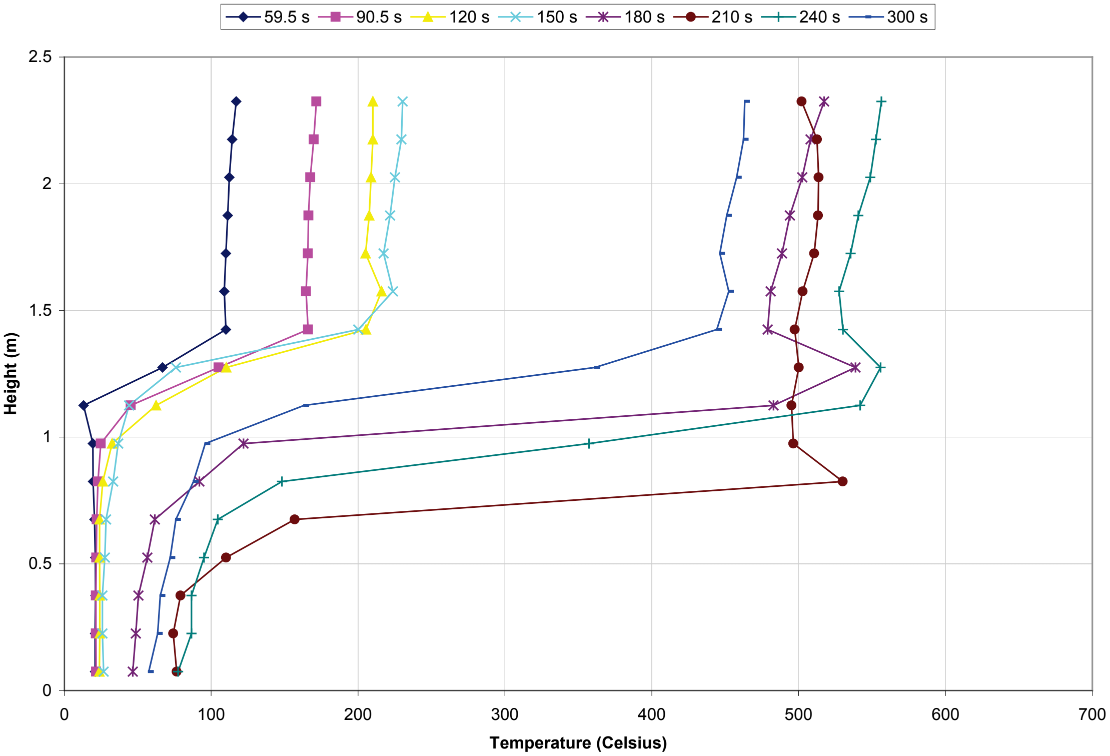

Figure 9-18 – Simulation Temperature Profile (J-21)

CHAIR L-21

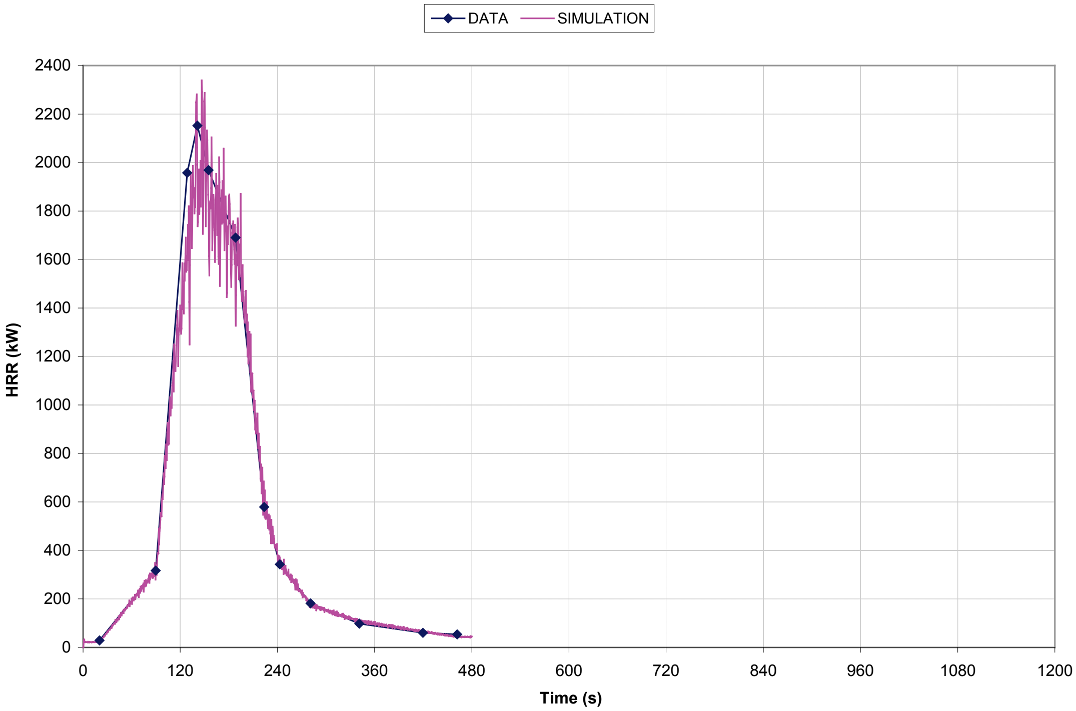

Figure 9-19 – HRR Comparison (L-21)

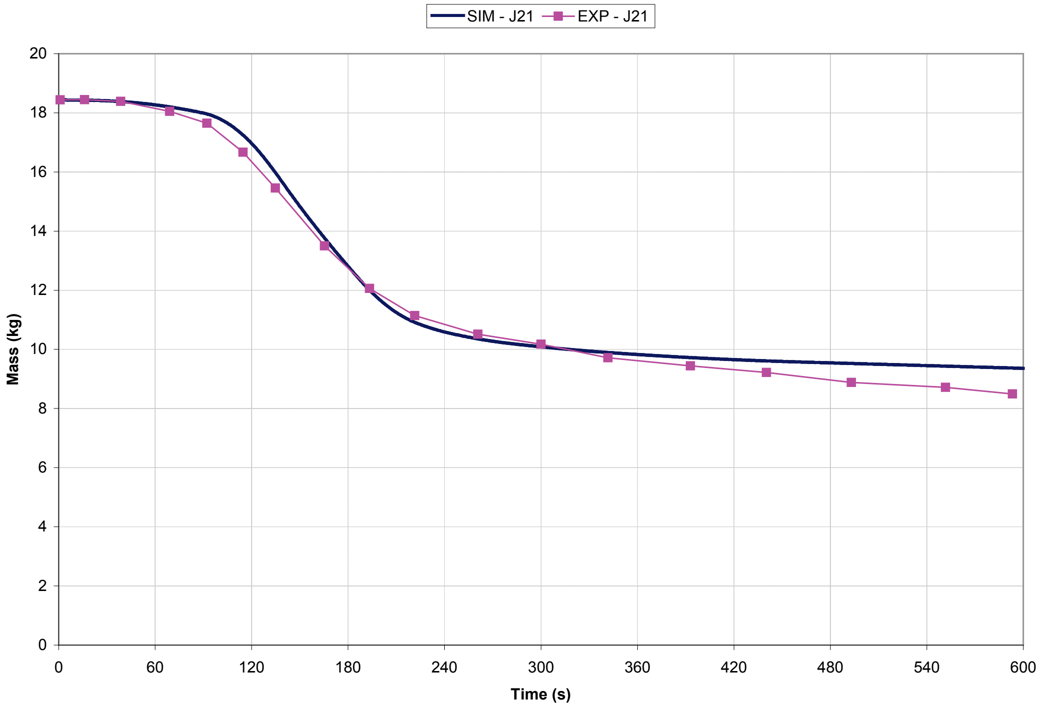

Figure 9-20 – Mass History Comparison (L-21)

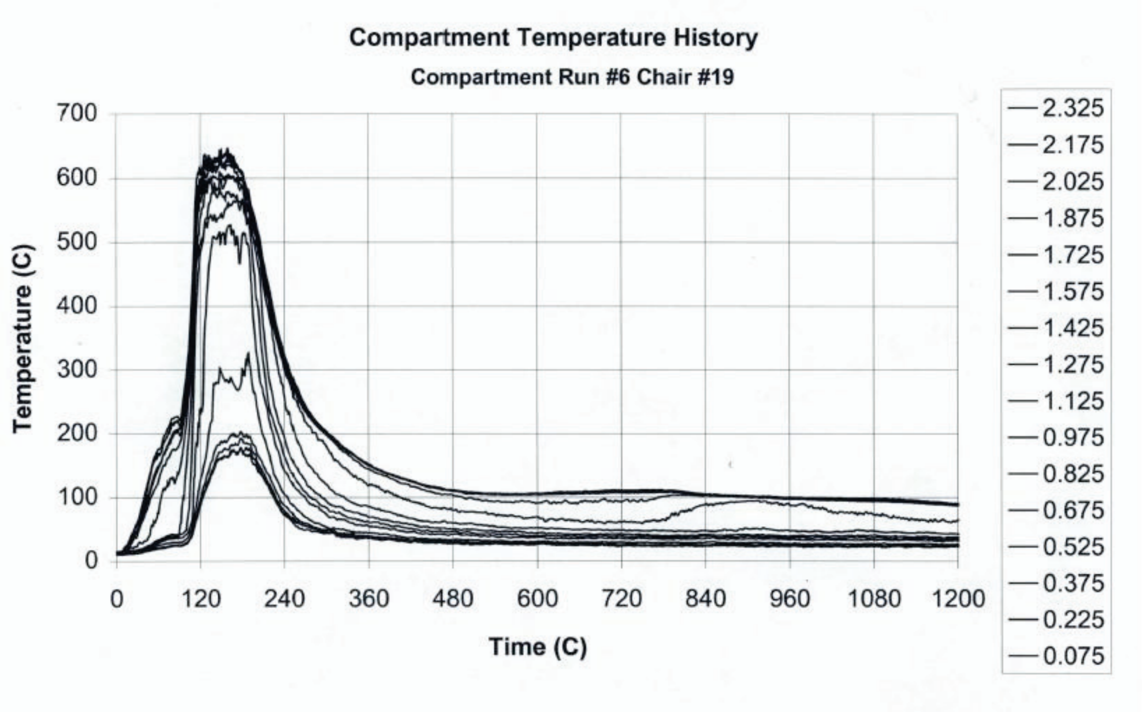

Figure 9-21 - Experiment Temperature History (L-21) (2)

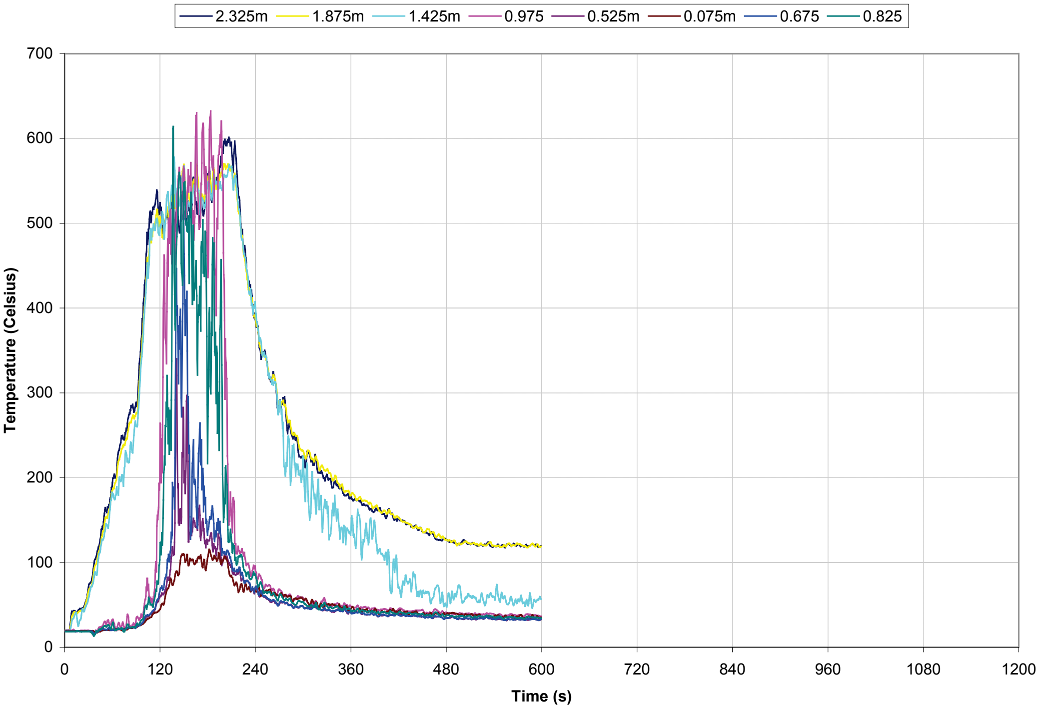

Figure 9-22 – Simulation Temperature History (L-21)

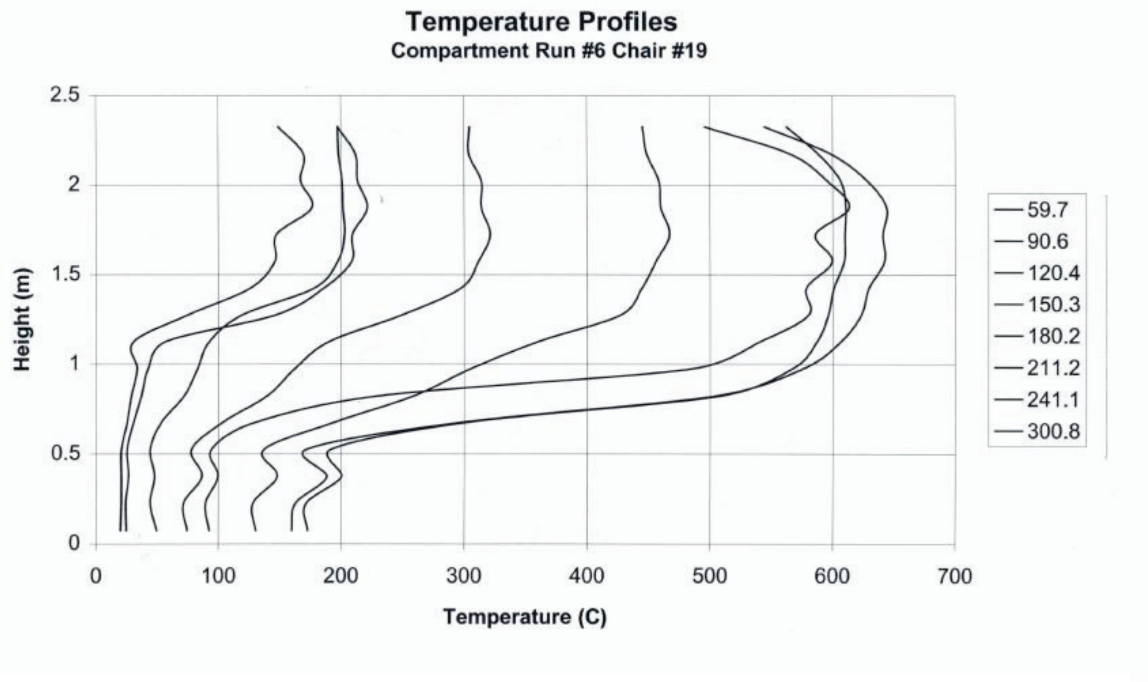

Figure 9-23 – Experiment Temperature Profile (L-21) (2)

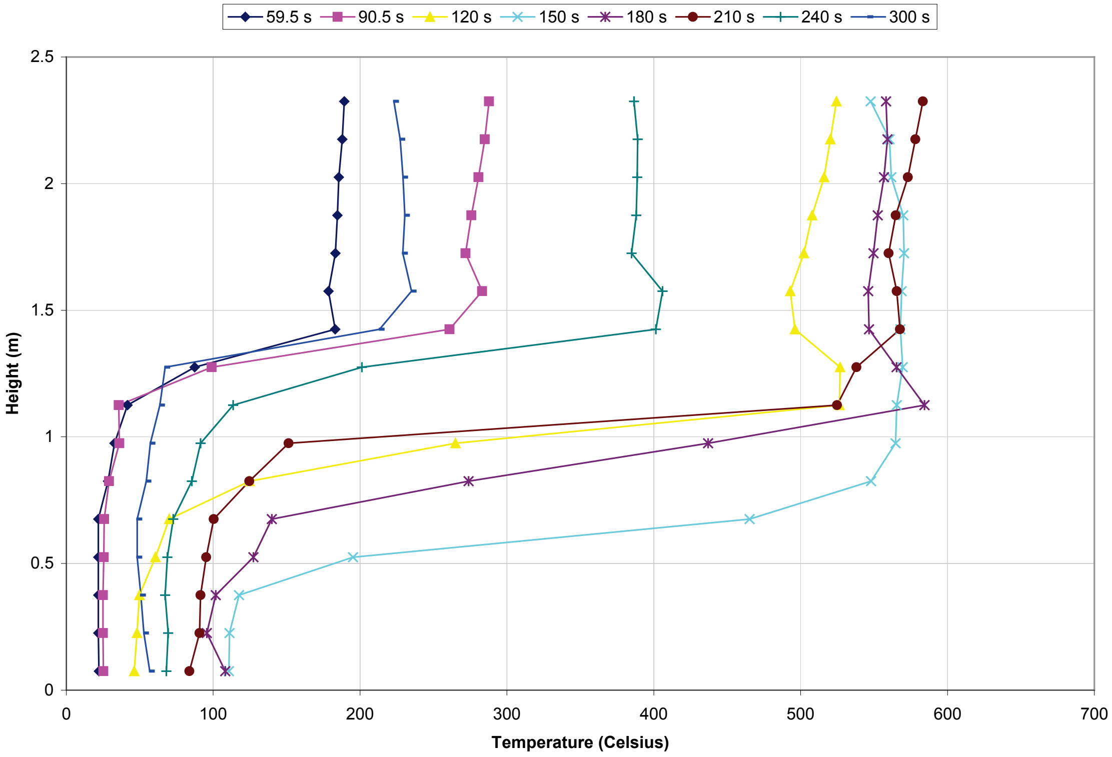

Figure 9-24 – Simulation Temperature Profile (L-21)

10 Appendix D

The following are ModFDS input files for the 7 simulations of Parkes' experiments using furniture calorimeter HRR data.

Vent: OPEN
Fire Location: CENTER

```
&HEAD  CHID='C-OPEN'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - CENTER - OPEN - 0.05 mesh'/
&MISC  RESTART=.TRUE./
&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=92,48,24, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0/  MESH #1

%DEFINES THE FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='PINK'/

&SURF  ID='CEILING'  MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='GREEN'/

&SURF  ID='FLOOR'    MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='BLUE'/

&MATL  ID='FIBERBOARD'
       CONDUCTIVITY_RAMP='COND_RAMP'
       DENSITY=288.
       SPECIFIC_HEAT=1.13
       EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP'       T=20          F=0.043/
&RAMP  ID='COND_RAMP'       T=204.3       F=0.052/
&RAMP  ID='COND_RAMP'       T=426.7       F=0.081/
&RAMP  ID='COND_RAMP'       T=648.9       F=0.147/
&RAMP  ID='COND_RAMP'       T=871.1       F=0.193/
&RAMP  ID='COND_RAMP'       T=1093.3      F=0.288/

&VENT  MB=XMIN       SURF_ID='OPEN'/
&VENT  MB=XMAX       SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2        SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2        SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2       SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2       SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0       SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0       SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0,2.4,1.2,1.2        SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2       SURF_ID='OPEN'/

&OBST  XB=1.7,1.9,1.1,1.3,0.0,0.05       SURF_IDS='BURNER','INERT','INERT'/

//FREE BURN HRRPUA OF HEPTANE//
&SURF  ID='BURNER', HRRPUA=2262.23, RAMP_Q='HRRPUA_RAMP'/
&RAMP ID='HRRPUA_RAMP', T=0,F=0/
&RAMP ID='HRRPUA_RAMP', T=10,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=35,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=60,F=0.38/
&RAMP ID='HRRPUA_RAMP', T=90,F=0.53/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.62/
&RAMP ID='HRRPUA_RAMP', T=175,F=0.66/
&RAMP ID='HRRPUA_RAMP', T=255,F=0.77/
```

```
&RAMP ID='HRRPUA_RAMP', T=350,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=480,F=0.84/
&RAMP ID='HRRPUA_RAMP', T=960,F=0.86/
&RAMP ID='HRRPUA_RAMP', T=1175,F=0.92/
&RAMP ID='HRRPUA_RAMP', T=1355,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=1530,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=1740,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=2260,F=0.97/
&RAMP ID='HRRPUA_RAMP', T=2440,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=2810,F=1/
&RAMP ID='HRRPUA_RAMP', T=3025,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=3495,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=3575,F=0.93/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
       DT_HRR=0.5
       DT_RESTART=20.
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='HRRPUV'
       PLOT3D_QUANTITY(3)='TEMPERATURE'/

//GAUGE HEAT FLUX//
&DEVC  XYZ=1.2,1.2,0       QUANTITY='GAUGE HEAT FLUX' IOR=+3 ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0       QUANTITY='GAUGE HEAT FLUX' IOR=+3 ID='HF_2'/

//TEMPERATURE AT 1 LOCATION//
&DEVC  XYZ=0.15,2.3,0.05   QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15   QUANTITY='THERMOCOUPLE'    ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.25   QUANTITY='THERMOCOUPLE'    ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.35   QUANTITY='THERMOCOUPLE'    ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.45   QUANTITY='THERMOCOUPLE'    ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.55   QUANTITY='THERMOCOUPLE'    ID='TC11'/
&DEVC  XYZ=0.15,2.3,0.65   QUANTITY='THERMOCOUPLE'    ID='TC13'/
&DEVC  XYZ=0.15,2.3,0.75   QUANTITY='THERMOCOUPLE'    ID='TC15'/
&DEVC  XYZ=0.15,2.3,0.85   QUANTITY='THERMOCOUPLE'    ID='TC17'/
&DEVC  XYZ=0.15,2.3,0.95   QUANTITY='THERMOCOUPLE'    ID='TC19'/
&DEVC  XYZ=0.15,2.3,1      QUANTITY='THERMOCOUPLE'    ID='TC20'/
&DEVC  XYZ=0.15,2.3,1.05   QUANTITY='THERMOCOUPLE'    ID='TC21'/
&DEVC  XYZ=0.15,2.3,1.1    QUANTITY='THERMOCOUPLE'    ID='TC22'/
&DEVC  XYZ=0.15,2.3,1.15   QUANTITY='THERMOCOUPLE'    ID='TC23'/


//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05    QUANTITY='U-VELOCITY'      ID='U1'/
&DEVC  XYZ=0,1.2,0.15      QUANTITY='U-VELOCITY'      ID='U3'/
&DEVC  XYZ=0,1.2,0.25      QUANTITY='U-VELOCITY'      ID='U5'/
&DEVC  XYZ=0,1.2,0.35      QUANTITY='U-VELOCITY'      ID='U7'/
&DEVC  XYZ=0.0,1.2,0.45    QUANTITY='U-VELOCITY'      ID='U9'/
&DEVC  XYZ=0.0,1.2,0.55    QUANTITY='U-VELOCITY'      ID='U11'/
&DEVC  XYZ=0.0,1.2,0.65    QUANTITY='U-VELOCITY'      ID='U13'/
&DEVC  XYZ=0.0,1.2,0.75    QUANTITY='U-VELOCITY'      ID='U15'/
&DEVC  XYZ=0.0,1.2,0.85    QUANTITY='U-VELOCITY'      ID='U17'/
&DEVC  XYZ=0.0,1.2,0.95    QUANTITY='U-VELOCITY'      ID='U19'/
&DEVC  XYZ=0.0,1.2,1.0     QUANTITY='U-VELOCITY'      ID='U20'/
&DEVC  XYZ=0.0,1.2,1.05    QUANTITY='U-VELOCITY'      ID='U21'/
&DEVC  XYZ=0.0,1.2,1.1     QUANTITY='U-VELOCITY'      ID='U22'/
&DEVC  XYZ=0.0,1.2,1.15    QUANTITY='U-VELOCITY'      ID='U23'/
&TAIL/
```

Vent: OPEN
Fire Location: REAR

```
&HEAD  CHID='R-OPEN'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - REAR - OPEN - 0.05 mesh'/
&MISC  RESTART=.TRUE./
&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=92,48,24, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0/  MESH #1

%DEFINES THE FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='PINK'/

&SURF  ID='CEILING'  MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='GREEN'/

&SURF  ID='FLOOR'    MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='BLUE'/

&MATL  ID='FIBERBOARD'
       CONDUCTIVITY_RAMP='COND_RAMP'
       DENSITY=288.
       SPECIFIC_HEAT=1.13
       EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP'       T=20          F=0.043/
&RAMP  ID='COND_RAMP'       T=204.3       F=0.052/
&RAMP  ID='COND_RAMP'       T=426.7       F=0.081/
&RAMP  ID='COND_RAMP'       T=648.9       F=0.147/
&RAMP  ID='COND_RAMP'       T=871.1       F=0.193/
&RAMP  ID='COND_RAMP'       T=1093.3      F=0.288/

&VENT  MB=XMIN       SURF_ID='OPEN'/
&VENT  MB=XMAX       SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2         SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2         SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2        SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2        SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0        SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0        SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0,2.4,1.2,1.2         SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2        SURF_ID='OPEN'/

&OBST  XB= 2.9,3.1,1.1,1.3,0.0,0.05       SURF_IDS='BURNER','INERT','INERT'/

//FREE BURN HRRPUA OF HEPTANE//
&SURF  ID='BURNER', HRRPUA=2262.23, RAMP_Q='HRRPUA_RAMP'/
&RAMP ID='HRRPUA_RAMP', T=0,F=0/
&RAMP ID='HRRPUA_RAMP', T=10,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=35,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=60,F=0.38/
&RAMP ID='HRRPUA_RAMP', T=90,F=0.53/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.62/
&RAMP ID='HRRPUA_RAMP', T=175,F=0.66/
&RAMP ID='HRRPUA_RAMP', T=255,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=350,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=480,F=0.84/
&RAMP ID='HRRPUA_RAMP', T=960,F=0.86/
&RAMP ID='HRRPUA_RAMP', T=1175,F=0.92/
&RAMP ID='HRRPUA_RAMP', T=1355,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=1530,F=0.95/
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&RAMP ID='HRRPUA_RAMP', T=1740,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=2260,F=0.97/
&RAMP ID='HRRPUA_RAMP', T=2440,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=2810,F=1/
&RAMP ID='HRRPUA_RAMP', T=3025,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=3495,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=3575,F=0.93/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
       DT_HRR=0.5
       DT_RESTART=20.
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='HRRPUV'
       PLOT3D_QUANTITY(3)='TEMPERATURE'/

//GAUGE HEAT FLUX//
&DEVC  XYZ=1.2,1.2,0        QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0        QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_2'/

//TEMPERATURE AT 1 LOCATION//
&DEVC  XYZ=0.15,2.3,0.05    QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15    QUANTITY='THERMOCOUPLE'    ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.25    QUANTITY='THERMOCOUPLE'    ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.35    QUANTITY='THERMOCOUPLE'    ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.45    QUANTITY='THERMOCOUPLE'    ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.55    QUANTITY='THERMOCOUPLE'    ID='TC11'/
&DEVC  XYZ=0.15,2.3,0.65    QUANTITY='THERMOCOUPLE'    ID='TC13'/
&DEVC  XYZ=0.15,2.3,0.75    QUANTITY='THERMOCOUPLE'    ID='TC15'/
&DEVC  XYZ=0.15,2.3,0.85    QUANTITY='THERMOCOUPLE'    ID='TC17'/
&DEVC  XYZ=0.15,2.3,0.95    QUANTITY='THERMOCOUPLE'    ID='TC19'/
&DEVC  XYZ=0.15,2.3,1       QUANTITY='THERMOCOUPLE'    ID='TC20'/
&DEVC  XYZ=0.15,2.3,1.05    QUANTITY='THERMOCOUPLE'    ID='TC21'/
&DEVC  XYZ=0.15,2.3,1.1     QUANTITY='THERMOCOUPLE'    ID='TC22'/
&DEVC  XYZ=0.15,2.3,1.15    QUANTITY='THERMOCOUPLE'    ID='TC23'/


//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05     QUANTITY='U-VELOCITY'      ID='U1'/
&DEVC  XYZ=0,1.2,0.15       QUANTITY='U-VELOCITY'      ID='U3'/
&DEVC  XYZ=0,1.2,0.25       QUANTITY='U-VELOCITY'      ID='U5'/
&DEVC  XYZ=0,1.2,0.35       QUANTITY='U-VELOCITY'      ID='U7'/
&DEVC  XYZ=0.0,1.2,0.45     QUANTITY='U-VELOCITY'      ID='U9'/
&DEVC  XYZ=0.0,1.2,0.55     QUANTITY='U-VELOCITY'      ID='U11'/
&DEVC  XYZ=0.0,1.2,0.65     QUANTITY='U-VELOCITY'      ID='U13'/
&DEVC  XYZ=0.0,1.2,0.75     QUANTITY='U-VELOCITY'      ID='U15'/
&DEVC  XYZ=0.0,1.2,0.85     QUANTITY='U-VELOCITY'      ID='U17'/
&DEVC  XYZ=0.0,1.2,0.95     QUANTITY='U-VELOCITY'      ID='U19'/
&DEVC  XYZ=0.0,1.2,1.0      QUANTITY='U-VELOCITY'      ID='U20'/
&DEVC  XYZ=0.0,1.2,1.05     QUANTITY='U-VELOCITY'      ID='U21'/
&DEVC  XYZ=0.0,1.2,1.1      QUANTITY='U-VELOCITY'      ID='U22'/
&DEVC  XYZ=0.0,1.2,1.15     QUANTITY='U-VELOCITY'      ID='U23'/
&TAIL/
```

Vent: SOFFIT
Fire Location: CENTER

```
&HEAD  CHID='C-SOFFIT'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - CENTER - SOFFIT - 0.05 mesh'/
&MISC  RESTART=.TRUE./
&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=92,48,24, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0/  MESH #1

%DEFINES THE FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='PINK'/

&SURF  ID='CEILING'  MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='GREEN'/

&SURF  ID='FLOOR'    MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='BLUE'/

&MATL  ID='FIBERBOARD'
       CONDUCTIVITY_RAMP='COND_RAMP'
       DENSITY=288.
       SPECIFIC_HEAT=1.13
       EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP'       T=20          F=0.043/
&RAMP  ID='COND_RAMP'       T=204.3       F=0.052/
&RAMP  ID='COND_RAMP'       T=426.7       F=0.081/
&RAMP  ID='COND_RAMP'       T=648.9       F=0.147/
&RAMP  ID='COND_RAMP'       T=871.1       F=0.193/
&RAMP  ID='COND_RAMP'       T=1093.3      F=0.288/

&VENT  MB=XMIN       SURF_ID='OPEN'/
&VENT  MB=XMAX       SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2         SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2         SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2        SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2        SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0        SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0        SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0,2.4,1.2,1.2         SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2        SURF_ID='OPEN'/
&OBST  XB=0.0,0.045,0.0,2.4,1.0,1.2       SURF_ID='WALL'/

&OBST  XB=1.7,1.9,1.1,1.3,0.0,0.05        SURF_IDS='BURNER','INERT','INERT'/

//FREE BURN HRRPUA OF HEPTANE//
&SURF  ID='BURNER', HRRPUA=2262.23, RAMP_Q='HRRPUA_RAMP'/
&RAMP ID='HRRPUA_RAMP', T=0,F=0/
&RAMP ID='HRRPUA_RAMP', T=10,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=35,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=60,F=0.38/
&RAMP ID='HRRPUA_RAMP', T=90,F=0.53/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.62/
&RAMP ID='HRRPUA_RAMP', T=175,F=0.66/
&RAMP ID='HRRPUA_RAMP', T=255,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=350,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=480,F=0.84/
&RAMP ID='HRRPUA_RAMP', T=960,F=0.86/
&RAMP ID='HRRPUA_RAMP', T=1175,F=0.92/
&RAMP ID='HRRPUA_RAMP', T=1355,F=0.93/
```

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&RAMP ID='HRRPUA_RAMP', T=1530,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=1740,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=2260,F=0.97/
&RAMP ID='HRRPUA_RAMP', T=2440,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=2810,F=1/
&RAMP ID='HRRPUA_RAMP', T=3025,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=3495,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=3575,F=0.93/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
       DT_HRR=0.5
       DT_RESTART=20.
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='HRRPUV'
       PLOT3D_QUANTITY(3)='TEMPERATURE'/

//GAUGE HEAT FLUX//
&DEVC  XYZ=1.2,1.2,0       QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0       QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_2'/

//TEMPERATURE AT 1 LOCATION//
&DEVC  XYZ=0.15,2.3,0.05   QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15   QUANTITY='THERMOCOUPLE'    ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.25   QUANTITY='THERMOCOUPLE'    ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.35   QUANTITY='THERMOCOUPLE'    ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.45   QUANTITY='THERMOCOUPLE'    ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.55   QUANTITY='THERMOCOUPLE'    ID='TC11'/
&DEVC  XYZ=0.15,2.3,0.65   QUANTITY='THERMOCOUPLE'    ID='TC13'/
&DEVC  XYZ=0.15,2.3,0.75   QUANTITY='THERMOCOUPLE'    ID='TC15'/
&DEVC  XYZ=0.15,2.3,0.85   QUANTITY='THERMOCOUPLE'    ID='TC17'/
&DEVC  XYZ=0.15,2.3,0.95   QUANTITY='THERMOCOUPLE'    ID='TC19'/
&DEVC  XYZ=0.15,2.3,1      QUANTITY='THERMOCOUPLE'    ID='TC20'/
&DEVC  XYZ=0.15,2.3,1.05   QUANTITY='THERMOCOUPLE'    ID='TC21'/
&DEVC  XYZ=0.15,2.3,1.1    QUANTITY='THERMOCOUPLE'    ID='TC22'/
&DEVC  XYZ=0.15,2.3,1.15   QUANTITY='THERMOCOUPLE'    ID='TC23'/


//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05    QUANTITY='U-VELOCITY'      ID='U1'/
&DEVC  XYZ=0,1.2,0.15      QUANTITY='U-VELOCITY'      ID='U3'/
&DEVC  XYZ=0,1.2,0.25      QUANTITY='U-VELOCITY'      ID='U5'/
&DEVC  XYZ=0,1.2,0.35      QUANTITY='U-VELOCITY'      ID='U7'/
&DEVC  XYZ=0.0,1.2,0.45    QUANTITY='U-VELOCITY'      ID='U9'/
&DEVC  XYZ=0.0,1.2,0.55    QUANTITY='U-VELOCITY'      ID='U11'/
&DEVC  XYZ=0.0,1.2,0.65    QUANTITY='U-VELOCITY'      ID='U13'/
&DEVC  XYZ=0.0,1.2,0.75    QUANTITY='U-VELOCITY'      ID='U15'/
&DEVC  XYZ=0.0,1.2,0.85    QUANTITY='U-VELOCITY'      ID='U17'/
&DEVC  XYZ=0.0,1.2,0.95    QUANTITY='U-VELOCITY'      ID='U19'/
&DEVC  XYZ=0.0,1.2,1.0     QUANTITY='U-VELOCITY'      ID='U20'/
&DEVC  XYZ=0.0,1.2,1.05    QUANTITY='U-VELOCITY'      ID='U21'/
&DEVC  XYZ=0.0,1.2,1.1     QUANTITY='U-VELOCITY'      ID='U22'/
&DEVC  XYZ=0.0,1.2,1.15    QUANTITY='U-VELOCITY'      ID='U23'/
&TAIL/
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Vent: SOFFIT
Fire Location: REAR

```
&HEAD  CHID='R-SOFFIT'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - REAR - SOFFIT - 0.05 mesh'/
&MISC  RESTART=.TRUE./
&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=92,48,24, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0/  MESH #1

%DEFINES THE FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='PINK'/

&SURF  ID='CEILING'  MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='GREEN'/

&SURF  ID='FLOOR'    MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='BLUE'/

&MATL  ID='FIBERBOARD'
       CONDUCTIVITY_RAMP='COND_RAMP'
       DENSITY=288.
       SPECIFIC_HEAT=1.13
       EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP'       T=20          F=0.043/
&RAMP  ID='COND_RAMP'       T=204.3       F=0.052/
&RAMP  ID='COND_RAMP'       T=426.7       F=0.081/
&RAMP  ID='COND_RAMP'       T=648.9       F=0.147/
&RAMP  ID='COND_RAMP'       T=871.1       F=0.193/
&RAMP  ID='COND_RAMP'       T=1093.3      F=0.288/

&VENT  MB=XMIN       SURF_ID='OPEN'/
&VENT  MB=XMAX       SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2        SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2        SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2       SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2       SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0       SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0       SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0,2.4,1.2,1.2        SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2       SURF_ID='OPEN'/
&OBST  XB=0.0,0.045,0.0,2.4,1.0,1.2      SURF_ID='WALL'/

&OBST  XB= 2.9,3.1,1.1,1.3,0.0,0.05      SURF_IDS='BURNER','INERT','INERT'/

//FREE BURN HRRPUA OF HEPTANE//
&SURF  ID='BURNER', HRRPUA=2262.23, RAMP_Q='HRRPUA_RAMP'/
&RAMP ID='HRRPUA_RAMP', T=0,F=0/
&RAMP ID='HRRPUA_RAMP', T=10,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=35,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=60,F=0.38/
&RAMP ID='HRRPUA_RAMP', T=90,F=0.53/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.62/
&RAMP ID='HRRPUA_RAMP', T=175,F=0.66/
&RAMP ID='HRRPUA_RAMP', T=255,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=350,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=480,F=0.84/
&RAMP ID='HRRPUA_RAMP', T=960,F=0.86/
&RAMP ID='HRRPUA_RAMP', T=1175,F=0.92/
&RAMP ID='HRRPUA_RAMP', T=1355,F=0.93/
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&RAMP ID='HRRPUA_RAMP', T=1530,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=1740,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=2260,F=0.97/
&RAMP ID='HRRPUA_RAMP', T=2440,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=2810,F=1/
&RAMP ID='HRRPUA_RAMP', T=3025,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=3495,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=3575,F=0.93/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
       DT_HRR=0.5
       DT_RESTART=20.
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='HRRPUV'
       PLOT3D_QUANTITY(3)='TEMPERATURE'/

//GAUGE HEAT FLUX//
&DEVC  XYZ=1.2,1.2,0        QUANTITY='GAUGE HEAT FLUX'  IOR=+3        ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0        QUANTITY='GAUGE HEAT FLUX'  IOR=+3        ID='HF_2'/

//TEMPERATURE AT 1 LOCATION//
&DEVC  XYZ=0.15,2.3,0.05    QUANTITY='THERMOCOUPLE'     ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15    QUANTITY='THERMOCOUPLE'     ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.25    QUANTITY='THERMOCOUPLE'     ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.35    QUANTITY='THERMOCOUPLE'     ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.45    QUANTITY='THERMOCOUPLE'     ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.55    QUANTITY='THERMOCOUPLE'     ID='TC11'/
&DEVC  XYZ=0.15,2.3,0.65    QUANTITY='THERMOCOUPLE'     ID='TC13'/
&DEVC  XYZ=0.15,2.3,0.75    QUANTITY='THERMOCOUPLE'     ID='TC15'/
&DEVC  XYZ=0.15,2.3,0.85    QUANTITY='THERMOCOUPLE'     ID='TC17'/
&DEVC  XYZ=0.15,2.3,0.95    QUANTITY='THERMOCOUPLE'     ID='TC19'/
&DEVC  XYZ=0.15,2.3,1       QUANTITY='THERMOCOUPLE'     ID='TC20'/
&DEVC  XYZ=0.15,2.3,1.05    QUANTITY='THERMOCOUPLE'     ID='TC21'/
&DEVC  XYZ=0.15,2.3,1.1     QUANTITY='THERMOCOUPLE'     ID='TC22'/
&DEVC  XYZ=0.15,2.3,1.15    QUANTITY='THERMOCOUPLE'     ID='TC23'/


//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05     QUANTITY='U-VELOCITY'       ID='U1'/
&DEVC  XYZ=0,1.2,0.15       QUANTITY='U-VELOCITY'       ID='U3'/
&DEVC  XYZ=0,1.2,0.25       QUANTITY='U-VELOCITY'       ID='U5'/
&DEVC  XYZ=0,1.2,0.35       QUANTITY='U-VELOCITY'       ID='U7'/
&DEVC  XYZ=0.0,1.2,0.45     QUANTITY='U-VELOCITY'       ID='U9'/
&DEVC  XYZ=0.0,1.2,0.55     QUANTITY='U-VELOCITY'       ID='U11'/
&DEVC  XYZ=0.0,1.2,0.65     QUANTITY='U-VELOCITY'       ID='U13'/
&DEVC  XYZ=0.0,1.2,0.75     QUANTITY='U-VELOCITY'       ID='U15'/
&DEVC  XYZ=0.0,1.2,0.85     QUANTITY='U-VELOCITY'       ID='U17'/
&DEVC  XYZ=0.0,1.2,0.95     QUANTITY='U-VELOCITY'       ID='U19'/
&DEVC  XYZ=0.0,1.2,1.0      QUANTITY='U-VELOCITY'       ID='U20'/
&DEVC  XYZ=0.0,1.2,1.05     QUANTITY='U-VELOCITY'       ID='U21'/
&DEVC  XYZ=0.0,1.2,1.1      QUANTITY='U-VELOCITY'       ID='U22'/
&DEVC  XYZ=0.0,1.2,1.15     QUANTITY='U-VELOCITY'       ID='U23'/
&TAIL/
```

Vent: DOOR
Fire Location: CENTER

```
&HEAD  CHID='C-DOOR'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - CENTER - DOOR - 0.05 mesh'/
&MISC  RESTART=.TRUE./
&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=92,48,24, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0/  MESH #1

%DEFINES THE FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='PINK'/

&SURF  ID='CEILING'  MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='GREEN'/

&SURF  ID='FLOOR'    MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='BLUE'/

&MATL  ID='FIBERBOARD'
       CONDUCTIVITY_RAMP='COND_RAMP'
       DENSITY=288.
       SPECIFIC_HEAT=1.13
       EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP'       T=20          F=0.043/
&RAMP  ID='COND_RAMP'       T=204.3       F=0.052/
&RAMP  ID='COND_RAMP'       T=426.7       F=0.081/
&RAMP  ID='COND_RAMP'       T=648.9       F=0.147/
&RAMP  ID='COND_RAMP'       T=871.1       F=0.193/
&RAMP  ID='COND_RAMP'       T=1093.3      F=0.288/

&VENT  MB=XMIN       SURF_ID='OPEN'/
&VENT  MB=XMAX       SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2        SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2        SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2       SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2       SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0       SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0       SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0,2.4,1.2,1.2        SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2       SURF_ID='OPEN'/
%VENT  XB=0.0,0.0,1.0,1.4,0.0,1.0        SURF_ID='OPEN'%
&OBST  XB=0.0,0.045,0.0,2.4,1.0,1.2      SURF_ID='WALL'/
&OBST  XB=0.0,0.045,0.0,1.0,0.0,1.0      SURF_ID='WALL'/
&OBST  XB=0.0,0.045,1.4,2.4,0.0,1.0      SURF_ID='WALL'/
&OBST  XB=1.7,1.9,1.1,1.3,0.0,0.05       SURF_IDS='BURNER','INERT','INERT'/

//FREE BURN HRRPUA OF HEPTANE//
&SURF  ID='BURNER', HRRPUA=2262.23, RAMP_Q='HRRPUA_RAMP'/
&RAMP ID='HRRPUA_RAMP', T=0,F=0/
&RAMP ID='HRRPUA_RAMP', T=10,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=35,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=60,F=0.38/
&RAMP ID='HRRPUA_RAMP', T=90,F=0.53/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.62/
&RAMP ID='HRRPUA_RAMP', T=175,F=0.66/
&RAMP ID='HRRPUA_RAMP', T=255,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=350,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=480,F=0.84/
&RAMP ID='HRRPUA_RAMP', T=960,F=0.86/
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```
&RAMP ID='HRRPUA_RAMP', T=1175,F=0.92/
&RAMP ID='HRRPUA_RAMP', T=1355,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=1530,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=1740,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=2260,F=0.97/
&RAMP ID='HRRPUA_RAMP', T=2440,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=2810,F=1/
&RAMP ID='HRRPUA_RAMP', T=3025,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=3495,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=3575,F=0.93/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
       DT_HRR=0.5
       DT_RESTART=20.
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='HRRPUV'
       PLOT3D_QUANTITY(3)='TEMPERATURE'/

//GAUGE HEAT FLUX//
&DEVC  XYZ=1.2,1.2,0       QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0       QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_2'/

//TEMPERATURE AT 1 LOCATION//
&DEVC  XYZ=0.15,2.3,0.05   QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15   QUANTITY='THERMOCOUPLE'    ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.25   QUANTITY='THERMOCOUPLE'    ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.35   QUANTITY='THERMOCOUPLE'    ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.45   QUANTITY='THERMOCOUPLE'    ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.55   QUANTITY='THERMOCOUPLE'    ID='TC11'/
&DEVC  XYZ=0.15,2.3,0.65   QUANTITY='THERMOCOUPLE'    ID='TC13'/
&DEVC  XYZ=0.15,2.3,0.75   QUANTITY='THERMOCOUPLE'    ID='TC15'/
&DEVC  XYZ=0.15,2.3,0.85   QUANTITY='THERMOCOUPLE'    ID='TC17'/
&DEVC  XYZ=0.15,2.3,0.95   QUANTITY='THERMOCOUPLE'    ID='TC19'/
&DEVC  XYZ=0.15,2.3,1      QUANTITY='THERMOCOUPLE'    ID='TC20'/
&DEVC  XYZ=0.15,2.3,1.05   QUANTITY='THERMOCOUPLE'    ID='TC21'/
&DEVC  XYZ=0.15,2.3,1.1    QUANTITY='THERMOCOUPLE'    ID='TC22'/
&DEVC  XYZ=0.15,2.3,1.15   QUANTITY='THERMOCOUPLE'    ID='TC23'/


//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05    QUANTITY='U-VELOCITY'      ID='U1'/
&DEVC  XYZ=0,1.2,0.15      QUANTITY='U-VELOCITY'      ID='U3'/
&DEVC  XYZ=0,1.2,0.25      QUANTITY='U-VELOCITY'      ID='U5'/
&DEVC  XYZ=0,1.2,0.35      QUANTITY='U-VELOCITY'      ID='U7'/
&DEVC  XYZ=0.0,1.2,0.45    QUANTITY='U-VELOCITY'      ID='U9'/
&DEVC  XYZ=0.0,1.2,0.55    QUANTITY='U-VELOCITY'      ID='U11'/
&DEVC  XYZ=0.0,1.2,0.65    QUANTITY='U-VELOCITY'      ID='U13'/
&DEVC  XYZ=0.0,1.2,0.75    QUANTITY='U-VELOCITY'      ID='U15'/
&DEVC  XYZ=0.0,1.2,0.85    QUANTITY='U-VELOCITY'      ID='U17'/
&DEVC  XYZ=0.0,1.2,0.95    QUANTITY='U-VELOCITY'      ID='U19'/
&DEVC  XYZ=0.0,1.2,1.0     QUANTITY='U-VELOCITY'      ID='U20'/
&DEVC  XYZ=0.0,1.2,1.05    QUANTITY='U-VELOCITY'      ID='U21'/
&DEVC  XYZ=0.0,1.2,1.1     QUANTITY='U-VELOCITY'      ID='U22'/
&DEVC  XYZ=0.0,1.2,1.15    QUANTITY='U-VELOCITY'      ID='U23'/
&TAIL/
```

Vent: DOOR

Fire Location: FRONT

```
&HEAD  CHID='F-DOOR'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - FRONT - DOOR - 0.05 mesh'/
&MISC  RESTART=.TRUE./
&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=92,48,24, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0/  MESH #1

%DEFINES THE FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='PINK'/

&SURF  ID='CEILING'  MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='GREEN'/

&SURF  ID='FLOOR'    MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='BLUE'/

&MATL  ID='FIBERBOARD'
       CONDUCTIVITY_RAMP='COND_RAMP'
       DENSITY=288.
       SPECIFIC_HEAT=1.13
       EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP'       T=20          F=0.043/
&RAMP  ID='COND_RAMP'       T=204.3       F=0.052/
&RAMP  ID='COND_RAMP'       T=426.7       F=0.081/
&RAMP  ID='COND_RAMP'       T=648.9       F=0.147/
&RAMP  ID='COND_RAMP'       T=871.1       F=0.193/
&RAMP  ID='COND_RAMP'       T=1093.3      F=0.288/

&VENT  MB=XMIN       SURF_ID='OPEN'/
&VENT  MB=XMAX       SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2        SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2        SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2       SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2       SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0       SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0       SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0,2.4,1.2,1.2        SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2       SURF_ID='OPEN'/
%VENT  XB=0.0,0.0,1.0,1.4,0.0,1.0        SURF_ID='OPEN'%
&OBST  XB=0.0,0.045,0.0,2.4,1.0,1.2      SURF_ID='WALL'/
&OBST  XB=0.0,0.045,0.0,1.0,0.0,1.0      SURF_ID='WALL'/
&OBST  XB=0.0,0.045,1.4,2.4,0.0,1.0      SURF_ID='WALL'/
&OBST  XB= 0.5,0.7,1.1,1.3,0.0,0.05      SURF_IDS='BURNER','INERT','INERT'/

//FREE BURN HRRPUA OF HEPTANE//
&SURF  ID='BURNER', HRRPUA=2262.23, RAMP_Q='HRRPUA_RAMP'/
&RAMP ID='HRRPUA_RAMP', T=0,F=0/
&RAMP ID='HRRPUA_RAMP', T=10,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=35,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=60,F=0.38/
&RAMP ID='HRRPUA_RAMP', T=90,F=0.53/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.62/
&RAMP ID='HRRPUA_RAMP', T=175,F=0.66/
&RAMP ID='HRRPUA_RAMP', T=255,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=350,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=480,F=0.84/
&RAMP ID='HRRPUA_RAMP', T=960,F=0.86/
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&RAMP ID='HRRPUA_RAMP', T=1175,F=0.92/
&RAMP ID='HRRPUA_RAMP', T=1355,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=1530,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=1740,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=2260,F=0.97/
&RAMP ID='HRRPUA_RAMP', T=2440,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=2810,F=1/
&RAMP ID='HRRPUA_RAMP', T=3025,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=3495,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=3575,F=0.93/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
       DT_HRR=0.5
       DT_RESTART=20.
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='HRRPUV'
       PLOT3D_QUANTITY(3)='TEMPERATURE'/

//GAUGE HEAT FLUX//
&DEVC  XYZ=1.2,1.2,0       QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0       QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_2'/

//TEMPERATURE AT 1 LOCATION//
&DEVC  XYZ=0.15,2.3,0.05   QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15   QUANTITY='THERMOCOUPLE'    ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.25   QUANTITY='THERMOCOUPLE'    ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.35   QUANTITY='THERMOCOUPLE'    ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.45   QUANTITY='THERMOCOUPLE'    ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.55   QUANTITY='THERMOCOUPLE'    ID='TC11'/
&DEVC  XYZ=0.15,2.3,0.65   QUANTITY='THERMOCOUPLE'    ID='TC13'/
&DEVC  XYZ=0.15,2.3,0.75   QUANTITY='THERMOCOUPLE'    ID='TC15'/
&DEVC  XYZ=0.15,2.3,0.85   QUANTITY='THERMOCOUPLE'    ID='TC17'/
&DEVC  XYZ=0.15,2.3,0.95   QUANTITY='THERMOCOUPLE'    ID='TC19'/
&DEVC  XYZ=0.15,2.3,1      QUANTITY='THERMOCOUPLE'    ID='TC20'/
&DEVC  XYZ=0.15,2.3,1.05   QUANTITY='THERMOCOUPLE'    ID='TC21'/
&DEVC  XYZ=0.15,2.3,1.1    QUANTITY='THERMOCOUPLE'    ID='TC22'/
&DEVC  XYZ=0.15,2.3,1.15   QUANTITY='THERMOCOUPLE'    ID='TC23'/


//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05    QUANTITY='U-VELOCITY'      ID='U1'/
&DEVC  XYZ=0,1.2,0.15      QUANTITY='U-VELOCITY'      ID='U3'/
&DEVC  XYZ=0,1.2,0.25      QUANTITY='U-VELOCITY'      ID='U5'/
&DEVC  XYZ=0,1.2,0.35      QUANTITY='U-VELOCITY'      ID='U7'/
&DEVC  XYZ=0.0,1.2,0.45    QUANTITY='U-VELOCITY'      ID='U9'/
&DEVC  XYZ=0.0,1.2,0.55    QUANTITY='U-VELOCITY'      ID='U11'/
&DEVC  XYZ=0.0,1.2,0.65    QUANTITY='U-VELOCITY'      ID='U13'/
&DEVC  XYZ=0.0,1.2,0.75    QUANTITY='U-VELOCITY'      ID='U15'/
&DEVC  XYZ=0.0,1.2,0.85    QUANTITY='U-VELOCITY'      ID='U17'/
&DEVC  XYZ=0.0,1.2,0.95    QUANTITY='U-VELOCITY'      ID='U19'/
&DEVC  XYZ=0.0,1.2,1.0     QUANTITY='U-VELOCITY'      ID='U20'/
&DEVC  XYZ=0.0,1.2,1.05    QUANTITY='U-VELOCITY'      ID='U21'/
&DEVC  XYZ=0.0,1.2,1.1     QUANTITY='U-VELOCITY'      ID='U22'/
&DEVC  XYZ=0.0,1.2,1.15    QUANTITY='U-VELOCITY'      ID='U23'/
&TAIL/
```

Vent: DOOR

Fire Location: REAR

```
&HEAD  CHID='R-DOOR'
       TITLE='COMPARTMENT EFFECTS ON HRR OF FUEL - REAR - DOOR - 0.05 mesh'/
&MISC  RESTART=.TRUE./
&TIME  T_END=3600.0/

%DEFINES COMPARTMENT SIZE AND MESH SIZE
&MESH  IJK=92,48,24, XB=-1.0,3.6,0.0,2.4,0.0,1.2, MPI_PROCESS = 0/  MESH #1

%DEFINES THE FUEL
&REAC  ID='HEPTANE'  C=7.   H=16./

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='PINK'/

&SURF  ID='CEILING'  MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='GREEN'/

&SURF  ID='FLOOR'    MATL_ID='FIBERBOARD' THICKNESS=0.02       COLOR='BLUE'/

&MATL  ID='FIBERBOARD'
       CONDUCTIVITY_RAMP='COND_RAMP'
       DENSITY=288.
       SPECIFIC_HEAT=1.13
       EMISSIVITY=0.9/

&RAMP  ID='COND_RAMP'       T=20          F=0.043/
&RAMP  ID='COND_RAMP'       T=204.3       F=0.052/
&RAMP  ID='COND_RAMP'       T=426.7       F=0.081/
&RAMP  ID='COND_RAMP'       T=648.9       F=0.147/
&RAMP  ID='COND_RAMP'       T=871.1       F=0.193/
&RAMP  ID='COND_RAMP'       T=1093.3      F=0.288/

&VENT  MB=XMIN       SURF_ID='OPEN'/
&VENT  MB=XMAX       SURF_ID='WALL'/
&VENT  XB=0.0,3.6,0.0,0.0,0.0,1.2         SURF_ID='WALL'/
&VENT  XB=0.0,3.6,2.4,2.4,0.0,1.2         SURF_ID='WALL'/
&VENT  XB=-1.0,0.0,2.4,2.4,0.0,1.2        SURF_ID='OPEN'/
&VENT  XB=-1.0,0.0,0.0,0.0,0.0,1.2        SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0, 2.4,0.0,0.0        SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,0.0,0.0        SURF_ID='OPEN'/
&VENT  XB=0.0,3.6,0.0,2.4,1.2,1.2         SURF_ID='FLOOR'/
&VENT  XB=-1.0,0.0,0.0,2.4,1.2,1.2        SURF_ID='OPEN'/
%VENT  XB=0.0,0.0,1.0,1.4,0.0,1.0         SURF_ID='OPEN'%
&OBST  XB=0.0,0.045,0.0,2.4,1.0,1.2       SURF_ID='WALL'/
&OBST  XB=0.0,0.045,0.0,1.0,0.0,1.0       SURF_ID='WALL'/
&OBST  XB=0.0,0.045,1.4,2.4,0.0,1.0       SURF_ID='WALL'/
&OBST  XB= 2.9,3.1,1.1,1.3,0.0,0.05       SURF_IDS='BURNER','INERT','INERT'/

//FREE BURN HRRPUA OF HEPTANE//
&SURF  ID='BURNER', HRRPUA=2262.23, RAMP_Q='HRRPUA_RAMP'/
&RAMP ID='HRRPUA_RAMP', T=0,F=0/
&RAMP ID='HRRPUA_RAMP', T=10,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=35,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=60,F=0.38/
&RAMP ID='HRRPUA_RAMP', T=90,F=0.53/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.62/
&RAMP ID='HRRPUA_RAMP', T=175,F=0.66/
&RAMP ID='HRRPUA_RAMP', T=255,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=350,F=0.77/
&RAMP ID='HRRPUA_RAMP', T=480,F=0.84/
&RAMP ID='HRRPUA_RAMP', T=960,F=0.86/
```

```
&RAMP ID='HRRPUA_RAMP', T=1175,F=0.92/
&RAMP ID='HRRPUA_RAMP', T=1355,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=1530,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=1740,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=2260,F=0.97/
&RAMP ID='HRRPUA_RAMP', T=2440,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=2810,F=1/
&RAMP ID='HRRPUA_RAMP', T=3025,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=3495,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=3575,F=0.93/

&DUMP  DT_PL3D=20.
       DT_DEVC=0.5
       DT_HRR=0.5
       DT_RESTART=20.
       WRITE_XYZ=.TRUE.
       PLOT3D_QUANTITY(1)='U-VELOCITY'
       PLOT3D_QUANTITY(2)='HRRPUV'
       PLOT3D_QUANTITY(3)='TEMPERATURE'/

//GAUGE HEAT FLUX//
&DEVC  XYZ=1.2,1.2,0        QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_1'/
&DEVC  XYZ=2.4,1.2,0        QUANTITY='GAUGE HEAT FLUX' IOR=+3        ID='HF_2'/

//TEMPERATURE AT 1 LOCATION//
&DEVC  XYZ=0.15,2.3,0.05    QUANTITY='THERMOCOUPLE'    ID='TC1'/
&DEVC  XYZ=0.15,2.3,0.15    QUANTITY='THERMOCOUPLE'    ID='TC3'/
&DEVC  XYZ=0.15,2.3,0.25    QUANTITY='THERMOCOUPLE'    ID='TC5'/
&DEVC  XYZ=0.15,2.3,0.35    QUANTITY='THERMOCOUPLE'    ID='TC7'/
&DEVC  XYZ=0.15,2.3,0.45    QUANTITY='THERMOCOUPLE'    ID='TC9'/
&DEVC  XYZ=0.15,2.3,0.55    QUANTITY='THERMOCOUPLE'    ID='TC11'/
&DEVC  XYZ=0.15,2.3,0.65    QUANTITY='THERMOCOUPLE'    ID='TC13'/
&DEVC  XYZ=0.15,2.3,0.75    QUANTITY='THERMOCOUPLE'    ID='TC15'/
&DEVC  XYZ=0.15,2.3,0.85    QUANTITY='THERMOCOUPLE'    ID='TC17'/
&DEVC  XYZ=0.15,2.3,0.95    QUANTITY='THERMOCOUPLE'    ID='TC19'/
&DEVC  XYZ=0.15,2.3,1       QUANTITY='THERMOCOUPLE'    ID='TC20'/
&DEVC  XYZ=0.15,2.3,1.05    QUANTITY='THERMOCOUPLE'    ID='TC21'/
&DEVC  XYZ=0.15,2.3,1.1     QUANTITY='THERMOCOUPLE'    ID='TC22'/
&DEVC  XYZ=0.15,2.3,1.15    QUANTITY='THERMOCOUPLE'    ID='TC23'/


//VELOCITY AT CENTER OF OPENING//
&DEVC  XYZ=0.0,1.2,0.05     QUANTITY='U-VELOCITY'      ID='U1'/
&DEVC  XYZ=0,1.2,0.15       QUANTITY='U-VELOCITY'      ID='U3'/
&DEVC  XYZ=0,1.2,0.25       QUANTITY='U-VELOCITY'      ID='U5'/
&DEVC  XYZ=0,1.2,0.35       QUANTITY='U-VELOCITY'      ID='U7'/
&DEVC  XYZ=0.0,1.2,0.45     QUANTITY='U-VELOCITY'      ID='U9'/
&DEVC  XYZ=0.0,1.2,0.55     QUANTITY='U-VELOCITY'      ID='U11'/
&DEVC  XYZ=0.0,1.2,0.65     QUANTITY='U-VELOCITY'      ID='U13'/
&DEVC  XYZ=0.0,1.2,0.75     QUANTITY='U-VELOCITY'      ID='U15'/
&DEVC  XYZ=0.0,1.2,0.85     QUANTITY='U-VELOCITY'      ID='U17'/
&DEVC  XYZ=0.0,1.2,0.95     QUANTITY='U-VELOCITY'      ID='U19'/
&DEVC  XYZ=0.0,1.2,1.0      QUANTITY='U-VELOCITY'      ID='U20'/
&DEVC  XYZ=0.0,1.2,1.05     QUANTITY='U-VELOCITY'      ID='U21'/
&DEVC  XYZ=0.0,1.2,1.1      QUANTITY='U-VELOCITY'      ID='U22'/
&DEVC  XYZ=0.0,1.2,1.15     QUANTITY='U-VELOCITY'      ID='U23'/
&TAIL/
```

11 Appendix E

The following are ModFDS input files for the 5 simulations of Denize/Girgis experiments using furniture calorimeter HRR data.

G-21 Chair

```
&HEAD  CHID='G21_Mod'
       TITLE='GIRGIS - ModFDS - G21'/

% MESH OF 0.1
&MESH  IJK=44,24,24,
       XB=-0.8,3.6,0,2.4,0,2.4/

&TIME  T_END=600/

%DEFINES FUEL
&REAC  ID='POLYURETHANE'
       C=1    H=1.8  O=0.3  N=0.05 SOOT_YIELD=0.17      CO_YIELD=0.04/

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='GIB' THICKNESS=0.025      COLOR='POWDER BLUE'/
&SURF  ID='CEILING'  MATL_ID='GIB' THICKNESS=0.025      COLOR='PINK'/

&SURF  ID='FLOOR'
       MATL_ID='PLYWOOD','GIB'
       COLOR='SLATE GRAY'
       THICKNESS=0.0125,0.0125/

&MATL  ID='GIB'
       CONDUCTIVITY=0.12
       DENSITY=680
       SPECIFIC_HEAT_RAMP='SH_RAMP'
       EMISSIVITY=0.9/

&RAMP ID='SH_RAMP', T=0,F=.900/
&RAMP ID='SH_RAMP', T=105,F=38.000/
&RAMP ID='SH_RAMP', T=140,F=2.000/
&RAMP ID='SH_RAMP', T=200,F=1.000/
&RAMP ID='SH_RAMP', T=205,F=9.000/
&RAMP ID='SH_RAMP', T=220,F=1.000/
&RAMP ID='SH_RAMP', T=400,F=.900/
&RAMP ID='SH_RAMP', T=700,F=.800/

&MATL  ID='PLYWOOD'
       CONDUCTIVITY=0.12
       DENSITY=545
       SPECIFIC_HEAT=1.215
       EMISSIVITY=0.9/

% DEFINING ROOM
&VENT  MB=XMAX                          SURF_ID='WALL'/
&VENT  XB=0,3.6,2.4,2.4,0,2.4           SURF_ID='WALL'/
&VENT  XB=-0.8,0,2.4,2.4,0,2.4          SURF_ID='OPEN'/
&VENT  XB=0,3.6,0,0,0,2.4        SURF_ID='WALL'/
&VENT  XB=-0.8,0,0,0,0,2.4       SURF_ID='OPEN'/
&OBST  XB=0,0.025,0,0.8,0,2             SURF_ID='WALL'/
&OBST  XB=0,0.025,1.6,2.4,0,2           SURF_ID='WALL'/
&OBST  XB=0,0.025,0,2.4,2,2.4           SURF_ID='WALL'/
&VENT  MB=ZMIN                          SURF_ID='FLOOR'/
```

```
&VENT  XB=-0.8,0,0,2.4,2.4,2.4          SURF_ID='OPEN'/
&VENT  XB=0,3.6,0,2.4,2.4,2.4           SURF_ID='CEILING'/

&MATL  ID='FABRIC'
       FYI='100% POLYPROPYLENE'
       SPECIFIC_HEAT = 4.74
       CONDUCTIVITY = 0.058
       DENSITY = 184.0/

&MATL  ID='FOAM'
       FYI='VARIES FOR CHAIRS - POLYURETHANE AUDITORIUM FOAM'
       SPECIFIC_HEAT = 1.88
       CONDUCTIVITY = 0.0214
       DENSITY = 28.0/

&SURF  ID='UPHOLSTERY'
       MATL_ID(1:2,1)='FABRIC','FOAM'
       COLOR='BLUE'
       THICKNESS(1:2)=0.002,0.01
       HEAT_OF_VAPORIZATION=1500/

&SURF  ID='CUSHION'
       MATL_ID(1:2,1)='FABRIC','FOAM'
       COLOR='GREEN'
       THICKNESS(1:2)=0.002,0.1
       HEAT_OF_VAPORIZATION=1500/


% DEFINING FUEL
&OBST XB=2.9,3.5,0.2,0.75,0.0,0.3, SURF_ID='UPHOLSTERY'/ % BASE
&OBST XB=2.9,3.5,0.1,0.2,0.0,0.65, SURF_ID='UPHOLSTERY'/ % LT ARMREST
&OBST XB=2.9,3.5,0.75,0.85,0.0,0.65, SURF_ID='UPHOLSTERY'/ % RT ARMREST
&OBST XB=3.4,3.5,0.2,0.75,0.3,0.8, SURF_ID='CUSHION'/ % BACK CUSHION

&OBST XB=2.9,3.4,0.2,0.75,0.3,0.39,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=2.9,3.1,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.2,0.35,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.6,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.35,3.4,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION

&OBST XB= 3.1, 3.35, 0.35, 0.6, 0.39, 0.4, SURF_ID='BURNER', COLOR='ORANGE'/

&SURF  ID='BURNER',  HRRPUA=10905,  RAMP_Q='HRRPUA_RAMP'/  %HRR  CURVE  FROM  DENIZE
THESIS
&RAMP ID='HRRPUA_RAMP', T=4,F=0.01/
&RAMP ID='HRRPUA_RAMP', T=15,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=24,F=0.12/
&RAMP ID='HRRPUA_RAMP', T=35,F=0.2/
&RAMP ID='HRRPUA_RAMP', T=49,F=0.26/
&RAMP ID='HRRPUA_RAMP', T=61,F=0.3/
&RAMP ID='HRRPUA_RAMP', T=75,F=0.31/
&RAMP ID='HRRPUA_RAMP', T=82,F=0.37/
&RAMP ID='HRRPUA_RAMP', T=90,F=0.43/
&RAMP ID='HRRPUA_RAMP', T=98,F=0.5/
&RAMP ID='HRRPUA_RAMP', T=109,F=0.48/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.48/
&RAMP ID='HRRPUA_RAMP', T=125,F=0.59/
&RAMP ID='HRRPUA_RAMP', T=131,F=0.75/
&RAMP ID='HRRPUA_RAMP', T=138,F=0.86/
&RAMP ID='HRRPUA_RAMP', T=145,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=150,F=1/
&RAMP ID='HRRPUA_RAMP', T=156,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=164,F=0.93/
```

```
&RAMP ID='HRRPUA_RAMP', T=166,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=173,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=185,F=0.91/
&RAMP ID='HRRPUA_RAMP', T=192,F=0.84/
&RAMP ID='HRRPUA_RAMP', T=201,F=0.76/
&RAMP ID='HRRPUA_RAMP', T=210,F=0.7/
&RAMP ID='HRRPUA_RAMP', T=225,F=0.67/
&RAMP ID='HRRPUA_RAMP', T=229,F=0.58/
&RAMP ID='HRRPUA_RAMP', T=237,F=0.52/
&RAMP ID='HRRPUA_RAMP', T=244,F=0.47/
&RAMP ID='HRRPUA_RAMP', T=248,F=0.4/
&RAMP ID='HRRPUA_RAMP', T=261,F=0.36/
&RAMP ID='HRRPUA_RAMP', T=281,F=0.32/
&RAMP ID='HRRPUA_RAMP', T=303,F=0.26/
&RAMP ID='HRRPUA_RAMP', T=327,F=0.24/
&RAMP ID='HRRPUA_RAMP', T=352,F=0.2/
&RAMP ID='HRRPUA_RAMP', T=372,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=396,F=0.19/
&RAMP ID='HRRPUA_RAMP', T=425,F=0.14/
&RAMP ID='HRRPUA_RAMP', T=463,F=0.11/
&RAMP ID='HRRPUA_RAMP', T=499,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=531,F=0.07/
&RAMP ID='HRRPUA_RAMP', T=561,F=0.08/
&RAMP ID='HRRPUA_RAMP', T=590,F=0.05/
&DUMP  DT_PL3D=20,
       DT_DEVC=0.5,
       DT_HRR=0.5,
       DT_RESTART=20,
       DT_SLCF=20,
       WRITE_XYZ=.TRUE./

% THERMOCOUPLES
&DEVC XYZ=0.05,1.75,0.075, QUANTITY='THERMOCOUPLE', ID=T1/
&DEVC XYZ=0.05,1.75,0.225, QUANTITY='THERMOCOUPLE', ID=T2/
&DEVC XYZ=0.05,1.75,0.375, QUANTITY='THERMOCOUPLE', ID=T3/
&DEVC XYZ=0.05,1.75,0.525, QUANTITY='THERMOCOUPLE', ID=T4/
&DEVC XYZ=0.05,1.75,0.675, QUANTITY='THERMOCOUPLE', ID=T5/
&DEVC XYZ=0.05,1.75,0.825, QUANTITY='THERMOCOUPLE', ID=T6/
&DEVC XYZ=0.05,1.75,0.975, QUANTITY='THERMOCOUPLE', ID=T7/
&DEVC XYZ=0.05,1.75,1.125, QUANTITY='THERMOCOUPLE', ID=T8/
&DEVC XYZ=0.05,1.75,1.275, QUANTITY='THERMOCOUPLE', ID=T9/
&DEVC XYZ=0.05,1.75,1.425, QUANTITY='THERMOCOUPLE', ID=T10/
&DEVC XYZ=0.05,1.75,1.575, QUANTITY='THERMOCOUPLE', ID=T11/
&DEVC XYZ=0.05,1.75,1.725, QUANTITY='THERMOCOUPLE', ID=T12/
&DEVC XYZ=0.05,1.75,1.875, QUANTITY='THERMOCOUPLE', ID=T13/
&DEVC XYZ=0.05,1.75,2.025, QUANTITY='THERMOCOUPLE', ID=T14/
&DEVC XYZ=0.05,1.75,2.175, QUANTITY='THERMOCOUPLE', ID=T15/
&DEVC XYZ=0.05,1.75,2.325, QUANTITY='THERMOCOUPLE', ID=T16/

% ANIMATION OF TEMPERATURE PROFILE
&SLCF XB=0,3.6,1.75,1.75,0,2.4, QUANTITY='TEMPERATURE', VECTOR=.TRUE./

% HEAT FLUX GAUGES
&DEVC XYZ=1.8,1.2,0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='HF1'/
&DEVC XYZ=1.8,1.2,0, QUANTITY='NET HEAT FLUX', IOR=+3, ID='HF2'/

% MOL FRACTION (CO2, CO, O2)
&DEVC XYZ=0.6,1.2,2.2, QUANTITY='carbon dioxide', ID=CO2_1/
&DEVC XYZ=1.8,1.2,2.2, QUANTITY='carbon dioxide', ID=CO2_2/
&DEVC XYZ=3.0,1.2,2.2, QUANTITY='carbon dioxide', ID=CO2_3/

&TAIL/
```

H-21 Chair

```
&HEAD  CHID='H21_Mod'
       TITLE='GIRGIS - ModFDS - H21'/

% MESH OF 0.1
&MESH  IJK=44,24,24,
       XB=-0.8,3.6,0,2.4,0,2.4/

&TIME  T_END=600/

%DEFINES FUEL
&REAC  ID='POLYURETHANE'   C=1    H=1.8  O=0.3  N=0.05/

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'     MATL_ID='GIB' THICKNESS=0.025      COLOR='POWDER BLUE'/

&SURF  ID='CEILING'  MATL_ID='GIB' THICKNESS=0.025      COLOR='PINK'/

&SURF  ID='FLOOR'
       MATL_ID='PLYWOOD','GIB'
       COLOR='SLATE GRAY'
       THICKNESS=0.0125,0.0125/

&MATL  ID='GIB'
       CONDUCTIVITY=0.12
       DENSITY=680
       SPECIFIC_HEAT_RAMP='SH_RAMP'
       EMISSIVITY=0.9/

&RAMP ID='SH_RAMP', T=0,F=.900/
&RAMP ID='SH_RAMP', T=105,F=38.000/
&RAMP ID='SH_RAMP', T=140,F=2.000/
&RAMP ID='SH_RAMP', T=200,F=1.000/
&RAMP ID='SH_RAMP', T=205,F=9.000/
&RAMP ID='SH_RAMP', T=220,F=1.000/
&RAMP ID='SH_RAMP', T=400,F=.900/
&RAMP ID='SH_RAMP', T=700,F=.800/

&MATL  ID='PLYWOOD'
       CONDUCTIVITY=0.12
       DENSITY=545
       SPECIFIC_HEAT=1.215
       EMISSIVITY=0.9/

% DEFINING ROOM
&VENT  MB=XMAX                            SURF_ID='WALL'/
&VENT  XB=0,3.6,2.4,2.4,0,2.4             SURF_ID='WALL'/
&VENT  XB=-0.8,0,2.4,2.4,0,2.4            SURF_ID='OPEN'/
&VENT  XB=0,3.6,0,0,0,2.4          SURF_ID='WALL'/
&VENT  XB=-0.8,0,0,0,0,2.4         SURF_ID='OPEN'/
&OBST  XB=0,0.025,0,0.8,0,2               SURF_ID='WALL'/
&OBST  XB=0,0.025,1.6,2.4,0,2             SURF_ID='WALL'/
&OBST  XB=0,0.025,0,2.4,2,2.4             SURF_ID='WALL'/
&VENT  MB=ZMIN                            SURF_ID='FLOOR'/
&VENT  XB=-0.8,0,0,2.4,2.4,2.4            SURF_ID='OPEN'/
&VENT  XB=0,3.6,0,2.4,2.4,2.4             SURF_ID='CEILING'/

&MATL  ID='FABRIC'
       FYI='100% POLYPROPYLENE'
       SPECIFIC_HEAT = 4.74
       CONDUCTIVITY = 0.058
       DENSITY = 184.0/
```

```
&MATL  ID='FOAM'
       FYI='VARIES FOR CHAIRS - POLYURETHANE AUDITORIUM FOAM'
       SPECIFIC_HEAT = 1.423
       CONDUCTIVITY = 0.0214
       DENSITY = 37.0/

&SURF  ID='UPHOLSTERY'
       MATL_ID(1:2,1)='FABRIC','FOAM'
       COLOR='BLUE'
       THICKNESS(1:2)=0.002,0.01/

&SURF  ID='CUSHION'
       MATL_ID(1:2,1)='FABRIC','FOAM'
       COLOR='GREEN'
       THICKNESS(1:2)=0.002,0.1/


% DEFINING FUEL
&OBST XB=2.9,3.5,0.2,0.75,0.0,0.3, SURF_ID='UPHOLSTERY'/ % BASE
&OBST XB=2.9,3.5,0.1,0.2,0.0,0.65, SURF_ID='UPHOLSTERY'/ % LT ARMREST
&OBST XB=2.9,3.5,0.75,0.85,0.0,0.65, SURF_ID='UPHOLSTERY'/ % RT ARMREST
&OBST XB=3.4,3.5,0.2,0.75,0.3,0.8, SURF_ID='CUSHION'/ % BACK CUSHION

&OBST XB=2.9,3.4,0.2,0.75,0.3,0.39,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=2.9,3.1,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.2,0.35,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.6,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.35,3.4,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION

&OBST XB= 3.1, 3.35, 0.35, 0.6, 0.39, 0.4, SURF_ID='BURNER', COLOR='ORANGE'/

&SURF ID='BURNER', HRRPUA=13394, RAMP_Q='HRRPUA_RAMP'/ %HRR CURVE FROM DENIZE
THESIS
&RAMP ID='HRRPUA_RAMP', T=5,F=0.02/
&RAMP ID='HRRPUA_RAMP', T=17,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=26,F=0.07/
&RAMP ID='HRRPUA_RAMP', T=37,F=0.06/
&RAMP ID='HRRPUA_RAMP', T=44,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=53,F=0.12/
&RAMP ID='HRRPUA_RAMP', T=64,F=0.14/
&RAMP ID='HRRPUA_RAMP', T=75,F=0.18/
&RAMP ID='HRRPUA_RAMP', T=85,F=0.23/
&RAMP ID='HRRPUA_RAMP', T=86,F=0.3/
&RAMP ID='HRRPUA_RAMP', T=92,F=0.37/
&RAMP ID='HRRPUA_RAMP', T=103,F=0.36/
&RAMP ID='HRRPUA_RAMP', T=109,F=0.44/
&RAMP ID='HRRPUA_RAMP', T=115,F=0.52/
&RAMP ID='HRRPUA_RAMP', T=120,F=0.6/
&RAMP ID='HRRPUA_RAMP', T=130,F=0.66/
&RAMP ID='HRRPUA_RAMP', T=134,F=0.75/
&RAMP ID='HRRPUA_RAMP', T=136,F=0.84/
&RAMP ID='HRRPUA_RAMP', T=140,F=0.93/
&RAMP ID='HRRPUA_RAMP', T=144,F=0.99/
&RAMP ID='HRRPUA_RAMP', T=151,F=1/
&RAMP ID='HRRPUA_RAMP', T=157,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=164,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=167,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=172,F=0.91/
&RAMP ID='HRRPUA_RAMP', T=181,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=189,F=0.99/
&RAMP ID='HRRPUA_RAMP', T=199,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=204,F=0.89/
```

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&RAMP ID='HRRPUA_RAMP', T=213,F=0.79/
&RAMP ID='HRRPUA_RAMP', T=222,F=0.71/
&RAMP ID='HRRPUA_RAMP', T=224,F=0.63/
&RAMP ID='HRRPUA_RAMP', T=232,F=0.62/
&RAMP ID='HRRPUA_RAMP', T=240,F=0.59/
&RAMP ID='HRRPUA_RAMP', T=243,F=0.51/
&RAMP ID='HRRPUA_RAMP', T=251,F=0.48/
&RAMP ID='HRRPUA_RAMP', T=262,F=0.4/
&RAMP ID='HRRPUA_RAMP', T=281,F=0.31/
&RAMP ID='HRRPUA_RAMP', T=296,F=0.26/
&RAMP ID='HRRPUA_RAMP', T=319,F=0.21/
&RAMP ID='HRRPUA_RAMP', T=338,F=0.16/
&RAMP ID='HRRPUA_RAMP', T=363,F=0.15/
&RAMP ID='HRRPUA_RAMP', T=385,F=0.12/
&RAMP ID='HRRPUA_RAMP', T=412,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=444,F=0.07/
&RAMP ID='HRRPUA_RAMP', T=481,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=511,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=545,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=582,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=601,F=0.04/


&DUMP  DT_PL3D=20,
       DT_DEVC=0.5,
       DT_HRR=0.5,
       DT_RESTART=20,
       DT_SLCF=20,
       WRITE_XYZ=.TRUE./

% THERMOCOUPLES
&DEVC XYZ=0.05,1.75,0.075, QUANTITY='THERMOCOUPLE', ID=T1/
&DEVC XYZ=0.05,1.75,0.225, QUANTITY='THERMOCOUPLE', ID=T2/
&DEVC XYZ=0.05,1.75,0.375, QUANTITY='THERMOCOUPLE', ID=T3/
&DEVC XYZ=0.05,1.75,0.525, QUANTITY='THERMOCOUPLE', ID=T4/
&DEVC XYZ=0.05,1.75,0.675, QUANTITY='THERMOCOUPLE', ID=T5/
&DEVC XYZ=0.05,1.75,0.825, QUANTITY='THERMOCOUPLE', ID=T6/
&DEVC XYZ=0.05,1.75,0.975, QUANTITY='THERMOCOUPLE', ID=T7/
&DEVC XYZ=0.05,1.75,1.125, QUANTITY='THERMOCOUPLE', ID=T8/
&DEVC XYZ=0.05,1.75,1.275, QUANTITY='THERMOCOUPLE', ID=T9/
&DEVC XYZ=0.05,1.75,1.425, QUANTITY='THERMOCOUPLE', ID=T10/
&DEVC XYZ=0.05,1.75,1.575, QUANTITY='THERMOCOUPLE', ID=T11/
&DEVC XYZ=0.05,1.75,1.725, QUANTITY='THERMOCOUPLE', ID=T12/
&DEVC XYZ=0.05,1.75,1.875, QUANTITY='THERMOCOUPLE', ID=T13/
&DEVC XYZ=0.05,1.75,2.025, QUANTITY='THERMOCOUPLE', ID=T14/
&DEVC XYZ=0.05,1.75,2.175, QUANTITY='THERMOCOUPLE', ID=T15/
&DEVC XYZ=0.05,1.75,2.325, QUANTITY='THERMOCOUPLE', ID=T16/

% ANIMATION OF TEMPERATURE PROFILE
&SLCF XB=0,3.6,1.75,1.75,0,2.4, QUANTITY='TEMPERATURE', VECTOR=.TRUE./


% HEAT FLUX GAUGES
&DEVC XYZ=1.8,1.2,0, QUANTITY='GAUGE_HEAT_FLUX', IOR=+3, ID='HF1'/
&DEVC XYZ=1.8,1.2,0, QUANTITY='NET HEAT FLUX', IOR=+3, ID='HF2'/

&TAIL/
```

I-21 Chair

```
&HEAD  CHID='I21_Mod'
TITLE='GIRGIS - ModFDS - I21'/

% MESH OF 0.1
&MESH  IJK=44,24,24,
       XB=-0.8,3.6,0,2.4,0,2.4/

&TIME  T_END=600/

%DEFINES FUEL
&REAC  ID='POLYURETHANE'   C=1    H=1.8  O=0.3  N=0.05/

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'    MATL_ID='GIB' THICKNESS=0.025     COLOR='POWDER BLUE'/

&SURF  ID='CEILING' MATL_ID='GIB' THICKNESS=0.025     COLOR='PINK'/

&SURF  ID='FLOOR'
       MATL_ID='PLYWOOD','GIB'
       COLOR='SLATE GRAY'
       THICKNESS=0.0125,0.0125/

&MATL  ID='GIB'
       CONDUCTIVITY=0.12
       DENSITY=680
       SPECIFIC_HEAT_RAMP='SH_RAMP'
       EMISSIVITY=0.9/

&RAMP ID='SH_RAMP', T=0,F=.900/
&RAMP ID='SH_RAMP', T=105,F=38.000/
&RAMP ID='SH_RAMP', T=140,F=2.000/
&RAMP ID='SH_RAMP', T=200,F=1.000/
&RAMP ID='SH_RAMP', T=205,F=9.000/
&RAMP ID='SH_RAMP', T=220,F=1.000/
&RAMP ID='SH_RAMP', T=400,F=.900/
&RAMP ID='SH_RAMP', T=700,F=.800/

&MATL  ID='PLYWOOD'
       CONDUCTIVITY=0.12
       DENSITY=545
       SPECIFIC_HEAT=1.215
       EMISSIVITY=0.9/

% DEFINING ROOM
&VENT  MB=XMAX                          SURF_ID='WALL'/
&VENT  XB=0,3.6,2.4,2.4,0,2.4           SURF_ID='WALL'/
&VENT  XB=-0.8,0,2.4,2.4,0,2.4          SURF_ID='OPEN'/
&VENT  XB=0,3.6,0,0,0,2.4        SURF_ID='WALL'/
&VENT  XB=-0.8,0,0,0,0,2.4       SURF_ID='OPEN'/
&OBST  XB=0,0.025,0,0.8,0,2             SURF_ID='WALL'/
&OBST  XB=0,0.025,1.6,2.4,0,2           SURF_ID='WALL'/
&OBST  XB=0,0.025,0,2.4,2,2.4           SURF_ID='WALL'/
&VENT  MB=ZMIN                          SURF_ID='FLOOR'/
&VENT  XB=-0.8,0,0,2.4,2.4,2.4          SURF_ID='OPEN'/
&VENT  XB=0,3.6,0,2.4,2.4,2.4           SURF_ID='CEILING'/

&MATL  ID='FABRIC'
       FYI='100% POLYPROPYLENE'
       SPECIFIC_HEAT = 4.74
       CONDUCTIVITY = 0.058
       DENSITY = 184.0/
```

```
&MATL  ID='FOAM'
       FYI='VARIES FOR CHAIRS - POLYURETHANE AUDITORIUM FOAM'
       SPECIFIC_HEAT = 1.504
       CONDUCTIVITY = 0.0214
       DENSITY = 35.0/

&SURF  ID='UPHOLSTERY'
       MATL_ID(1:2,1)='FABRIC','FOAM'
       COLOR='BLUE'
       THICKNESS(1:2)=0.002,0.01/

&SURF  ID='CUSHION'
       MATL_ID(1:2,1)='FABRIC','FOAM'
       COLOR='GREEN'
       THICKNESS(1:2)=0.002,0.1/


% DEFINING FUEL
&OBST XB=2.9,3.5,0.2,0.75,0.0,0.3, SURF_ID='UPHOLSTERY'/ % BASE
&OBST XB=2.9,3.5,0.1,0.2,0.0,0.65, SURF_ID='UPHOLSTERY'/ % LT ARMREST
&OBST XB=2.9,3.5,0.75,0.85,0.0,0.65, SURF_ID='UPHOLSTERY'/ % RT ARMREST
&OBST XB=3.4,3.5,0.2,0.75,0.3,0.8, SURF_ID='CUSHION'/ % BACK CUSHION

&OBST XB=2.9,3.4,0.2,0.75,0.3,0.39,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=2.9,3.1,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.2,0.35,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.6,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.35,3.4,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION

&OBST XB= 3.1, 3.35, 0.35, 0.6, 0.39, 0.4, SURF_ID='BURNER', COLOR='ORANGE'/

&SURF ID='BURNER', HRRPUA=15162, RAMP_Q='HRRPUA_RAMP'/ %HRR CURVE FROM DENIZE
THESIS
&RAMP ID='HRRPUA_RAMP', T=3,F=0.01/
&RAMP ID='HRRPUA_RAMP', T=10,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=22,F=0.06/
&RAMP ID='HRRPUA_RAMP', T=36,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=44,F=0.11/
&RAMP ID='HRRPUA_RAMP', T=49,F=0.14/
&RAMP ID='HRRPUA_RAMP', T=55,F=0.17/
&RAMP ID='HRRPUA_RAMP', T=63,F=0.17/
&RAMP ID='HRRPUA_RAMP', T=72,F=0.16/
&RAMP ID='HRRPUA_RAMP', T=83,F=0.19/
&RAMP ID='HRRPUA_RAMP', T=91,F=0.22/
&RAMP ID='HRRPUA_RAMP', T=93,F=0.27/
&RAMP ID='HRRPUA_RAMP', T=95,F=0.35/
&RAMP ID='HRRPUA_RAMP', T=97,F=0.42/
&RAMP ID='HRRPUA_RAMP', T=100,F=0.48/
&RAMP ID='HRRPUA_RAMP', T=104,F=0.57/
&RAMP ID='HRRPUA_RAMP', T=107,F=0.63/
&RAMP ID='HRRPUA_RAMP', T=113,F=0.71/
&RAMP ID='HRRPUA_RAMP', T=118,F=0.75/
&RAMP ID='HRRPUA_RAMP', T=124,F=0.79/
&RAMP ID='HRRPUA_RAMP', T=131,F=0.79/
&RAMP ID='HRRPUA_RAMP', T=136,F=0.79/
&RAMP ID='HRRPUA_RAMP', T=140,F=0.82/
&RAMP ID='HRRPUA_RAMP', T=142,F=0.86/
&RAMP ID='HRRPUA_RAMP', T=148,F=0.88/
&RAMP ID='HRRPUA_RAMP', T=154,F=0.89/
&RAMP ID='HRRPUA_RAMP', T=159,F=0.91/
&RAMP ID='HRRPUA_RAMP', T=167,F=0.95/
&RAMP ID='HRRPUA_RAMP', T=174,F=1/
```

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&RAMP ID='HRRPUA_RAMP', T=180,F=0.96/
&RAMP ID='HRRPUA_RAMP', T=192,F=0.9/
&RAMP ID='HRRPUA_RAMP', T=199,F=0.85/
&RAMP ID='HRRPUA_RAMP', T=204,F=0.8/
&RAMP ID='HRRPUA_RAMP', T=207,F=0.72/
&RAMP ID='HRRPUA_RAMP', T=215,F=0.7/
&RAMP ID='HRRPUA_RAMP', T=220,F=0.61/
&RAMP ID='HRRPUA_RAMP', T=225,F=0.54/
&RAMP ID='HRRPUA_RAMP', T=236,F=0.51/
&RAMP ID='HRRPUA_RAMP', T=242,F=0.43/
&RAMP ID='HRRPUA_RAMP', T=256,F=0.35/
&RAMP ID='HRRPUA_RAMP', T=270,F=0.27/
&RAMP ID='HRRPUA_RAMP', T=281,F=0.22/
&RAMP ID='HRRPUA_RAMP', T=298,F=0.2/
&RAMP ID='HRRPUA_RAMP', T=321,F=0.18/
&RAMP ID='HRRPUA_RAMP', T=340,F=0.14/
&RAMP ID='HRRPUA_RAMP', T=363,F=0.12/
&RAMP ID='HRRPUA_RAMP', T=378,F=0.13/
&RAMP ID='HRRPUA_RAMP', T=400,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=433,F=0.07/
&RAMP ID='HRRPUA_RAMP', T=466,F=0.06/
&RAMP ID='HRRPUA_RAMP', T=498,F=0.05/
&RAMP ID='HRRPUA_RAMP', T=526,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=561,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=591,F=0.04/

&DUMP  DT_PL3D=20,
       DT_DEVC=0.5,
       DT_HRR=0.5,
       DT_RESTART=20,
       DT_SLCF=20,
       WRITE_XYZ=.TRUE./

% THERMOCOUPLES
&DEVC XYZ=0.05,1.75,0.075, QUANTITY='THERMOCOUPLE', ID=T1/
&DEVC XYZ=0.05,1.75,0.225, QUANTITY='THERMOCOUPLE', ID=T2/
&DEVC XYZ=0.05,1.75,0.375, QUANTITY='THERMOCOUPLE', ID=T3/
&DEVC XYZ=0.05,1.75,0.525, QUANTITY='THERMOCOUPLE', ID=T4/
&DEVC XYZ=0.05,1.75,0.675, QUANTITY='THERMOCOUPLE', ID=T5/
&DEVC XYZ=0.05,1.75,0.825, QUANTITY='THERMOCOUPLE', ID=T6/
&DEVC XYZ=0.05,1.75,0.975, QUANTITY='THERMOCOUPLE', ID=T7/
&DEVC XYZ=0.05,1.75,1.125, QUANTITY='THERMOCOUPLE', ID=T8/
&DEVC XYZ=0.05,1.75,1.275, QUANTITY='THERMOCOUPLE', ID=T9/
&DEVC XYZ=0.05,1.75,1.425, QUANTITY='THERMOCOUPLE', ID=T10/
&DEVC XYZ=0.05,1.75,1.575, QUANTITY='THERMOCOUPLE', ID=T11/
&DEVC XYZ=0.05,1.75,1.725, QUANTITY='THERMOCOUPLE', ID=T12/
&DEVC XYZ=0.05,1.75,1.875, QUANTITY='THERMOCOUPLE', ID=T13/
&DEVC XYZ=0.05,1.75,2.025, QUANTITY='THERMOCOUPLE', ID=T14/
&DEVC XYZ=0.05,1.75,2.175, QUANTITY='THERMOCOUPLE', ID=T15/
&DEVC XYZ=0.05,1.75,2.325, QUANTITY='THERMOCOUPLE', ID=T16/

% ANIMATION OF TEMPERATURE PROFILE
&SLCF XB=0,3.6,1.75,1.75,0,2.4, QUANTITY='TEMPERATURE', VECTOR=.TRUE./

&TAIL/
```

J-21 Chair

```
&HEAD  CHID='J21_Mod'
       TITLE='GIRGIS - ModFDS - J21_1'/

% MESH OF 0.1
&MESH  IJK=44,24,24,
       XB=-0.8,3.6,0,2.4,0,2.4/

&TIME  T_END=600/

%DEFINES FUEL
&REAC  ID='POLYURETHANE'   C=1    H=1.8  O=0.3  N=0.05/

%DEFINES WALLS,CEILING AND FLOOR
&SURF  ID='WALL'    MATL_ID='GIB' THICKNESS=0.025     COLOR='POWDER BLUE'/

&SURF  ID='CEILING' MATL_ID='GIB' THICKNESS=0.025     COLOR='PINK'/

&SURF  ID='FLOOR'
       MATL_ID='PLYWOOD','GIB'
       COLOR='SLATE GRAY'
       THICKNESS=0.0125,0.0125/

&MATL  ID='GIB'
       CONDUCTIVITY=0.12
       DENSITY=680
       SPECIFIC_HEAT_RAMP='SH_RAMP'
       EMISSIVITY=0.9/

&RAMP ID='SH_RAMP', T=0,F=.900/
&RAMP ID='SH_RAMP', T=105,F=38.000/
&RAMP ID='SH_RAMP', T=140,F=2.000/
&RAMP ID='SH_RAMP', T=200,F=1.000/
&RAMP ID='SH_RAMP', T=205,F=9.000/
&RAMP ID='SH_RAMP', T=220,F=1.000/
&RAMP ID='SH_RAMP', T=400,F=.900/
&RAMP ID='SH_RAMP', T=700,F=.800/

&MATL  ID='PLYWOOD'
       CONDUCTIVITY=0.12
       DENSITY=545
       SPECIFIC_HEAT=1.215
       EMISSIVITY=0.9/

% DEFINING ROOM
&VENT  MB=XMAX                           SURF_ID='WALL'/
&VENT  XB=0,3.6,2.4,2.4,0,2.4            SURF_ID='WALL'/
&VENT  XB=-0.8,0,2.4,2.4,0,2.4           SURF_ID='OPEN'/
&VENT  XB=0,3.6,0,0,0,2.4         SURF_ID='WALL'/
&VENT  XB=-0.8,0,0,0,0,2.4        SURF_ID='OPEN'/
&OBST  XB=0,0.025,0,0.8,0,2              SURF_ID='WALL'/
&OBST  XB=0,0.025,1.6,2.4,0,2            SURF_ID='WALL'/
&OBST  XB=0,0.025,0,2.4,2,2.4            SURF_ID='WALL'/
&VENT  MB=ZMIN                           SURF_ID='FLOOR'/
&VENT  XB=-0.8,0,0,2.4,2.4,2.4           SURF_ID='OPEN'/
&VENT  XB=0,3.6,0,2.4,2.4,2.4            SURF_ID='CEILING'/

&MATL  ID='FABRIC'
       FYI='100% POLYPROPYLENE'
       SPECIFIC_HEAT = 4.74
       CONDUCTIVITY = 0.058
       DENSITY = 184.0/
```

```
&MATL  ID='FOAM'
       FYI='VARIES FOR CHAIRS - POLYURETHANE AUDITORIUM FOAM'
       SPECIFIC_HEAT = 1.462
       CONDUCTIVITY = 0.0214
       DENSITY = 36.0/

&SURF  ID='UPHOLSTERY'
       MATL_ID(1:2,1)='FABRIC','FOAM'
       COLOR='BLUE'
       THICKNESS(1:2)=0.002,0.01/

&SURF  ID='CUSHION'
       MATL_ID(1:2,1)='FABRIC','FOAM'
       COLOR='GREEN'
       THICKNESS(1:2)=0.002,0.1/

% DEFINING FUEL
&OBST XB=2.9,3.5,0.2,0.75,0.0,0.3, SURF_ID='UPHOLSTERY'/ % BASE
&OBST XB=2.9,3.5,0.1,0.2,0.0,0.65, SURF_ID='UPHOLSTERY'/ % LT ARMREST
&OBST XB=2.9,3.5,0.75,0.85,0.0,0.65, SURF_ID='UPHOLSTERY'/ % RT ARMREST
&OBST XB=3.4,3.5,0.2,0.75,0.3,0.8, SURF_ID='CUSHION'/ % BACK CUSHION

&OBST XB=2.9,3.4,0.2,0.75,0.3,0.39,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=2.9,3.1,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.2,0.35,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.1,3.35,0.6,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION
&OBST XB=3.35,3.4,0.2,0.75,0.39,0.4,SURF_ID='CUSHION'/ % SEAT CUSHION

&OBST XB= 3.1, 3.35, 0.35, 0.6, 0.39, 0.4, SURF_ID='BURNER', COLOR='ORANGE'/

&SURF  ID='BURNER',  HRRPUA=9261,  RAMP_Q='HRRPUA_RAMP'/  %HRR  CURVE  FROM  DENIZE
THESIS
&RAMP ID='HRRPUA_RAMP', T=6,F=0.02/
&RAMP ID='HRRPUA_RAMP', T=21,F=0.04/
&RAMP ID='HRRPUA_RAMP', T=32,F=0.08/
&RAMP ID='HRRPUA_RAMP', T=45,F=0.11/
&RAMP ID='HRRPUA_RAMP', T=53,F=0.12/
&RAMP ID='HRRPUA_RAMP', T=62,F=0.14/
&RAMP ID='HRRPUA_RAMP', T=73,F=0.11/
&RAMP ID='HRRPUA_RAMP', T=78,F=0.16/
&RAMP ID='HRRPUA_RAMP', T=84,F=0.19/
&RAMP ID='HRRPUA_RAMP', T=94,F=0.17/
&RAMP ID='HRRPUA_RAMP', T=100,F=0.22/
&RAMP ID='HRRPUA_RAMP', T=111,F=0.18/
&RAMP ID='HRRPUA_RAMP', T=125,F=0.15/
&RAMP ID='HRRPUA_RAMP', T=136,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=141,F=0.06/
&RAMP ID='HRRPUA_RAMP', T=156,F=0.09/
&RAMP ID='HRRPUA_RAMP', T=162,F=0.15/
&RAMP ID='HRRPUA_RAMP', T=170,F=0.21/
&RAMP ID='HRRPUA_RAMP', T=176,F=0.26/
&RAMP ID='HRRPUA_RAMP', T=181,F=0.41/
&RAMP ID='HRRPUA_RAMP', T=184,F=0.52/
&RAMP ID='HRRPUA_RAMP', T=189,F=0.63/
&RAMP ID='HRRPUA_RAMP', T=194,F=0.75/
&RAMP ID='HRRPUA_RAMP', T=200,F=0.85/
&RAMP ID='HRRPUA_RAMP', T=204,F=0.94/
&RAMP ID='HRRPUA_RAMP', T=216,F=1/
&RAMP ID='HRRPUA_RAMP', T=227,F=0.98/
&RAMP ID='HRRPUA_RAMP', T=246,F=0.94/
&RAMP ID='HRRPUA_RAMP', T=253,F=0.85/
&RAMP ID='HRRPUA_RAMP', T=256,F=0.8/
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```
&RAMP ID='HRRPUA_RAMP', T=268,F=0.79/
&RAMP ID='HRRPUA_RAMP', T=283,F=0.78/
&RAMP ID='HRRPUA_RAMP', T=294,F=0.7/
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&RAMP ID='HRRPUA_RAMP', T=325,F=0.54/
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L-21 Chair

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       XB=-0.8,3.6,0,2.4,0,2.4/

&TIME  T_END=600/

%DEFINES FUEL
&REAC  ID='POLYURETHANE'   C=1    H=1.8  O=0.3  N=0.05/

%DEFINES WALLS,CEILING AND FLOOR
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&SURF  ID='CUSHION'
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12 Appendix F

Results for the 4 other types of chairs (H-21, I-21, J-21, and L-21) simulated in ModFDS using furniture calorimeter MLR data from Denize's experiments (3) and comparing to Girgis' experiments (2).

CHAIR H-21

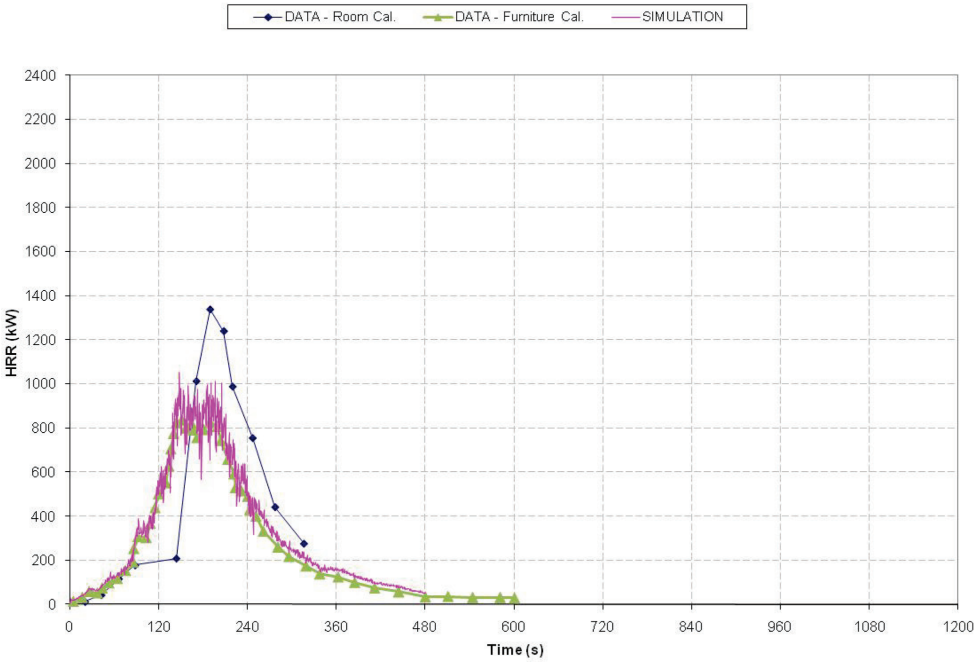

Figure 12-1 – ModFDS HRR Comparison (H-21)

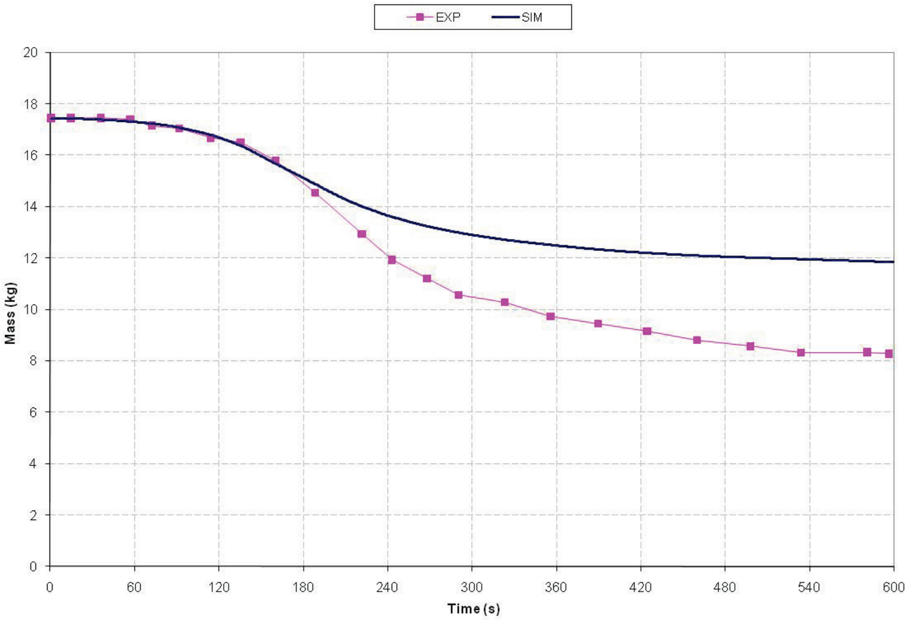

Figure 12-2 – ModFDS Mass History Comparison (H-21)

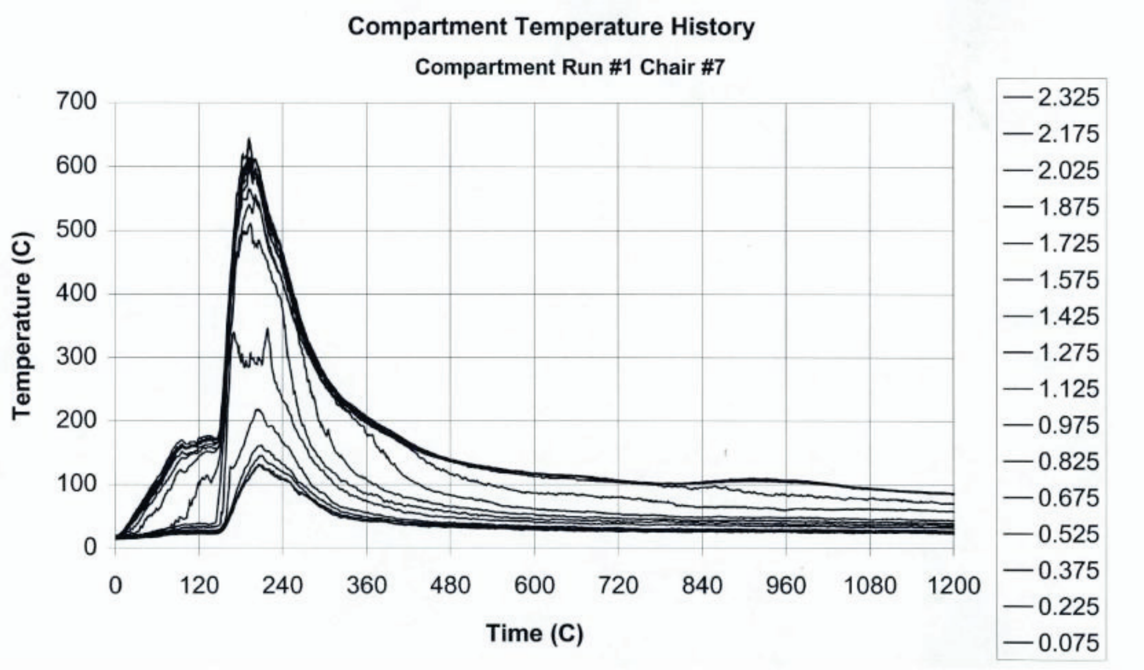

Figure 12-3 – Experiment Temperature History (H-21) (2)

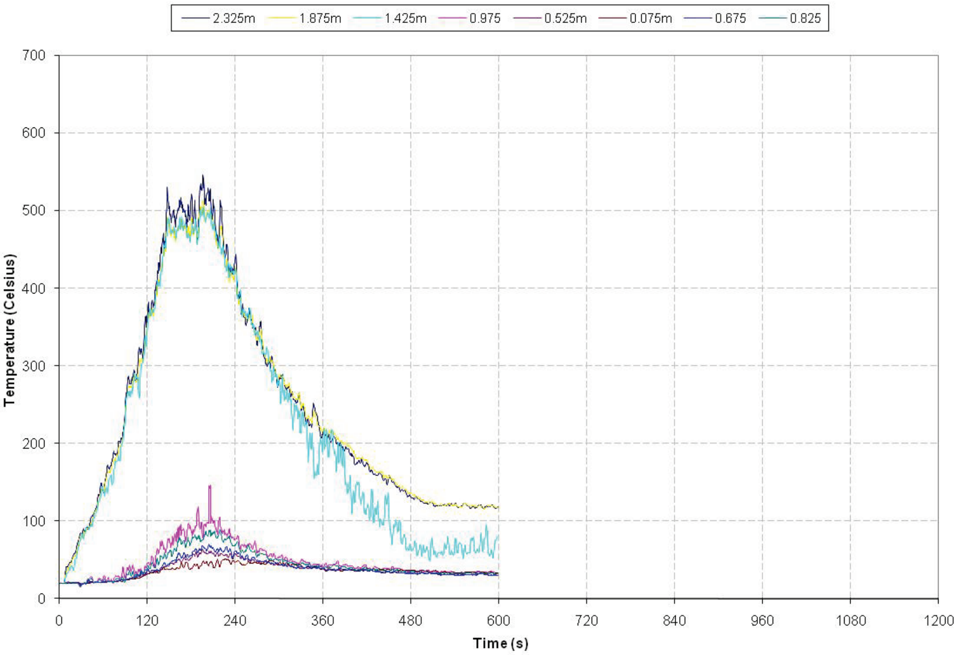

Figure 12-4 – ModFDS Simulation Temperature History (H-21)

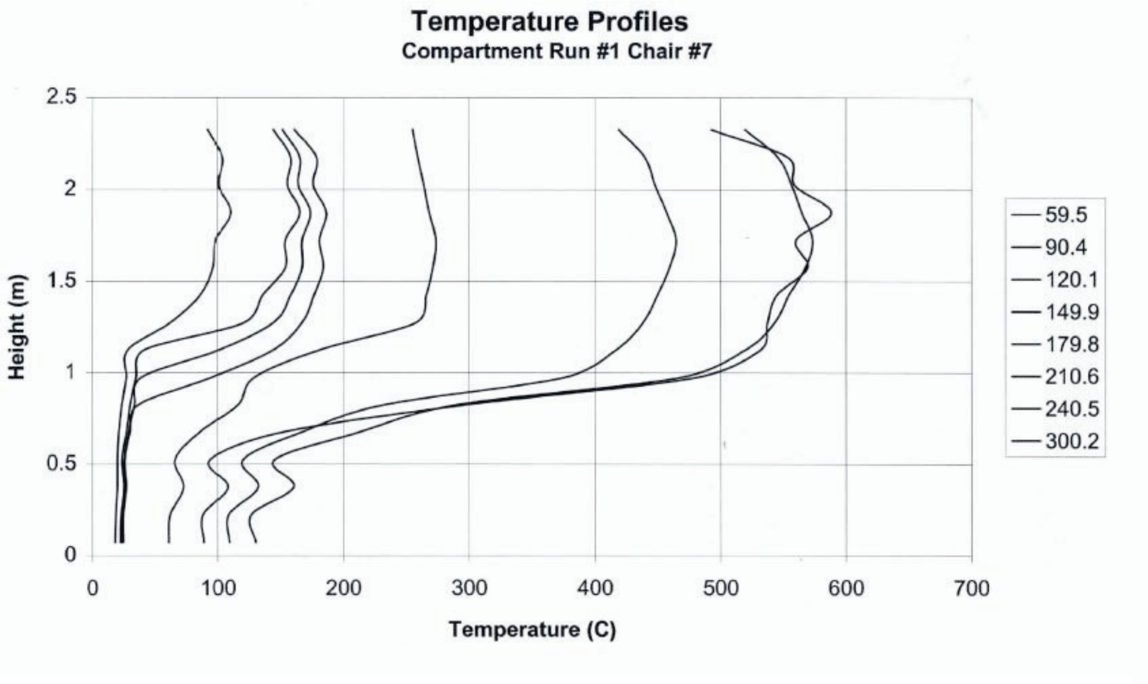

Figure 12-5 –Experiment Temperature Profiles (H-21) (2)

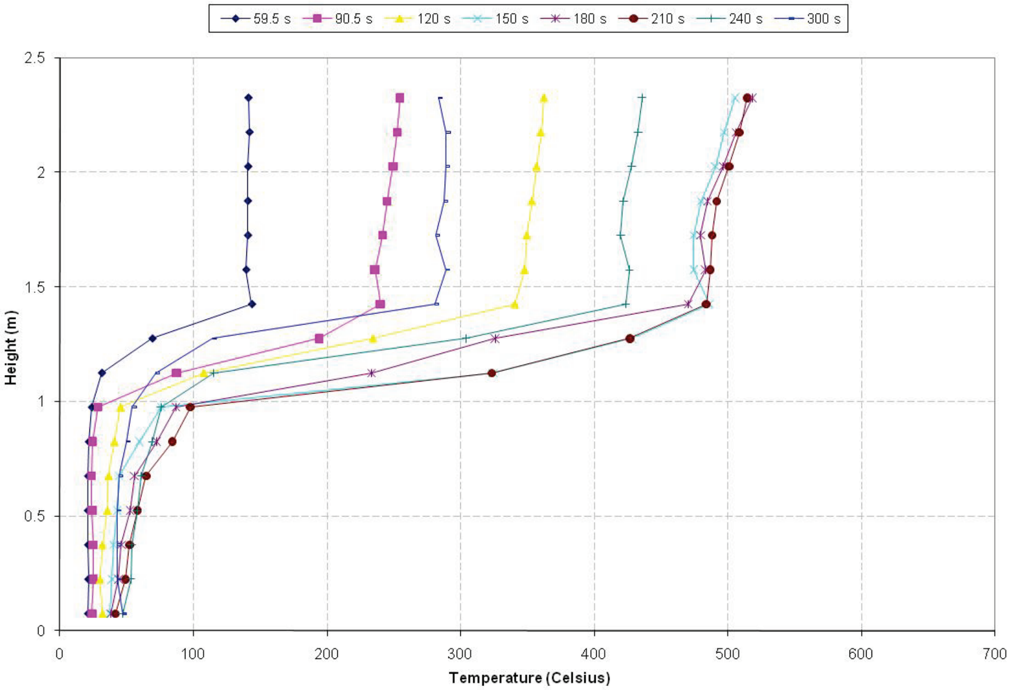

Figure 12-6 – ModFDS Simulation Temperature Profiles (H-21)

CHAIR I-21

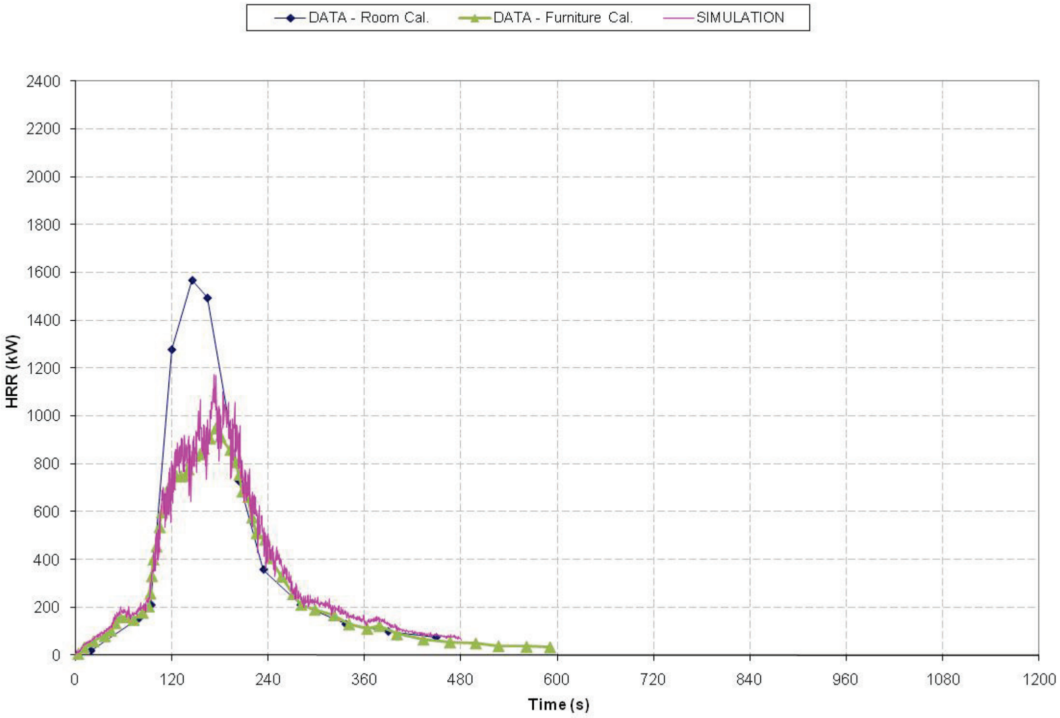

Figure 12-7 – ModFDS HRR Comparison (I-21)

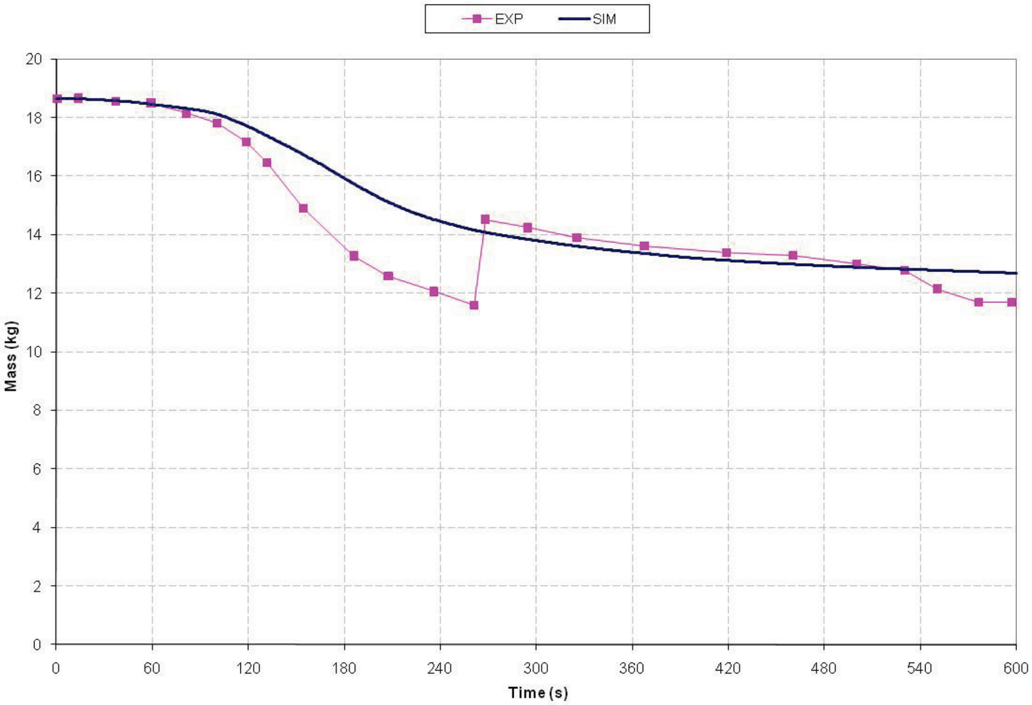

Figure 12-8 – ModFDS Mass History Comparison (I-21)

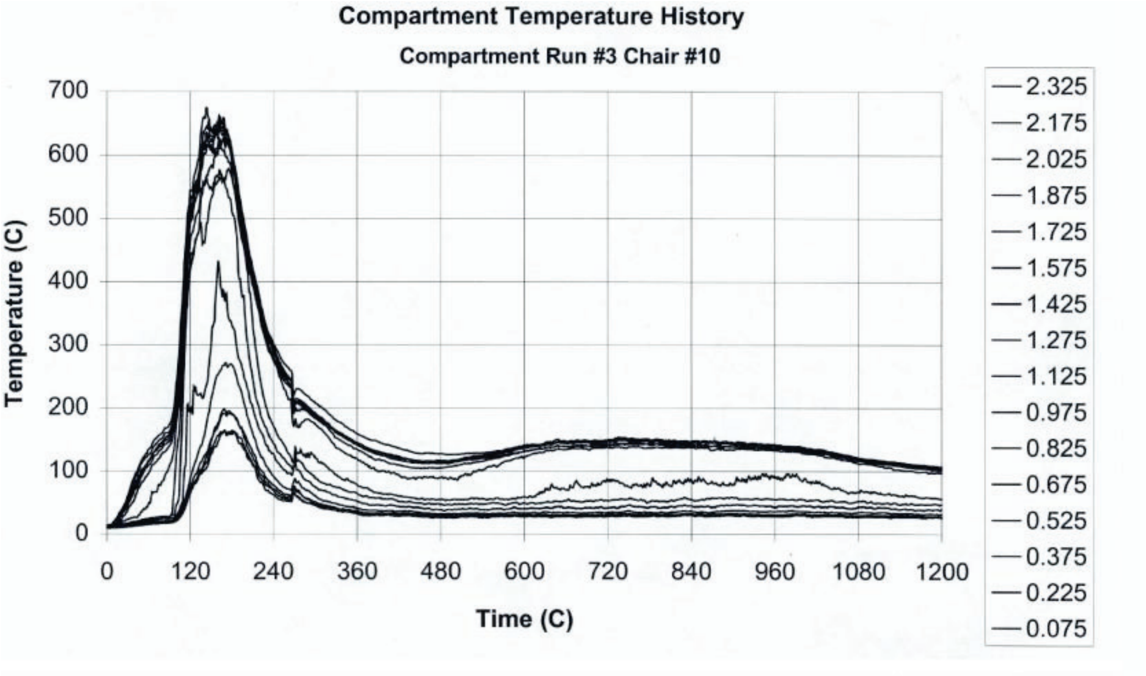

Figure 12-9 - Experiment Temperature History (I-21) (2)

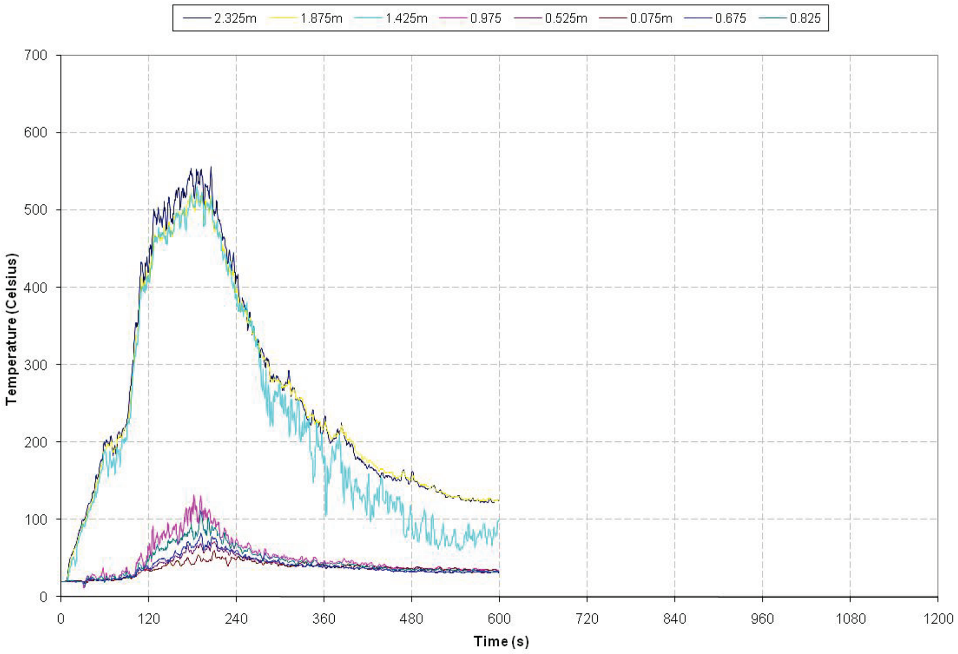

Figure 12-10 – ModFDS Simulation Temperature History (I-21)

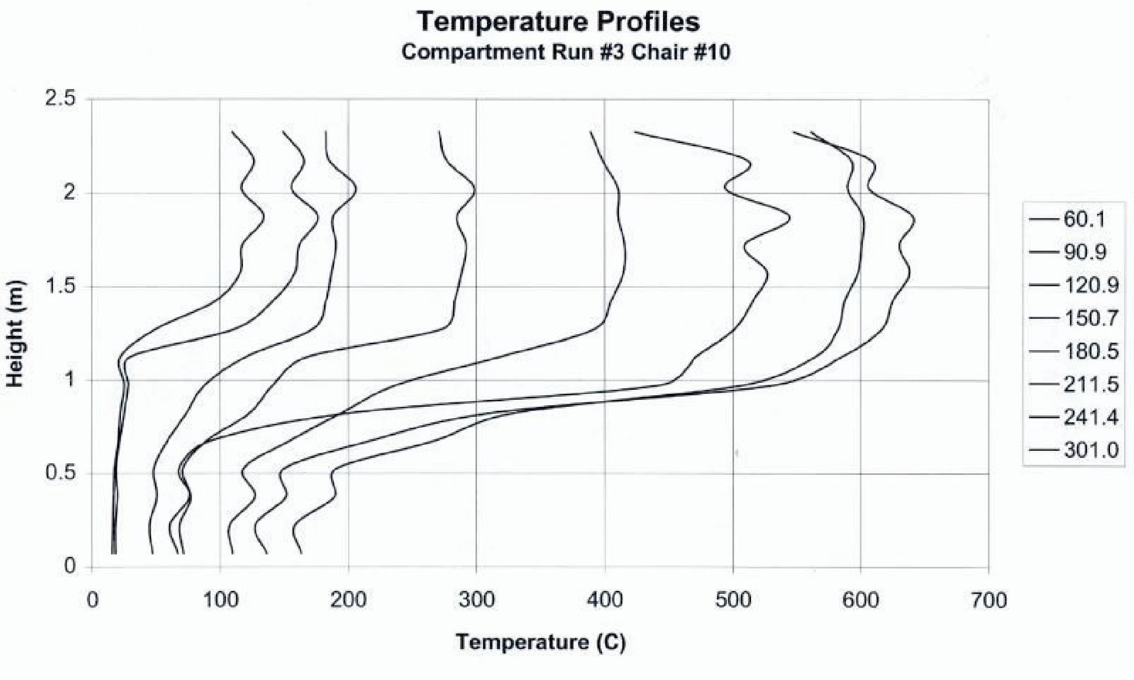

Figure 12-11 – Experiment Temperature Profile (I-21) (2)

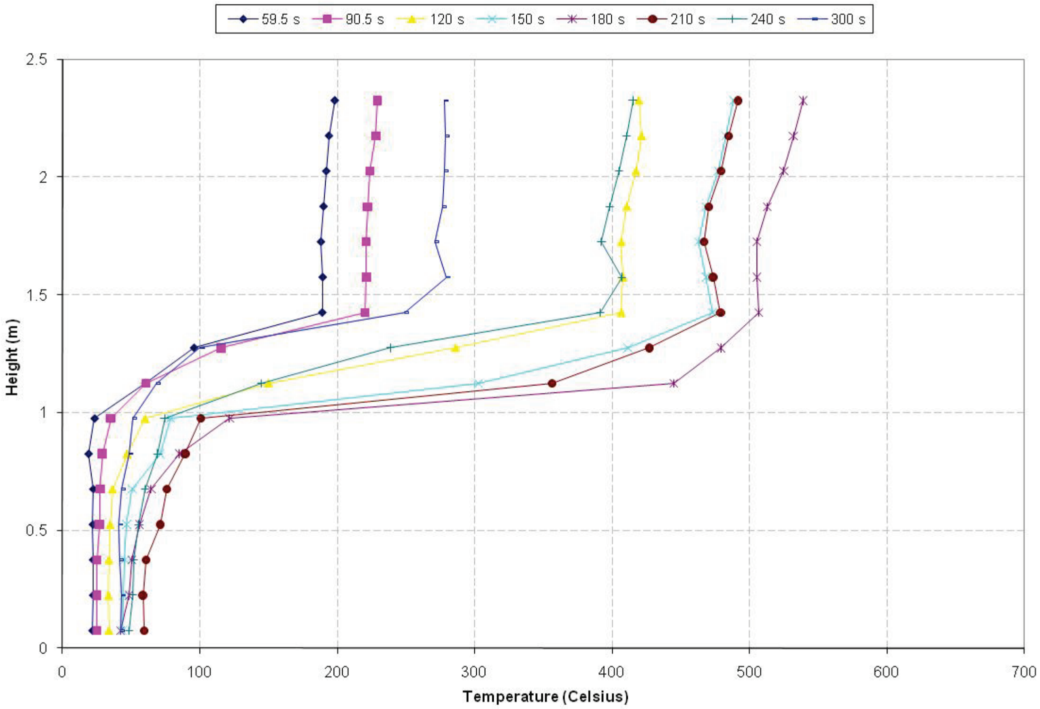

Figure 12-12 – ModFDS Simulation Temperature Profile (I-21)

CHAIR J-21

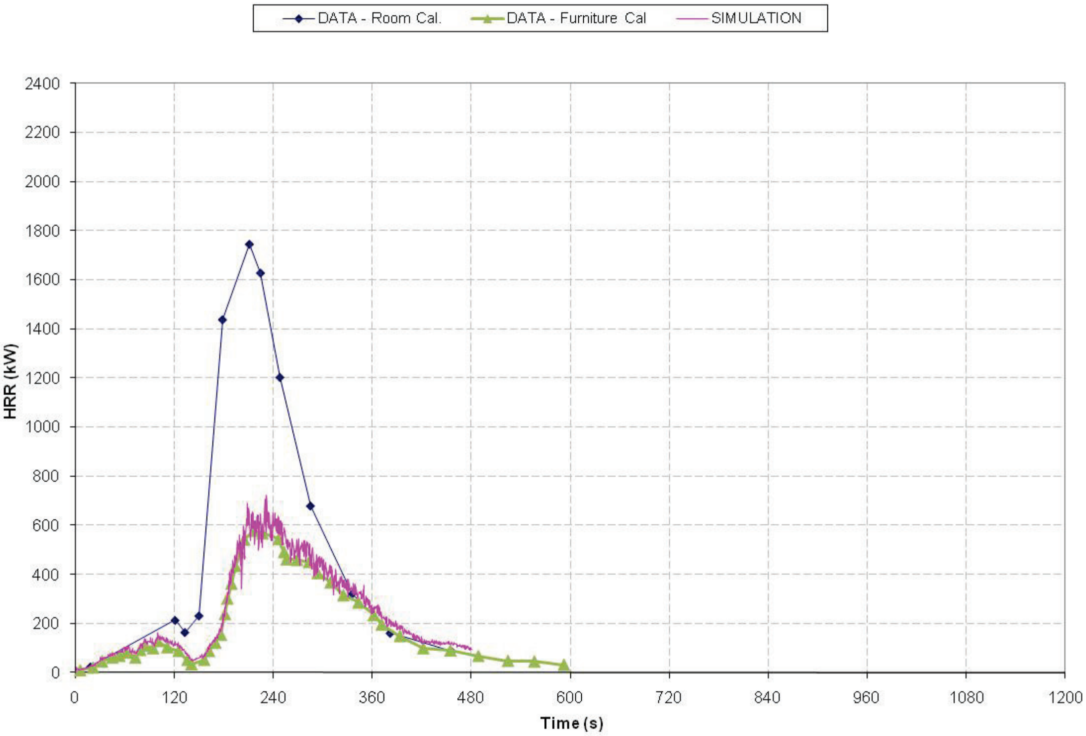

Figure 12-13 – ModFDS HRR Comparison (J-21)

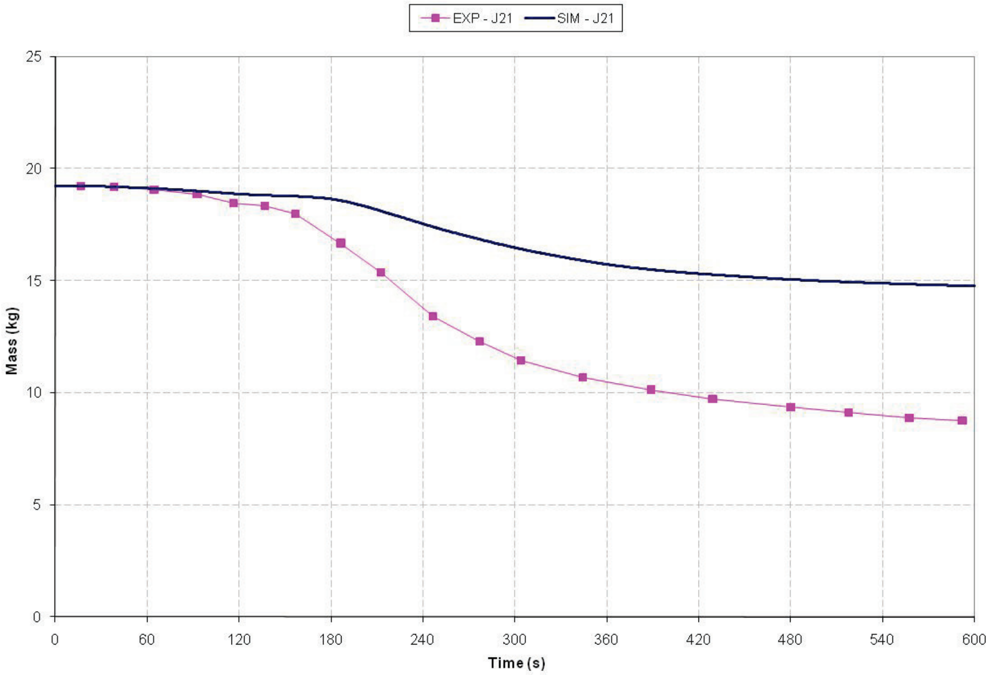

Figure 12-14 – ModFDS Mass History Comparison (J-21)

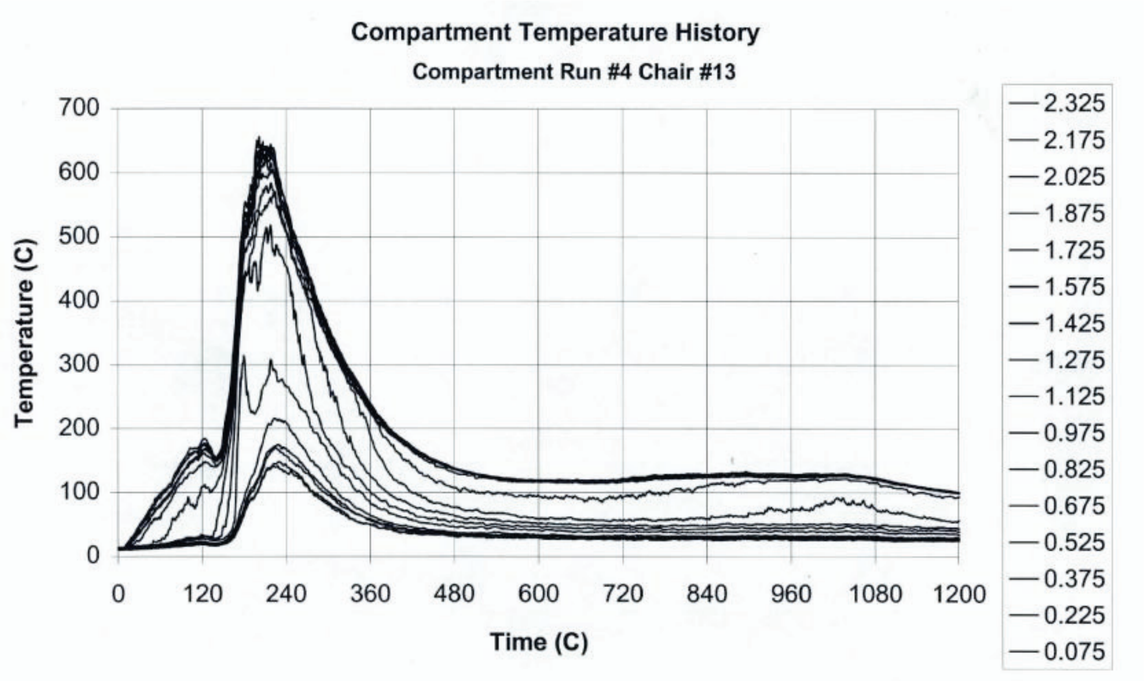

Figure 12-15 - Experiment Temperature History (J-21) (2)

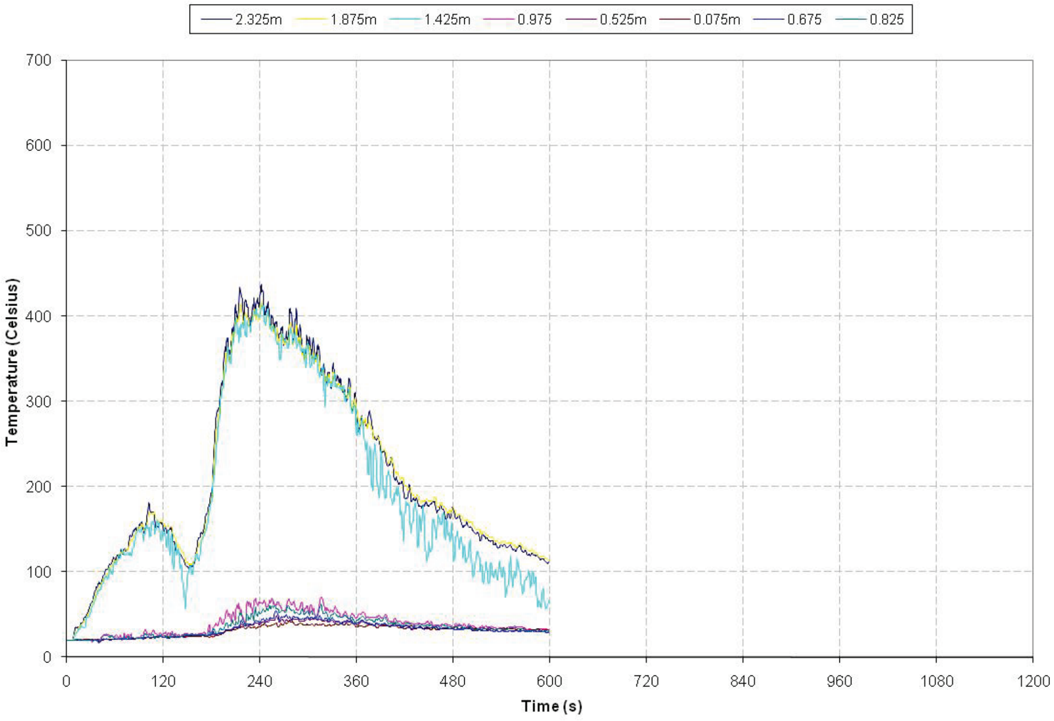

Figure 12-16 – ModFDS Simulation Temperature History (J-21)

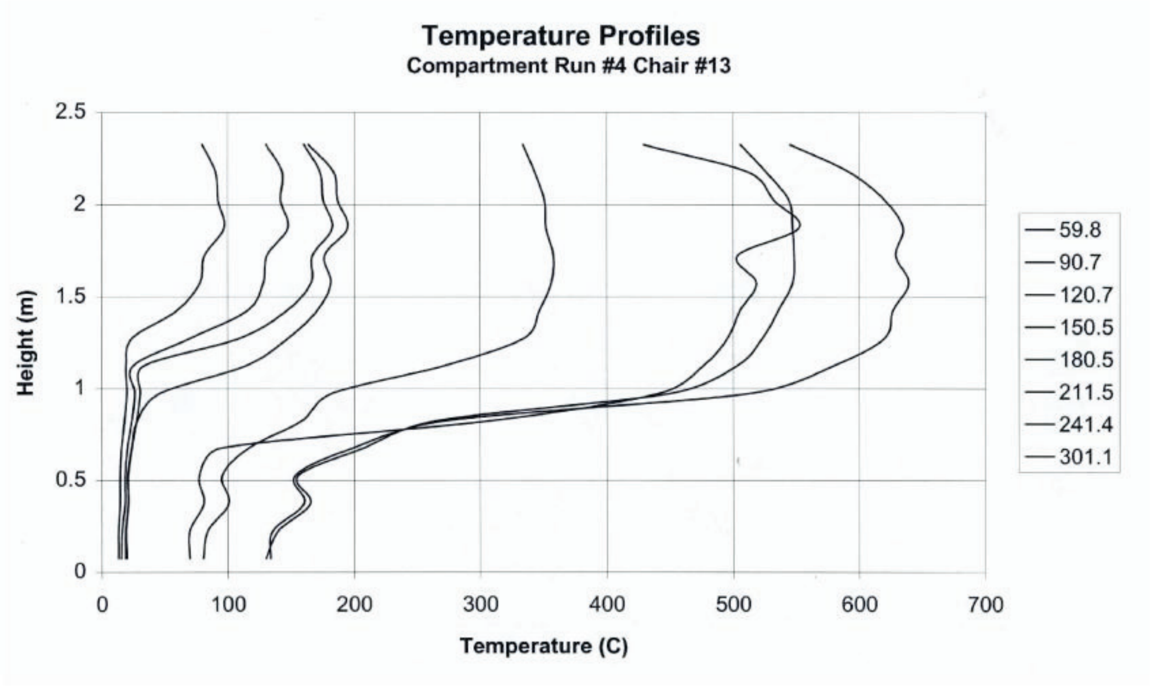

Figure 12-17 - Experiment Temperature Profile (J-21) (2)

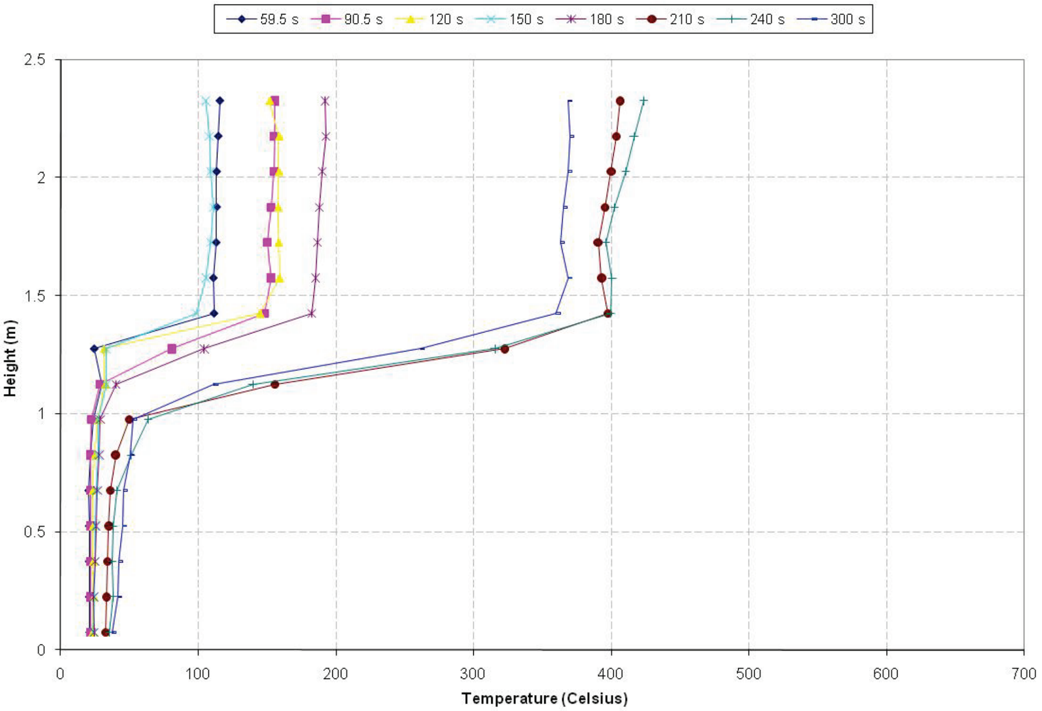

Figure 12-18 – ModFDS Simulation Temperature Profile (J-21)

CHAIR L-21

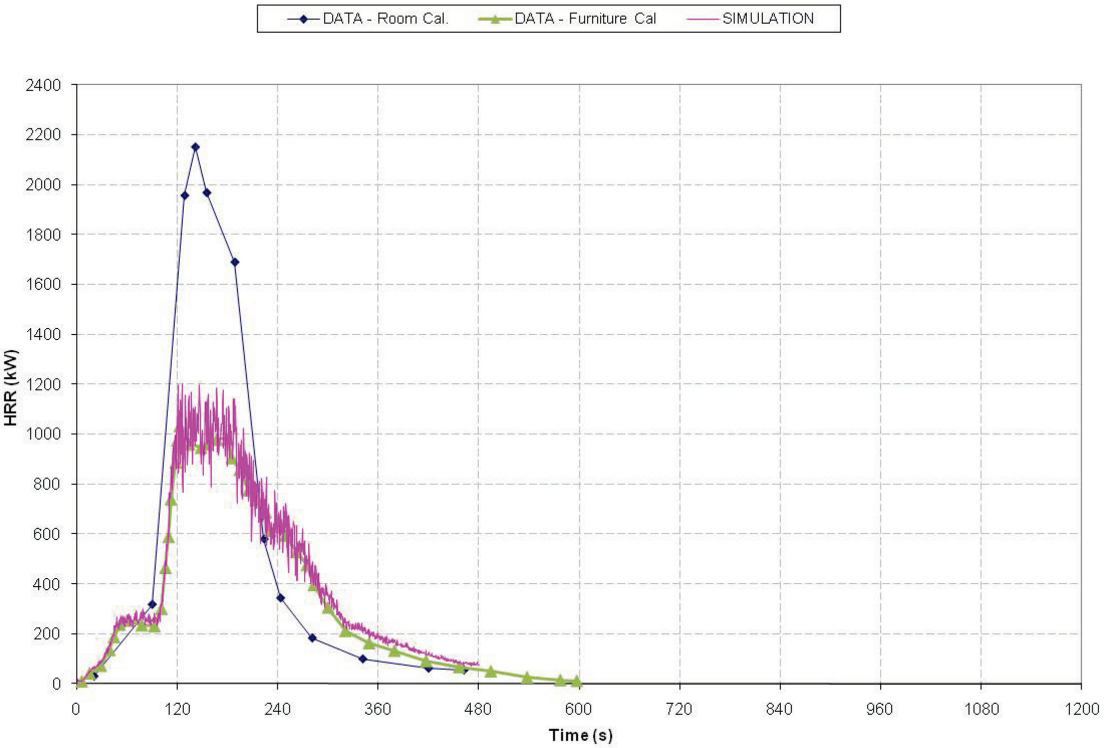

Figure 12-19 – ModFDS HRR Comparison (L-21)

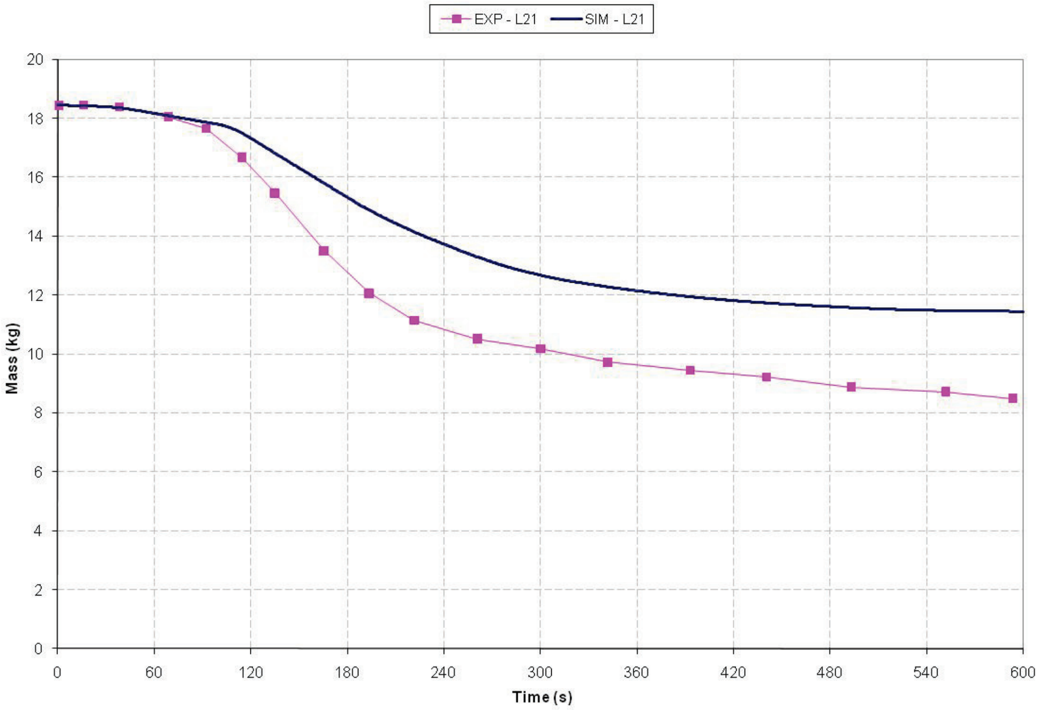

Figure 12-20 – ModFDS Mass History Comparison (L-21)

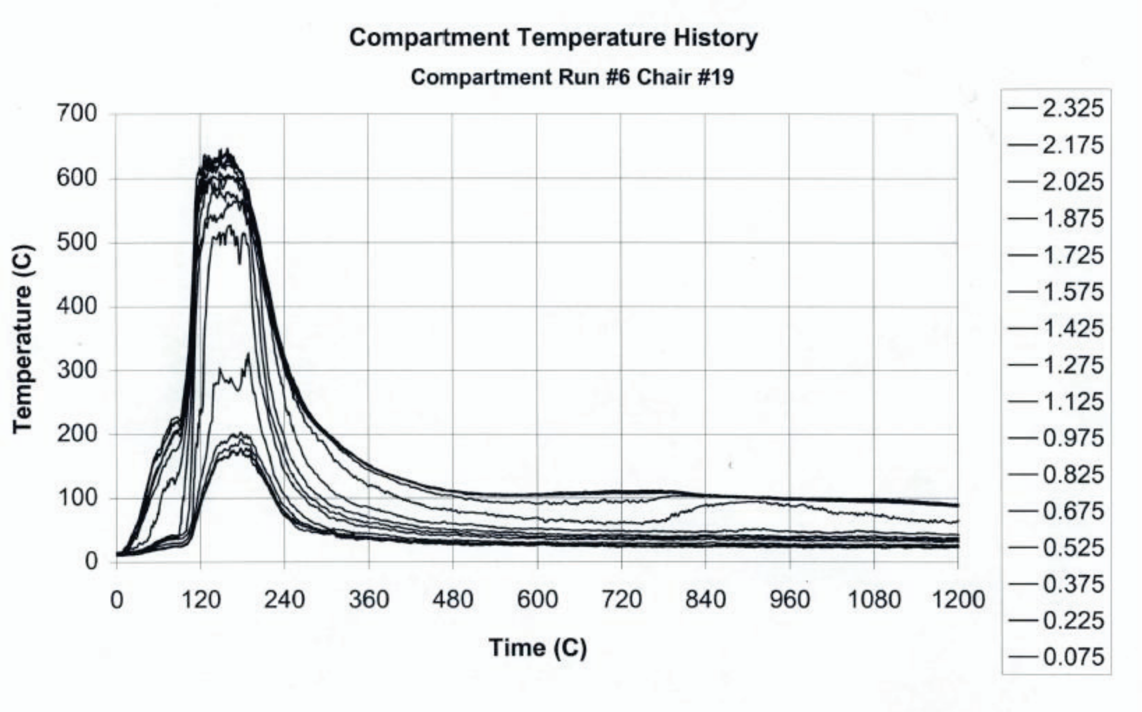

Figure 12-21 – ModFDS Experiment Temperature History (L-21) (2)

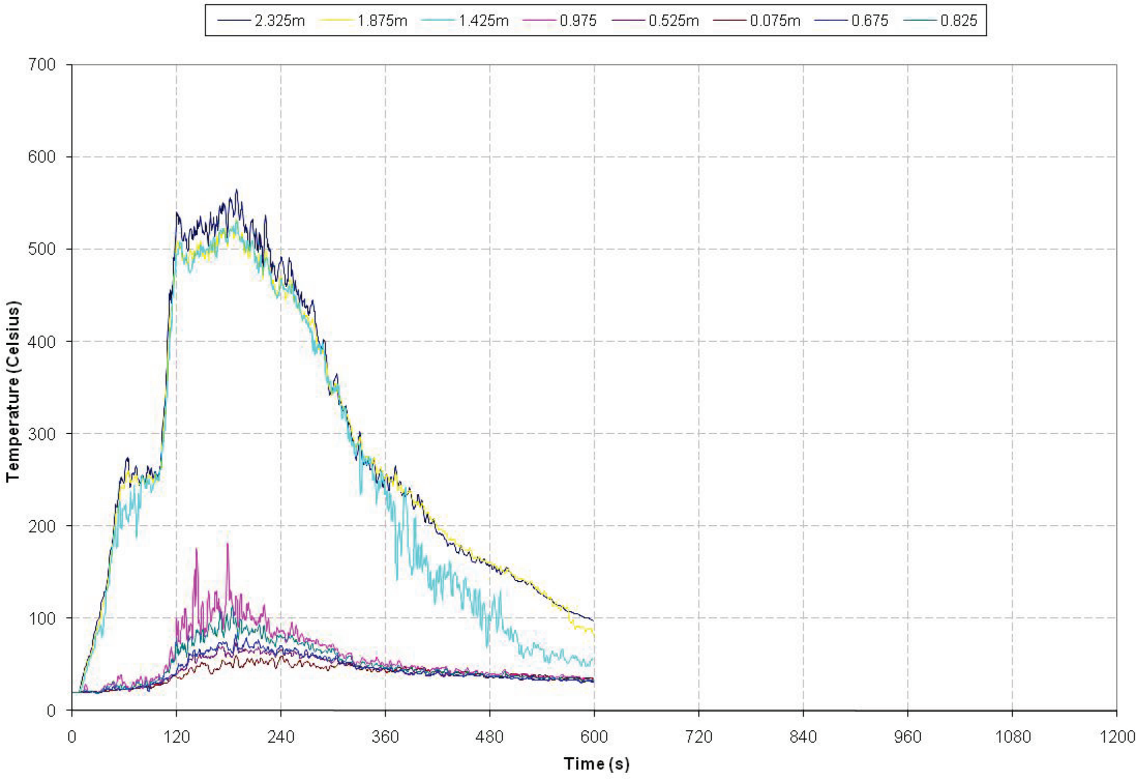

Figure 12-22 – Simulation Temperature History (L-21)

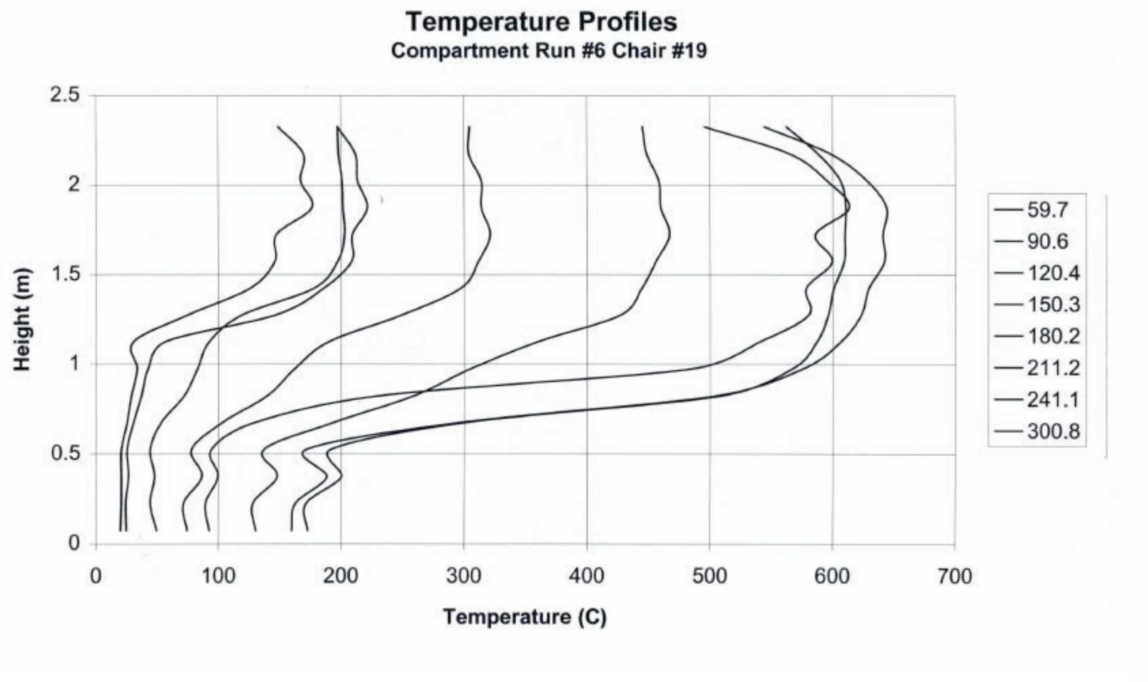

Figure 12-23 – Experiment Temperature Profile (L-21) (2)

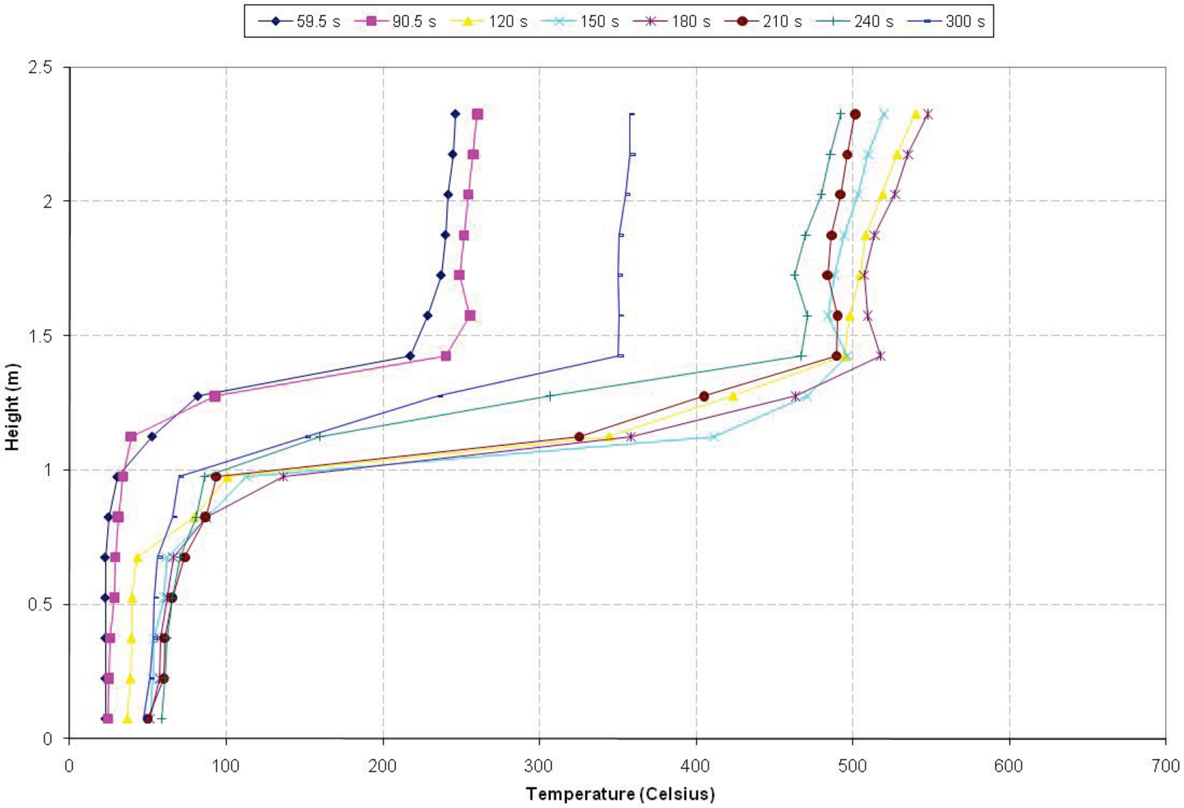

Figure 12-24 – ModFDS Simulation Temperature Profile (L-21)

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